Review of Input and Output Equipment Used in Computing Systems

Joint AIEE-IRE-ACM Computer Conference

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REVIEW OF INPUT AND OUTPUT EQUIPMENT USED IN COMPUTING SYSTEMS

SYSTEMS

JOINT AIEE-IRE-ACM COMPUTER CONFERENCE

PAPERS AND DISCUSSIONS PRESENTED AT THE
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JOINT AIEE-IRE-ACM CONFERENCE COMMITTEE

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FOREWORD

The Joint AIEE-IRE-ACM Computer Conference took place on December 10–12, 1952, in New York, N.Y., to discuss the characteristics and performance of input-output equipment as it applies to large-scale electronic digital computers. The conference was held under the direction of the Joint Committee appointed by the Committee on Computing Devices of the American Institute of Electrical Engineers, the Electronic Computers Committee of the Institute of Radio Engineers, and the Council of the Association for Computing Machinery.

Input-output equipment presents an ever-changing and expanding problem and encompasses a very broad field of devices. This conference stressed those devices which have been brought to the point of working equipment by the various computing groups in an attempt to acquaint a large body of engineers with the present status of the art. Interest in this subject is high; over 1,100 members of the industry were present at some time during the 3-day presentation.

An innovation for the computing industry on the east coast was the display of actual hardware in the exhibition booths adjoining the lecture hall. Interest in these devices was extremely keen and, although the size of the exhibition was limited due to lack of space, it is felt that this demonstration added materially to the success of the conference.

The papers presented in this volume represent a fairly complete documentation of the input-output art as it exists at present. It is a sequel to the first publication resulting from the Philadelphia conference in 1951, entitled "Review of Electronic Digital Computers."

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Keynote Address

NORMAN H. TAYLOR

THE Joint AIEE–Institute of Radio Engineers (IRE)–Association for Computing Machinery (ACM) Computer Conference Committee certainly is gratified that the second annual conference is receiving the same enthusiastic support from such a wide group of engineers as did the first conference in December 1951 in Philadelphia, Pa.

It was very reassuring during the planning of this conference to hear from our Publications Committee that the sales of the 1951 publication have totaled over 1,600 copies and that the demand is still high. I should like to thank R. S. Gardner of AIEE Headquarters and Robert Walker of the International Business Machines Corporation for the fine job they have done in publishing the results of the 1951 meeting.

In selecting a topic for the 1952 meeting, the Joint Committee has chosen one of the most controversial parts of our computing systems. Terminal or input-output equipment as it applies to digital computers is one of the broadest, most involved, most varied, and most difficult subjects to discuss in a 3-day meeting.

The problem of input-output equipment becomes critical when electronics is introduced to the computing field. When computation is done with a desk calculator, there is no real problem of terminal equipment. A human being is quite versatile and fast enough in his reaction to provide a reasonable match between the mechanical arithmetic element of a desk calculator and the notebook from which he gets the problem and writes the answer. If an operator should spend half his time punching keys to insert numbers in a machine or writing answers in a notebook, it would not seem alarming or too time-consuming. When the electronic tube is substituted for the gears and relays in a desk calculator, the speed of doing arithmetic is increased a thousand times. The rate at which a man can feed data to or accept data from an electronic computer is very slow compared to the speed of such a device. Some mechanical or electronic aids are needed to match this terrific innovation. I should like to emphasize this concept of matching a man's speed to a computer's

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speed because most of the in-out facilities discussed will be attempting in some way to match the very high internal computation speed of a modern electronic computer to a physical concept that a man can use.

An interesting analogy has been proposed to this matching problem. If a person should travel to Philadelphia from New York by airplane, he would spend 45 minutes going from the city to the airport, 20 minutes on the airplane, and another 45 minutes going from the Philadelphia airport to that city. This, I feel, is a bad mismatch between terminal facilities and transportation media and expresses what I mean regarding a mismatch in time scales.

There are two solutions to this problem. One is to avoid the use of an airplane between New York and Philadelphia as being impractical and come to the conclusion that high-speed transportation is no good for short hauls. The other is to attempt to improve the terminal facilities so that local transportation to airports takes less time. There may be proponents of both these solutions, but presumably most of us would be interested in improving the terminal facilities to make use of a new high-speed medium.

Just as the airplane is most useful when it takes a traveler to the place to which he wants to go, so the computer is useful only when it solves a problem in a manner which is acceptable to its user.

In considering what we want electronic digital computers to do, we find that there are three main categories of activity and a separate type of machine for each: the scientific calculator, the business machine, and the automatic controller. As each of these machines serves a different purpose, it will be expected that the input-output terminal equipment will be somewhat different for each type.

Types of Machine

THE SCIENTIFIC CALCULATOR

Of the three types, the scientific calculator places the least demand on terminal facilities. Scientific problems often demand that a large amount of calculation be done from a small amount of data. The high-speed machine does the calculation in a reasonable time, and a man may be able to insert data fast enough to

keep the machine busy. If the answer is simple, a man can absorb it rapidly, and no complex equipment is necessary. If the answer is complex, he may have to wait until it can be printed or typed by the machine. This application is analogous to taking the airplane trip from New York to Los Angeles; the terminal trips are not really any different than on the trip to Philadelphia, but the total accomplishment is so much greater that no one complains. Computer-wise, no one worries much about the time it takes to insert or extract a scientific problem, and a simple input typewriter and output printer are sufficient equipment.

BUSINESS MACHINE

From this the problem goes to the other extreme when we consider most business machine computers. The quantity of input data is apt to be large, the quantity of output data equally large, but the number of internal operations on each of these pieces of data may be quite small. Here the problem of matching the high-speed internal portion of the system to the rather low-speed input and output devices becomes acute. If it is not organized carefully with the proper use of matching devices, the whole application may become wasteful and useless. Many of the papers to be presented will deal with this problem of matching low-speed inputs to high-speed computer, others with matching high-speed computer to the low-speed output medium.

Some designers have attempted to speed up the actual terminal devices in an attempt to make this speed match easier to attain. The high-speed printer, magnetic tapes, and films are typical examples.

Others have used buffer systems between the terminal equipment and the high-speed computer. This buffer technique usually consists of a memory device which can accept data at one rate of speed, hold it until needed, then deliver it at a different rate. It is a powerful technique on either input or output and does the same job in the time domain that a transformer does in the impedance domain. Both input and ouput buffers will be discussed.

Several media are capable of doing this speed transformation basic to the buffer approach; magnetic tapes, wires, and drums, optical films, and acoustic lines are some of the best known.

THE AUTOMATIC CONTROLLER

The third 'type of computer application which calls for special terminal equipment is automatic control. This

problem is not too different from that faced by the designer of business machine terminal equipment, but a few added boundary conditions are often imposed by the mechanism being controlled. The control designer cannot expect to change the device he is controlling to match his computer; he must match his computer to the device. A large amount of data usually appears at the input to the machine. Very often an added requirement calls for immediate action on these data, especially if they come from a device whose signal changes rapidly. The data are not always in digital form, and conversion equipment must often be employed before the data can be fed into the computer's terminal equipment. The paper by H. E. Burke, "Survey of Analogue-to-Digital Data Conversion," discusses no less than 17 basic principles used in this numeric process.

The speed transformation must take place, in most cases, in both input and output, and many of the techniques to be discussed in the business-machine field apply equally well to problems in control. A paper entitled "Numerically Controlled Milling Machine" by A. K. Susskind and James O. McDonough will discuss an unusual form of control device, a project which represents an entirely new type of activity for digital computers.

Basic Points of View

One can recognize that there are two basic points of view in comparing terminal equipment in the three categories of activity just discussed. These views are so different that they give rise to completely opposite kinds of input-output equipment and consequently cause much discussion on the pros and cons associated with such equipment.

The first places the computer in the center of the picture, and the terminal equipment surrounding this central portion in an array of feeder lines transporting data to and from the device. The terminal equipment plays the role of a service organization trying to keep the computer busy. If the central machine has to wait for data or hesitates in its rapid calculation to deliver results to the outside world, this school of thought immediately claims the inadequacy of the terminal equipment to be the cause.

The second approach inverts the problem. Large amounts of incoming data from many sources, sometimes from men, sometimes from machines, need to be processed and then delivered to a destination in the form of bills, number lists,

or dials of a machine. The computer here is an automatic switching center keeping the data flowing at a smooth rate with a maximum of efficiency between input and output terminals. A large amount of data calls for a fast machine; a small amount for a slower machine. Delays or bottlenecks in this system usually are blamed on the lack of flexibility in the computer instead of on the terminal facilities.

This is not an attempt to determine which of these two approaches is the better. Techniques and equipment chosen by one school of thought often are used by proponents of the other, and time and experience will probably answer this question of superiority as computers become used in the field for the varied applications of scientific calculations, business methods and data processing, and automatic control.

Review of the Program

BASIC TECHNIQUES

During the first portion of the program the papers are aimed at studying the basic techniques available to the designer of input-output equipment. These techniques apply to all kinds of equipment whether it is to be used in the scientific calculator, the business machine, or the automatic controller. One may call for a small amount of low-speed equipment, another for a larger amount of high-speed equipment but, in any case, certain basic principles are evident.

First, the data must be remembered or retained. This memory problem has been approached in many ways, but in the terminal equipment we usually have this requirement of writing at a slow rate and reading at a high rate for the input or the inverse for the output, and so a particular group of memory techniques has been employed in this area. Second, a speed change demands certain handling techniques, and Dr. Snyder has chosen the title "Devices for Transporting the Recording Media" for his discussion of this subject. In particular cases it becomes necessary to accomplish this speed transformation job in two or three steps. Devices then are needed which change from one medium to another both going into and coming out of the system.

The first papers describe the basic building blocks which are used today to construct a matching system between a man and a high-speed computer.

MACHINE ORGANIZATION

Five important computing groups present the organization of the input and

output of their machines during the program. Each accomplishes matching input and output speed with computer speed in a different way, but most of these basic techniques will be discussed later.

It is impossible to state explicitly the exact differences in these systems, but two trends are becoming evident. One trend is toward increasing the speed of terminal devices so that data can enter or leave the computer at faster and faster rates. This allows the use of simpler arrangement of control with a minimum amount of rather complicated high-speed equipment. As an example of this, multiple channel tapes with high densities of data and higher and higher speed printers are producing data at phenomenal rates. Another trend involves changing the organization of the machine so that several lower speed devices can operate in parallel. This approach complicates the control and uses more equipment to obtain the same data rate as the first mentioned method. The equipment used, however, is apt to be somewhat simpler, and the use of lower-speed tapes and printers is thus made possible.

It would be very unwise at this point in the development of the computer art to defend either of these two approaches as better than the other. It is wiser to encourage both approaches in order to cope with the broad problems which computers are called upon to solve.

OUTPUT EQUIPMENT

The final papers will stress output equipment used with computers. Four papers on printers have been grouped together. It would be impossible to have each designer in the country talk about his printer, so two survey papers are presented which give the over-all picture of the types of equipment developed in this area of activity.

On behalf of the Joint AIEE-IRE-ACM Computer Conference Committee, I would like to thank Dr. S. N. Alexander and Miss Margaret Fox for drawing up this broad, comprehensive program. The papers give a broad picture of what input-output devices have been developed, designed, and built to date. Focus is placed on working devices at the expense of ideas untried and unproved. Some of the devices are actually on display at the exhibition booths as tangible evidence of the progress to date in this field.

In closing, I should like to thank Perry Crawford and his committee for their initiative and energy in arranging the exhibitions, and Arthur Mohr and his committee on local arrangements for providing such excellent facilities.

Recording Techniques for Digital Coded Data

ARTHUR W. TYLER

THE communication links between the working interior of a digital computer and the external devices or persons that supply and make use of the data have long been recognized to be inadequate. It is also becoming apparent that this input-output equipment will be one of the major items of cost in the great majority of computer installations, particularly in the nonscientific field. An intensive development effort aimed at producing satisfactory input-output devices is necessary, and a survey of the techniques which might be used should materially assist this program. Two kinds of output equipment are required, one to produce coded records and the other to produce printed-type records. The comments to follow are directed primarily at digital coded recording.

A coded recording is used primarily as a means of transferring data from one device to another and to store data for future use. Data storage within a computer will not be considered as a recording process. The techniques overlap to some extent but the distinction will be made in terms of the amount of data that can be recorded. Specifically, a data recorder as distinguished from an internal storage unit is characterized by its indefinite capacity, its ability to record data as long as it is supplied with a recording medium.

The great variety of data-handling devices that will be used in the future will certainly involve the use of several different recording methods. In some cases it will be necessary to transcribe the data from one recorded form to another, to handle large quantities of data, and to record at very high rates. In the aggregate there will be so much coded data recorded that the storage elements will have to be very inexpensive. Chiefly because of this requirement, all of the recording techniques will have one outstanding common feature. The storage elements will have to be supported in some geometrical pattern on a suitable medium which permits selection to be accomplished by a mechanical movement

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of that medium. Accessibility will have to be sacrificed in favor of simplicity and low cost. The support usually takes the form of a long flexible tape which is moved past a device that records the data serially.

Although many of the materials that can be used as a recording medium are capable of recording signals of variable magnitude, reliability and simplicity dictate the use of a fundamentally binary code in which only the presence or absence of a signal is of significance. The binary digits are often grouped to form codes of more complicated structure, but no existing digital recorders use the signal magnitude as an additional dimension to increase the storage capacity.

An examination of the flow of data from one device to another reveals that there are three phases to be considered: the recording technique, the mechanical recording medium, and the playback technique. The data are assumed to originate in the form of electrical signals and eventually to be reproduced in the form of electric signals. The recording medium is the most critical phase of the process since limitations in the medium for the most part determine the success or failure of a recording method. All three phases must be considered as a combination in determining the merits of any specific material or technique because it is the combination which must be useful eventually. An ideal recording technique is useless unless there exists a satisfactory medium which will register and retain its output in a form that can be played back.

The characteristics of the medium which are of primary importance are

1. Low cost.

2. Compactness. A high storage density is useful not only in reducing the volume of the material that must be handled and stored but also in reducing the velocity with which the medium must be moved to achieve a high recording and playback rate.

3. Permanency. It will be necessary to keep some records for many years.

4. Erasability. For some applications it is desirable to be able to erase and rerecord new data. For other applications it is equally desirable not to be able to change the record.

5. Durability. Some records will be played back a large number of times.

6. Ease in handling and inspecting. Particular attention will have to be given to simplifying operational procedures for many applications that are now developing.

Desirable features to be sought in the recording and playback techniques are:

1. Simplicity and low cost. The equipment cost and maintenance charges will be the principal limitation to widespread use of this equipment.

2. Reliability. A high degree of reliability in reproducing the electric signals that were impressed on the recorder is of course desirable, and essential to some applications. However, it should be recognized that there are situations, such as the handling of statistical information, in which reliability can justifiably be sacrificed to attain other advantages.

3. Recording and playback rates. Here again a wide range of recording rate requirements will be encountered in practice and the available recording techniques limited accordingly.

The application will dictate the requirements, and that recording technique and type of medium which has the best combination of features will be selected for the job.

The mechanical nature of the recording medium and of the process of selection by moving the medium imposes limitations on the extent to which the inherent characteristics of the medium can be utilized. These limitations are for the most part in the same order of magnitude for all of the practical forms of recording now in use. This important point is brought about by the fact that our level of technological development permits the attainment of positional accuracies of a few thousandths of an inch, velocities of a few feet per second, and accelerations to produce these velocities in a few milliseconds with the materials which we must use. The cost of exceeding these limits soon becomes prohibitive. The proper combination of properties is more important than perfection in any one in selecting a recording medium.

The Recording Techniques

A quick survey of the techniques that are now being used for recording digital data reveals that they fall in three categories: mechanical, magnetic, and optical. These terms also describe three of the five fields of classical physics, namely, mechanics, sound, heat, light, and electricity and magnetism. This observation suggests that it might be worth while to digress for a moment to survey each of these five fields for information relative to digital recording. Recording techniques differ primarily in the way in which the medium is altered during the

recording process. The survey should emphasize techniques for altering or modulating the medium using the forms of energy studied in each field.

Mechanical modulation can be accomplished by removing material as in perforating, adding material as in printing, or displacing material as in embossing. All of these methods have been tried in one form or other. The perforating technique has been most commonly used not because it is the easiest way of recording but because of the convenience in playing back by mechanical means. The printing technique deserves much more attention than it has received and will be considered in more detail later. Embossing does not have any particular advantages.

In the field of sound there appears to be no useful technique for permanently modulating a mechanical medium. Sonic techniques are, of course, widely used for internal data storage but their application has been confined to that field.

From the field of heat there are available heat-sensitive papers which are used in facsimile recording. Modulation is accomplished by producing a chemical change in a suitable material by the application of heat. The technique could be applied to digital recording as well. In general, however, heat is the most difficult form of energy to control and is not likely to be very adaptable to this use.

There are many materials that can be altered under the influence of light. Photographic materials are the most widely used. Their success hinges on the use of a chemical means of amplifying the effect of the light. This procedure permits the achievement of extremely high optical efficiency in terms of the effect produced by a given amount of light energy. This high efficiency is reflected not only in the magnitude of the change but also in the time required to produce it. Photographic recordings have been made in time intervals less than 10^{-8} second. The only other optically sensitive materials which have a satisfactory combination of properties for digital recording are the phosphors. Materials are available which can store energy from optical excitation and which will radiate that energy later under the influence of optical stimulation. The process is repeatable so the medium is erasable. It is quite likely that a satisfactory phosphor could be developed for digital recording with a reasonable amount of effort. There are many photochemical reactions which might conceivably be developed into a useful form.

However, the likelihood of attaining sufficient sensitivity is not very great.

The field of electricity and magnetism offers many ways of producing modulation on a mechanical medium. Most of these methods are reversible and have the further advantage that the recording element is relatively simple because the source of information is in the form of electric signals. Electrochemical reactions, the deposition of electrostatic surface charge, electrical displacement in a dielectric material, and the magnetic orientation of permanent magnetic materials are representative of the methods that have been tried. Magnetic orientation is the only method which has developed into a practical recording means. The electrostatic technique has been applied successfully to internal storage.

The principal techniques that are now being used for recording digital coded data make use of perforated paper tape or cards and magnetic tape or wire as the recording medium. Photographic film has been tried but its use has not become general. There are two other recording techniques which have sufficient merit to warrant further study for some applications, namely, printed paper tape and photographic plates. Each of these five techniques will be discussed in detail. Somewhat more time will be devoted to the discussion of photographic techniques than to the others, not because they are considered to be more applicable, but because it has been specifically requested in view of the relative lack of published information on that subject.

Perforated paper tape is one of the simplest and oldest means of recording coded digital information. The tape is mechanically perforated during recording and the perforations are sensed mechanically during playback. Multiple channels are almost always used to store one symbol as a pattern of bits arranged in a lateral line. Use of a recording density of about 100 bits per square inch is common practice. Teletype equipment employing this principle has been used successfully for many years. The principal limitations of perforated paper recording are the relatively low operating speeds and recording densities that are practical to attain. The recent introduction of photoelectric sensing has improved the speed and reliability of playback. The real limitation, however, is the low storage density since that in effect also imposes a speed limitation due to the limited velocity with which it is practical to move the tape. There is little likelihood that the perforating

technique can be improved to overcome this limitation. Perforated paper tape will still be used, however, until the newer techniques are perfected.

Perforated paper cards have also been used very extensively for many years, particularly in the business machine field. Even though the storage density is only about 25 bits per square inch, there are so many other advantages arising from the discrete nature of the cards that they will certainly continue to play a prominent part in automatic computation. A good part of the flexibility and operating speed of punched-card equipment is attained by parallel operation in many channels. This feature increases the cost and maintenance of the equipment.

Magnetic recording is currently the most widely used recording method for those applications to which perforated tape or cards are unsuited. The flexibility of being able to erase and rerecord selected portions of the record is the most important single reason for this trend. The principle involved in magnetic recording has been known for a long time and has been extensively applied to sound recording. Various kinds of magnetic materials are employed. The usual form consists of a thin coating of finely divided iron oxide on a plastic tape. Plated metal tapes and plated or solid wire are also used. A binary digit is recorded by magnetizing a small area of the tape using the fringing flux near a small air gap in a magnetic circuit. The material has sufficient residual magnetism after the tape has passed the recording gap to remember the impressed signal. Playback is accomplished by passing the tape across the air gap of a similar magnetic circuit. When a magnetized spot is encountered, a voltage is induced in the playback head. This voltage is the time derivative of the recorded signal and must be treated accordingly.

Magnetic wire has not been used extensively because only one recording channel is available and the wire is more difficult to handle. With magnetic tape several channels can be recorded simultaneously. This feature provides a convenient means of increasing the recording rate without having to increase the tape velocity. It is more practical to provide multiple electronic circuits for recording and playback than it is to drive the tape faster, a further reflection of the fact that the mechanical problems associated with recording are the more severe. The use of multiple channels is also advantageous in some cases because of the code structure that is used.

There are several variations in the way in which the magnetized areas are used to represent the ones and zeros of binary digits. Perhaps the most straightforward method consists of recording ones and zeros as magnetic spots of opposite polarity on a background of unmagnetized material. When this record is played back, a positive and a negative voltage pulse is generated for each bit regardless of its value, so no additional synchronization is required. The two digits differ in the order in which the two pulses occur. If a synchronizing channel is employed to sample the other channels at definite locations, other techniques can be used which permit closer spacing of the pulses.

It has been found practical to record between 100 and 200 bits per inch in each channel. The spacing of channels across the width of the tape is restricted somewhat by the physical structure of the recording heads. About 20 channels per inch have been attained with careful design resulting in an over-all storage density in the order of 2,500 bits per square inch. The usual practice in recording from a computer is to group the data in blocks of some convenient size and separation on the tape thereby facilitating control of the flow of data to and from the recorder. In the case of magnetic recording the block separation is essential if it is desired to stop and start the tape, since the tape must be moving faster than a prescribed minimum velocity during playback in order to induce sufficient voltage in the pickup coil.

A magnetic storage element is unique among the common recording materials in that the stored signal has direction as well as magnitude. It can be used as a ternary storage element having three useful states, positive, negative, and zero, without having to resort to amplitude discrimination. This feature could be used to increase the recording density through the use of a ternary number system but it is ordinarily used to record binary digits without having to use the absence of a signal to denote the digit zero. This feature effectively doubles the storage density since it would otherwise require two binary storage elements to achieve the equivalent result.

The important desirable features of magnetic tape recording can be summarized as follows:

1. Relatively high storage density resulting in a compact record.

2. A high recording and playback rate compatible with the requirements of electronic computers.

3. Good flexibility due to the ability to erase and rerecord and to play back without delay.

4. Provision for multiple channels.

5. A high degree of permanency.

Magnetic tape has some disadvantages which are of more or less importance in specific applications. Among these are:

1. Intimate contact between the tape and the reading and recording head is necessary to take full advantage of some of the desirable properties. Close contact is difficult to maintain and results in excessive wear.

2. It is difficult to manufacture magnetic tape without producing an appreciable number of blemishes which render a localized area unsatisfactory. This situation will undoubtedly be improved in the future.

3. Data cannot be played back unless the tape is moving in excess of a minimum velocity.

4. The erasability feature permits the possibility of accidental or even malicious erasure of a record that is desired to be permanent.

5. It is difficult at best to inspect the tape visually, to determine what has been recorded particularly as an aid in troubleshooting.

Magnetic recording for digital purposes is still a relatively new technique. Further development to increase the reliability and reduce the cost of the equipment will very likely produce recorders which will play an important part in the handling of information for many purposes.

The Photographic Process

The photographic process is probably the most versatile and certainly one of the widely used recording techniques available. In the nondigital field and particularly in the field of pictorial reproduction where a large amount of detail must be recorded, photography is unsurpassed by any other recording technique. It is rather surprising, in view of its many useful properties, that it has not been tried more extensively in the digital field. It is the writer's belief that the principal reason for this lack of interest has been the preoccupation on the part of computer designers with recording techniques that are erasable. Now that a relatively greater amount of effort is being directed at solving the input-output problem, designers will be searching for other recording techniques and the use of photography will undoubtedly be studied extensively.

One of the chief attractions of photographic materials is the relatively high resolution of which they are capable. It is not unusual for images to be composed of distinguishable elements in the order of 0.001 inch in diameter. It is not too unreasonable to assume that digital recording with 1,000 bits per linear inch might be practical. However, it should be emphasized again that the limitations in digital recording are mechanical. The problems of transporting a continuous strip of 16- or 35-millimeter film are substantially the same as those encountered wth paper or magnetic tape. It becomes necessary to make the storage elements considerably larger than 0.001 inch in order to be able to locate them with adequate certainty during playback.

It is interesting to indulge in a little wishful thinking to see what might be done if the mechanical problems could be solved with sufficient precision. Photographic materials are available which can resolve at least 75,000 lines per inch, which represents the limit of our ability to measure the resolving power. It is already beyond the capabilities of optical instruments using visible light. The material must be exposed using an X-ray diffraction pattern and later examined in an electron microscope to observe the line structure. This photographic material could easily record over 5 billion bits per square inch with adequate definition.

The individual photographic storage element consists of a rectangular area containing a spot which is either transparent or opaque, to represent the two binary digits. Multiple-channel recording would almost always be used since it is one of the virtues of photographic recording. The use of a synchronizing channel to determine the position at which the other channels should be sampled is the most practical procedure. The spots can then occupy the full extent of the area allotted to them, thus providing the maximum tolerance for mechanical errors in positioning the film. The optical means of recording results in a channel spacing which is determined by mechanical positioning tolerances rather than by structural size limitations. A practical storage density is 100 spots per inch in the direction of film motion and 50 spots per inch laterally. The rectangular dimension is best for two reasons. There are a fewer number of disturbances contributing to the longitudinal positional error because of the mechanical scanning that takes place in that direction. Secondly, a dust particle or scratch is less likely to obliterate completely a rectangular spot than a square spot of equal area. The exact size and shape of the spots are not too critical. They can be somewhat smaller

if precautions are taken to eliminate dust and prevent scratching. We have played back spots of this size using photoelectric sensing several hundred million times without error.

The physical characteristics of the film support which carries the photographic emulsion are well suited to this use. These materials have been perfected over a period of many years for motion picture purposes. There is available a wealth of data and experience on the properties of film base and methods of transporting it from which a practical recorder design could easily be evolved. Film bases are subject to dimensional changes resulting from aging and varying atmospheric conditions. These effects have been thoroughly studied and are sufficiently small to be easily eliminated through proper design. The film support has excellent wearing qualities and can be mechanically guided to a tolerance of the order of 0.001 inch without much difficulty. It is quite practical to move the film support in sliding contact with a supporting structure provided the contact is outside of the recording area. Films handled in this way have a life expectancy of several thousand passes. However, an emulsion dust is formed under these conditions which tends to adhere to the film surface. This dust can be removed readily but it is preferable to handle the film entirely with rolling contact. This technique further increases the film life and materially reduces the collection of dust and scratches.

A wide variety of photographic emulsion types are available from which a selection can be made to meet the specific requirements of practically any recording problem. High-sensitivity emulsions can be selected to meet high recording rate requirements. High-contrast materials can be used to attain a large difference in optical transmission between the light and dark spots, effecting a high signal-to-noise ratio. Some materials can be reversed during processing to obtain clear spots in place of black spots, a feature which is particularly useful in some applications. The manufacturing techniques for photographic materials have been perfected to a point where very high quality can be maintained. The presence of a blemish that would obliterate one spot of the dimensions specified is extremely rare, certainly less than one in 100 million spots.

Both the recording and playback techniques used with photographic film will be based on optical methods. In many respects this is a considerable advantage, particularly since no physical contact

with the recording medium is required. It is also possible to record and play back in several channels with a single modulator and detector. This is accomplished by handling the channels in time sequence using optical scanning. Actually it is a single-channel method of recording in which optical means are used to record in a 2-dimensional pattern rather than in a linear array as a single channel ordinarily implies. This procedure requires both the flexibility which optical scanning provides and the high sensitivity and frequency response which is available with photographic recording and photoelectric playback.

Light sources with sufficient brightness and modulation capabilities are available for recording a pattern of dots on a photographic medium. A cathode-ray tube meets these requirements, especially when high recording frequencies are desired. An opaque mask with a series of rectangular apertures of the desired shape is placed over the face of the cathode-ray tube. An image of this mask is projected onto the film by a suitable optical system. The cathode-ray tube beam is displaced in such a way that it illuminates selected apertures in sequence. There are many ways of combining the beam deflection and the arrangement of apertures to use the film area efficiently and to realize such features as the positive recording of both zeros and ones. One satisfactory arrangement has two lateral rows of apertures each of which records in alternate channels. This permits placing the channels immediately adjacent to one another on the film and at the same time forming the spots with clearly defined edges. This technique has been used to record data at the rate of 1,000-000 bits per second.

Glow lamps may also be used as a source of illumination for the apertures in the spot-forming mask. A separate glow lamp is used for each channel. The recording rate is limited by the brightness and modulation capabilities of the glow lamp to about 1,000 bits per second per channel.

When recording rates in the order of ten per second or slower are satisfactory individual incandescent lamps can be used as the source of illumination. Incandescent lamps with fine filaments and gas filling can be modulated up to about 20 cycles per second. Individual electromagnetic shutters and a common light source are also quite satisfactory.

A very convenient method of shaping the spots in a single line without spaces between spots involves the use of what is called an optical light pipe. A trans-

parent glass or plastic rod can be bent into any reasonable shape, and light introduced at one end will emerge from the other end without much loss. A series of rectangular rods are arranged with their outlet ends forming a line of adjacent spots and their inlet ends at the light sources which are located in some other convenient geometrical arrangement.

A straightforward method of playback consists of illuminating the film with a steady light source and projecting an image of the film onto a row of photoelectric cells, one for each channel. The optical system is designed so that the image of each spot is projected onto an aperture which is smaller than the spot image to accommodate mechanical positioning errors. A synchronizing channel is used to generate a timing pulse when each row of spots is properly positioned in the optical system. The film can be moved either continuously or intermittently on a line-at-a-time basis. Lead-sulphide photoconductive cells are excellent detectors for this purpose. Multiple sensitive areas can be fabricated to any reasonable shape and size and can be grouped together on a single supporting surface. Lead-sulphide detectors are much more sensitive than vacuum phototubes for this application. Their frequency response, however, is limited to the order of 10,000 cycles per second.

A single photoelectric cell in conjunction with optical scanning can also be used for playback. A cathode-ray tube and mask, similar to that used for recording, serves as a light source and scanning system. Playback rates of 1,000,000 bits per second are attainable although there is some difficulty with the persistence of the phosphor at these frequencies.

The advantageous features of photographic film are:

1. A high storage density and the high recording rate which is thus made possible

2. A long wearing material

3. A high degree of permanency

4. Multiple channels and the applicability of optical scanning

5. Visibility of the record for inspection

6. There is another feature which is unattainable with any other recording medium and which is consequently a decided advantage for those applications that require it, namely, the ability to record a pictorial image along with the digital code. This image may consist of graphical data, a reduced image of a document, or any other information which is not conveniently expressible in digital form. This combination of microfilm recording and digital recording and control will embrace new fields which cannot be handled by either technique alone.

The disadvantages of using photographic film are principally the disadvantages of the photographic process in general. The materials must be handled in darkness, the images are nonerasable, and the material cost is relatively high. The principal disadvantage is the necessity of chemically processing the film before it can be played back. Techniques for processing the film have been greatly improved during the past few years and the development of automatic equipment is continuing. A processing machine no longer need be the cumbersome, time-consuming, and somewhat messy device that most people visualize. The disadvantages of processing can now be reduced to an acceptable level.

The principal drawback to the use of paper tape is the low storage density resulting in low recording rates. The use of optical sensing substantially eliminates playback limitations so, if there were available a recording technique capable of high recording rates and high storage density, this medium would find many applications. The mechanical printing technique used in the Eastman printer to be described by Mr. Thompson is adaptable to coded digital printing and will meet these requirements reasonably well. With very little change in design the electromagnetic hammers used in this printer could be grouped to print a pattern of dots of substantially the same size and spacing as that used with photographic film. Each hammer would print approximately 100 dots per inch in a separate channel. A total of about 20 channels could be accommodated with a spacing of about 1/50 of an inch per channel. A recording rate of about 2,000 bits per second per channel could easily be attained. There is no convenient way of erasing and rerecording but the material cost is so low that it would be practical to apply this recording technique to some applications which now require an erasable medium.

The advantages of this type of recording are high storage density, moderately high recording rates, visibility for inspection purposes, and low cost. Compared to other recording methods there are no serious disadvantages except possibly the necessity of using a carbon paper tape with the recording paper.

It has been pointed out that the storage density limitation of photographic materials is due to mechanical tolerances. It is possible to reduce the mechanical limitation materially by using an entirely different concept for the recorder design Instead of using a long tape, the recording medium is fabricated as a rigid disk which is provided with a precision bearing. Accurate rotational motion is available without great complication. A suitable recording medium is a photographic glass plate. The dimensional stability of the glass plate is limited only by thermal expansion and is consequently considerably better than film base. It is estimated that a storage density of about 1,000,000 bits per square inch could be achieved with a photographic disk recorder. A disk 6 inches in diameter could store over 10 million bits which is equivalent to about 150 feet of 35-millimeter film or 750 feet of 10-channel magnetic tape. One practical design uses a bank of glow lamps to record in multiple channels which are spiral shaped. The lamp bank is displaced radially as the disk rotates. The rotational method of transporting the glass disk eliminates trouble arising from scratches and provides a very long life. It would be necessary to take precautions to eliminate dust interference. Disturbances of this nature will no doubt impose a lower limit on the spot size that can be used. This limit must be determined experimentally.

The advantages of this type of recorder are extremely high storage density, small physical size, low material cost per bit, and relatively quick access to all of the data. The disadvantages are substantially the same as those associated with photographic film. There is the danger of breakage but glass plates in the form of disks are not particularly hard to handle.

In conclusion, it should be emphasized again that the most difficult part of the design of a digital recorder is the mechanical transporting and locating of the recording medium. Considerable effort in solving that problem thoroughly is well justified. All of the practical recording techniques should be exploited since all of them will find application in the great variety of digital recording that will soon be required. Emphasis should be placed on the development of simple devices since the largest potential field consists of the many small applications rather than the few large installations.

Discussion

K. P. Gray (Royal Canadian Navy): How many bits of information did you say existed on the 6-inch-diameter disk?

Mr. Tyler: About 10,000,000 bits can be put on a 6-inch disk. This allows for some spacing, because of the fact that they are distributed in a circle rather than in a straight array. The actual spot size that can be achieved is 0.001 inch on a side.

J. J. McDonald (Consolidated Engineering Corporation): What has been done with color to increase recording density?

Mr. Tyler: The cost of most color processes would be prohibitive, I believe. We have used color for one specialized purpose, not so much to increase recording density, but to provide a means of matching two numbers. The use of color will allow you to tell when the numbers are mismatched and, also, which number is the larger. However, as far as using it to increase recording density, I know of nothing that has been done.

Harry Smith (Sperry Gyroscope Company): I am interested in knowing how you would extract information, that is, playback from printed data on paper.

Mr. Tyler: The same type of equipment would be used that is used to play back Teletype tape. You would have to read the information photoelectrically by reflection rather than by transmission. This procedure is somewhat more difficult, but quite practical.

M. J. Relis (Control Instrument Company): What is the minimum time expected for a recording to play back with these photographic techniques, taking into account development time?

Mr. Tyler: That depends to a great extent on the application you have in mind. It is possible to process film and project an image from it in a fraction of a second. You could do that on a continuous basis. However, I see no reason for doing it for digital purposes. In a more conventional processing technique where the roll of film is removed from a recorder and then processed in a separate machine, a processing time of the order of a few minutes is possible.

Punched-Card to Magnetic-Tape Converter

E. BLUMENTHAL   F. LOPEZ

THE principal devices for converting source data to magnetic tape recording for Univac* are the card-to-tape converter and the Unityper.* Unityper is the logical conversation medium for input of otherwise untreated data. Files of punched cards, however, represent to the owner an investment of time and expense in preparing material for other treatment. The card-to-tape converter provides a means whereby these files can be made immediately available for use in Univac.

The specifications for the Univac system card-to-tape converter shown in Figure 1 evolved from consideration of the characteristics of various punched-card systems already in existence, and of the specifications of the more recently designed Univac.

The largest quantity of card-encoded data has been prepared on 12-row 80-column cards. Using this fact as a point of departure, the system was evolved to encompass four imperatives:

1. It must translate the punched code to the 6-bit Univac code, adding the appropriate check and sprocket pulses and detecting mispunchings as it converts.

2. It must distribute the 12-row 80-column data grouping within Univac's 720-digit block length, and insert the 2.4-inch space between blocks.

3. It must feed the cards through a sensing device in such a fashion as to tolerate off-punchings.

4. It must transport a tape and record on it.

The first problem is easily solved by a translating matrix which has 12 inputs from the photoelectric cell sensing array and 8 outputs to the channels of the recording head. This solution obviates the necessity of using any kind of memory in the converter, since the cards, feeding endwise, are sensed serially, and the material appears at the output in the order initially encoded on the cards.

The compromise between the 12-row 80-column grouping on the card and the 720-digit Univac block was effected by subdividing the block into 120-digit blockettes. The 80 digits of the card are encoded in the first 80 digit-positions of each blockette, and ignore symbols are read into the next 40 digit-positions. Effecting a 1 to 1 ratio between card and blockette presents an easy solution to the problem of inserting the space between blocks. This 2.4 inches of tape length is equivalent, at our recording speed, to 240 digit positions, or the data from two cards. Therefore a counter was designed into the system which feeds one card per cycle for six cycles (6 × 120 = 720), and then cycles twice with the card feed suppressed.

The card-feed and card-sensing design presented the weightiest problems because, in evolving them, it was essential to consider constantly the possibility of off-punched cards. These have always been a problem in sensing. It was desired to increase the tolerable limits of off-punching to an optimum.

Card Feed

The input bin of the card-to-tape converter stores 2,000 cards, which are fed at a cyclic rate of 470 per minute. Since two out of every eight are suppressed, the effective translation rate is 354 cards per minute.

The cards are fed endwise to a large openwork drum which carries them over a lineup of 12 photoelectric cells. The photoelectric cells read the punches, feeding their output to the translating matrix. The matrix output drives the head amplifiers, and so causes the head to record on the magnetic tape. Two cycling signals are produced at the same time: one for the read-6-suppress-2 cycle of the card feed, and the other a sprocket pulse to inspect the output of the photoelectric cells for every possible digit-position and establish the duty cycle of the recording head. At all times when cards are being fed through the senser, the center-drive motor on the tape panel moves the tape across the recording head at a continuous speed of 10 inches per second.

The input hopper is inclined 15 degrees toward the picker knife. This angle was chosen to obtain the condition whereby cards would slide to the picker knife of their own weight, and yet not load the end of the hopper with the full weight of the 2,000 cards. To overcome any possible warp in the cards, a carriage was designed which uses a typewriter return spring to apply pressure through a plate to the top of the stack.

A latch arrangement, operated by a magnet, controls the feed mechanism. Pulsing of the magnet causes the cards to feed; no pulse is provided during the suppress-2 part of the feed cycle. The system is consequently fail-safe.

The picker knife strips a card from the bottom of the deck and pushes it into the inject roller system. The inject rollers carry the card 6.375 inches and introduce it to a drum which is 30 inches in circumference. The rollers turn at a high rate of speed, and a considerable amount of experimentation went into finding the proper material to withstand the combined effects of speed, tension, and heat.

Reading Drum

The drum is geared to the inject rollers at a ratio slightly less than one, so that the card hits the drum stop at a higher speed than that of the drum. The card buckles because of the difference in speed. The act of buckling causes the card to be forced against the forward card stop. Another set of friction drives keeps the card on the drum after it leaves the inject rollers.

When the card has traveled on the
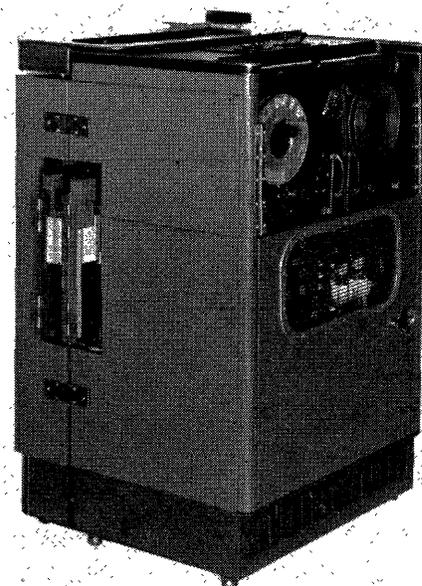
Figure 1. Card-to-tape converter

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drum far enough to conform to its circumference, the forward stop, operating from its cam, moves rearward. This forces the card against a rear fixed, stop, trapping the card and locating it accurately lengthwise. It is fixed widthwise by two rings around the circumference of the drum, between which the card is forced when it enters the drum.

The drum itself is openwork, consisting of narrow rings which fit between the card rows so as not to block light through the punches. There are three card positions equally spaced around its circumference. The spaces between the card positions are solid, except for a slot in the sixth row which extends one column-position ahead of column 1. This slot, with an associated gate circuit, is referred to as the leading edge detector. Its purpose is to disable the reading circuits if there is no card present. The channel 6 photoelectric cell, alerted during 'column 0' time, reads light if no card is present and locks the other photoelectric-cell circuits. No-card condition is detected as a misfeed except during the suppress-2 part of the feed cycle.

Reading Procedure

The photoelectric cells, which are rigidly mounted in a block, are too large to be placed in a row corresponding to the dimensions of a card row. They are therefore stacked in two alternate layers. All holes are blackened inside to prevent spurious reflections.

Light is obtained from two headlight bulbs mounted inside the drum. The light is collimated by two sets of condenser lenses. The two lamps are adjustable for maximum light on the photoelectric cells, and with respect to the lenses.

In order to decrease photoelectric-cell variation caused by temperature shift heaters were placed inside the photoelectric-cell block, and the heaters were regulated with thermostats and blowers. In addition, a special amplifier chassis was built which contains individual pots for each photoelectric cell, with a switch connecting each cell to a common meter for checking purposes. By regulating the light source and photoelectric-cell output, and by rigidly fixing the card on the drum, the essential features of the off-punch tolerance were determined.

Off-Punch Tolerance

The maximum lengthwise tolerance aimed at was ±0.043 inch. This figure was established because it is one-half the "period" of the punch-no-punch cycle: punched holes are 0.055 inch wide separated by a space 0.032 inch wide, or a total of 0.087 inch, half of which is 0.043. A hole off-punched by more than this figure actually would be in another column, and would be unreadable by any means.

One of the essential decisions in designing this tolerance into the system was to probe the photoelectric cell output at some time fixed in relation to the movement of the card, and so adjust the output that the probe would respond properly, not only at the point where a perfect punching would occur, but also at any point up to half the period on either side. In these circumstances, a pulse-envelope output from the photoelectric cells becomes desirable, since this makes the probing problem even simpler: a steady-state signal, caused by punchings in every possible position, can be inspected at any point and still provide the same answer.

This means, of course, that the light-admitting slit had to be at least so wide that as one punch of a continual series left the slit, another was already entering.

On the other hand, the worst condition, for inspecting purposes, is that in which punches occur in alternate positions. Here the slit should be only wide enough that the output is symmetrical; any imbalance would discriminate against the shorter alternation.

Figure 2 shows the photoelectric-cell block of the card-to-tape converter. Notice that the long dimension of each slit reads the short dimension of the punched hole. The slit is as long as the width of one hole plus one space between holes. In thus placing the reading slit perpendicular to the punched hole, we have permitted lateral off-punchings (in the long dimension of the hole) of half the length of the hole plus half the width of the slit, or 0.080 inch.

However, tolerance of off-punchings lengthwise to the card was not so simple to establish, since it involved consideration of time as related to movement of the card lengthwise.

In Figure 3, a card containing successive punches is shown, with its output wave form. This illustrates the relationship between slit and punched hole which permits a steady-state signal: the hole on the right is just beginning to leave the slit, but that on the left is about to enter it. The amount of light admitted to the photoelectric cell remains constant.

· For a 50-50 duty cycle, moreover, this slit will produce a symmetrical output, as indicated in Figure 4. Here the right-hand punching has completely left the slit, and no light is being admitted to the photoelectric cell. The card will travel 0.032 inch before the left-hand hole will start to admit light. This gives a rise
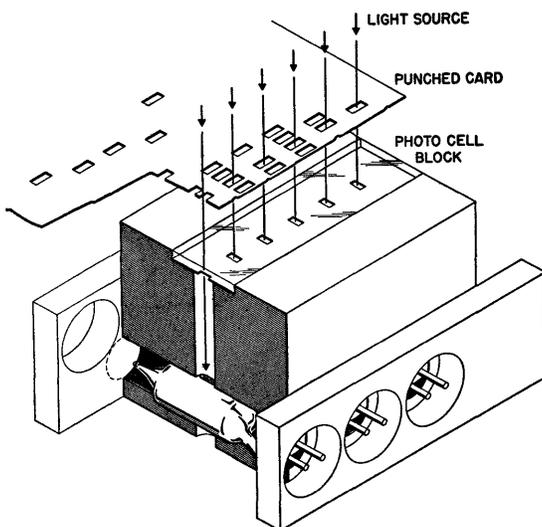

Figure 2 (left). Photoelectric cell block


SUCCESSIVE PUNCHES
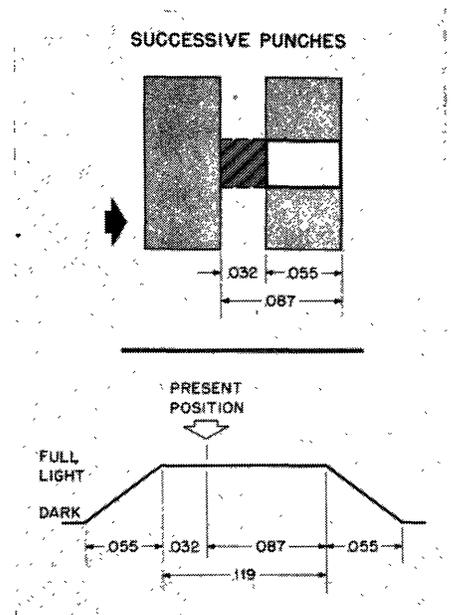
Figure 3 (right). Successive punches
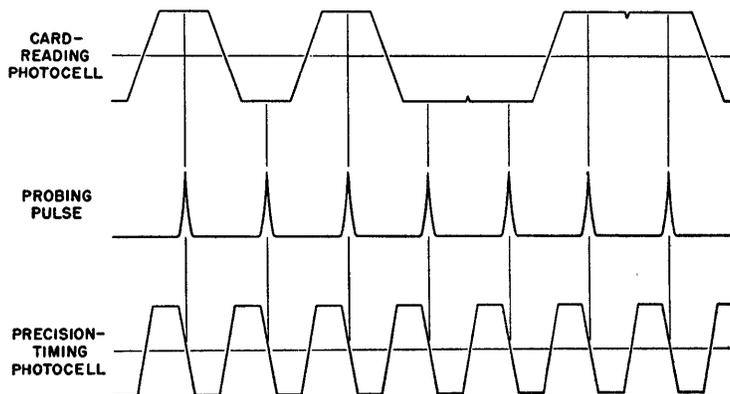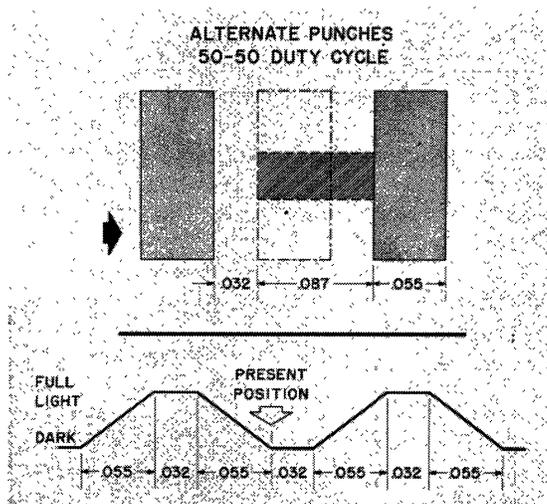
Figure 4 (left). Alternate punch—50-50 cycle

Figure 5 (above). Precision timing photoelectric cell

or fall time equal in any case to the width of a punched hole, and a duration at maximum or minimum equal to the space between punchings. The dimensions on the illustrations are spatial, but are equivalent to temporal dimensions, since the card is transported at constant speed.

The output of each photoelectric cell is fed to the screen grid of an associated read thyratron in the translating matrix. A critical relationship is established between photoelectric-cell output and thyratron: the bottom level of the wave form is clamped well below the thyratron cathode potential and, by a potentiometer adjustment of the output amplitude, the half-light point is set at the potential, which with proper control grid signal, will cause the thyratron to fire.

In the meantime, a probing pulse is applied to the control grids of all 12 read thyratrons simultaneously. The timing of the probe pulse, illustrated in Figure 5, is such that it coincides with the center point of the output wave form from a perfectly punched card. If the probe arrives at an extinguished thyratron at any point when the screen signal is below half-light, the thyratron remains extinguished. If the screen signal is above half-light potential, the tube fires and continues conducting until the thyratrons are cleared. The clear signal is generated at the end of each possible digit time by a monostable trigger pair, which functions as a delay flop and is triggered by the timing pulse.

Since the screen voltage which will fire the thyratron is the half-light level, the probe pulse can occur any time between half-light points and still read the photoelectric-cell output correctly. In terms of off-punching, this means that the punched hole may occur 0.043 inch, half its period, on either side of its correct position without misinterpretation.

The aforementioned probe pulse, shown in Figure 5, is generated by a timing photoelectric cell which is triggered by a comblike arrangement of slots around the periphery of the drum. The output of this photoelectric cell is applied to a class A amplifier the operating point of which is rigidly controlled. In this way the level around which the output of the amplifier varies is not affected by any change in the amplitude of the input. Fixing the operating point in this manner effects a fine control of time in terms of phase when the amplifier output is differentiated. The positive pulse resulting from the differentiation is the probing pulse applied to the read thyratrons.

A perfectly punched card, with holes in alternate positions of one row, is used in mounting and adjusting the combs which trigger the timing photoelectric cell. An oscilloscope relates the output of the card-reading photoelectric cell to the signal from the timing photoelectric cell.

When the trailing edge of the timing wave form and the positive probe pulses are centered with both maxima and minima of the card output, the comb is properly adjusted; compare Figure 5.

Recording

The digit or symbol set up in the 12 read thyratrons is translated into eight output lines driven by eight write thyratrons. Each of these drives one channel of the recording head, which is the standard head used throughout the Univac system. During all the time that the card-feed counter is operating, tape is transported at the rate of 10 inches per second across the head. No stepping device is needed, since no erasing operation is necessary, and however random digits may be on the tape, Uniservo* can

* Reg. U. S. Pat. Off.

still read them.

However, a 50-50 duty cycle of record and clear for the write thyratrons is established by a monostable trigger pair, used as a delay flop and triggered by the timing photoelectric cell. After the digit has been set up in the write thyratrons, the delay flop allows them to write for 50 per cent of the cycle, and then clears them to receive the next encoded combination. In this fashion the pulse pattern is inscribed on the tape.

Mispunch Detection

Checking is accomplished by inspecting the punched input through detection circuits operating from the alphabetical-numerical switch. If the cards are known to have purely numerical data on them, the numerical position of the switch causes the detection circuits to record the existence of two or more punches in the same column. If the data contain alphabetical material, the alphabetical position of the switch causes the circuits to record the existence of more than one punch in either the zone indicator or the numerical section of the column.

Whenever such meaningless combinations occur, the converter records a standard symbol in the position of the erroneous digit and records the same symbol as a sentinel in the 120th digit position of that blockette. The central computer is given the task of making the most of the situation. Any program operating on data converted from punched cards is designed to cover such mis-punchings.

Ejection

After the card has been picked up, injected, checked, sensed and the data

recorded, the forward card stop, under the control of its cam, opens. The curvature of the card around the drum causes the card, when released from the stop, to snap sharply against a set of guides which lead to the eject rollers. The eject rollers transport the card to the receiving magazine, which is spring-loaded, and which contains a shut-off switch in series with the feed latch magnet. When the bin is full, the switch opens, the latch is de-energized, and further card feed is prevented.

The product of the converter is a tape recorded in Univac code, with six blockettes of digits forming one block. Each blockette contains 80 useful digits and 40 ignore symbols. Each block is separated from its neighbor by 2.4 inches of tape, the space required for proper Uniservo operation.

Discussion

R. D. Bronson (Consolidated Vultee Aircraft): Will you give us the pros and cons on metallic recording tape as opposed to paper or plastic tape?

And will you tell us how long have you been using it?

Mr. Blumenthal: We believe our metal tape will last indefinitely. In our opinion, the long-term storage capabilities of plastic tape are not sufficiently well known. Even though we are working on plastic tape, we have not tried as yet to evaluate its worth in the computer system. It is probably acceptable for short-term use, but we would not recommend plastic tape, for example, to store a vast amount of data, which had been converted from punched cards, in the form of magnetic tape.

It was used on the first Univac tested, and has been in use as long as I have been with Eckert-Mauchly, which goes back to 1948. I do not know the exact date.

J. E. Carrico (Arthur Andersen and Company): What is the anticipated speed of the new card-to-tape converter?

Mr. Blumenthal: The minimum speed of the machine will be 200 cards per minute. It might run faster than that and, possibly, compare well with the present card-to-tape converter.

Converters Between Teletype Tape and IBM Cards

GLEN F. NIELSEN

THE purpose of this paper is to present the general characteristics of the International Business Machines Corporation's (IBM) type-63 card-controlled tape punch and type-43 tape-controlled card punch and to discuss how these machines can be used for the purpose of interchanging information between punched card calculating systems and machines employing Teletype tape input and output. In this discussion only presently available standard equipment will be considered.

Type-63 Card-Controlled Tape Punch

The type-63 machine consists of two main units, the card-reading unit and the tape-punching unit (Figure 1), which operate together to perform the following functions:

1. Sense information recorded in cards.

2. Analyze and convert the 12-unit card code to the 5-unit telegraphic code.

3. Punch the information into a paper

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tape at the rate of ten characters per second.

As the tape is fed out of the punching unit it is wound on the take-up reel. Since normal practice involves feeding the tape from the center of the roll on subsequent operations, no provision is made for rewinding the tape.

The inclusion of a pluggable control panel on the type-63 machine makes it extremely versatile. However, since the primary function of the machine is to produce tape which can be used to operate printing telegraph equipment, certain automatic functions have been built into it. If tapes are to be prepared for use with computers, an understanding of these automatic functions is essential. A brief description of the tape required to operate printing telegraph machines, hence the tape produced by the type 63, will serve to clarify this subject.

As illustrated in Table I, holes are perforated across the width of the tape and are used singly or in combination to represent characters or functions. There are 26 character codes and five functional codes. The functional codes represent operations on printing telegraph equipment such as space, carriage return (CR), line feed (LF), letters shift (LTRS), and figures shift (FIGS). The character codes represent all letters, digits, and special characters such as punctuation marks. Since there are only 31 possible punching combinations (blank columns in the tape are not used) each letter, digit, and special character cannot be represented by a unique combination. Therefore, a shift of the type basket (or platen) on printing telegraph machines must be effected in order to make dual use

Table I. Type 43 Tape-Controlled Card Punch

Character or Function	Telegraph Tape Code Tracks					Character or Function	Telegraph Tape Code Tracks				
	1	2	3	4	5		1	2	3	4	5
A	1	1	0	0	0	Q-1	1	1	1	0	1
B	1	0	0	1	1	R-4	0	1	0	1	0
C	0	1	1	1	0	S	1	0	1	0	0
D	1	0	0	1	0	T-5	0	0	0	0	1
E-3	1	0	0	0	0	U-7	1	1	1	0	0
F	1	0	1	1	0	V	0	1	1	1	1
G	0	1	0	1	1	W-2	1	1	0	0	1
H	0	0	1	0	1	X	1	0	1	1	1
I-8	0	1	1	0	0	Y-6	1	0	1	0	1
J	1	1	0	1	0	Z	1	0	0	0	1
K	1	1	1	1	1	LTRS	1	1	1	1	1
L	0	1	0	0	1	FIGS	1	1	0	1	1
M	0	0	1	1	1	LF	0	1	0	0	0
N	0	0	1	1	0	Space	0	0	1	0	0
O-9	0	0	0	1	1	CR	0	0	0	1	0
P-0	0	1	1	0	1						

The 1's and 0's are used in the code chart to indicate the presence and absence respectively of holes in the particular tape tracks.
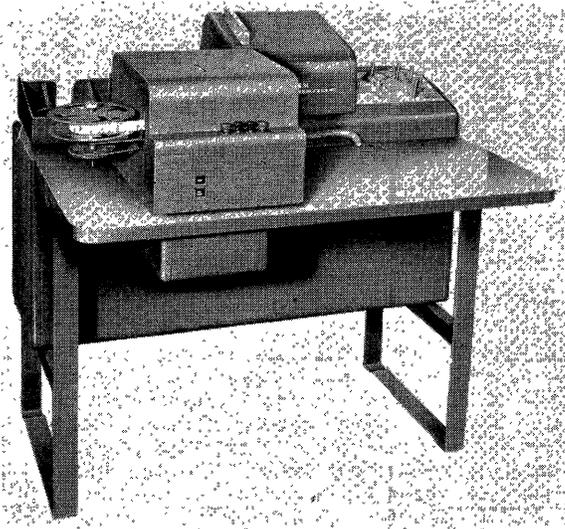
**Figure 1 (left). Type-63 card-controlled tape punch**
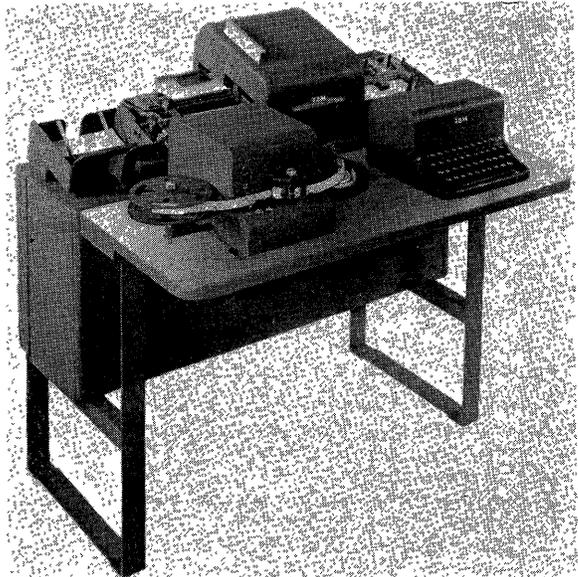
Figure 2 (right). Computer input tape prepared automatically from punched cards on the type 63

of some of the type bars. This shift is accomplished by means of the LTRS shift code or the FIGS shift code in the tape. Thus a 1 punch in the tape is interpreted as a digit 3 if it is preceded by a FIGS code and as a letter E if preceded by a LTRS code. It is not necessary, however, to precede each character with a LTRS or FIGS code. Generally speaking, one FIGS code in the tape is sufficient for all figures that follow until a letter is encountered. When a FIGS code precedes a letter code such as A or B, such a code is called a Figures A or Figures B. These codes are used for

Table II. Recode Chart Illustrating Schemes for Translating Decimal Information in a Card to Excess 3-Binary Representation in a Telegraph Tape

Cards Punched Automatically on Type 43 from a Computer Output Tape. The Type 63 can be Wired so that a 1 in the Card is Translated to a Space Code in the Tape, 2 to S, and so forth

Decimal Digit	Excess 3 Binary No.	Telegraph Character	Telegraph Code
Tracks 1-2-3-4 utilized for recording information			
0	0 0 1 1	A	2 1
1	0 1 0 0	Space	3
2	0 1 0 1	S	3 1
3	0 1 1 0	8-I	3 2
4	0 1 1 1	7-U	3 2 1
5	1 0 0 0	C.R	4
6	1 0 0 1	D	4 1
7	1 0 1 0	4-R	4 2
8	1 0 1 1	J	4 2 1
9	1 1 0 0	N	4 3
Tracks 1-2-3-5 utilized for recording information			
0	0 0 1 1	A	2 1
1	0 1 0 0	Space	3
2	0 1 0 1	S	3 1
3	0 1 1 0	8-I	3 2
4	0 1 1 1	7-U	3 2 1
5	1 0 0 0	5-T	5
6	1 0 0 1	Z	5 1
7	1 0 1 0	L	5 2
8	1 0 1 1	2-W	5 2 1
9	1 1 0 0	H	5 3

punctuation marks, fractions, and special functions.

As a result of the foregoing requirements, the type-63 machine automatically punches the FIGS code in the tape:

1. At the beginning of every card where the first character sensed is a digit or space.

2. At any time that the characters being sensed change from letters to digits.

3. Preceding a digit code which follows one or more spaces.

4. Following a Figures G code or CR code if the next code sensed is a digit or space.

In like manner, it automatically punches a LTRS code in the tape:

1. At the beginning of every card where the first character sensed is a letter.

2. At any time the characters being sensed change from digits to letters.

3. Following the Figures G code or CR code if the next card code sensed is a letter.

With the exception of these conditions, all other punching, as well as most of the control functions, is completely controlled by wiring on the pluggable control panel.[1] As the card advances column for column through the sensing station, the information sensed from the card is analyzed and punched in the tape being fed through the tape punch unit. Therefore, the sequence of information in the card must be the same as that desired in the tape although unwanted fields in the card may be skipped and additional information inserted by control panel wiring. For alphabetic characters, digits, or spaces, the card and the tape advance column for column. When it is necessary to insert a shift code in the tape (in accordance with the previously listed conditions), the card remains stationary while the tape unit completes the extra

punch cycle. The tape unit stops during skipping of information on the card and also while the card is released and a new one automatically fed.

By control panel wiring, information in any column or columns of the card may cause punching of any of the 31 possible tape codes. This is accomplished by the provision of a group of hubs on the control panel labeled "From Card." Hence when a 7 punch is sensed in the card an impulse is available at the 7 from-card hub. Another set of 31 hubs labeled "To Tape" is also provided. The "7 impulse" may be wired to any of these to-tape hubs. If for example, it were wired to the Figures L to-tape hub, then all 7's read in the card would result in punching a 2 and a 5 bit in the tape. In a similar manner the from-card hubs for the other digits may be wired to any desired to-tape hubs. From the foregoing it is obvious that the type 63 is capable of punching information in the tape in codes other than the conventional telegraph code. This subject of recoding will be covered in more detail later.

Type-43 Tape-Controlled Card Punch

The type-43 machine consists of three main units: the card-punch unit, the tape-reading unit, and the keyboard unit; see Figure 2.

The keyboard is an optional feature and is both moveable and removable. Its function is to provide for manual punching in a card, and it can be used concurrently with the tape reader or independently.

The card-punch unit and the tape-reading unit operate together to perform the following functions:

1. Sense the code perforations in the tape.

2. Analyze and convert the code perforations of the tape into the conventional IBM 12-unit code.

3. Punch the information into a card which in turn may be used in other punched-card machines.

Of the five previously mentioned functional telegraph codes only two are utilized to perform specific functions in the type-*43* machine. The LTRS code sets up circuits to cause succeeding tape codes to be interpreted as letters. In like manner, the FIGS code conditions the machine to interpret succeeding tape codes as figures. The space, LF, and CR codes in the tape can be translated to punch any desired card code but do not control any internal circuitry in the machine.

Information is punched in the card as the tape advances through the tape reader. (Note that the tape is fed to the reader from the center of the roll.) Therefore, the sequence of the information in the tape must be the same as that desired in the card although card columns can be skipped and additional information inserted between fields of information received from the tape. For alphabetic, numerical, and space code perforations the tape reader and punch units advance in step. During the reading of the shift codes, the tape reader advances one column of the tape but the punch unit remains stationary. During the time the card-punch rack is skipping or during duplicating operations, the card advances one or more columns while the tape reader remains latched up. The tape reader can further be controlled to stop while card punching continues. This permits gang punching information wired on the control panel, or duplicating from a master card, as well as interspersed key punching.

All machine operations[2] are under control of the pluggable control panel. By control panel wiring it is possible to check each card to determine that the card and tape are in step. More will be said about this feature later. Tape-reading and card-punching speeds are approximately ten columns per second.

Application of the Type-43 and Type-63 Machines

To see more clearly what is involved in preparing an input tape for a computer from punched cards and converting the results on the output tape to punched cards, consider the following hypothetical problem:

A deck of cards, each containing two 8-decimal digit numbers not in adjacent fields, is to be converted to tape. The decimal digits are to be punched in the tape as excess 3 binary numbers in successive columns of the tape. Results are recorded on the output tape of the computer in a similar manner and in the interests of simplicity it is assumed that they consist of a series of 8-decimal digit numbers. Each number is to be recorded on a separate card.

In the preparation of the input tape starting with a blank roll of tape it is necessary to run in a short length into the tape punch. This is accomplished, after manually threading the tape, by depression of the tape feed button. Depression of this button advances the tape through the punch and causes a series of consecutive LTRS shift codes to be punched. With the tape in position the first card can be fed to the sensing station and by control panel wiring it can be controlled to skip to the first desired column of the card. The first character is read and the machine determines that it is numerical, hence punches a FIGS shift code in the tape. Following this punch cycle the character itself causes punching of any desired code combination in the tape. Table II shows the codes to be punched by each digit if the digits are to be recorded as excess 3 binary numbers utilizing tape punching positions 1, 2, 3, and 4. For example, a zero in the card would be wired on the control panel to punch the telegraph code for an "A." Successive digits read from the card will cause punching of the codes as indicated in the Table. Note that once the machine is in 'figures case' it will remain so until the card is ejected. An exception to this occurs when a digit 5 is read and translated to punch the CR code—a 4 bit in the tape. Punching of the CR code automatically drops the type *63* out of figures case. When the digit following the 5 is read, the machine will again punch a FIGS code. It is possible to avoid this condition by utilizing tape tracks 1, 2, 3, and 5, which of course obviates the necessity of using the CR code. Table II also shows the codes to be punched by each digit to record them as excess 3 binary numbers utilizing tracks 1, 2, 3, and 5 in the tape. This scheme has an added advantage in that the LTRS and FIGS codes are the only ones that have a 4 bit in the tape, hence can easily be recognized by a computer. Figure 3 shows two cards and the tape that can be made from those cards.

The foregoing discussion assumes that the computer is a decimal machine. It seems equally appropriate to consider the preparation of input tapes for a binary machine. One comparatively simple method that may be employed is first to punch the data in decimal form in cards. Conventional punched-card calculators can then be used to convert the numbers from decimal to octal. Once the information is in octal notation in the card it is obvious that the type *63* can readily convert the data to binary form in the tape utilizing three tracks for recording successive three binary bit groups. This method should prove to be fast, accurate, and economical.

From the foregoing it is evident that if a type *63* is used for preparing the input tape then the computer must be able to recognize LTRS and FIGS codes and either to ignore such codes or use them for controlling internal switching at the beginning of each block of data. Also it is not possible to leave blank spaces in the


Figure 3. Computer input tape prepared automatically from punched cards on the type 063

Figure 4 (left). Cards punched automatically on type 43 from a computer output tape


Figure 5 (right). Locations of information holes with respect to feed holes

tape if it is made on type *63* and, in fact, the machine will stop if a column on the tape is not punched with some code.

Fewer problems are encountered in preparing the output tape on the computer for subsequent conversion to cards on the type-*43* machine. The only requirement is that a series of FIGS codes be punched in the beginning of the tape to provide for proper automatic run-in operation. LTRS codes could be used provided a FIGS codes is punched immediately preceding the first digit code in the tape. One FIGS code at the beginning of the tape is all that is required since the machine will remain in figures case with no exceptions unless a LTRS code is read from the tape. It is, of course, entirely practical to precede each 8-digit number on the tape with a FIGS code. Actually it is possible manually to set the tape in position to read the first character, and since the type *43* is normally in figures case, no FIGS codes are necessary.

It may be desirable to allocate one column at the beginning of each number on the tape for algebraic sign. If this is done, the codes used for sign indication may be recorded to punch or not punch an X in any desired card column. Such an indication for signs could also be used as a means of checking by control panel wiring to insure that the card and tape are in step. Figure 4 illustrates a section of output tape and the cards that can be made from this tape. Conversion from binary to octal can, of course, be accomplished if the tape is punched in the form previously mentioned.

Tape Characteristics

The tape-punching mechanism of the type *63* is designed, as previously men-

tioned, to produce tape for use with telegraph equipment. The tape itself is an oil-impregnated paper, 11/16 inch in width and 0.003 inch in thickness. While the supply reel will accommodate a full roll of tape 8 inches in diameter (1,000 feet), the take-up reel will not. Figure 5 illustrates the relationship between the information holes in the tape and the feed holes. Further as indicated in Figure 5, it is possible by a simple adjustment of tape guide plates to feed tapes up to 1 inch in width through the punching mechanism. Only five tracks may be punched, however, and the location of the holes relative to the lower edge of the tape must be as shown in Figure 5.

In the author's opinion, the tape described is not entirely suitable for photoelectric reading because of its poor opacity. Presumably the type *63* can handle other kinds of paper tape but some laboratory testing would be required to determine definitely whether a particular tape is suitable.

Conclusion

In the applications just described, the objective was to indicate some of the potentialities and to point out the few limitations of the types-*43* and -*63* machines. While it may be bothersome, the limitations must be taken into account when it is decided to use the types-*43* and -*63* machines as connecting links between two systems utilizing different input-output mediums.

If, however, the associated problems are faced realistically, the machines discussed provide an economical, fast, and accurate means of interchanging information between punched-card calculating systems and machines utilizing perforated-tape

input and output. Apart from the obvious advantages of linking two systems, there are two other advantages to be gained from use of the types *63* and *43*.

In manual preparation of input tapes the problem of correcting errors in the tape is always present. It is a considerably easier procedure to punch the data manually in cards, verify the cards, and, if errors are detected, repunch a few new cards. Such a procedure insures that the information ultimately recorded in a tape is error free.

Finally, another problem arises when it is necessary to make a copy of a tape and incorporate a few minor changes. This situation frequently occurs if a Teletype tape is used to control a machine's sequence of operations. It is an extremely laborious task to punch an entirely new program tape manually if only a few items are to be changed. Maintaining the program on a deck of cards is a highly practical solution to this problem, since modifying a program then requires changing only a few cards and punching a new tape automatically on the type *63*.

References

1. PRINCIPLES OF OPERATION—TYPE 63 CARD-CONTROLLED TAPE PUNCH, Form Number *22-5997-1*, International Business Machines Corporation, New York, N. Y.

2. PRINCIPLES OF OPERATION—Type 43 TAPE-CONTROLLED CARD PUNCH. Form Number *22-5691-1*, International Business Machines Corporation, New York, N. Y.

Discussion

Theodore Shapin, Jr. (University of Illinois): Our machinery interprets a sprocket hole only in the Teletype code as the decimal digit zero. How much of a modification would have to be made to your standard machines to handle this?

Mr. Nielsen: While this gets into the matter of company policy, I must admit it is a very minor modification. I suggest that you take your problem to your nearest IBM office where they can handle it directly.

Devices for Transporting the Recording Mediums

R. L. SNYDER

THE large-scale digital computers now in use have demonstrated that efficient operation of their internal elements can be maintained in a manner satisfactory to the users. They have also shown great versatility in the problems to which they can be applied. As a result, a demand for such devices has been spread from among scientific laboratories through industry, commerce, and government, for their application to a myriad of purposes. In most cases, the requirements of the problems can be accommodated by any of the general-purpose machines and in many instances more specialized, less elaborate units can be used. Almost all installations require that a means be provided for keeping information in a latent form which can be recorded and reproduced by automatic mechanisms, under the control of the machine, for introducing input and absorbing output information, and for storing data too voluminous to be kept in the machine's high-speed internal memory.

Many factors enter into the choice of the latent information storage mediums and of the type of mechanisms used in manipulating it. The purpose for which the installation is used is, of course, of primary importance. This will determine whether high handling speeds are necessary in the input, output, or intermediate equipment. Usually, the input data are relatively small, so that speed at this point is not essential. The output data may only amount to a yes-or-no answer, in which case a simple indicator is all that is needed, but usually the output is very extensive and high speeds are needed. If intermediate storage is necessary, it is because the information in the problems is too abundant to be contained in the machine's internal memory. Therefore, it may be assumed that fast operation should be provided. Frequently, when intermediate storage of information is required, the same type of equipment and often the identical devices are used for all three functions. Occasionally, a computing system is used in an

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establishment where much of the data processed by the machine have been accumulated in the past and are kept in such a form that they can be automatically interpreted. In this circumstance, it may be advantageous to have an input device of a type which will accommodate existing records. A second input device which can handle a more desirable type of record may be included in the system and the first input unit discarded after the old records have been processed or transcribed.

Other considerations determining the choice of record material and transport devices are the necessity for visual inspection of the records, the ability to reinscribe automatically an old record with new information, the type of computer to be served, the availability of devices already in use which may fulfill the requirement, and the time schedule which must be kept in completing the system, and, not the least important, the ingenuity of the designers.

In all designs, the method of handling latent information must be reliable and accurate. Reliability is necessary because frequent breakdowns cause lost computing time and require the provision of a greater number of maintenance people than would otherwise be needed. High frequency of failure also makes the maintenance of other parts of the system difficult. The degree of accuracy in operation required of these devices is such as to discourage a designer at the outset. If confusion of information occurs more often than once in 100,000 operations, the system will be practically useless. Satisfactory performance requires an error no

Figure 1. Perforated tape-handling devices used for input, output, and intermediate storage by the Bell relay computer, Aberdeen Proving Ground

more frequently than one in 10^6 to 10^7 operations.

Simplicity and convenience in operation are highly desirable to reduce the effort of mathematicians or other personnel using the system. It should be remembered that the efficiency of operation of an installation suffers as much if a computer is improperly operated for a day because of misunderstanding as it does if the machine is out of order for a day. Indeed, time wasted in this way is more costly than computer breakdown because it wastes the effort of the mathematicians and users as well as that of the technical personnel. Simplicity of operation is also desirable because the personnel, particularly where scientific computations are involved, usually changes frequently, and ease of instruction in itself saves time at the outset and enables an infrequent user to operate efficiently without instruction after a long absence.

Philosophy of Recording

In all systems of mechanized record keeping, wherein information is extracted from the recording mediums without human interpretation, it is recorded in a yes-or-no form. For example, if numbers are to be represented in decimal form, it is done by providing a particular character position with space for ten choices. Then to record, one of these spaces is marked or punched. The reading device then scans the position and finds that all but one of the choices are not marked and are therefore 'no,' the one choice which is marked indicating "yes." This system is common among card-handling devices where each position is provided with a column of characters ranging from zero to nine, and a hole is punched through one of the characters. Such a system provides a record that is easily interpreted by humans, but is somewhat wasteful of recording space and time.

Most efficient use of the recording medium can be made if the less familiar binary notation is used. In this system,
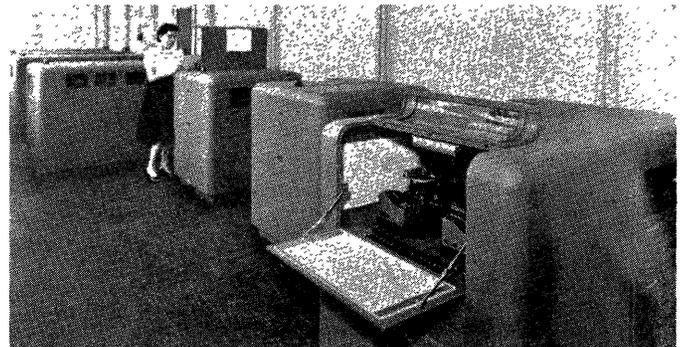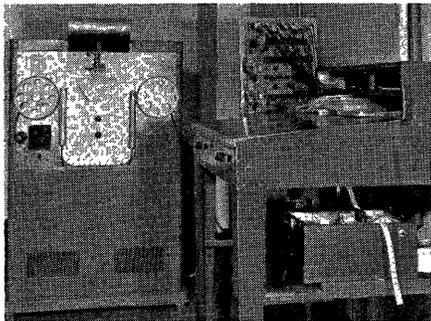
Figure 2. High-speed photoelectric tape reader and telegraph perforator used with EDVAC at Aberdeen Proving Ground

the numbers are the summation of combinations of different powers of two, whereas decimal numbers are the summation of constants, each of which is multiplied by a different power of ten. Binary notation, therefore, requires, only an indication as to whether or not a particular power of two or digit-position is to be counted in the summation. An example of the convenience of binary notation is found in the magnetic recording of digital information on wire. The information is stored in adjacent segments of the wire which form very small permanent magnets whose poles are displaced from one another longitudinally. Each elemental magnet following a characteristic marker, designating the beginning of a word (usually an unmagnetized section of the wire), represents a power of two or digit-position in the number. Whether or not a digit is to be counted in the summation is determined by the order in which the poles occur. If north precedes south, the element may represent one and if south precedes north, the element then represents a zero.

The relative efficiency of use of storage space of the binary notation over decimal notation used in mechanized record-keeping devices can be demonstrated by

comparing the number of choice spaces required to hold a number which can have any one of a thousand values. A decimal number will require three sets of ten choice spaces, whereas a binary number with a slightly greater range of values can be accommodated in ten spaces.

The simplicity and efficiency of binary notation is, however, offset to a considerable degree by its unfamiliarity and an inherent occular difficulty in reading of binary numbers by humans. Furthermore, the mechanization of conversion of decimal notation to binary, and conversely, requires arithmetic operations which involve expensive equipment, if a converter is used, or appreciable computing time and memory space in the computer if the conversion is carried out by a program in the computer.

There are, however, several kinds of notations which effect a compromise between the two extremes of efficiency and ease of interpretation. These can be exemplified by a discussion of binary coded decimal notation. It may be mentioned that a choice of two combinations can be had from one binary yes-or-no element, sometimes called a bit, four combinations from two such elements, eight from three, and 16 from four bits. Therefore, a decimal character having only ten possible values can be represented by four binary digits. So, to store any one of a thousand combinations, this system would require 12 elements. Although this notation is not as easy for humans to read as decimal numbers, it is much less difficult than is binary. Conversion between decimal and binary coded decimal information is quite easy technically, requiring only a simple matrix device. These systems are used extensively with tape records. For example, paper tapes may be arranged to have holes perforated in rows which are perpendicular to the length of the tape.

Figure 4. Card and tabulating equipment associated with ENIAC at Aberdeen Proving Ground

The holes are made by a group of four or more electrically driven punches operating in concert so that all of the information in each row is punched and may be read simultaneously. Such records are not difficult to interpret visually because each character lies in one position along the length of the tape.

It should be noted that most tapes accommodate more than four holes because most perforated-tape-handling equipment has been designed for communication service in which it is necessary to process alphameric information. Usually, if only numbers are to be recorded, such spare hole spaces are used for redundant checking. This is done when five hole spaces are available by punching the fifth space if, and only if, an even number of holes is
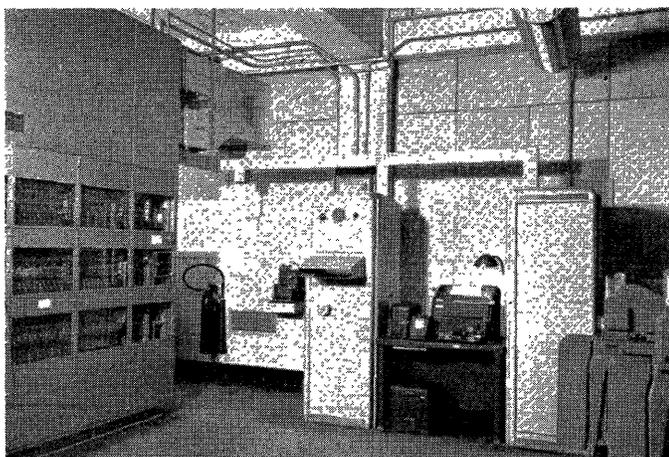
Figure 3 (left). ORDVAC with perforated tape-handling device in central background, and card-handling equipment at extreme right
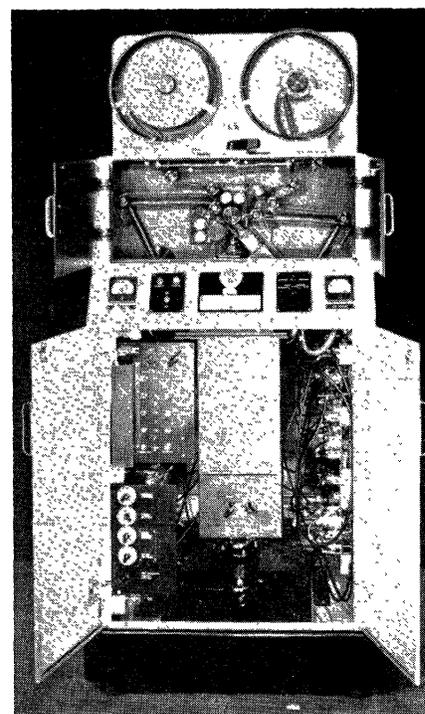
Figure 5 (right). Photographic input and output device

Courtesy Eastman Kodak Company

Snyder—Devices for Transporting the Recording Mediums
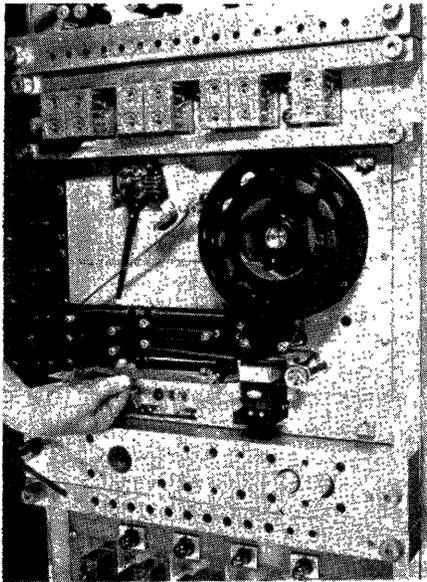
Courtesy Raytheon Manufacturing Company
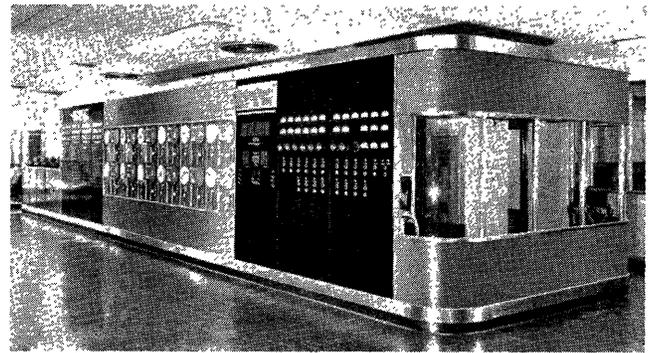
present in the four binary coded decimal spaces. When such a symbol is later read from the tape, a special circuit indicates an error if there is not an odd number of holes. Usually, there is also a circuit which will produce an error alarm if the binary value of a character is outside the decimal range.

In addition, a count may be made to ensure that each word or group of symbols has the correct number of characters. In some instances, particularly when magnetic tape is used as the recording medium the complement as well as the number is recorded and must be correctly reproduced, otherwise an error halt is effected. It has been proposed that triple recording be used and the system arranged to accept a number if two of the three records agree, so that fewer error halts will be experienced.

The method and degree of checking are of considerable importance in the design of latent-information-handling devices because the equipment, information storage capacity, time of operation, and maintenance requirements are all increased by these measures. These considerations are of particular moment in the development of magnetic-tape equipment because the reliability of these systems decreases with increases in the density of recording. So much checking may be required by dense recording that even more tape will be needed for closely packed information than for more conservative signal spacing.

The two exceptions to the use of yes-or-no notation in recording computer information are in the keyboarding or preparation of input information and the presentation of the printed output. In keyboarding, conventional symbols are present on the keyboard for the operator to see. The depression of a key causes a binary coded symbol corresponding to the character to be registered on the input medium. In the printing operation, ordinary symbols are recorded on paper by some form of automatic typewriter. Such devices are controlled from yes-or-no binary coded signals, either directly from the computer or from transcribing equipment extracting information from the recording medium used in the other operations described.

To provide a clearer understanding of how the principles discussed in the foregoing may be applied, some examples of each of those now in use are presented in the following.

Perforated Tapes

Perforated tapes have long been used by the telegraph systems for storing alphameric information relating to commerce and finance at relay points in their systems. The advanced development of mechanisms for perforating and reading tape and the availability of tape-handling equipment caused its adaptation to computer use. Tape is easily handled mechanically, can be interpreted visually, and can be rapidly scanned by photoelectric devices. Unfortunately, recording by punching is very slow, standard telegraph punches are capable of perforating only a few characters per second. Some work is being carried on to develop high-speed punches, but at present the equipment available is entirely inadequate for electronic computers.

One of the first installations to use perforated tape is the Bell relay computer at Aberdeen Proving Ground, Md. Figure 1 shows the input-output and tape-processing equipment associated with this computer. Input tapes are prepared on keyboarding equipment which produces a typed copy for easy checking. These tapes, along with tape on which are re-
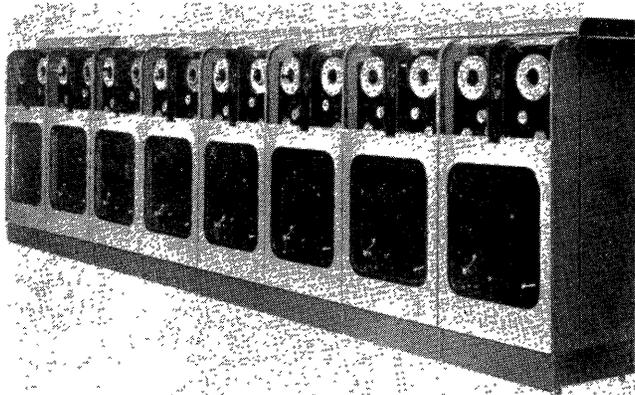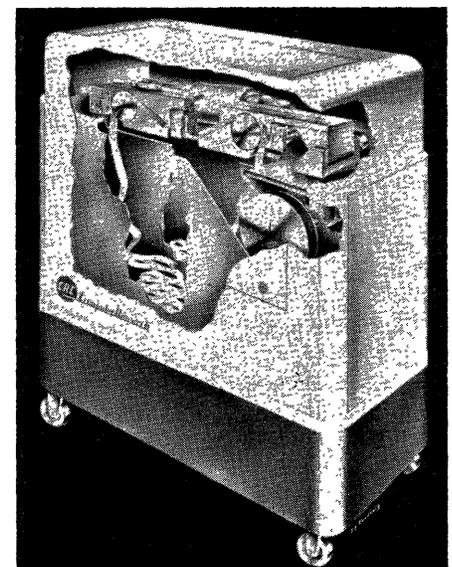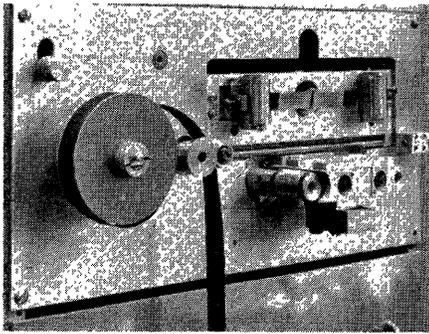
Figure 10. Mechanism of squeeze roller tape transport, Aberdeen Proving Ground

corded standard routines, are placed at their starting points in the mechanical tape reader. The mechanism then advances the tape automatically on instructions from the computing system. Output punches also automatically advance new tape from reels as needed. The tape used is a special 6-hole Teletype tape which is recorded in a biquinary code and provides redundancy for self-checking. The computer is a relay machine, so that the comparatively slow speed of about two characters per second in the tape equipment complements the deliberate pace of the calculations. This system is exceedingly reliable; few errors occur other than those caused by key punching and practically all errors are immediately detected and cause the machine to halt. The recording is performed by low-speed punches and the reading by mechanical feelers actuating contacts.

Several other perforated-tape installations have been made in high-speed computing systems. Among these are the SEAC at the National Bureau of Standards, the computer at the Institute for Advanced Study, the Ordvac built at the University of Illinois, and the Edvac recently completed at Aberdeen Proving Ground. Figure 2 shows the Edvac installation with a Western Union tape punch on the desk shelf at the lower right of the illustration, a standard telegraphic unit, and a high-speed photoelectric tape reader in the background. The former can produce about four characters per second, whereas the latter can read at the rate of 1,200 symbols per second. The punch is automatic once it has been threaded with new tape. The reader is designed for automatic operation, having servo-controlled reels and an automatic capstan; however, it is seldom used with automatic control because it is easier to pull the tape by hand than to set up the reels. The internal memory is sufficiently large to hold an extensive program and the speed of the reader is so

great that the time for pulling the tape is negligible. These shortcomings are noted because they emphasize the necessity for simplicity of operation. A tape transport mechanism which is much easier to use is shown in Figure 10. The serious unbalance of the speeds between the input and output of this system and others like it has brought about programs for the development of better recording devices.

Punched Cards

One of the means employed to obtain greater output speeds has been the installation of standard card-handling equipment. In these installations, information can be handled at rates of about 100 characters per second. These speeds are obtained by using many relatively slow electromechanical punches to perforate each card. One standard commercial card punch uses cards accommodating 80 characters perforated by 80 separate punches. This speed can be, in effect, increased by clever manipulation of the logic relating to the arrangements of the perforation patterns. Figure 3 is a picture of the Ordvac at the Ballistic Research Laboratories at Aberdeen where the original perforated-tape equipment is shown in the central background and the card-handling devices manufactured by the International Business Machines Corporation at the extreme right. The computer is shown to the left. In this installation, the perforated information patterns in the cards are made to correspond to a similar pattern in the high-speed internal electrostatic memory, so

that the meaning of the patterns can be made to conform to any logic desired. At this writing, each card is used to store 24 40-binary-digit words, wherein each word is equivalent to about 12 decimal characters. The card-handling devices operate at the speed of about 80 to 100 cards per minute so that the system is capable of transferring the equivalent of approximately 400 decimal characters per second. Cards which have been keyboarded to record input information and cards which have subroutines which may have been generated by the computer, are assembled in stacks which are placed in the reader. New cards are stacked in a hopper in the punch to receive output or intermediate information. The output cards are then run through a tabulating machine for final printing. These devices cannot be reversed to permit searching for information as can the tape equipment.

Figure 4 shows the older installation of the card-handling equipment in the Eniac system at Aberdeen Proving Ground. This is somewhat slower because the cards are used with the standard commercial notation. The card systems are very satisfactory because long development and years of experience have brought about great reliability in card mechanisms and in tabulation equipment. Furthermore, the information is at all times easily re-arranged to fit into various routines.

Photographic Recording

Another means of automatically handling information in a way that can be
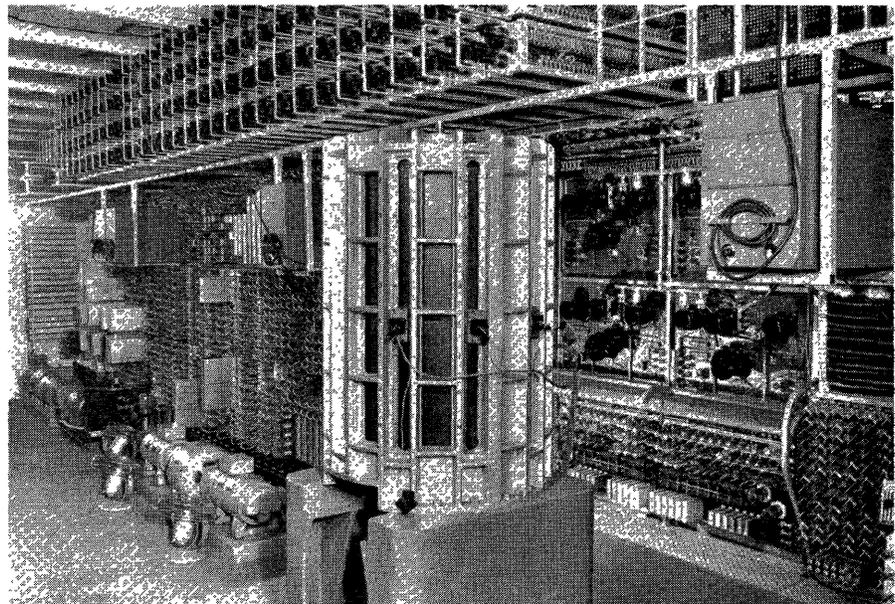
Figure 11. A magnetic memory drum associated with Mark IV computer, Harvard University

visually interpreted and at the same time handled automatically at high speeds involves photographic processes. Such a system developed at Eastman Kodak Company for "Project Whirlwind" is shown in Figure 5. This equipment uses motion picture film which is automatically exposed to patterns on the face of a cathode-ray tube for recording, and which is scanned photoelectrically for reproduction. The information is recorded in a redundant binary code which provides facilities for checking. The patterns consist of rows of dots which represent binary numbers and their complements. About 2,500 bits per square inch are accommodated. Several of these mechanisms have been made and, in themselves, performed satisfactorily. However, the time and the difficulties involved in the development of the film, and the high cost of the medium, have made it appear likely that they will not be widely used in the near future for handling coded information. Nevertheless, it appears that the development of film-handling equipment is necessary to produce mechanisms which will be required to handle information that must be stored in pictorial form.

Magnetic Tapes

From the standpoint of mechanization, probably the most versatile means of storing latent information for computers is that involving magnetic recording and reproduction. In devices of this type, the surface of the storage medium, which is composed of magnetizable material, is placed near to, or in contact with, a small electromagnet called a head, which may be energized by a pulse of electric
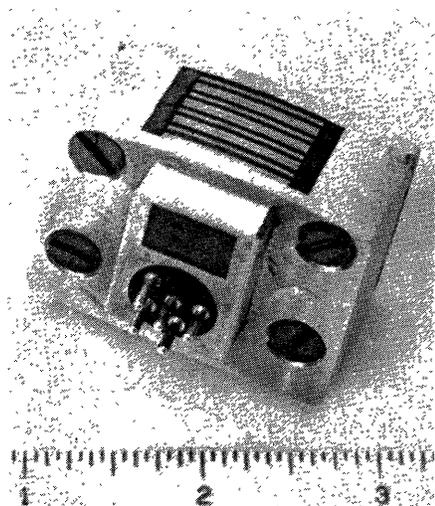
current that causes a strong magnetic field to pass in and out of an elemental area of the magnetic surface so that this area thereafter remains magnetized. The magnetized area may then be transported to some other place for storage and can later be brought under the poles of the head where the motion of the magnetized area past the poles causes a slight amount of flux to build up and subside in the core structure of the head and generate a voltage across its coil. The polarity of the field from the magnetic region is determined by the direction of the current in the recording head which is so chosen that in one direction it will represent a binary one, and in the other direction a binary zero. Usually, the poles are arranged on the magnetic surface in such a way that they succeed one another in the direction of motion, in which case the recording is said to be longitudinal. They may be oriented at right angles to the direction of travel, in which case the recording is said to be transverse. In some instances, where thin magnetic recording mediums are employed, magnetization is through the medium with a pole on either side of the record. Magnetic records can be made extremely rapidly. A good recording can be made by a pulse the duration of which is less than a microsecond. The magnetized regions can be exceedingly small. In contact recording, some areas are of the order of 0.01 inch wide and 0.005 inch long. With such high densities of information, very conservative mechanical speeds can be used to transfer information rapidly enough to fulfill all the requirements of electronic devices. Magnetic records may be reproduced a very large number of times without destruction, will last indefinitely, and may, in many types of equipment, be modified with no more trouble than the simple operation of recording over the previous record. In some instances, erasure by high-frequency magnetic fields may be required before a new record can be superimposed over an old one.

One of the most commonly used kinds of magnetic record is made on flexible tape having a ferromagnetic surface. Usually the magnetization is longitudinal and the tape is run in contact with the recording and reproducing heads. The density of recording on tape varies over wide limits. In a longitudinal direction, it ranges from 25 to 400 per inch and in a transverse direction from 4 to 32 tracks per inch.

In Figure 6 is shown a magnetic tape drive developed by the Raytheon Manufacturing Company and used in a number of installations. The unit in the illustration is installed in the Raydac.
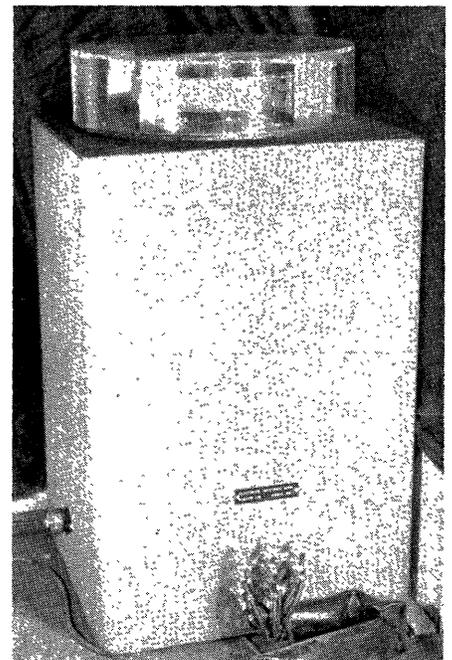
Figure 13. Small commercial drum

This tape carries six channels, is equipped with bidirectional servos, and has the unique feature of having visible photoelectrically read address markers on the back of the tape to facilitate rapid search operations. Also to be noted is the rather elaborate tape-tensioning system. The density of recording is not standard on these units, being chosen to fit the particular installation. Another commercially available tape transport system is shown in Figure 7. This unit is called the Uniservo and is manufactured by the Eckert-Mauchly division of the Remington Rand Corporation. It employs metallic tapes with multiple channel recording. The picture shows a battery of eight units. Figure 8 shows the magnetic tape installation on the Mark IV computer built at the computation laboratory at Harvard University. These transports utilize a very fast vacuum-type accelerator and brake. Another commercial unit is shown in Figure 9 which is made by the Computer Research Corporation and utilizes a principle developed at the National Bureau of Standards. This principle is better illustrated in Figure 10, which shows a similar device built at Aberdeen Proving Ground to handle both magnetic and perforated tapes. In this transport mechanism, tape is laid in a slot under which are placed magnetic heads or photoelectric cells, depending on the type of tape to be used. The cover carries two magnetically moved idler rolls and when it is closed, the tape lies between the idlers and two capstans which rotate in

Figure 14 (left). Drum using non-return-to-zero recording
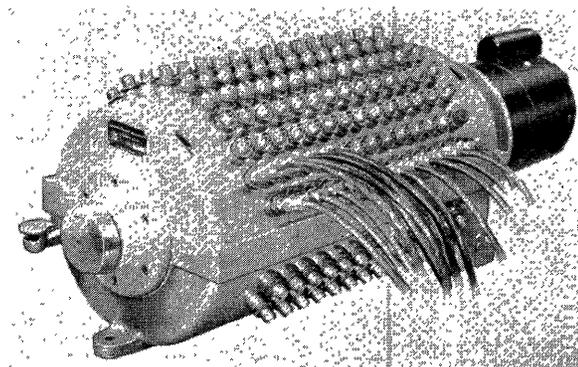
Courtesy Engineering Research Associates

Figure 16 (right). Teleprinters used to process output of EDVAC and ORDVAC at Aberdeen Proving Ground
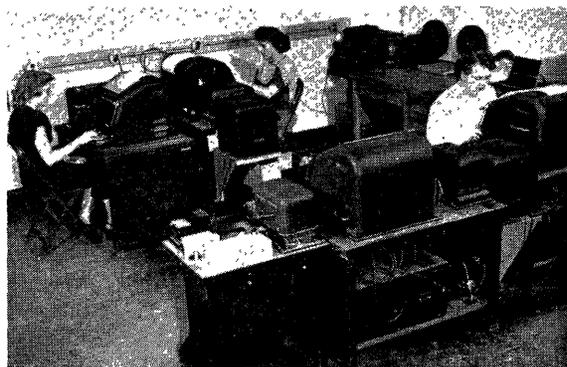
opposite directions. The tape is then drawn from the reel by manually controlled electrically driven rollers into a basketlike receptacle. The tape can be moved in either direction by actuation of one idler roll magnet which causes the tape to be squeezed between the actuated roll and one capstan. This action causes the tape to be pulled toward the actuated side. Braking is constantly applied by a spring-loaded shoe.

It may be noted that in all magnetic-tape transport mechanisms considerable effort has been made to achieve rapid acceleration and deceleration. This characteristic is necessary because the amplitude of the signal generated in the output system is proportional to the speed with which the elemental magnets pass the reading head. Slow starting and stopping cause the first few and the last few characters to be so poorly read that their information is unreliable. This condition is particularly important when the space between words is very small.

Magnetic tape, as the medium of recording of digital information, is very attractive because the recording and the reproducing speeds may be as great or as small as desired; bidirectional operation can be provided; many tracks may be used; and the information can be erased and recorded without difficulty. Though the users of magnetic tape have

found many serious difficulties they have, it is pleasant to state, to a great extent surmounted them. Outstanding among these have been the difficulties caused by particles of foreign matter which lift the tape from the head at a critical instant, irregularities in magnetic and physical properties of the tape, and in making the tape track through the guides and rollers.

Wire

In an effort to achieve a denser storage of information, and possibly alleviate some of the dust and irregularity troubles encountered with tape, the National Bureau of Standards and the Institute for Advanced Study have conducted research to produce magnetized-wire-handling equipment. To date, such a system has not been satisfactorily used. It is also beset with mechanical difficulties, the principal one being that of manipulating the wire so that no snarls or kinks result. The trend seems to be toward using wire held in special capsules from which it is never removed except for a very short section that passes between rolls in the capsules to contact the head.

Drums

Probably the most successful magnetic recording devices so far used in con-

junction with computing machines are rotating drums. Unfortunately these devices can only be used for intermediate storage because the medium of recording is the surface of a heavy cylinder which turns in precise bearings and, therefore, cannot be removed from the equipment and placed in a filing cabinet. The capacity of such drums varies from 500,-000 to about 3,000,000 bits of binary information. The surface of the drum is coated with magnetic material and exposed to heads which record circumferential tracks that are displaced in an axial direction from one another by their own widths plus a slight space necessary to provide sufficient isolation to prevent crosstalk. The heads clear the surface of the drum by about 0.002 inch. The density of recording along the circumference of the drum may lie between 10 and 150 bits per inch. The speed of rotation of the drum ranges from 1,200 to 7,200 rpm.

A typical installation is shown in Figure 11 which is the drum associated with the Mark IV computer at Harvard University. A head assembly for this drum is shown in Figure 12. A small commercially available drum made by the Electronic Computer Corporation is shown in Figure 13. Another commercially built drum which was manufactured by Engineering Research Associates is shown

Figure 15 (left). Mark IV automatic electric typewriter at Harvard University

Figure 17 (right). Shepard high-speed printer at Aberdeen Proving Ground

Snyder—Devices for Transporting the Recording Mediums
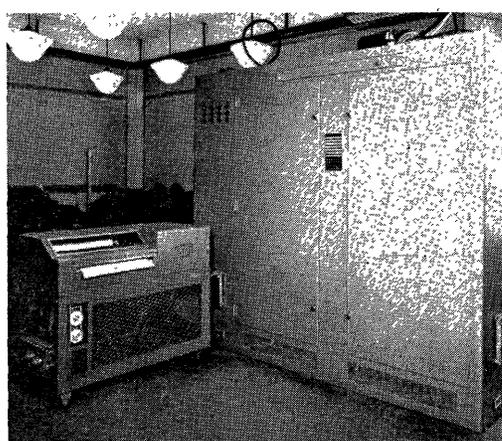
in Figure 14. This company records on its drum in what is called a nonreturn-to-zero system. In this type of recording, only the changes in the polarity of the bits are noted; that is, only those signals are used which are generated when a binary digit is succeeded by another binary digit of opposite sign. This type of recording is advantageous because it has been found that the signal developed in this fashion is much greater and less ambiguous than those reproduced from conventional pulse recordings where each pulse is resolved in the output circuits. This system requires slightly more complex circuits to reproduce the signal, but by its use the storage capacity of the drum is considerably increased.

Preparation Devices

Most of the manually encoded data for large-scale computers are prepared on standard tape- or card-punching keyboards, modified only to the extent necessary to provide the symbols peculiar to the particular work. Such equipment has long been available and little improvement can be desired because this is the one instance in which all of the speed requirements have been fulfilled.

Printing Devices

The output of computing machines, which must be in a form to be read by humans, is generally presented by auto-matic typewriters. These typewriters may be controlled by the computer directly or by transcribing equipment which interprets information from the computer's input-output medium. The transcribing procedure is more commonly used because most of the automatic typewriters are so slow that valuable computing time would be wasted if the machine had to be stopped while the printers performed their tasks. Figure 15 shows the electric typewriter complement for Mark IV.

An installation using the conventional Teleprinters at Aberdeen Proving Ground is shown in Figure 16. Also shown is equipment used to prepare perforated tapes. A more advanced development is shown to the left in Figure 17. It is a very-high-speed rotary printer manufactured by Shepard Laboratories for Aberdeen. This is one of the class of printers which are also made in different designs by Potter Instrument Company and Wheaton Engineering Corporation. In it a number of sets of all of the characters to be used are arranged around the circumference of a rotor. Directly beneath the rotor is a typewriter ribbon underneath which is the paper from a roll on which the printing is to be done. Beneath the paper is a row of electrically operated hammers. The drum rotates at some speed between 5 to 30 revolutions per second. The hammers are then energized by a decoding apparatus at such a time that they will strike the paper against the inked ribbon and the rotor when the desired character is in the proper position. Such a printer is fast enough to keep pace with the fastest computer and no intermediate storage is needed to conserve time.

Conclusion

At the moment of writing, it appears that magnetic recording devices are the most flexible units for handling the mediums used for manipulation of latent digital information. However, the mechanical difficulties which now beset their use indicate that much more research and development will be necessary before completely satisfactory systems are available. For certain applications, perforated cards and tapes will probably be more satisfactory than any other medium, particularly where the amount of data to be handled is small, visual inspection is desirable, and redundancy is to be avoided. Photographic storage of pictorial information, and possibly printed output matter, needs considerable development but will undoubtedly perform valuable functions which cannot be otherwise accomplished. Simpler and less expensive automatic printers must be developed. When it is remembered that serious work on these devices commenced little more than 5 years ago, the progress in their development must certainly be the source of considerable satisfaction to those working in this field.

Discussion

L. Difford (National Bureau of Standards): Will you please give more detail on the Shepard printer?

Mr. Snyder: I shall describe it as completely as I can. The print roll consists of a cylinder about 16 inches long, having 56 character wheels on it. It has a typewriter ribbon, about an inch wide and slightly skewed, underneath the roll and clearing it by some 0.005 to 0.01 inch. The paper, I believe, is about 16 inches wide. There is a row of hammers aligned beneath the paper at intervals of about 3/16 inch. The printing does not extend over the full width of the paper.

The time of flight of a hammer striking the paper appears to be about 2.7 milliseconds, and the dwell time has been guessed at as being about 8 microseconds. The hammers are actuated by thyratrons.

Mr. Difford: You said 15 lines per second. Is there any way of speeding this up?

Mr. Snyder: That is most conservative, because the print roll is rotating at 30 revolutions per second, and one revolution is assumed to be allowed for paper shift.

Actually, a quarter of a revolution is sufficient, and these printers have been operated with 60 revolutions per second. The problem appears to be one of moving the paper rapidly rather than of getting the hammers to strike accurately.

W. P. Byrnes (Teletype Corporation): What is the maximum number of channels or rows across the width of the tape envisaged at the time for either magnetic or perforated tape?

Mr. Snyder: That is a very hard question to answer. I have heard of some magnetic tapes as wide as 6 inches, involving something like 30–50 tracks. I have also seen some installations where there is a single track on magnetic tape 1/4 inch wide. In the perforated tapes, the standard 5-hole Teletype tape is, of course, quite useful. The 6-hole tape was used in the relay type of computers, but some tapes, if one may call them that, have been as wide as the standard punched card, that is, 80-column tapes. I believe they have been used in the selective sequence calculator at the International Business Machines Corporation in New York City. I do not think there is any limit in either case, except for magnetic tapes, where the dust problem may cause serious difficulty.

Mr. Byrnes: In some cases, it may be desirable to represent more than one decimal digit across the roll of tape.

Mr. Snyder: It may also be desirable for checking.

Mr. Byrnes: What speed of reading and perforating paper tape is considered adequate at present?

Mr. Snyder: At present, the best perforation speed that I happen to be aware of is in the Ordvac card-punching system, which punches the equivalent of about 400 characters per second. I think that is more rapid than is absolutely necessary for a device to be very useful to the computing industry. I think, from 100 characters per second up would be very useful for many applications.

Mr. Byrnes: That also goes for reading tape?

Mr. Snyder: Yes, but reading perforated tape is easy with photoelectric devices—perhaps not easy, but it is quite amenable to a little effort, shall we say? There is no limitation to reading photoelectrically.

Mr. Byrnes: Is it true that reading mechanically requires less associated equipment?

Mr. Snyder: I think that was true some time ago, but with the introduction of

transistor photoelectric cells, the output is sufficient to drive almost any kind of equipment. For any other kind of electric device it is necessary to provide some coupling network. I do not think you gain appreciably in the signal level by just using contacts driven by mechanical feelers. Certainly, one amplifier tube is cheaper than a set of contacts for maintenance. If you use some of the gray tapes and photo-multipliers, you can get enough light through without any difficulty, even with paper tape.

Mr. Byrnes: Would you repeat the name of the company that puts out this line-at-a-time printer of which you spoke?

Mr. Snyder: The Shepard Laboratories at Summit, N. J.

M. M. Astrahan (International Business Machines Corporation): Do you know where this transistor photoelectric cell is being used?

Mr. Snyder: It is used on the Aberdeen tape reader, which I described in some detail.

Mr. Astrahan: Is it in operation?

Mr. Snyder: Yes, but they are having trouble getting enough of the transistors; the transistors are apparently going to become available, if the grapevine information I have had is true.

B. Lippel (Signal Corps Engineering Laboratories): Photographic means have been described for rapid printers. Would you care to comment?

Mr. Snyder: There is a type that was described by Engineering Research Associates. There are a great number of printing devices that use photographic reproduction, some that are derived from cathode-ray tubes whose deflection is controlled to write actual letters, and some that are controlled by masks, and I believe a few by monoscopes. I believe for writing legible

decimal and alphabetic characters, photographed cathode-ray images will certainly be the fastest system that can be employed because such recording can be done quite easily at the rate of a character per microsecond. However, very few of the present large-scale computers can hope to keep up with such a scheme; in fact, none of them come anywhere near such speeds. The development problem, I think, is one that needs a little more work before such devices will be acceptable.

Mr. Astrahan: I think the cathode-ray output on Whirlwind is sometimes used. Photographs are taken of the screen, and various characters and other displays are obtained that way. It is not a high-speed device, but they get some interesting figures on it.

R. F. Johnson (University of Toronto): Could you say anything about the availability of electrosensitive paper for printers?

Mr. Snyder: I have not had any experience with them or talked with anyone, other than to have heard of the use of Teledeltos papers in place of perforated tapes to produce a rather quick recording and a photo-electrically readable record. The actual printing of characters I have not seen, nor have I read of its being carried out. It seems to me a neglected field.

K. M. Rehler (Raytheon Manufacturing Company): On that roller type similar to SEAC units, what is the acceleration time and tape distance, and the maximum speed?

Mr. Snyder: In the unit shown, the tape runs at 8 feet a second, it stops in about 0.030 inch, I believe. The starting distance is about the same.

Mr. Rehler: Would that take the normal width?

Mr. Snyder: The unit, an experimental model, is designed so that the paper channel can be varied in width up to 1 inch. There

is space under it for placing either photoelectric or magnetic pickup devices.

W. H. Ware (Rand Corporation): Mr. Snyder has stated that he does not know of any output equipment which utilized Teledeltos paper, and that he considers this an overlooked possibility. I should like to contribute the following information.

In June, 1951, there was completed at the Institute for Advanced Study, Princeton, N. J., a high-speed printer utilizing Teledeltos paper. The intended use of this device was to print rapidly, in binary notation, the contents of the internal memory, either for initial checking or for monitoring the progress of a problem. The 1,024 words of the memory were to be displayed 2 to the line, 40 columns in each word. It subsequently evolved that this moving stylus Teledeltos printer could also be used to construct curves or bar graphs; and even, if the data within the internal memory were first operated on by a suitable interpretive code, to print decimal characters.

This device is based on a Western Union 3-stylus Telefax machine, originally intended for remote delivery of telegrams. As modified mechanically and associated with suitable electronics, the printer is capable of printing, on standard $8^{1}/_{2}$-inch paper roll, 80 columns of binary information (either mark or not) with suitable center and edge margins. It produces 1,000 lines per minute and hence 80,000 bits per minute are printed. Provision is made to print each line of data more than one time (a maximum of eight) in order to give immunity against statistical flcutuations in the behavior of the paper.[1]

REFERENCE

1. A TELEDELTOS OUTSCRIBER, W. H. Ware. *Transactions*, Institute of Radio Engineers (New York, N. Y), number PGI—1, April 1953.

Buffering Between Input-Output and the Computer

A. L. LEINER

THIS paper will discuss some of the basic methods or general principles which have been applied for carrying out the transfer of words between input-output equipment and the high-speed memory of computers. Since general principles can best be demonstrated by showing them exemplified in particular cases, specific selected systems which accomplish this buffering will be discussed. (In doing so, however, an attempt will be

made to avoid detailed descriptions of specific pieces of equipment.) The particular selection chosen represents, of necessity, a quite incomplete sample from the total of available methods. Omission of some of the many alternative methods for accomplishing similar objectives in no way implies that the methods

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omitted are inferior to the methods presented.

Nature of the Buffering Problem

Before proceeding further, it will be well to consider for a moment the special nature of the relationship between the internal circuitry of present-day high-speed digital computers and the external input-output equipment through which they communicate with the outside world. The first and most obvious difference between these unequal partners is the much slower operating rates of the external input-output equipment, but the main distinction between the two is the fact that the external devices (whether high-speed magnetic recording equipment or mechanical typewriters) are bound by mechanical inertia or friction

and therefore in most cases are incapable of following in rigorous synchronism with the high-speed internal electronic circuitry. On this account, the input-output equipment does not communicate directly with the high-speed units of the computer but rather with special buffering equipment which in turn communicates with the high-speed memory. This buffering equipment, since it is in direct communication with the memory, must be capable of operating at the same rate as the memory and its associated computing units. Efficiency generally suggests, therefore, that such equipment be constructed out of the same basic electronic building blocks as the regular computing units. In the following discussion this is assumed to be the case, not only for whatever special buffer word storage is needed, but also for the circuitry communicating directly with the slower moving nonsynchronous outside world.

Subdivision of Buffering Process

The process of buffering between an external input and the computer may be divided into three distinct phases. The first phase consists of the conversion of a nonsynchronous pulse signal (generally of irregular repetition frequency and uncertain duration) into a unique pulse signal, synchronous with, and of a shape acceptable to, the high-speed internal switching circuitry of the computer. The source of the external input signal may range all the way from a push-button switch contact up to the output of an amplifier of a magnetic recording unit capable of transmitting pulse code at the rate of many thousands of binary digits per second. In the first step of the input process, we carry through to the point where an individual binary digit is stored inside the computer in the form generally used for storing individual binary digits elsewhere throughout the computing system (for example, flip-flop storage). In the second phase of the input process, the assembly of successive binary digits into complete words is considered. This part of the process generally involves the counting of digits as they are received, the shifting of previously received digits into new storage locations in order to make room for subsequent digits, and the dispatch of signals indicating that a complete word or block of words is ready for transmission further along towards the high-speed memory of the computer. In the third phase of the process the procedure is considered for transporting such completed words from these temporary buffer storage locations to their final

locations in the high-speed memory. This part of the process generally involves the counting of completed words or blocks of words, keeping track of the high-speed memory addresses into which successive words are to be transferred, and other related considerations.

The output process, in which information is transferred from the high-speed memory to the external unit, involves nearly exactly the same procedures, carried out in reverse order. For those aspects of the processes which have already been mentioned, identical equipment can be used in carrying out both the input and the output operation. The distinction between the two operations lies mainly in the terminal magnetic reading-recording equipment, keyboard printers, and so forth.

The following discussion will show how these three phases of the buffering process can be carried out by special types of buffering equipment, such as pulse-synchronizing systems, specialized storage registers, and associated control mechanisms.

Properties of Circuitry

The subsequent discussion will be confined to buffering systems which can be constructed out of internal circuitry possessing the following characteristics:

1. The entire computer operates in synchronism under control of a central clock.

2. One of the elementary basic building blocks is a signal-generating unit which provides (under control of the central clock) reshaped, retimed, standard output signals whenever suitably triggered. Signals of either positive or negative polarity are available from these units.

3. Another elementary block is the coincidence gate (AND-gate) which transmits a signal from its output only when every one of its inputs receives positive signals in unison. The presence of a negative signal is interpreted in the same way as the absence of a positive signal, and conversely. A single negative signal can thus be made to inhibit all output from such a gate.

4. Another elementary block is the mixer (OR-gate), which transmits a signal from its output whenever one or more of its inputs receives a signal.

5. Another elementary block is the electrical delay line (or equivalent) capable of delaying incoming signals up to several pulse repetition times.

These qualifications do not restrict the generality of the discussion, since both serial and parallel computing systems can be constructed out of the elementary blocks described. Because more variety in the choice of methods for buffering is possible in serial than in parallel systems,

more examples of the former will be described.

Pulse Synchronization

FUNCTION OF PULSE SYNCHRONIZER

The most critical link between the internal and external equipment, bridging the gap between the slow outside world and the high-speed internal circuitry of the computer, is the pulse-synchronizing unit. This unit accomplishes the first phase of the buffering process, which is the conversion of a nonsynchronous signal to a synchronous one.

The pulse-synchronizing circuitry receives from outside of the machine an input signal which is both unsynchronized (with respect to the internal clock's pulse repetition rate) and nonstandard (with respect to the internal circuitry's pulse shape and duration). It is the function of the pulse synchronizer to derive from this input signal new internal signals possessing the following characteristics: First, the new internal signals must consist of standard-shaped pulses of a sort acceptable to the internal high-speed switching circuitry of the machine and, second, there must be an exact one-to-one correspondence in meaning between the signals received from the outside and the pulses transmitted to the computer. This correspondence must persist even though the external triggering signal might long outlast the triggered internal pulse. For example, a signal from a relay contact lasting 100 milliseconds must result in only a single pulse of 1-microsecond duration, not 100,000 such pulses.

To accomplish these functions, a pulse-synchronizing system of the type under discussion must possess the following abilities:

1. It must be capable of detecting an incoming signal at any nonsynchronous time and of storing it for an arbitrary period pending the occurrence of the internal synchronous timing pulse which transmits the news of the signal's arrival into the internal circuitry of the computer.

2. It must always transmit to the computer only pulses of standard time width. In doing so, it must contend with the fact that the partial overlap of a synchronized pulse and a nonsynchronized pulse (such as the coincidence of the leading edge of even a very long nonsynchronous input with the trailing edge of a standard internal timing pulse) tends to introduce substandard-width 'spikes' or 'slivers' into the system. Since as many as 10^{10} pulses per day are to be handled, the absence of even highly improbable time coincidences capable of causing malfunctions of this sort cannot be left to chance.
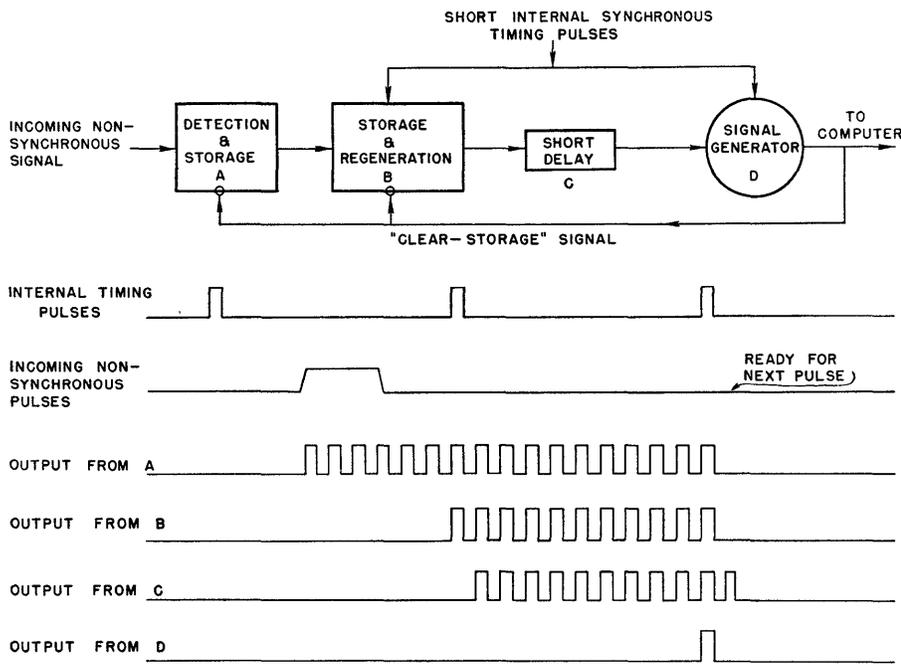
Figure 1. Pulse synchronizer system

3. It must be able to distinguish between the beginning of a new signal and the continuance of an old signal that has already been accepted, and it must be able to do this over a sufficiently wide range of input pulse widths.

Description of a Pulse Synchronizing System

An example of a simple synchronizing system, used in the SEAC, is illustrated in block diagram form in the upper half of Figure 1.

The system shown is triggered on the left by an incoming nonsynchronous signal. In block A, this signal can be detected and stored until such time as one of the series of short internal synchronous timing pulses continuously emitted by the computer shall occur. As soon as the next such timing pulse occurs, the signal in A is transmitted into a similar storage unit B, where it remains for the full duration of an interval between timing pulses. During the period in which the signal is stored in B, the pulse has opportunity to be regenerated into the full standard width and shape acceptable to the internal circuitry of the computer. This period of storage in B is effected in the following manner: Attached to the output of B is a short delay line C which provides an output signal from B, slightly delayed. This delay is longer than the duration of an internal timing pulse but shorter than the interval between successive timing pulses. The output of this delay line is fed into a signal generator D through a coincidence gate which is controlled by the timing pulse signals.

Because of the presence of the delay line C, the signal from B cannot reach D until after the timing pulse that allowed B to be loaded has disappeared. Signal source D, therefore, cannot emit before the appearance of the timing pulse next following the one which loaded the signal into B. The input signal therefore remains in storage unit B for the full duration of the interval between timing pulses. If, as the result of the overlap of a nonsynchronous leading edge from A with the trailing edge of a timing pulse, the signal loaded into B is a substandard spike, the spike will, during its stay in B, either be regenerated into a full-fledged signal or else degenerate and disappear before the occurrence of the next timing pulse. In the latter case, storage unit B is certain to receive a full pulse from A at the time of the second timing pulse, since by that time the full body of the pulse will have been received in storage unit A. The signal generator D, therefore, transmits a synchronized fully standard signal to the computing
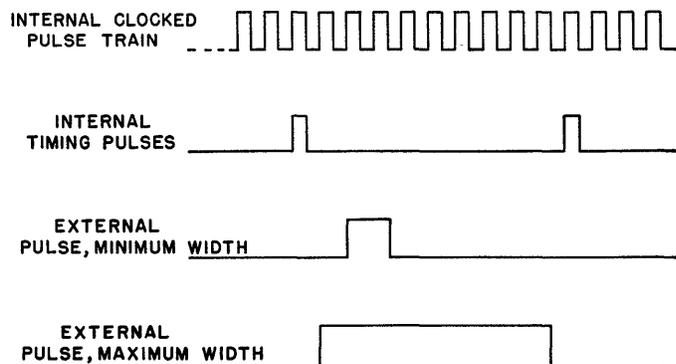
circuitry. At the same time, it sends 'Clear-storage' signals to units A and B, thereby making them available for receipt of subsequent input signals.

The lower half of Figure 1 consists of idealized oscillograms which show the timing interrelationship between the various pulses involved. Figure 2 shows the relationships between the widths of the internal and external pulses.

It is important to note that with this system the external pulses are limited as to permissible range of width, the minimum being at least that width necessary to span two successive internal clocked pulses, and the maximum width being the interval between successive timing pulses. Since the timing pulses can be generated by counting down the internal clock pulses (in the example illustrated here, every tenth clock pulse is a timing pulse), the range of acceptable pulse widths may be extended indefinitely by reducing the frequency of the timing pulses. If this is done, however, the maximum acceptance repetition rate will be correspondingly reduced because this maximum rate is equal to one-half of the timing pulse rate. Accordingly, if a synchronizer of this type is to be used in conjunction with a variety of devices of widely varying rates (for example, mechanical typewriters and high-speed magnetic tape units), some sort of pulse-forming circuitry is required in front of A in order to standardize the pulse widths of the signals received from the mechanical devices. This pulse-forming circuitry reduces the input pulse duration to less than one-half the time interval between pulses transmitted at the maximum repetition rate of the highest-speed units.

Description of a Pulse-Former System

In Figure 3 a simple type of pulse-former system, which can be constructed out of standard computing elements, is shown. With this type of device the external signal is fed via a coincidence gate A into a signal-generating unit B,

Figure 2. Approximate pulse width limits for pulse synchronizer

Leiner—Buffering Between Input-Output and the Computer
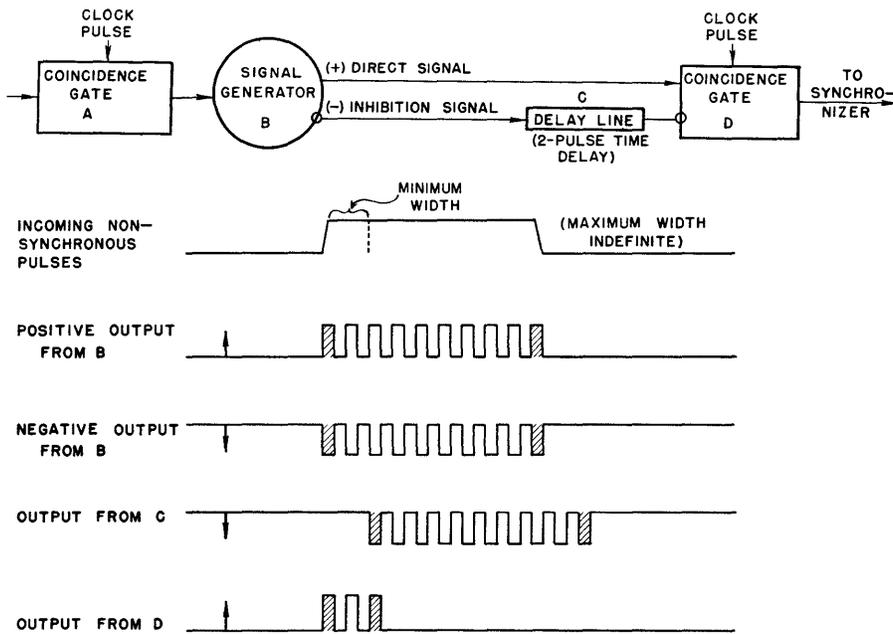
Figure 3. Pulse—former system

delay line storage register with re-circulation time 1 millisecond, the input-output rates in the absence of buffer storage space for more than one binary digit at a time would be limited to one pulse per millisecond (1,000 digits per second), whereas provision for the accumulation of 50 binary digits and their transfer in a group into the memory once per millisecond might permit net input rates of up to 50,000 bits per second.

In general, if

T = access time of high-speed memory
r = maximum rate of input (total number of binary digits per unit time)
B = minimum required pickup buffer capacity

then

$$B \geq rT$$

which furnishes a lower limit for B.

Several other considerations arise, however, which affect the choice of size for buffer storage of this sort. First of all, the size of the buffer must be consistent with the possibility of its being loaded at rate r from the outside. That is, if t = access time to pickup buffer, and n = number of digits loaded into the pick up buffer in a group, then

$$n \geq rt, \text{ or } t \leq n/r$$

This sets an upper limit for the access time, t. Now, as a general rule, the capacity B, and the access time t increase together. This is certainly true of the re-circulating delay-line type of storage register. For this case, if f = the internal pulse repetition rate for the pickup buffer register, then

$$B = ft$$

Combining the previous two equations

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causing this unit to emit standard pulse trains (positive and negative). Because of the uncertain timing coincidence between the external signal and the internal clocking pulses feeding into A, the first signal emitted by signal generator B may be of substandard width unacceptable to the standard internal circuitry. Pulses of this sort are shown shaded (see the lower half of Figure 3). The negative, or inhibition, signal is transmitted through a delay line C which imposes a delay of two pulse times. This inhibition signal together with the direct positive signal from B is fed into a coincidence gate D. As the figure indicates, the output of D can consist of no more than three pulses regardless of how long the initial external trigger pulse extends over its indicated minimum (approximately two internal pulse times). Of these, the first and last may be substandard in width, but the second is sure to be of full standard shape and width. Since at least one acceptable pulse signal is produced, the output of D can be applied to the input of pulse-synchronizing units of the type described.

Assembly of Digits into Words

USE OF PICKUP BUFFER REGISTERS

For the purpose of this discussion, the second major phase of the buffering process is considered to be the assembly of individual digits into complete words and their storage in a buffer pickup register prior to their insertion into the high-speed memory. This step is not called for by any over-riding logical principle but is an effective means for bridging the gap be-

tween the rate of access to existing serial high-speed memory equipment and the pulse rates available from magnetic recording equipment. For installations in which input-output rates no greater than one binary digit per access time to the high-speed memory are tolerable, this step can be omitted with a considerable gain in system simplicity.

If we assume, however, that the external units produce (or can absorb) information at higher rates some sort of pickup buffer storage register is indicated, which can hold at least the number of binary digits capable of being produced by the external unit in a single access time. For example, for a circulating acoustic

Figure 4. Recirculating delay line pickup register (left-to-right procession)

Figure 5. Recirculating delay line pickup register (right-to-left precession)

mation stored in the register into a delay line storage unit capable of holding ten binary digits of information. (For example, if the repetition rate of the pulse train is 1 megacycle, the delay line would introduce a delay of slightly under 10 microseconds between the time a pulse signal leaves tube A until the time the same signal reaches tube B.) During the normal standby condition, a pulse emitted by tube B is fed back into tube A via gate H. Gate H is held conducting by the pulse train labeled "Hold." By properly adjusting the length of the delay line in the storage unit, the total recirculation time for a pulse to make a complete circuit of the loop from tube A back again to tube A can be made equal to exactly 10 microseconds. The AND-gate S is also driven by tube B but through a delay line D capable of introducing a delay of exactly one digit time (in this case 1 microsecond). When gate S, rather than gate H, is held conducting, the total recirculation time around the loop becomes, therefore 11 microseconds rather than 10. By means of gate I, new information originating in the digit-sensing unit associated with one of the input devices can be inserted into the recirculation system.

The lower half of Figure 4 illustrates the timing relationships required for the control inputs of gates H, I, and S, respectively, in order to load a new binary digit into the register and at the same time

$B \leq nf/r$

which sets an upper limit for B. Hence

$rT \leq B \leq nf/r$

This is consistent only if

$rT \leq nf/r$

that is, if

$r \leq \sqrt{nf/T}$

Using a system of this sort, this last

equation sets an upper limit for the total over-all input rate r. For this maximum rate r the minimum required buffer capacity then becomes

$B = \sqrt{nfT}$

PRECESSING-LOOP TYPE OF PICKUP REGISTER

In Figure 4 an example of a simple precessing-loop type of pickup register is shown. The driver tube A transmits the pluse train that represents the infor-

Figure 6. Staticizer pickup register

Figure 7. Multi-channel connection to staticizer pickup register

TO CHANNEL
No.1 No.2 No.3 No.4

1 2 3 4 5 6 ----- 48 49 50 → TO COMPUTER & SERIAL MEMORY

No.1 No.2 No.3 No.4
FROM CHANNEL OF MULTI-CHANNEL INPUT UNIT

CONTROL PULSES:
SHIFT(RIGHT): 4 PULSES
SHIFT(LEFT): 46 PULSES
TRANSFER OUT: 50 PULSES
OTHERWISE, SAME AS IN
PRECEDING EXAMPLE
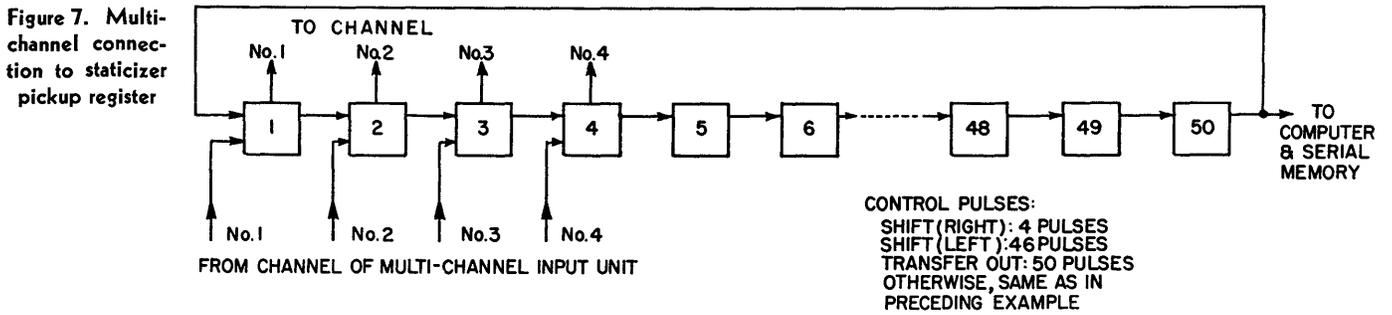
preserve the information digits previously loaded into the register via the same gate. This old information is preserved by "shifting to the left," that is, by delaying the entire previous contents of the recirculation loop 1 microsecond and inserting the new information pulse arriving via gate I into the gap thereby vacated by the postponement of the first pulse. The new digit is inserted by means of the single control pulse labeled "Insert." This pulse also causes the 'hold' pulse train to be interrupted for exactly ten pulse times and the 'shift' train to be substituted in its stead. (The initial pulse of the 'shift' train, shown in dotted lines, would be omitted if it were necessary to erase a previously stored digit from the position for which the new pulse is intended, that is, if the storage register had not been cleared immediately prior to the initiation of the input operation.) By repeating this procedure ten times, the pickup register will be loaded with a new digit every time an 'insert' pulse occurs and the ten new digits thus received will appear at A (as they recirculate) in consecutive serial order exactly in reverse of the order in which they were received from the outside.

Figure 5 illustrates a system similar to the foregoing except that the incoming information is stored in the recirculating register in the same serial order in which

it was received. This system differs from the preceding system primarily in the arrangement of the delay lines. The capacity of the main storage unit is reduced by one binary digit, and the 1-bit delay line D is located in the 'hold' path instead of in the 'shift' path. Also the 'insert' pulse occurs at the end of the 'shift' train instead of at the beginning.

In the precessing-loop type of pickup register, the information received from outside is made available to the input gate of the high-speed memory as a serial pulse train. A more elaborate type of pickup register suitable for use in conjunction with both serial and parallel types of memories will now be considered.

Staticizer Type of Pickup Register (Shift Register)

In Figure 6, the staticizer type of pickup register is illustrated. This type, although it involves considerably more equipment than the previous type, was used in the SEAC because of its compatibility with the parallel electrostatic storage-tube memory to which it is an essential adjunct.

The lower right-hand side of Figure 6 provides a key to the graphical notation employed in the upper half of the figure by showing the physical contents of one of the rectangular blocks illustrated there. Each of these numbered blocks represents

a discrete dynamic recirculating delay line storage unit of one binary digit capacity. In this dynamic flip-flop, the elementary digit storage is accomplished by recirculating the pulse signal around a closed loop containing a driver tube, a 1-bit delay line, and a pair of gates in cascade. The function performed by such a device corresponds in many respects with that of the well-known Eccles-Jordan trigger pair flip-flop, both devices possessing the ability to store a single binary digit.

Each one of the flip-flops represented by the numbered blocks in Figure 6 communicates with an individual electrostatic memory tube. In the example illustrated, a single binary digit can be transferred in either direction between storage unit and memory tube, and this can be done simultaneously for all 50 units. The lower left-hand side of Figure 6 illustrates the control pulse trains. In practice, 'hold' and 'shift' pulses do not occur simultaneously. As long as the 'hold' train is on, therefore, the contents of each individual storage unit is preserved unchanged. For each shift pulse, however, the contents of each cell is transferred to its neighbor on the right. Hence, a pulse train of 50 shift pulses will make the entire contents of the shift register available in serial order at the output of storage unit number *50*. A

TO OUTPUT UNITS

FROM INPUT UNITS

PICK-UP REGISTER

48-STAGE SHIFT REGISTER STATICIZER

ADDER

48 BIT DELAY LINE
ADDER REGISTER

48 BIT CIRCULATING DELAY LINE LOOP

FROM SERIAL MEMORY

TO SERIAL MEMORY

---- PATH USED FOR INPUT
········· PATH USED FOR OUTPUT
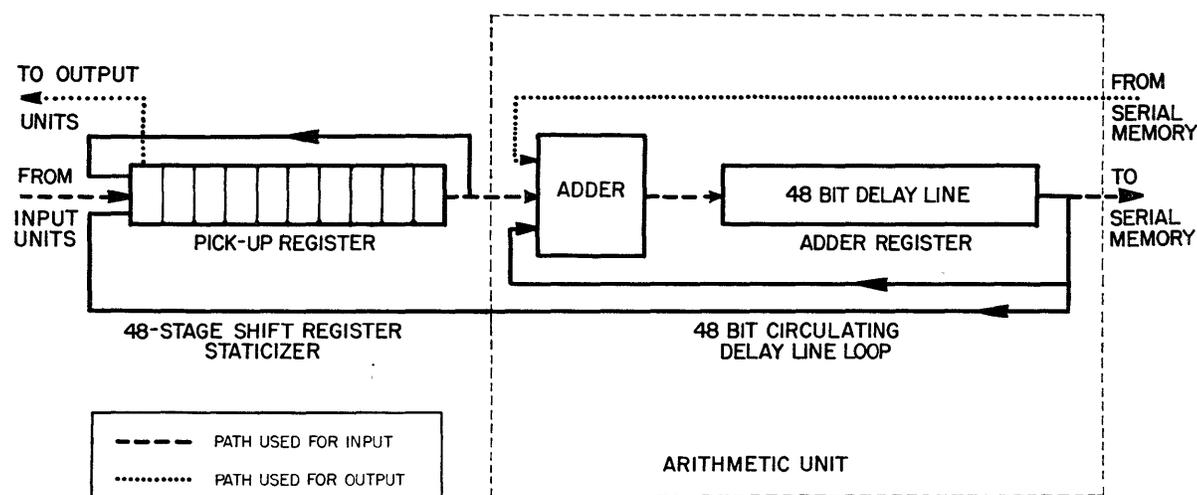
ARITHMETIC UNIT

Figure 8. Use of arithmetic register for input-output buffer storage

train of exactly 49 such pulses will do the same thing and, furthermore, by means of the connection between unit number *50* and unit number *1*, can make the contents of each cell come to rest finally in the neighboring cell immediately at its left. (This is equivalent to a left shift of one place.) By means of these control pulses it is clear that a series of signal pulses entering unit number *1* from an input device, so long as they arrive less frequently than once every 50 pulse repetition times, can be arrayed in the pickup register in such a manner as to be available later either to the parallel memory or to the serial memory in either direct or reverse order.

Likewise, as Figure 7 shows, simultaneous input from multichannel input units can achieved very simply. For direct-order distribution of incoming characters, four shift pulses are used; for reverse-order distribution, 46 shift pulses are needed.

COUNTING-OFF DIGITS PER WORD

The process of counting-off incoming input digits in order to distribute them to the high-speed memory in blocks of uniform size can be carried out by at least two distinct methods. The first method involves the use of any of the wide variety of addition, subtraction, comparison circuits which can be fashioned out of every type of digital computing building blocks.

An alternative method which, while less flexible, often requires considerably less equipment, makes use of a special marker digit stored inside the pickup register itself. This digit is inserted into the previously cleared pickup register immediately before starting an input operation. It is stored temporarily in the digit position that is scheduled to be occupied eventually by the final digit of the incoming word. This marker digit will be shifted along with the newly inserted information digits as each new information pulse is entered into the

pickup register. At each successive shift cycle, therefore, this marker pulse will be detectible, at some fixed tap in the pickup register, at a progressively varying phase of the shift cycle (or recirculation cycle). For example, referring to Figure 6, if the shift register shown is cleared prior to the insertion of the first digit from the input unit and a marker pulse inserted in storage cell number *50*, then, after the first information has been inserted and 49 shift pulses have been given, the marker will come to rest in cell number *49*. After each successive information digit is received and the shift is carried out, the marker pulse will be found one step further to the left. After 49 information digits have been received, the marker will finally reach cell number *1* coincident with the last pulse of the shift train. Therefore, by gating the output of cell *50* with the last pulse of each shift train, the coincidence of these two signals can be interpreted as signifying that the next incoming information digit will complete the word. If this fact is stored, its presence can cause the next 'insert' signal to transfer the contents of the pickup register further along on its journey towards the memory.

Transfer of Words between Pickup Register and High-Speed Memory

NEED FOR FURTHER BUFFER STORAGE

The transfer of the contents of a pickup register of the staticizer, or shift-register, type to a high speed parallel memory is quite a rapid and straightforward process. The pickup register can be cleared out broadside and made ready to accept new information in a single memory access time, which is usually considerably less than even the lateral shift-out time for the register. In the case of a serial memory, however, we are faced with the choice of holding the pickup register inactive between word pickups up to one full serial memory access time (thereby reducing the maximum net input rate) or else of transferring its contents into some additional buffer storage. This additional storage should preferably be of a more economical type of construction than a pickup register and can even be some

storage facility already provided in the computer for performing another function which can be temporarily suspended when the need arises.

USE OF ARITHMETIC REGISTER AS BUFFER STORAGE

In the SEAC, for example, the adder register in the arithmetic unit is available for this purpose, since computing and input-output operations do not proceed concurrently. Figure 8 illustrates this procedure for both input and output. The arrangement illustrated is particularly economical with respect to requirements for control circuitry since input-output operations use exactly the same mechanism as the arithmetic operations for communicating with the serial memory both in actual word transfer routes, specification and location of proper addresses, and so forth.

USE OF RESERVED SECTIONS OF HIGH-SPEED MEMORY FOR BUFFER STORAGE

The previous method, since it makes use of the adder register for holding input-output words, requires suspension of arithmetic operations while input-output is taking place. Another method, which is used in several commercial machines, and which avoids this disadvantage, employs a special reserved portion of the high-speed memory for this purpose. Input and output transfers each take place to or from one of these special reserved areas, which usually are large enough to hold a considerable number of words. In some machines, special block transfer commands are provided for rapidly transferring substantial blocks of words in a group between the reserved area and the remainder of the high-speed memory.

CONCURRENT TRANSFER USING TIME-SHARING METHODS

Another method for achieving concurrent computation and input-output operations, which does not employ special registers or special reserved areas in the high-speed memory for the purpose of accumulating large fixed blocks of words, applies a time-sharing principle to the use of the access circuitry of the serial memory. This procedure, as used in the Dyseac, permits words to be transferred in blocks of any desired size between any part of the high-speed memory and the input-output equipment. In this system, no special transfers within the high-speed memory are required and no appreciable interference with use of the memory by the computing facilities of the machine occurs.
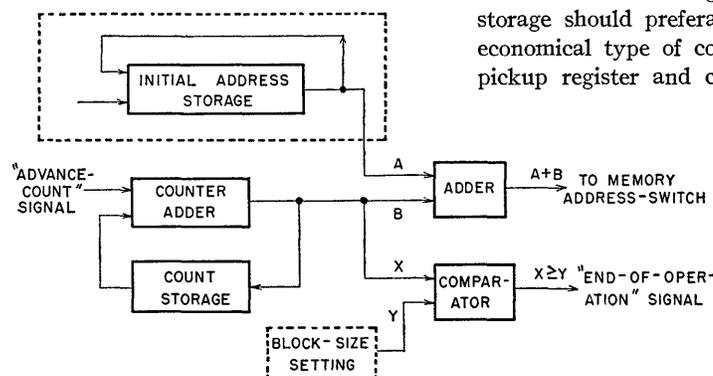
Figure 9. Address regulation and word count system, method A

Figure 10. Address regulation and word count system, method B

Figure 10. Address regulation and word count system, method B

external-to-internal speed ratio K, this coincidence factor equals $2K/(N+1)$. Time-sharing becomes practicable under such circumstances if, whenever a conflict does occur, the satisfaction of the computing units' access demands is suspended for an extra recirculation period. This results in an increase of N minor cycles over the average duration $(N+1)/2$ so that the net relative increase in total elapsed time is

$$\left(\frac{2K}{N+1}\right)\left(\frac{N}{\dfrac{N+1}{2}}\right)=\frac{4K}{N+2} \text{ approximately}$$

The reason for the efficacy of a scheme of this sort is contained in the fact that, with serial delay line memories of presently available access times and pulse - packing densities, a single memory tank holds several words (between 8 and 32 for various current models) and, as a result, the computing facilities require access to the high-speed memory for only a limited percentage of the time. To illustrate this fact, consider a recirculating serial memory tank containing N words. Let A_1 and A_2 respectively denote the address timing numbers which identify the phase in the recirculation cycle at which two word positions become available $(0 \leq A \leq N-1)$. The time interval T in minor cycles, which the computer must wait after receiving the word in A_1 before the word in A_2 becomes accessible, is

$T=(A_2-A_1)$, if $A_2>A_1$

or

$T=(A_2-A_1)+N$, if $A_2 \leq A_1$

The average value of T over all possible combinations of A_1 and A_2 can be shown to be

$\bar{T}=(N+1)/2$ minor cycles

This represents the average access time of the memory if the coder has specified access references in a completely random sequence. At the expense of some extra labor in problem preparation, this time can be somewhat reduced by assigning addresses in so-called optimum timing sequence, but it has been generally found that for short tanks (N less than 10) the extra effort required is hardly commensurate with the benefit received. Even if the attempt is made, however, the occurrence of long operations (such as multiplication and division, which in most computers take several extra minor cycles) tends to increase the average value of the elapsed time per individual memory reference back towards the value cited. It can be said, therefore, that the

memory is referred to by the computer on the average only a fraction $(1/\bar{T})$ of the time which is in the neighborhood of $2/(N+1)$ (For example, an 8-word tank would be referred to on the average not more often than about 22 per cent of the time.)

Input-output rates, on the other hand, are such that the net flow of information between computer and outside in a typical case might take place at pulse repetition rates not greater than, say, 5 per cent of the internal memory pulse repetition rate. Thus, in this case, the external equipment would demand access to the memory not more often than about 5 per cent of the time. That is, the memory can present 20 words to the computing units during the time the external unit needs to produce just one word. The probability of conflicting demands on the memory occurring simultaneously by the computing and input-output units, therefore, in this case would be 22 per cent of 5 per cent or about 1 per cent of the time. In general, for an

If, instead of time-sharing the memory switch, a large block of input words is accumulated in a special buffer memory and, at the end of the operation, transferred consecutively at the rate of one minor cycle per word, the net relative time increase is simply K.

If, on the other hand, this latter process is multiplexed so as to allow the transfers between the special buffer tanks and the high-speed memory tanks to take place simultaneously over p parallel channels, the time lost is reduced to K/p. The two methods are comparable in speed, therefore, when

$p=(N+2)/4$

(In the Dyseac system $N=8$, which is equivalent in speed to $p=2.5$. No large buffer memory is required.)

REGULATION OF TRAFFIC FLOW TO AND FROM MEMORY

In most machines, input-output word transfers are generally handled in fairly

| SUB-CYCLE	CONDITION	SIGNIFICANCE	ACTION
①	$A \geq A \geq F$	OPERATION COMPLETED	HALT INPUT-OUTPUT
②	$A \geq B \geq F$	CONFLICT WITH COMPUTING ADDRESS	HALT COMPUTING
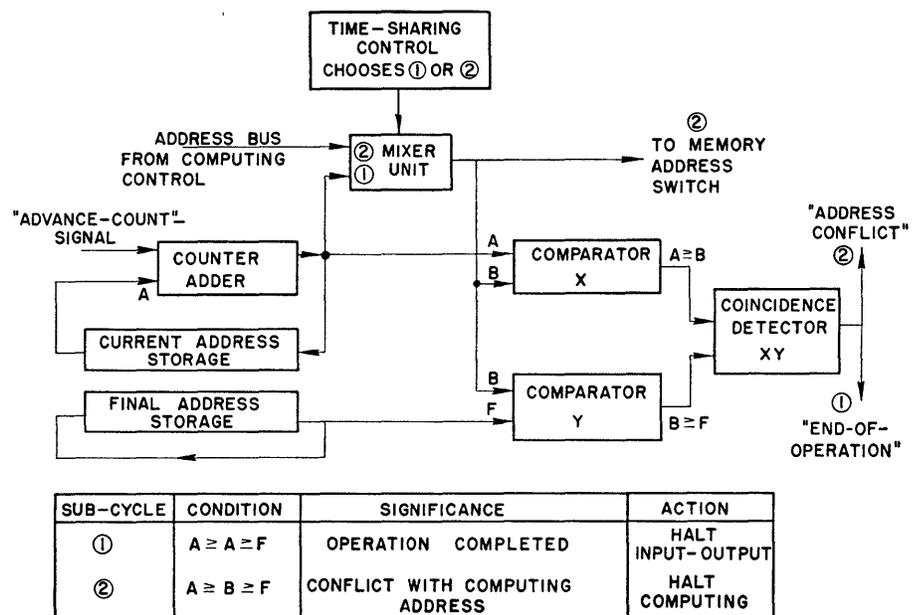
Figure 11. Address regulation and word count system, method C (concurrent time-sharing system)

large blocks. In systems in which successive words are transferred one at a time between input-output buffers and high-speed memory as the input-output operations proceeds, provision must be made for keeping track of the successive addresses in the high-speed memory to or from which the successive words are to be transferred. At the same time, some sort of tally or count must be kept so as to be able to determine when the requisite number of words have been transferred and the operation should be terminated. In Figure 9, a simple system for carrying out both these processes is illustrated. The figure shows an adder of which one input is fed from a register which contains a record of the initial address in the block of memory addresses between which transfers are to be made. The other input to the adder is fed from a counter (or 'add-one' unit) capable of holding a number equal in magnitude to the number of words in the largest block size in which input-output word transfers are carried out. If the counter is initially cleared, it is evident that the output of the adder which is transmitted to the memory switch will designate the initial address in the block. If an 'advance-count' signal is transmitted to the counter at the end of each complete word transfer, the adder will then transmit to the memory switch the next address with which communication is desired. At the same time, if the output of the counter is also transmitted to a comparator circuit that is fed also by a size-of-block signal, the end of the operation will be signified when the comparator emits a signal signifying that both inputs match. It will be noted that the contents of the initial-address register are not altered as the operation proceeds. This makes it possible to use the instruction register itself, which contains the input-output instruction that specifies the parameters of the input-output operation, as the source of the initial address. This procedure makes the inclusion of a special initial-address register unnecessary but requires that no new instructions be executed pending the completion of the input-output operation. When concurrent computing and input-output operations are desired, therefore, some sort of special storage register needs to be used.

Figure 10 illustrates a somewhat different system. In this system the contents of a register that originally contained the initial address in the block are successively modified by passage through a counter so that the register always contains the current address to which transfers are to be made. In another register,

the fixed final address in the block is preserved unchanged and compared with the current address by means of a comparator in order to determine when the input-output operation should terminate. In this case also, both registers might be replaced by the central instruction register provided concurrent input-output and computing is not required.

When a time-sharing concurrent input-output and computing scheme is employed, a further modification such as is shown in Figure 11 may be introduced. These modifications are inserted for the purpose of carrying out an additional function that is required by the adoption of a concurrent time-sharing scheme, namely, monitoring the areas in the high-speed memory which are involved in input-output operations that are still being executed. The purpose of such monitoring is to prevent the computational manipulation of data in these memory areas whenever such manipulation would be inconsistent with the as-yet-unsatisfied input-output command. For example, if the programmer should direct that a given section of the memory be loaded from an external input unit and then afterwards should direct that the contents of a memory location in this section be used as the source of an instruction, the program would have to be halted temporarily until the designated memory location has actually received the word intended for it from the input unit. Similarly, after an output instruction has been given, the machine should not be permitted to write into any location affected by this output order until the word in that location has actually been transmitted outside. Thus, with a concurrent time-sharing input-output system automatic interlocks are needed to halt the computation program temporarily to allow for the minimum time needed to insure that certain conditions like these are fulfilled.

In the system used in the Dyseac, illustrated in Figure 11, the two comparator units X and Y are employed not only to count the requisite number of words needed to complete the operation but also to determine whether or not any address request emanating from the computing control lies between the boundary limits specified by the current address and the final address pertaining to the input-output operation then in progress. This procedure is carried out by means of a time-sharing control unit which alternately channels into the mixer unit a signal either from the current address storage register or from the address bus that transmits address

requests from the computing control units. During the first part of each minor cycle, gate number 1 conducts; during the second part, gate number 2. In addition, whenever an input-output word is ready to be transmitted between the buffer storage and the high-speed memory, gate number 1 is made conducting during both halves of the minor cycle. When this happens, therefore, the memory switch (which operates only during the second half of each minor cycle) is directed to the memory address stored in the current address storage register. During the first part of a minor cycle, therefore, an output signal from the coincidence unit XY signifies that the current address has become equal to the final address, thereby signaling that the operation has been completed. When an output is detected from the same coincidence unit during the second part of a minor cycle, it signifies that the memory location sought for by the computing unit lies within the area in the memory which the pending input-output operation has not yet processed. This conflict signal (subject to appropriate conditions) is used to suspend computing operations temporarily until the progress of the input-output operation shall have removed the conflict.

Conclusion

These few examples illustrate some of the methods currently being employed by system designers for effecting the transfer of information efficiently and economically between high-speed digital computers and their associated input-output equipment. Limitations of space have prevented mention of such important topics as:

1. Methods by which the computer may be made to search in its input medium for information stored in locations not immediately accessible to the input reading heads.

2. Methods by which pulse code entering the machine from the several reading heads of a multichannel magnetic tape unit may be arranged inside the computer in their intended order, even though the order of their receipt has been disarranged as a result of skewing of the magnetic tape.

3. Methods for controlling several input or output units which transfer information to and from the high-speed memory concurrently, and whose operations are intimately intermeshed in such a way that the sequencing of the operations performed by each unit is regulated by the progress of the operations performed by the others.

Problems of the latter sort, concerned with the development of methods by which high-speed digital data-processing equipment can be harnessed efficiently

into an over-all system partnership with widely varied types of input-output equipment, are now assuming increasing importance. Compared to these problems the purely computing design problems, such as the design of higher-speed multipliers and the like, are far less critical and present fewer unsolved difficulties. This is partly because the principles of arithmetic processing are well defined and partly because the devices for carrying out such processes occupy logically isolated blocks inside a homogeneous system. For the latter reason, the task of coordinating such devices with other parts of the over-all system has usually offered relatively little difficulty. On the other hand, the task of creating a smooth-working system out of a heterogeneous collection of input-output and computing equipment possessing grossly unequal operating properties and performance rates is a critical challenge to the system designer today.

SEAC Input-Output System

S. GREENWALD

THE Standards Eastern Automatic Computer (SEAC) is a high-speed computing machine located on the grounds of the National Bureau of Standards at Washington, D. C. It was completed in May 1950 and for most of the time since then has been working on a schedule of 24 hours per day, 7 days per week. The machine is of a serial nature, uses a mercury delay line memory, and may be operated in either the 3- or 4-address mode, at the choice of the operator. The internal circuitry of SEAC is synchronous and works at the rate of 1 megacycle. A word length of 48 binary digits is used, of which there are 45 useful digits including the sign. The remaining three digit times are primarily useful for checking and for allowing sufficient switching time between orders.

Input or output operations on SEAC are accomplished either one word at a time or, more generally, eight words at a time. The reason for using eight words is that a single mercury delay line, of which there are 64 in SEAC, will hold that much information. A block of eight words is known as a group, and any number of groups up to the capacity of the memory may be read in or out by modifying the tape orders appropriately as the operation proceeds.

The input-output equipment had rather modest beginnings and started off with modified Teletype equipment. This included a tape reader and a keyboard for input operations, and a Teletype printer for output operations. Figure 1 shows part of the input-output equipment and also includes the operator's console.

It soon became evident that there was much to be gained by the use of magnetic-tape and wire-handling devices in speeding up the input and output processes, and thereby putting the various parts of the machine in better balance. For this reason work started on two kinds of equipment:

1. Magnetic-tape units devised primarily as an auxiliary memory. These units will hold up to 24,000 words on a 1,200-foot tape, as compared with the high-speed memory which holds only 512 words.
2. Wire-handling units. These are commercial units with necessary modifications. They are used primarily as a means of getting a program or data into the machine (input dumper) or obtaining finished data out of the machine (output dumper).

The whole philosophy of the system was to build equipment that would make the machine a more useful tool, not by attempting to build multichannel units with high-performance servos but rather with emphasis on simplicity, low cost, and reliability. Thus, as will be seen later, the tape unit which was eventually designed by the Electronic Computer Laboratory uses no servos and reads and records on a single channel only.

Before going into a description of individual units, it might be well to look at a diagram of the over-all system. The block diagram in Figure 2 shows in a very general way how the various pieces of input-output gear fit in with the computer.

The large box in the center is the computer, containing arithmetic and control circuits, shift register, and control, and other chassis involved in input and output operations. The one beneath represents the memory. The smaller

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boxes above the computer represent the Teletype unit, the two magnetic wire units, and the four magnetic tape units. The signals to and from this equipment pass through a selector relay chassis. The Teletype has its own separate communication with the machine, partly because of the number of leads involved and partly for historical reasons. Selection of any of the seven units can be made manually or automatically by the manual selector or the automatic selector.

In the computer proper there are the following units: First is the Teletype supervisory control. Among other functions, this chassis causes either the input or output transmitter-distributor (TD) to operate, properly shapes the pulses from the Teletype, counts characters and words, and so forth. The synchronizer changes the asychronous signals from the Teletype or magnetic equipment to synchronous signals required by the computer. The read chassis is used on input operations. It examines pulses from the input equipment and decides whether a binary one or zero is being received. The record chassis works only on output operations. It produces 12-microsecond pulses on one of two output lines. These ultimately energize a recording head in one of the tape or wire units. The tape and wire control has several functions. It furnishes directional signals which cause tapes to move in forward or reverse directions. It also controls the print rates and the spacing between groups of words on the tape.

The shift register is the speed changer in the machine. Pulses come off the tape at approximately a 6-kc rate; pulses from the Teletype come much more slowly, only 24 pulses per second. The problem is to insert these into a machine which operates at 1 megacycle. Roughly, what happens on input operations is that the shift register is filled up slowly and when the entire word is in place, it is fired endwise into the arithmetic circuits and
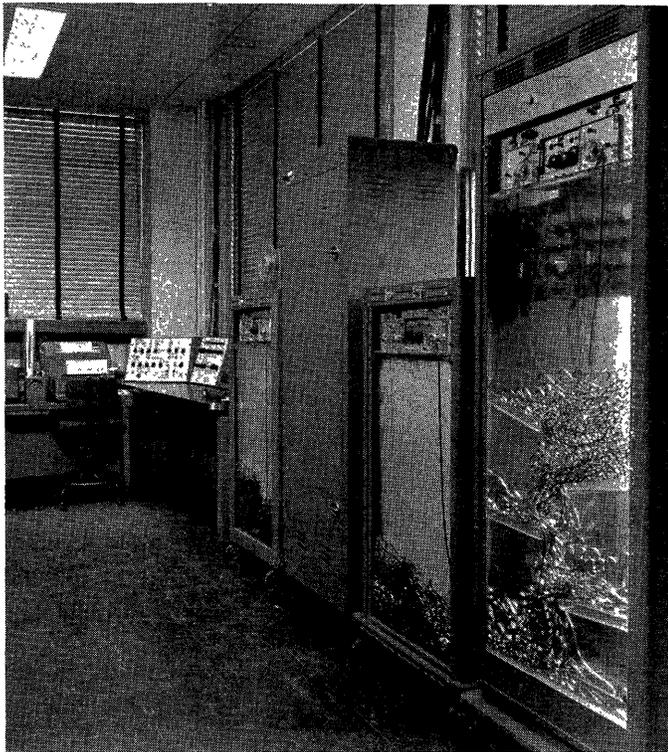
Figure 1 (left). Some of the input-output equipment used with SEAC
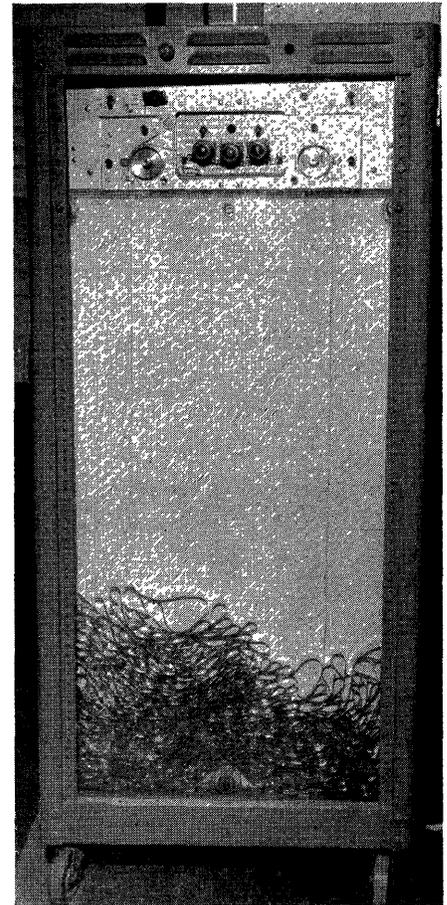
Figure 3 (right). Front view of magnetic tape unit

memory. Likewise, on output operations the memory feeds information into the shift register at the regular computer rate. It is then fed out at a high audio rate to the tape and wire units or at a much slower rate to the Teletype equipment.

So much for the over-all view. Now, each of these units may be examined in somewhat greater detail.

Tape Units

In examining one of the tape units, it will be noticed, in Figure 3, that there are two capstans: the one on the right causes forward motion, that on the left, reverse motion. In either case a small jam roller forces the tape against the capstan. The speed of tape motion is 5 feet per second. The tape is allowed to fall into either of two plate-glass compartments by merely folding over itself. There are no reels in the system. The tape is oxide-coated plastic and is also coated with a very thin layer of aluminum on the reverse side. The aluminum coating is very important in preventing electrostatic troubles, whereby the tape

tends to stick to itself and to the glass. There are three heads (left to right), erase, read, and record. These are standard commercially available single-channel tape heads. Several switches can be noticed in the illustration. These control the motor speed, printing, and erasing, and permit the tape to be moved under manual or computer control.

Access to the circuitry is from the back. Each tape unit has a similar chassis which communicates with the computer through two cables, one for d-c and filament power, a second mainly for signals. A typical chassis is shown in Figure 4.

There are actually four circuits on each chassis located in the tape unit:

1. *Writing circuits.* A positive 12-microsecond signal on one of the two lines from the computer is amplified, and energizes one side of a center-tapped write head for a one and the other side for a zero. In this way the tape is magnetized in opposite directions and gives the characteristic bipolarity signals when read back. The rate at which signals are impressed on the tape is determined by a multivibrator in the computer and is presently set somewhat higher than 6 kc.

2. *Reading circuits.* Also on this chassis is a preamplifier to pick up the weak signals from the read head and through a 2-stage amplifier to bring them up to a standard 2-volt level.
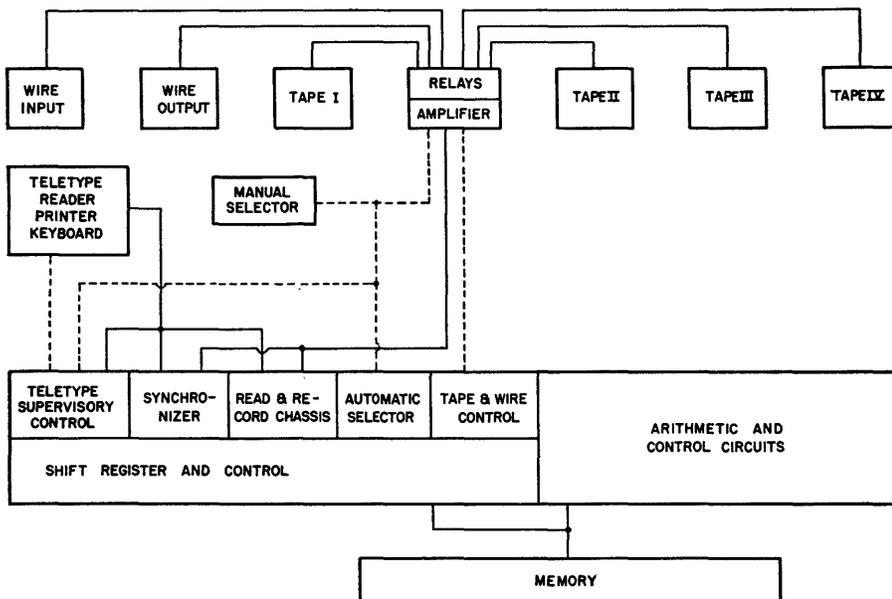
Figure 2. Block diagram of SEAC showing input-output units
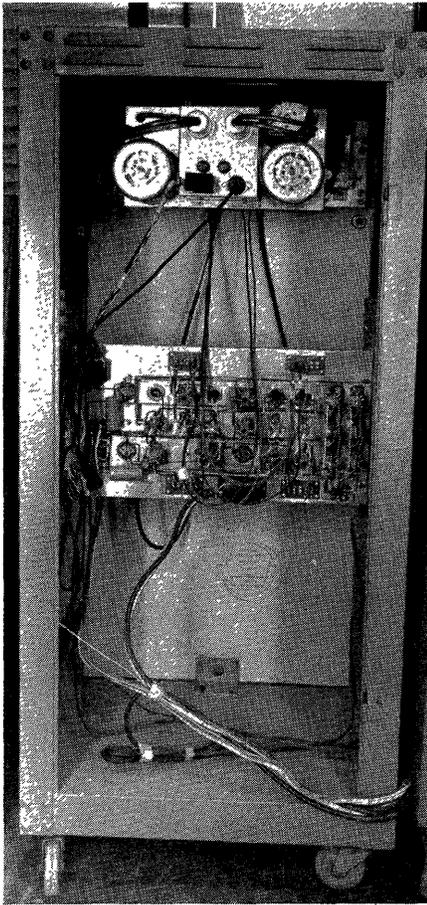
Figure 4. Interior view of the tape unit taken from the back

Figure 6. Teletype equipment used with SEAC

3. *Erase circuits.* The erase signal is brought from the selector relay chassis at about a 10-volt level, is amplified and transformer-coupled to the erase head at a level of about 200–250 volts. A 100-kc sine wave is used for erasing.

4. *Solenoid circuits.* The chassis also contains amplifiers to operate the solenoids, which in turn cause the tape to move in either direction. Pickup time is of the order of 5 milliseconds and most of this time is spent in energizing the solenoids.

It should be pointed out that the tape movement and reading and recording are under the automatic control of the machine. However, erasing is a manual operation independent of the machine. Before a tape is used, it is completely erased. This can be done ahead of time if desired, so no computer time is lost. For example, it is possible to use three of the tape units with the computer while erasing the fourth unit. There had been some thought at one time of causing the erase circuits to be activated automatically along with the print circuits but the extra complication was not thought worth while for these applications.

Input-Output Dumpers

Figure 5 shows the "input and output dumpers." It is a modified version of a commercially available dictating unit that uses magnetic wire. The changes made include mechanical modifications to speed up the wire to 8 feet per second. The head was changed to permit higher fidelity signals to be obtained. The electronic circuitry was completely replaced by circuits similar to those used in the tape units, with one exception. The input dumper can be used for reading only, and the output dumper can be used for recording only. Two switches have been provided on each unit. These permit the wire to be manipulated into position for a given program.

This kind of unit has turned out to be tremendously convenient. Each mathematician using the machine generally has several of the snap-in cartridges which fit into the main unit. These he keeps with him for use whenever he has computer time. Various programs are marked off as shown. Dozens of different programs, problems, or sets of data can be stored on a single cartridge. Also, test routines are recorded to be used by the engineers during testing or maintenance periods. The method of initially recording these programs on the cartridge will be described later, in the paper on auxiliary equipment. By using the wire unit, it is possible to load the acoustic memory completely in 12 seconds, including switch manipulation.

Teletype Unit

Figure 6 shows the Teletype equipment that is now in use. It consists of a modified Teletype tape reader, keyboard,

Figure 5. Input and output dumpers: note the wire cartridge on the right
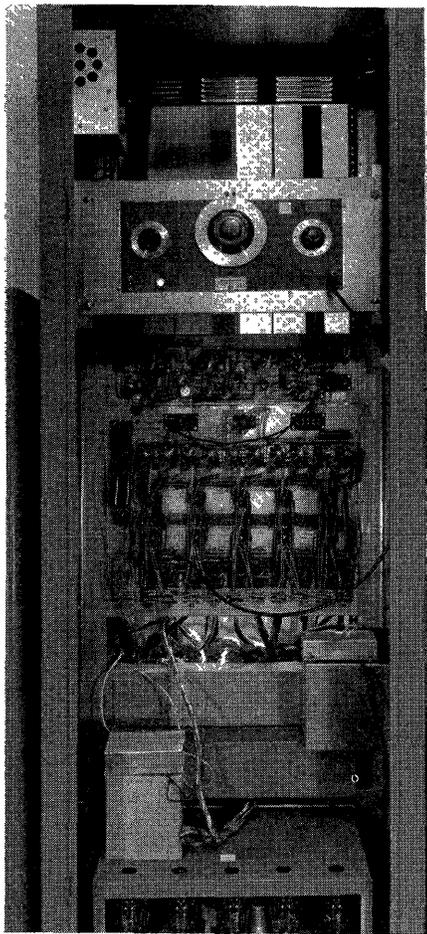
Figure 7. Selector relay unit

punch, and printer. A hexadecimal or base-16 code is used. This employs the numbers 0 through 9 and the letters *A* through *F*. Five-hole paper tape is used to provide not only for the numbers but for sign, space, and carriage return. Essentially, what happens on input is as follows: One line of the Teletype paper tape is above the metal sensing fingers in the tape reader. These fingers move upward in one operation and set up the four binary digits in parallel. Because of the organization of the input-output system this information must be sent to the computer bit by bit in serial fashion. This is the function of the TD, on which a rotating brush examines four small segments previously energized by the fingers. This information is transmitted to the Teletype supervisory control where the signals are shaped before being sent to the rest of the computer.

When printing out information, another TD is set in motion. This output TD merely sets the rate at which the computer information will be printed. Signals from the computer are sent through the supervisory control and during the revolution of the TD, the code

bars are set up in the Teletype printer, after which the appropriate key is struck.

Teletype is mainly used now for manual input and output operations. For example, suppose we wish to troubleshoot a particular routine. By means of the Teletype we can ask that the contents of a particular memory cell be printed out. If it is incorrect, a correct word can be inserted via the keyboard.

The Teletype equipment seems to be most useful in three ways: for troubleshooting the machine, for troubleshooting new programs, and for those programs where there is a great deal of computation but very little output data. However, because of their speed, magnetic tape and wire are used for practically all programs.

Teletype operates at six characters per second, giving about 24 binary digits. Since a word in SEAC is 48 bits, this takes 2 seconds per word. To fill the memory from Teletype therefore takes 1,024 seconds or about 17 minutes.

On the other hand, the wire works at about 3.2 kc. So each word of 48 bits takes about 1/64 of a second. If we add the time taken by 512 words, plus the time for gaps between groups of eight words, plus starting time, we come out with a figure of 12 to 13 seconds to fill the memory completely. This is at least a factor of 85 over Teletype.

Selector Relay Unit and Selection System

The unit which provides the communication between the magnetic units and the computer is the selector relay chassis. This chassis contains a bank of ten relays. Each one is 8-pole and of the plug-in variety. One or more may be energized when a particular input-output operation is called for.

The cabinet shown in Figure 7 not only

houses the relays but other equipment as well. One is the master oscillator which provides the low-level erase signals to all tape units. The other is the amplifier which receives signals from the pre-amplifiers in the wire and tape units. This chassis takes the 2-volt signals and amplifies and shapes them, so that at the output terminals a standard 3-microsecond 18-volt signal is obtained. These are the signals that are then sent to the computer for interpretation. In this cabinet is located a 4-inch speaker on which one can listen in on the tape and wire signals. This turns out to be very useful in monitoring programs.

The only other unit remaining to be described outside the computer is the manual selector panel. As shown in Figure 8, it contains a bank of ten main switches. Each switch is designated by a given hexadecimal code such as 03, 05, 06, 09, and so on. Each switch has 11 positions, one Off position, and ten for ten possible input-output units, of which seven are now used.

Perhaps at this point it would be well to explain the selection system. An order in SEAC may be described by 11 hexadecimal digits plus a sign. In a tape order, the second and third most significant digits in the code determine the input or output unit to be used.

Figure 9 contains an example of a typical tape input order in SEAC. Each code number, such as 03, 05, and so on, is generally related to a specific piece of equipment. However this is not always the case, as will be shown. Thus, 03 in general, means Teletype will be used; 05 means input dumper; 06, output dumper, and so on. Let us take a typical problem. Here the coder might designate input from wire, put most of his output data on tape unit number *1*, and print out occasional words on Teletype to indicate
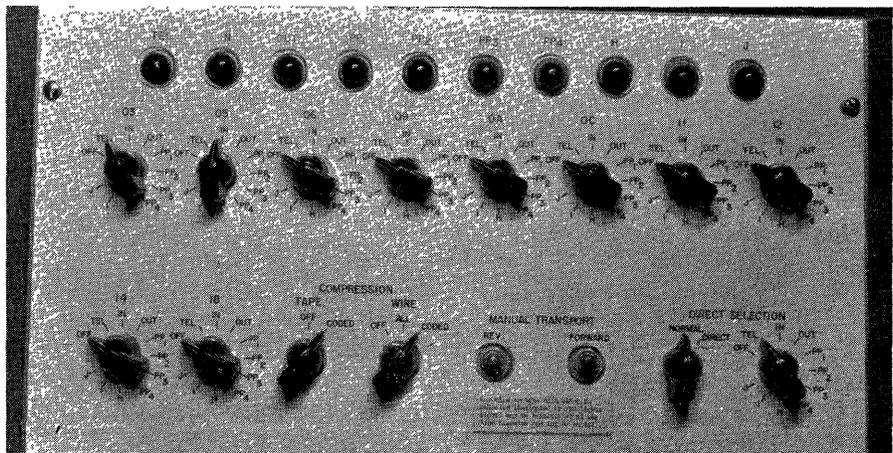
Figure 8. Manual selector panel

Typical tape order

O O 3 OIO4OICO ±

X X X	O	O	O	O	O	
	O	O	O	I	I	03
	O	O	I	O	I	05
	O	O	I	I	O	06
	O	I	O	O	I	09
	O	I	O	I	O	OA
	O	I	I	O	O	OC
	I	O	O	O	I	II
	I	O	O	I	O	I2
	I	O	I	O	O	I4
	I	I	O	O	O	I8

SWITCH CODE
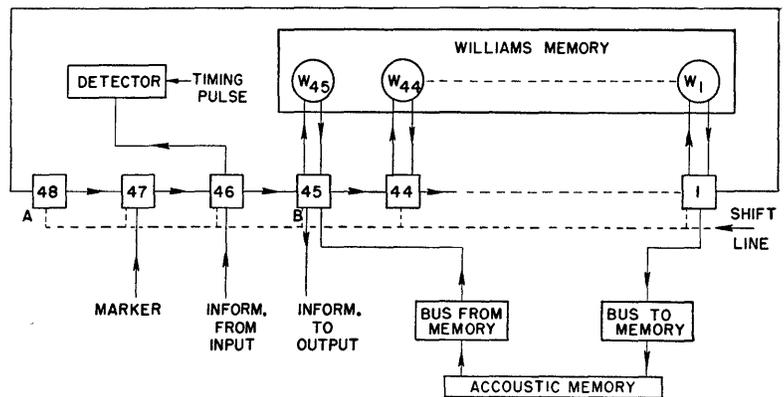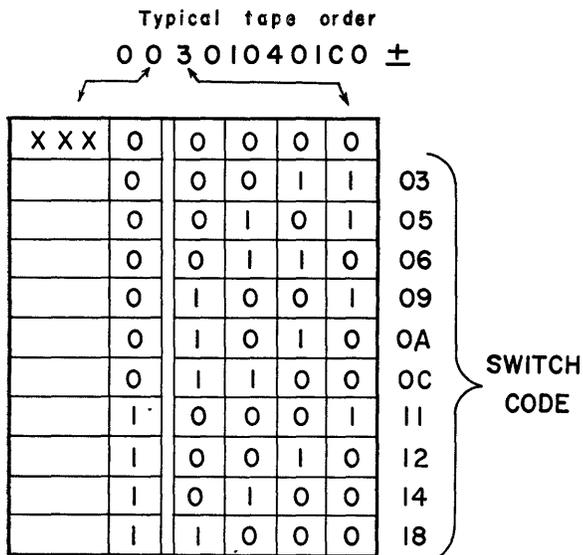
Figure 9 (left). Selector code

Figure 11 (above). Block diagram of the shift register

Figure 10. These two racks contain the circuitry of the shift register and its control

the present stage of the problem. He would then set up the switches in the normal ways, 03 to Teletype, 05 to input dumper, and 09 to tape unit number 1. However, suppose that at the time the problem was to be run on the computer, trouble was encountered with the first tape unit. All the coder has to do is set code 09 to tape unit number 2 by means of the 09 switch on the selector panel. Now all references for 09 go to tape unit number 2. In other words a given code number can mean any unit as designated by the switch on the control panel. The flexibility of the system means that units do not have to be continually plugged in and out when trouble is encountered. Furthermore, the operator can use the unit that is most appropriate for the present state of a given program. Coded selection can always be overridden by the direct selector switch, if desired.

The code system is based on the energizing of at least two out of five input lines. Thus, of the two hexadecimal characters only five binary digits are used. This particular method appeared to give the advantage of economy of equipment, where no more than ten input-output units were expected to be used.

This system also makes it possible to record on two or more units at once, providing they are compatible. Thus all four tape units could record simultaneously the same information if necessary.

Shift Register

It might be interesting to describe the means of going from relatively slow input equipment to the high-speed portion of the machine. This is the function of the shift register, which in this case acts as a speed changer.

As can be seen from Figure 10, the shift register and its control comprise two racks of equipment. Its size and complexity are due to its many functions. Only three of these functions will be mentioned:
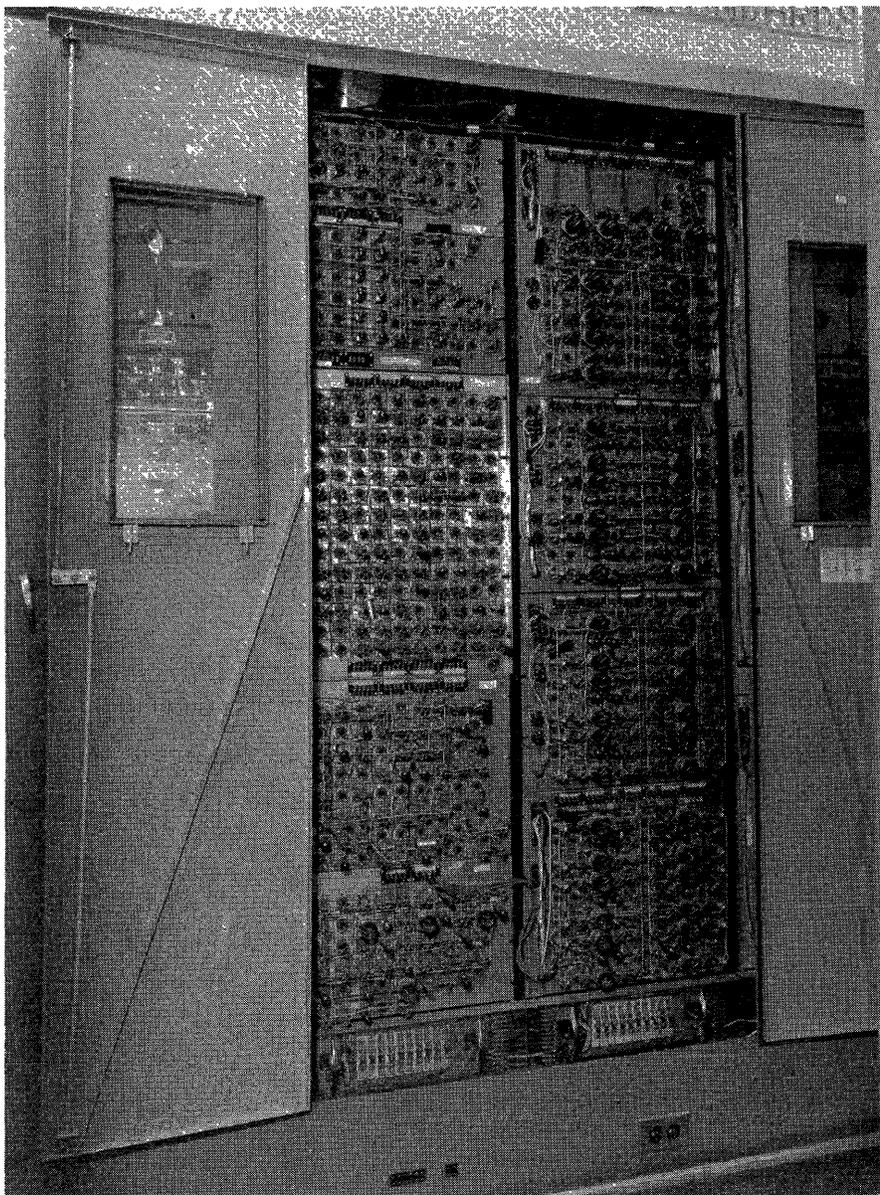
1. Inversion of words.

2. Acting as intermediary between the input-output equipment and the serial acoustic memory.

3. Acting as a register for an experimental Williams memory that uses the parallel mode.

The need for inverting numbers or words is brought about as follows. The normal method of writing numbers on paper or putting numbers into the machine via keyboard is to put them in with the most significant digit written first. Thus in writing 38945 we first write the three, then the eight, and so on. However, the machine uses the number with the least significant figure first, for obvious reasons, in addition, subtraction, and so on.

Figure 11 shows in very simplified form, the method by which the shift register does its work. There are 48 flip-flops arranged to form a closed loop. Note that the shift register only shifts in one direction, to the right.

An input operation starts with the-clearing of the shift register and the in-jection of a so-called marker pulse in stage 47. Its function is to indicate when an operation is completed. After the marker is inserted, the first pulse from the tape or Teletype is entered in position 46. Soon after this, the loop is shifted by a train of 47 pulses. At the end of this time the marker has advanced one stage to the left, that is, stage 48, and the first digit is in stage 47. The second digit is now placed in stage 46, and this same type of shift takes place again.

This is done 47 times until the marker ends up in stage 46, the most significant digit in stage 45, the next most significant digit in stage 44, and the least significant digit in stage 1. The fact that the marker is detected by the timing pulse at this time indicates that the word is now in position. The control changes, so that the loop is broken at A and B, and the next shift train affects only the first 45 stages. This time a 45-pulse train is generated which shifts the word along the bus where it is routed to the memory.

This is the manner in which words are put into the acoustic memory. Getting words out of memory is somewhat similar and proceeds as follows. The marker is again set up in stage 47, and the number is brought into the shift register via stage 45. By shifting 45 times, the word is gotten into position with the least significant digit in stage 1. At a signal from the tape unit that it is ready for information, the digit in 45 is transferred to the tape unit and about 2 microseconds later a shift of 47 steps takes place. This puts the contents of stage 44 in position 45, and that of stage 45 in position 46. At the next signal the pulse in 46 is eradicated and that in 45 read out. When the marker finally gets into position 46, the shift register signals the computer that the operation is over and we are ready to proceed with the next operation.

This completes the general description of the SEAC input-output system with the exception of two units, the read chassis and the synchronizer chassis. However, circuits performing similar functions are described in the paper on auxiliary equipment.

Input-Output Devices Used With SEAC

JAMES L. PIKE

THE input-output devices that are used with SEAC can be classified rather generally as either low-speed or high-speed equipment. In the low-speed class, the use of Teletype equipment for the baisc keyboard and printer, useful in troubleshooting and program checks, was suggested because of its reliability and its availability.

The principle followed in adapting Teletype to our computer was to avoid any modification to the basic mechanism that would affect its reliability. The code bars were reground and filled in where necessary, to alter the code. Most of the function bars were removed and the few remaining were modified with respect to the code they recognize. A Teletype transmitter-distributor (TD) is used to provide the timing signals to the computer for output printing at the standard Teletype rate.

Work is now in progress on adapting Flexowriter apparatus to the basic input-output functions of a computer. Its operating rate is slightly higher, about 10 characters per second as compared with six for Teletype. The Flexowriter has several advantages in that it may be adapted to perform functions not readily possible with Teletype apparatus. It offers such additional features as upper and lower case letters, 6- or 7- unit code, color change, and tabulating.

The basic difference in the two types of equipment is that Teletype operates sequentially and Flexowriter operates in parallel. The Teletype apparatus is well suited to serial input-output since it includes distributing and collecting apparatus. The Flexowriter, since it is not designed to be operated over long lines, handles the units in each code character

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simultaneously on separate lines. In many types of computer circuitry, of course, this is a preferable arrangement. The standard Flexowriter system comprises a punched-paper tape reader and a punch built into an electric typewriter as one complete unit. The Teletype machine in use with SEAC for some two and one-half years has proved quite reliable, and it remains to be seen whether Flexowriter equipment will provide similar reliability.

High-Speed Input-Output

As soon as SEAC was put into routine operation, it became evident that a faster system for getting information into and out of the computer would be highly desirable. On many problems the time spent reading punched-paper tape input or printing output on the Teletype printer was more than 95 per cent of the computer time on the problem. This very inefficient use of the computer was remedied by the addition of input-output dumper units. These are magnetic wire recording devices adapted from the mechanism of an office dictating machine, as pictured in Figure 1. This equipment was chosen

because of the ease of handling the recording medium. The wire is contained on two spools in a closed metal cartridge. This cartridge, shown in Figure 2, carries a pointer traveling over a replaceable paper scale on which the contents of the recorded wire may be labeled. These units can be switched to manual control so that the desired program may be positioned on the wire for input and then switched to computer control so that when the program calls for input from this particular source, it is automatically read in. Typical read-ins require only a few seconds, the speed of the wire being 120 times as fast as when it was recorded from Teletype tape.

The mechanical part of the office-dictating machine may be purchased from the manufacturer unwired and without the associated electronic equipment. One modification required for computer input-output use is a change in the motor capstan size to produce the desired speed, in this case 8 feet per second both forward and reverse. Auxiliary equipment requires a very slow wire speed, about 1 inch per second for transferring information to or from punched tape. For this application a second motor with gear train is mounted in line with the regular motor. The shafts are coupled by means of an overrunning clutch so that either speed may be obtained by simply switching on the appropriate motor.

Another important modification is replacement of the low-quality recording-reproducing head used in the office machine with a higher quality recording head as the Brush *BK. 908*. The mounting requires modification to fit the small space available, but this head produces a much cleaner wave form on the recorded pulses. The cartridges as supplied for office use contain about 1,800 feet of

stainless steel wire (3.75 minutes at 8 feet per second). This can be replaced with plated wire, which will allow about twice the pulse packing. Trouble was encountered in attempting to use a cartridge which contains four times as much wire. The difference in the diameters of the spools as the wire reels from the full to the empty spool requires additional guides to keep it in line with the recording head. In spite of the additional guides, there is considerable trouble with misalignment of the wire, and at present use of these cartridges is simply discontinued. The recorder mechanism contains two oiled cork disk clutches operated by solenoids to engage the forward and reverse spool-driving shafts. These solenoids are wired directly into vacuum tube control circuits. The clutches require periodic maintenance to assure their reliable operation.

Considerable trouble has been encountered with the latching system for holding the cartridge into the wire drive mechanism. In many cases the latches became disengaged while the wire was running and allowed the cartridge to jump away from the spool drivers, usually causing the wire to break. Recently the mechanical arrangement for engaging these latches was modified in such a way as to eliminate this trouble. There has still been occasional breakage of wire which is not explained. The plated wire, which gives better recording performance, is somewhat weaker and

more brittle mechanically. Considering the great increase in operating efficiency offered by this system, the occasional trouble with broken wire is tolerable. An operator particularly anxious not to lose his time assignment on the computer because of a broken wire may record duplicate programs on separate cartridges and thus have a spare in case of accidental breaking. As in the original operating system of the wire recorder, the engagement of the clutch solenoid closes contacts which start the motor. This gives an acceleration from stand-still to full-speed of the wire in approximately 1 second. Adequate gaps in the recorded program must therefore be provided to allow the wire to reach full operating speed before it enters the information area. This means that it is most efficient to use this device for input or output information requiring few stops and starts between long runs of data.

Auxiliary Memory

A computer such as SEAC has a necessarily limited storage capacity in its internal high-speed memory. With many types of problems this is a serious limitation and requires that information be transmitted out of the computer for storage to be re-entered into the computer later in the program. This means that the speed with which the storage and re-entering can be accomplished is a major factor in the over-all operating speed. A

Figure 1 (left). Inside view of input-output dumper wire drive
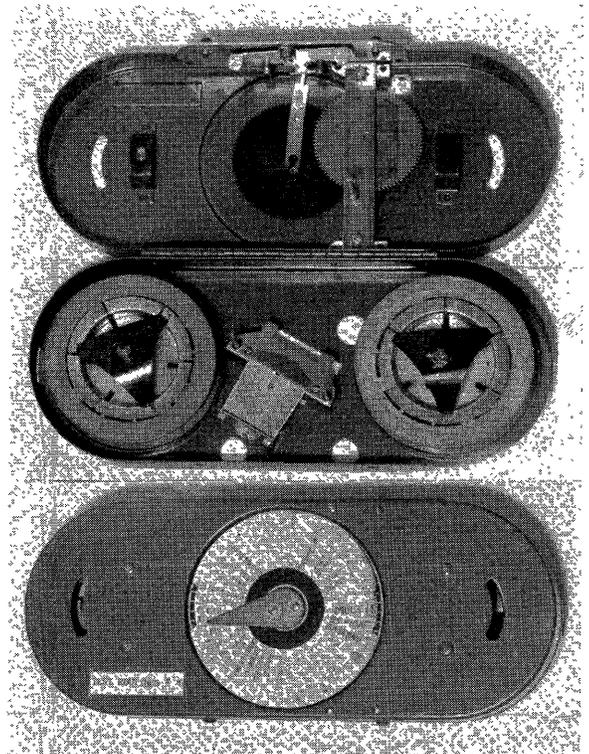
Figure 2 (right). Wire input-output cartridge
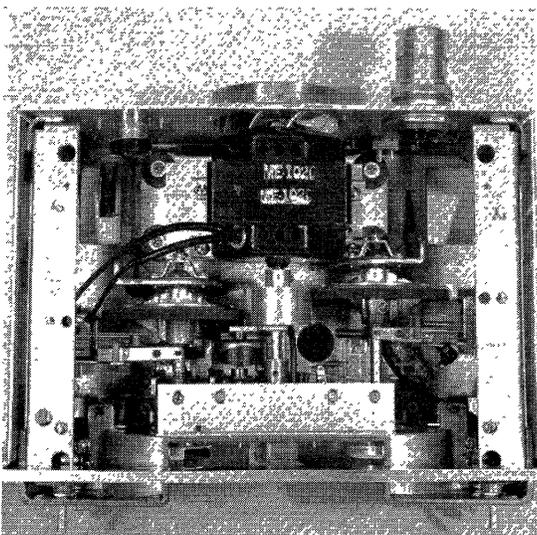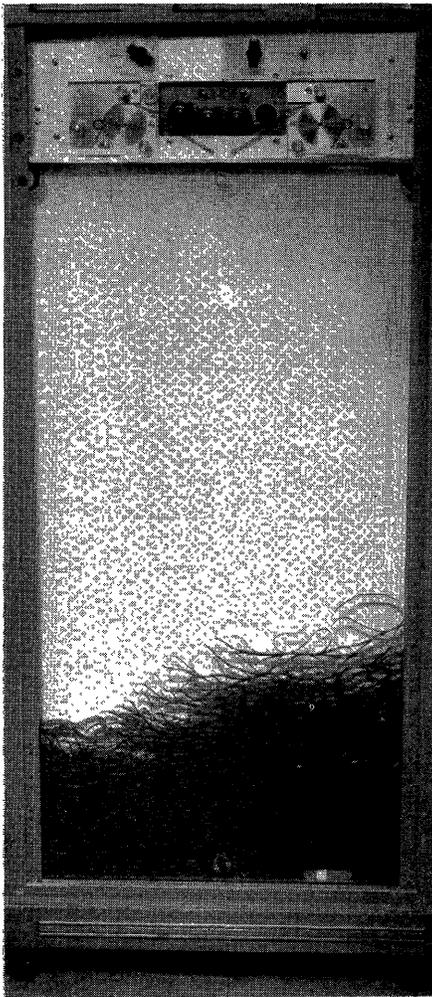
Figure 3 (left). Front view of auxiliary memory tape drive
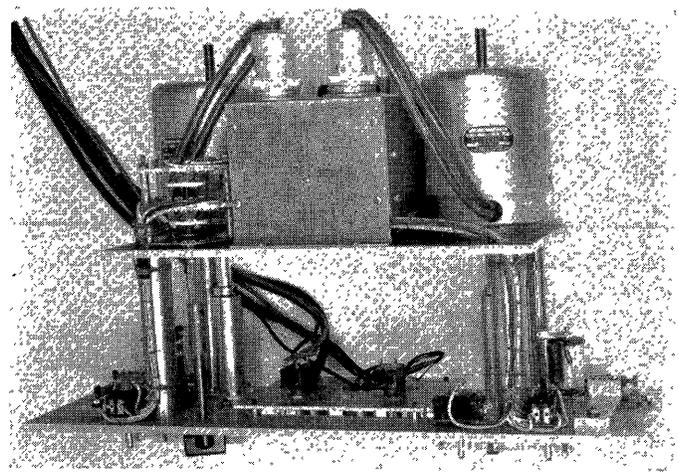
Figure 4 (right). Interior view of auxiliary memory tape drive

common technique is to employ complex and expensive servomechanisms to achieve rapid start, stop, and reversal of the magnetic medium in the magnetic recording device.

In the laboratory a system was devised to solve quickly and economically the problem of overflow memory for the SEAC without the use of servomechanisms. As seen in Figure 3, the device for moving the magnetic tape comprises a capstan turning continuously and a jam roller which may be moved into contact with the capstan by means of a solenoid. The complete tape drive mounts two of these capstan assemblies rotating in opposite directions with the recording heads between. The tape hangs loosely over the capstans and is accelerated to its running speed, typically 5 feet per second, when the jam roller is engaged. The total acceleration time including the solenoid lag is about 5 milliseconds. Individual motors of the dual-speed hysteresis type drive each capstan (Figure 4). They are so mounted as to allow easy replacement by motors of a different speed.

The capstans are smooth stainless steel giving very little friction against the loose tape. The jam roller is simply a small ball bearing with a nylon tire pressed on it. The solenoid which moves the jam roller about 0.020-inch is adapted from the coil of a short telephone-type relay.

The four units now in use with SEAC use single-channel bipolar recording with a-c erase on 1/4-inch tape. The use of wider tape and multichannel systems is entirely feasilbe. The tape is stored in a "tank" where it falls in loose random folds from the capstan as shown in Figure 3. This tank is formed by the space between two plates separated by slightly more than the tape width. There is no tendency for the tape to twist parallel to the faces of the tank and therefore no opportunity for snarls to form in the tape. The SEAC units can be operated with up to 3,600 feet of tape in a tank 19 inches wide and 3 feet high. Separate tanks are used to receive the tape from each capstan with the ends of the tape prevented from passing through the mechanism. A single tank may be used with the tape spliced into a continuous loop, but the use of more than about 400 feet of tape in this way may prove difficult.

One difficulty encountered in the use of these tape drives came from the strong tendency of the tape to acquire an electrostatic charge as it passes through the drive mechanism. The charge can be strong enough to cause the tape to stick to the tank near the top until it backs up into the mechanism and is damaged by a sharp fold or fouls the jam roller. This trouble is completely eliminated by the use of a tape now available with an evaporated aluminum film on the back surface. If lucite is used for the tank, this must also be treated to prevent the accumulation of static charges on the surface.

Another problem arises from the presence of flaws in the magnetic tape. Commercially available tape has many small imperfections in the magnetic oxide coating which are quite undetectable in ordinary audio work but cause loss of one or more digits of information in pulse work. With multichannel apparatus there are several systems for avoiding these flaws, but since we are operating a single-channel system, an attempt was made to improve the tape surface mechanically. A technique has been experimentally developed which is quite effective in eliminating flaws from ordinary tape. The recording flaws are caused by nodules of the oxide which project above the normal surface and lift the tape away from the head. They may be removed by passing the tape surface across a properly shaped scraping blade. The physical characteristics of the flaws vary with the manufacturing method, and this technique applies to the product of only one manufacturer, Scotch-type 111.

A third difficulty arises from the use of plastic tape with this storage method. If a 1,200-foot tape is left immobile in the tank for a day or so, it develops kinks at the loops which will cause the tape to jump away from the recording head at the light pressures it is preferable to use. If the pressure pad is tightened to eliminate this trouble, it causes increased wear on the tapes and heads. A fair compromise may be made by using only about 600 feet of tape in a tank. If a base material of improved resilience is developed, an increase in storage volume will be facilitated. The simplification derived from avoiding the reel inertia problem is paid for by inconvenience in changing tape. This is quite tolerable when the device is used solely as an auxiliary memory.

Auxiliary Equipment to SEAC Input-Output

RUTH C. HAUETER

THE two previous papers have been concerned principally with input-output units and equipment that is actually attached to the SEAC. That which is now described is physically separate from SEAC. This equipment allows the slow work of preparing input programs and data, and of printing the results to be accomplished without using valuable computer time.

The first step in preparing an input cartridge for SEAC is to prepare a punched paper tape from the coder's program. Teletype equipment which has been modified to conform with the SEAC code is used. There are several reasons for having this intermediate step rather than having the program typed directly onto the magnetic wire. First, it makes the wire-recording equipment much simpler, as the wire can be continuously moving. Also, the paper tape can be easily corrected, eliminating the necessity for complicated error-checking circuits. Also, in case of trouble with the wire input to the machine, or in case the wire should be damaged or erased, the paper tape can be read into the computer through the Teletype input or the program re-recorded on wire from the already corrected paper tape.

In SEAC, a hexadecimal code is used for the Teletype characters. This works out well since the actual word length in the mercury tanks is 48 bits. Also, since there are 16 different orders in SEAC, it was a good choice for the instruction word. In the 3-address mode of operation, there are 12 bits to an address, so three characters specify one address. In 4-address operation, where there are 10 bits to an address, one character has to contain part of two addresses. If an octal code had been used, more than one character would have been necessary for the order, and more typing would have to be done. Also, the hexadecimal code requires no change when decimal information is used, since the first 10 characters are identical. As a small convenience, SEAC also uses two of the characters above 10 with the decimal code to provide a decimal point and a space.

The Inscriber

When the paper tape is correct, its information is transcribed onto magnetic wire for rapid computer input. The unit which does this transfer is called the inscriber. The function of this unit, the use of the cartridge for wire handling, and the use of the cartridge in SEAC, have already been explained briefly.

Whenever there is a considerable delay between input instructions, such as when the machine is halted for a manual operation or when there is a lot of computing between instructions, there must be enough space between the blocks on the wire to allow the wire to stop and then get up to speed again. In SEAC, the complete routine is usually read in before problem computation is started. The spaces between blocks then need only be long enough for SEAC to compute its next read-in instruction. Data are read into the computer several blocks at a time, so again the long space need be inserted only when the wire is allowed to stop. A control on the inscriber allows the operator to change the length of the space at will.

In Figure 1, the block diagram of the inscriber is shown. The punched paper tape reader is a modified Teletype transmitter-distributor. As characters are sensed by the tape reader, the brush passing over four narrow segments on the special commutator provides the recording signals for the wire. Counters are used to halt the tape reader at the end of

each block, while the wire continues to move. A high-speed forward motor position is used to read, erase, and test record. By reading is meant audible monitoring of the wire. Used wires can be erased on the unit, and in case bad recording spots are suspected, a test recording of alternating positive and negative pulses can be made, and the wire checked. However, with the wire now in use, this checking does not appear to be necessary.

The inscriber has been in operation for $1\frac{1}{2}$ years and gets almost constant use for 16 hours of the day. It is shown in Figure 2. The unit on top is an auxiliary erase unit.

The Outscriber

The unit which performs the reverse function of the inscriber is the outscriber. Beginning with a magnetic wire on which information has been printed by SEAC, it counts the pulses on the wire, stores the information they represent until it has received enough for one character, and then punches this character on a paper tape. During the punching operation, more pulses are coming along and the operation is repeated.

A punched paper tape is produced instead of a printed copy because both card punching and typewriter printing require variable timing cycles for different operations. In the card punch, the card feed time is much longer than the time of punching a column, and in the printer the carriage return time is variable and can be many times longer than the time required to punch a character. By using the punched paper tape it is possible to run the magnetic wire at a constant speed. This reduces difficulties caused by starting and stopping the wire, particularly since the wire drive used has such poor start-and-stop performance. These difficulties are aggravated by the very high gain necessary in the reading amplifier.

Grouping the information which is
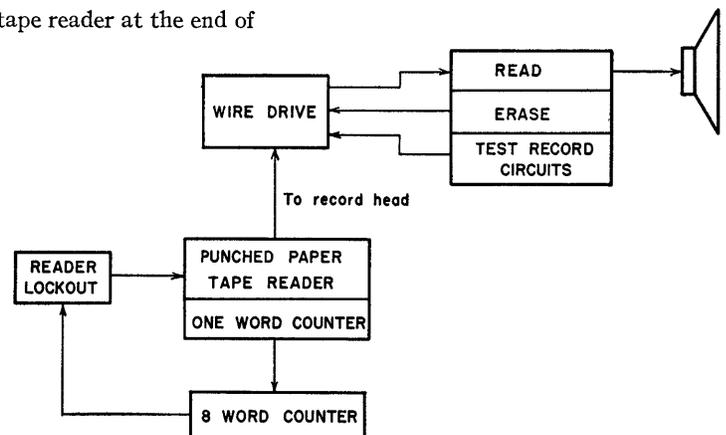
Figure 1. Block diagram of the NBS inscriber

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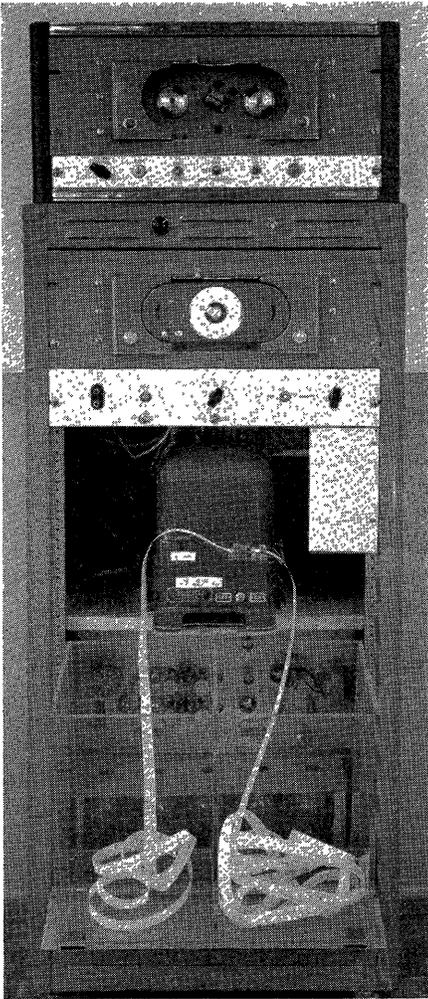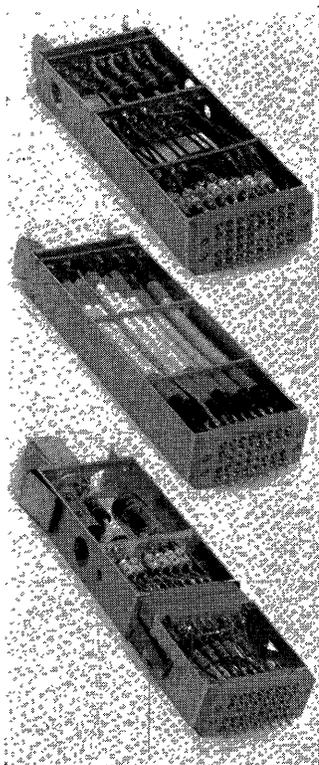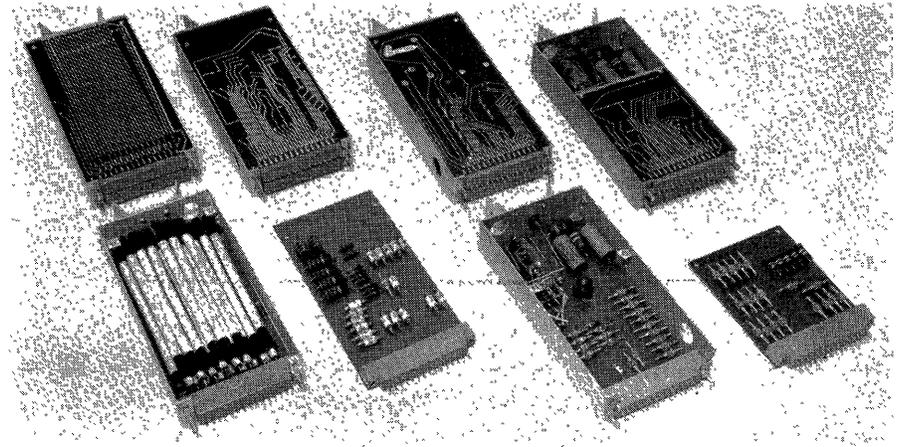
Figure 4. Printed-circuit packages showing exterior and interior construction

coming serially from the wire into characters requires a serial-to-parallel conversion. This means the serial information must be routed into the proper channels. If a character has four bits, four channels are necessary. If a 6-bit character is desired, six channels would be necessary. At the time the outscriber was being planned, a simple modification to SEAC which would enable the alphabet to be used was being considered, and since it involved only a small increase in equipment, it was decided to have either 4- or 6-channel operation available in the outscriber.

As much checking is used as could easily be included without an overbalancing amount of equipment. Since there is already a pulse counter which counts up to one character, a character was decided upon as the most logical unit for checking operation. Also, since the computer prints in blocks, it is easy to sense the gap between blocks and, by examining the counter at this time, obtain an error check. If an error is detected, the wire is halted and an indicator is lit to catch the attention of the operator.

Since the design of a hand-wired 1-stage package for SEAC-type circuitry was almost complete at the time the outscriber was being planned, it was decided to design the outscriber around these packages. This would provide operating experience with the packages before incorporating them into any future computers. SEAC-type circuitry requires synchronous operation based on a 1-megacycle clock. Figure 3 shows several typical packages. A tube and gating package is on the right, next to it is a delay line package, and on the left a package which contains various terminations for the delay lines. Two other computer groups co-operated with National Bureau of Standards (NBS) in the design of these units and they have computers now under construction using similar packages.

A computer is also under construction at NBS, using printed circuit packages

Figure 2 (above). The NBS inscriber

Figure 3 (left). Hand-wired packages, forerunners to the printed-circuit packages

Figure 5 (below). Block diagram of the NBS outscriber
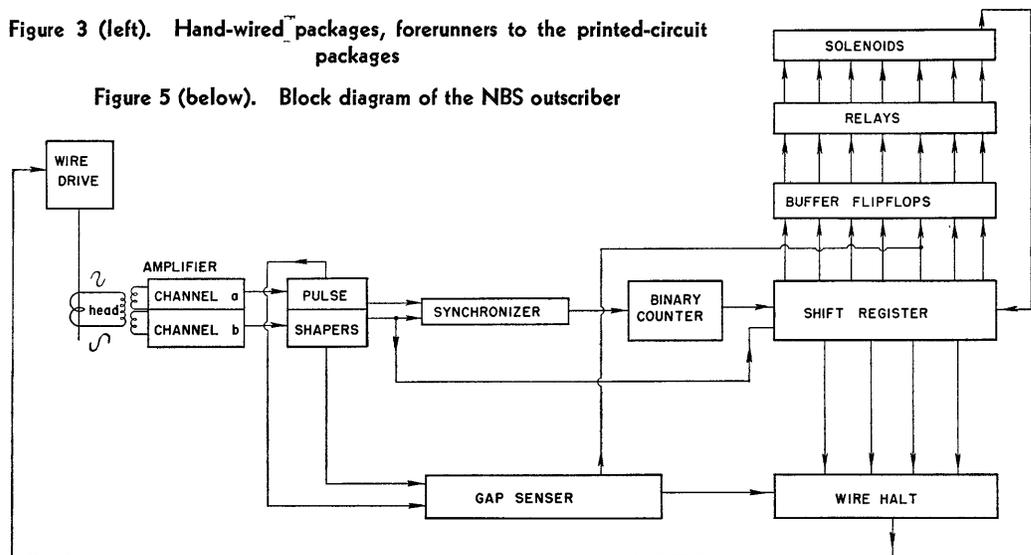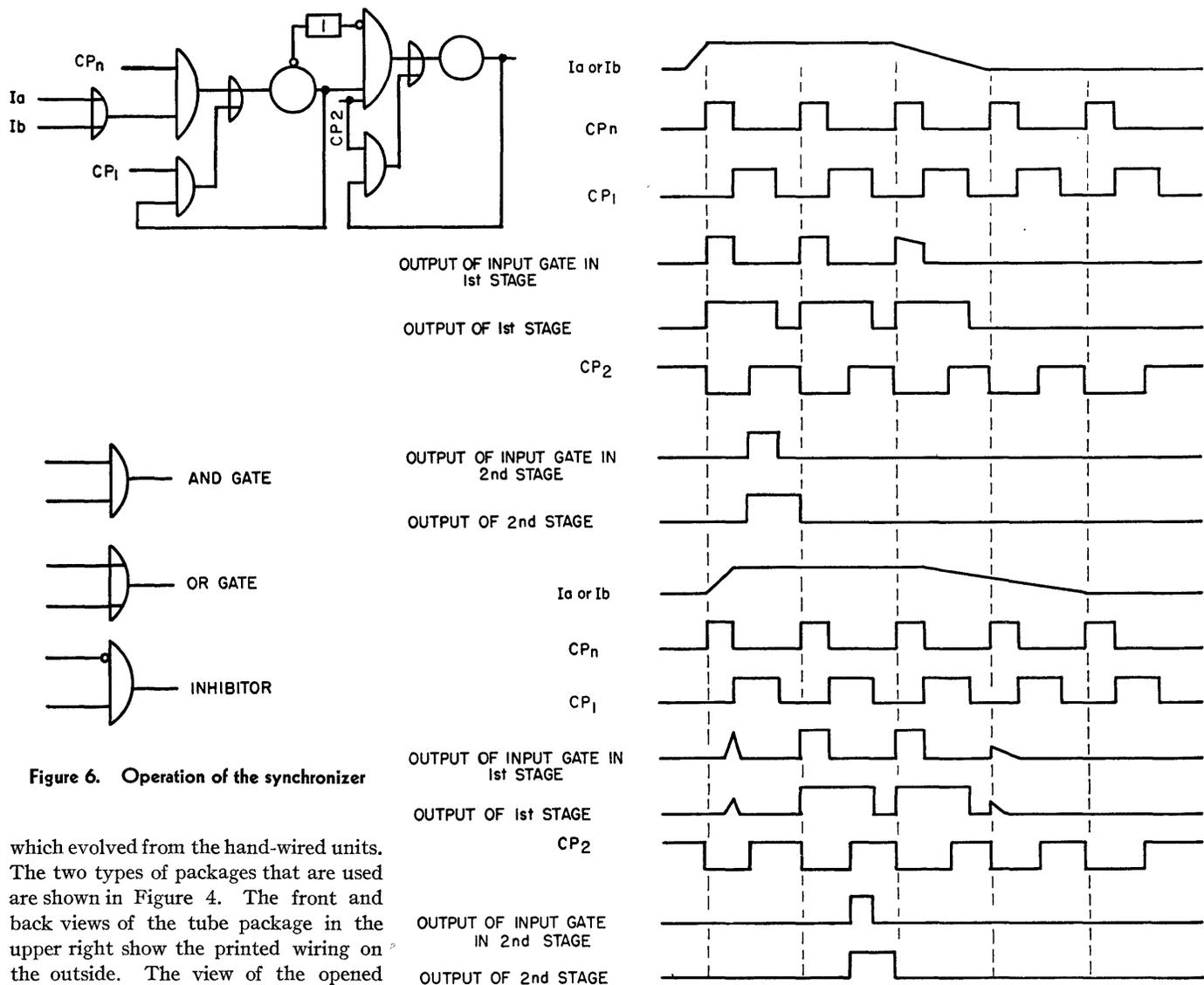
Figure 6. Operation of the synchronizer

which evolved from the hand-wired units. The two types of packages that are used are shown in Figure 4. The front and back views of the tube package in the upper right show the printed wiring on the outside. The view of the opened package below them shows the components inside. The front and back views of the delay line package, which includes the terminations for the lines, are shown in the upper left, and again the opened package is shown below.

The make-up of a SEAC word has already been explained in S. Greenwald's paper. As the word comes from the computer, the space and sign characters are differentiated from other characters only by their position in the word and, to a certain extent, by the information they contain. This means that counting of characters is necessary. This is done in the printer rather than in the outscriber. A Flexowriter punch is the terminal equipment on the outscriber. The typewriter used for printing from the paper tape is a Flexowriter. Flexowriter equipment was used mainly because, although promising for future computer work, it had had very little operating experience. Using it in the outscriber was one way of getting some of this experience.

These are the basic parts that are necessary in the outscriber as planned:

1. Wire drive.

2. Amplifier.

3. Some method of distinguishing a one from a zero.

4. Synchronizer: A device which can take a long slow pulse and produce one and only one pulse synchronized with a clock pulse.

5. Counter: To determine when enough pulses have been received to make a character.

6. Register: To store information contained in a character as the count progresses.

7. Buffer register: To store information for one character during punching while new information comes in.

The block diagram in Figure 5 shows how these parts fit together in the SEAC outscriber.

The wire drive has already been described by J. L. Pike. The pulse packing and wire speed are such that the punch is driven at about 12 characters per second. In both the inscriber and the outscriber, the pulse packing on the wire is very con-

servative. The wire drive is controlled by both manual switches and the error-checking circuit. The high-speed forward and reverse positions, as well as the low-speed reverse, are used for manual positioning of the wire. The low-speed forward is used for transcribing information only.

A high-gain low-frequency 2-channel amplifier is used. It must have high gain since the wire is moving only about 1 inch per second, and the signal induced in the head therefore is only about 200 microvolts. The 2-channel amplifier is needed to tell whether the signal on the wire is a one or zero. Pulses of opposite polarity are fed into the two channels of the amplifier by a center-tapped transformer. For each pulse on the wire there is a positive pulse in each channel. If the pulse in channel B follows the pulse in channel A, the pulse on the wire is a one. The method used is very similar to that used in SEAC. The low-pass amplifier has a cut-off of about 500 cycles. This is
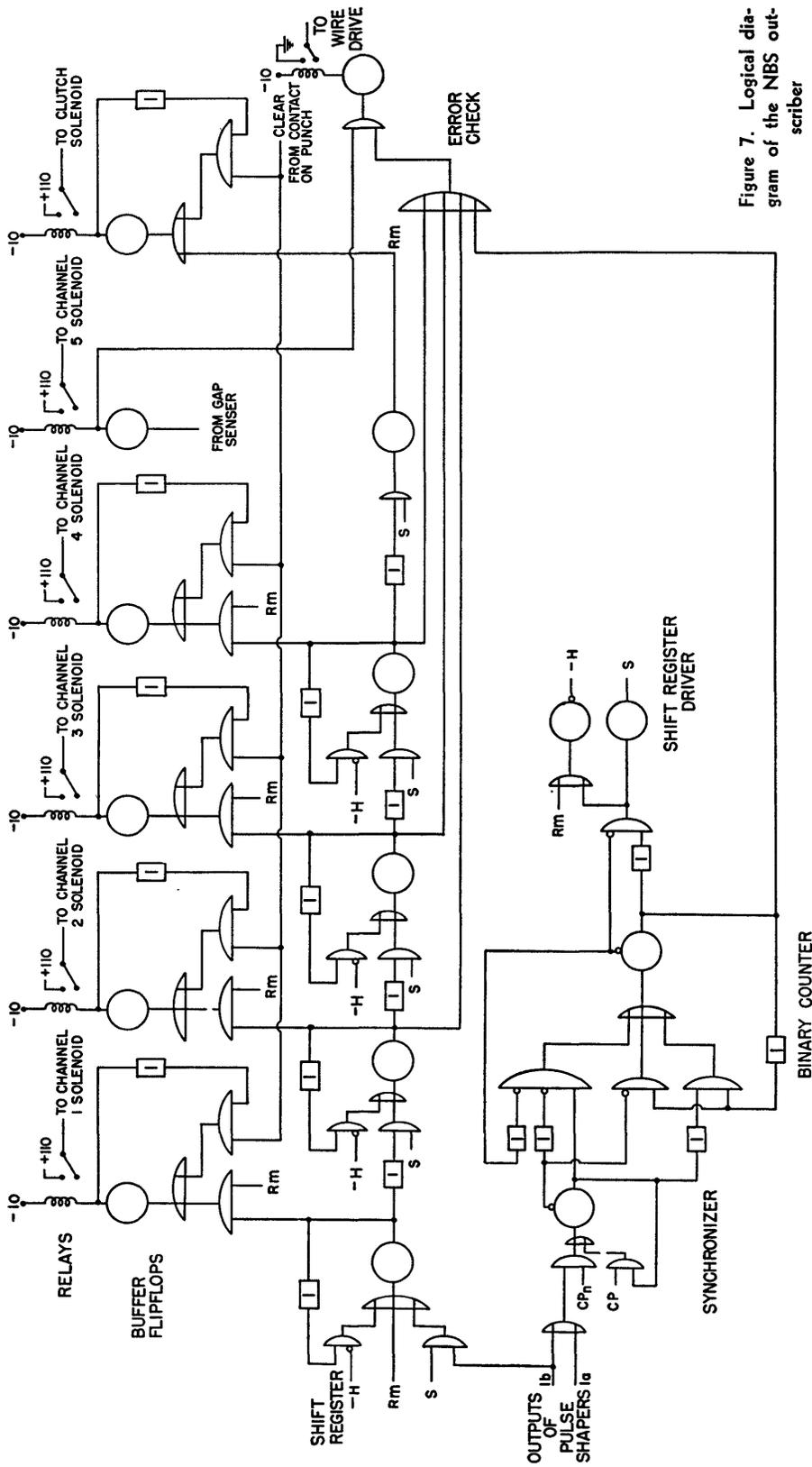
adequate for passing the signal and is desirable to prevent stray noise from being picked up.

The eventual use of the information from the amplifier is to drive gates in the part of the outscriber that is built from SEAC-type circuitry. Each gate load is about 10 milliamperes, which cannot be supplied by the high-impedance output of the amplifier. This current can be supplied by a tube and transformer as used in the computer-type circuitry. However, a signal applied to a pulse transformer must have a sharp rise, much sharper than that coming from the amplifier. This requires the use of pulse shapers in the outscriber, one for each channel of the amplifier. These consist of a Schmitt trigger circuit, which produces a square pulse for each positive pulse from the amplifier, followed by a pulse amplifier with a step-down transformer. This combination produces a pulse capable of driving several gates.

The circuitry from here on is the SEAC-type, which means that all signals have to be synchronized with the 1-megacycle clock. The output of the pulse shaper is a long pulse (2 to 5 microseconds) in comparison with the clock pulse (0.5 microsecond), and arrives completely asynchronously with the clock. The function of the synchronizer is to start with this pulse and produce a single half-microsecond pulse synchronized with the clock. There is a pulse out of the synchronizer for each pulse from the two pulse shapers, or two for each pulse on the wire. The synchronizer feeds these to the binary counter, which is a dynamic flip-flop, and produces one pulse for each two received, or one for each pulse on the wire. However, the pulse is produced at the time of the second pulse from the synchronizer, so that examination of the channel B output at this time will give the information as to whether the pulse on the wire was a one or zero.

The various ways of counting, such as a series of binary counters, a ring counter, and shift register, were considered and the amount of equipment required for the counter and register determined for each. Since the shift register both counts and stores information, it required the least equipment. The shift register is a series of dynamic flip-flops and works as follows: A marker is set in the first stage of the shift register, all others being cleared. Whenever a pulse is received from the binary counter, the marker is shifted to the next stage, and the first stage is reset if the pulse on the wire is a one, but not if it is a zero. When the next pulse is received from the binary counter, the marker is
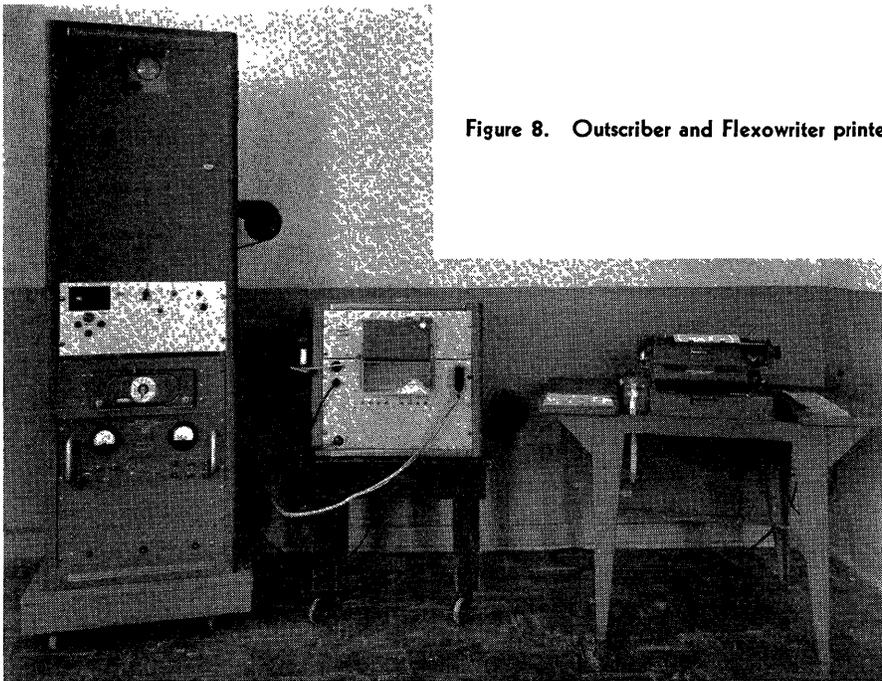
Figure 8. Outscriber and Flexowriter printer

shifted down another stage, the information is shifted to the second stage, and the first stage again reset or not, according to whether the pulse on the wire is a one or zero. This continues until the marker reaches the final stage, when the information in the other stages is dumped into the buffer flip-flops, the shift register cleared, and the marker reset.

The buffer flip-flops are also dynamic flip-flops, one for each stage of the shift register, which are set when the marker reaches the last stage of the shift register if the corresponding shift register stage is set at that time. The last buffer flip-flop is set each time, since it contains the information that enough pulses have been received for a character and that it is therefore time to punch. They are reset by a signal from the punch which indicates that the punching cycle has started and the information being stored is no longer needed.

A method of driving a relay directly

from the output of a dynamic flip-flop was worked out which, equipmentwise, made relays seem the best way of driving the solenoids in the punch. These solenoids require a current of approximately 0.25 ampere to operate. The energizing of the relays begins as soon as the buffer flip-flops are set.

Contacts on the relays provide the power necessary to energize solenoids on the punch, which in turn set up interposers when channels are to be punched. The relay on the last buffer flip-flop (which gives the signal to punch) energizes the clutch solenoid which causes the motor shaft and the punch-operating shaft to be engaged, and starts the punch cycle. Once the operating shaft is engaged, the clutch solenoid armature can be released. Similarly, a cam causes a bail to lock the interposers in place so they cannot be changed during the punching operation and the solenoids which set the interposers can then be de-energized. At approximately the same time, a contact sends a signal to the buffer flip-flops, resetting them.

During the gap, if there has been no error, the first stage of the shift register should contain the marker and the other shift register stages, and the binary counter should contain nothing. If any of these stages except the first shift register stage are on, the error-checking circuit halts the wire and the wire-halt indicator is lit. The chance of an error getting through is very slight, as there would have

Figure 9 (below). View of the outscriber showing use of packages

Figure 10 (right). Wiring and switch panel of the outscriber
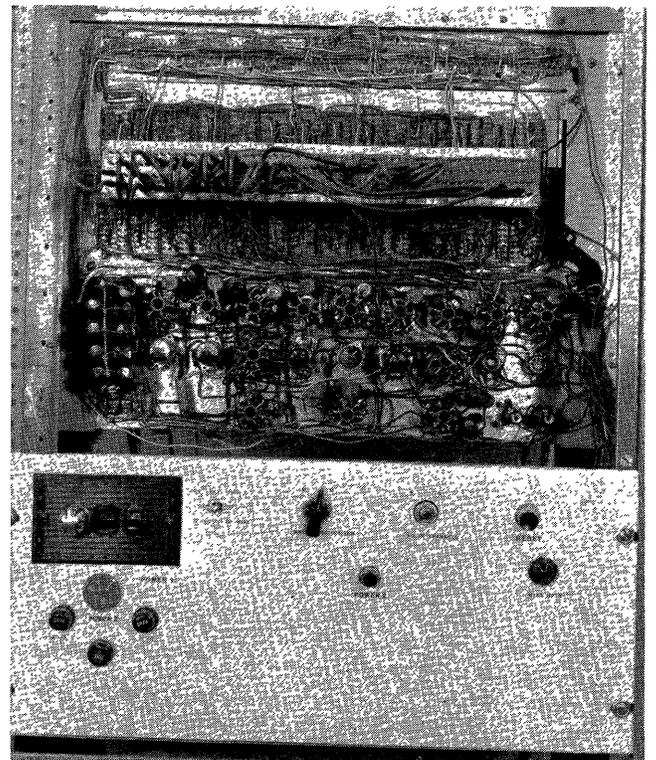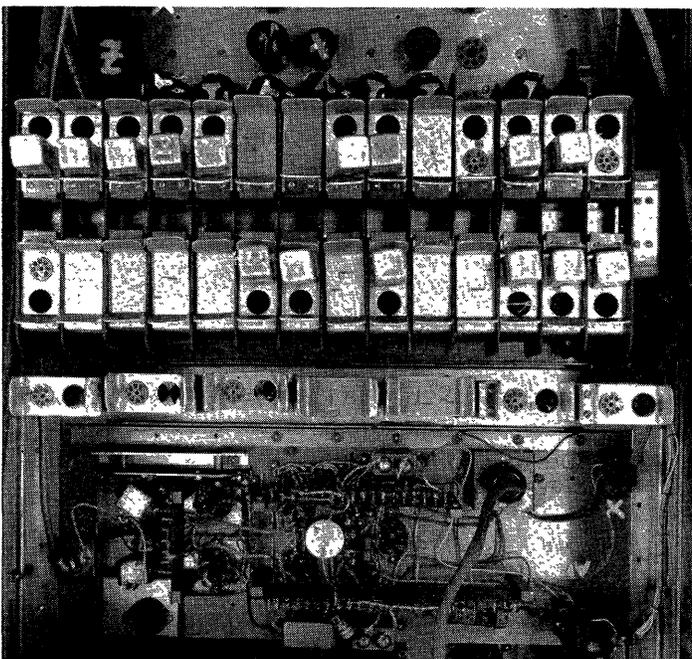
to be eight (or a multiple of eight) pulses gained or lost before the error would not be caught.

In case of an error, the operator can reverse the wire through the block in which the error was sensed by using the low-speed reverse position and trying again.

In 4-channel operation, the gap senser is also used to provide a fifth channel punch at the beginning of each block. This is used only as an aid to the operator to assist him in locating information visually on the punched tape.

One part which was rather blithely passed over, and which will now be described further, is the synchronizer. Figure 6 shows the logical diagram of this part as well as some idealized pulses. An AND gate or coincidence gate gives output when there are signals on all inputs. An OR gate gives output when any input has a signal on it. There is no output from an AND gate when an inhibitor input has a negative signal. The basic idea of the synchronizer is to use a narrow clock pulse to sample the signal coming in. If enough of a pulse is produced at the output of the transformer for the regeneration gate to catch and hold the output up as long as CP_1 lasts, a regular pulse is produced. If it does not, only a spike will be produced. However, the input pulse is long enough so that a full pulse will be produced at the next narrow clock pulse time. The second stage examines the output of the first stage. If only a spike comes through, it will be gone before CP_2 is up. The first regular pulse gets through the input gate and is lengthened by the regeneration gate. The

length of Ia and Ib is such that there will always be at least two full pulses from the first stage. However, only one gets through the second stage because the negative of each pulse arrives 1 microsecond later to inhibit the next one, allowing only the first one to get through. This also means that a weak pulse toward the end causes no concern, since there is always a stronger pulse to inhibit it. The top group of signals shows a case where the first pulse that gets through the input gate is a full CP_N, and produces a normal pulse. The bottom group shows the other case where the first pulse is a spike and does not produce a normal pulse. The next pulse then produces it.

Figure 7 shows the logical description of the main part of the outscriber with the parts that are used in 4-channel operation. The logical parts that comprise the various blocks previously described are labeled. It will be noticed that the second stage of the synchronizer is combined with the binary counter. Attention is directed on the logical diagram to the method of recognizing a one on the wire. The binary counter is set by the first pulse from the pulse shapers. In case of a one, the first pulse is on Ia. The pulse on Ib turns it off. Between times, it produces a train of regular half-microsecond pulses. The gate which generates S is continually inhibited as long as this train lasts. However, after the train, the 1-microsecond delay line lets one pulse get through, producing S. Ib is still on at this time and the coincidence of Ib and S in the first stage of the shift register indicates a one.

The outscriber has been in operation for about a year and is usually in operation at least 16 hours a day. Figure 8 shows the outscriber and the Flexowriter printer. The unit on the left contains everything but the punch and some of the power supplies. Figure 9 shows the package part of the outscriber and Figure 10 shows the wiring side of the packages. The over-all performance is much neater than the wiring. The switch panel is in the lower part of the picture. The switch with the knob missing is the 4-to-6-channel switch which is never changed, since we have operated only with four channels up to this time.

The punched tape produced by the outscriber is fed into the printer where the proper characters, including sign and space, are interpreted. The number of columns up to four can be selected by a switch. The method of determining when a character is to be interpreted as sign or space is to use a contact on the carriage to sense the position of the sign. The space or carriage return always follows the sign.

The paper tape can also be used to punch cards. This operation merely makes square holes out of round ones. Two different units are used. The first one is a card punch ordinarily used for manual punching from a keyboard. A Flexowriter reader and a system of relays for code conversion were added. The other tape-to-card unit required only very minor alterations for use with SEAC. The first one was modified only because this commercial equipment was not available at the time.

Operational Experience with SEAC

ERNEST F. AINSWORTH

THE input-output to SEAC is principally accomplished with magnetic wire, and to the best of the author's knowledge no other computer in operation at this time uses this means. Of course, it is much faster than Teletype tape; it takes 17 minutes to load the high-speed memory from Teletype and this can be done in 10 seconds with the wire cartridge. But it also

has many other factors in its favor when compared to other fast methods.

It is extremely convenient to carry to and from the machine. At present The Laboratory has 250 of these cartridges and each operator has several to contain his codes and results.

A cartridge can contain a fairly large amount of information, about 14,000 words. This is enough to load the high-

speed memory many times and is the equivalent of over 7 hours of Teletype tape reading. Many programs may be put on the same cartridge, so the position indicator on the face of the cartridge makes it easy for the operator to select a given program. One other device which has been found to be useful is the loud speaker connected to the amplifier. This enables the operator to detect the location of the information exactly and also seems to give him a sense of satisfaction when he is able to hear something going on.

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The wire units are comparatively inexpensive. They consist of commercially available parts with some modification.

This system has been in operation about a year and a half and we are fairly well pleased with its performance. No statistics have been recorded on the failure rate of these units, but it is low enough so that very little thought is given to them, and operators are mildly annoyed when they fail to work the first time. Since there is no checking of input-output in SEAC a summing technique is used to detect read-in errors. After the machine has taken in information, it is instructed to sum up all the information just read in and print out the sum. If the sum is correct, it is allowed to continue; if not, the information is read in again.

One of the objectionable features of the equipment as it is presently used is the long start-stop time. It takes over one second for the wire to attain full speed. When first installed, the start was much faster but this resulted in many broken wires. It did not appear possible to overcome this difficulty without considerable modification of the original equipment, so slower operation was employed. It was not the jerk of sudden starting that broke the wire, but the operation of the clutches threw out a slack loop when the wire stopped. When started again the wire developed a kink and broke. Plated wire breaks very easily when kinked.

Wire breakage is one of the troubles with a system of this kind. Sometimes it is due to operator error, sometimes to mechanical failure. Often it is impossible to say which. At any rate, it does not happen very often and we do not consider it a serious objection. In a 6-month period, about 10 to 20 wires break, out of the 250 cartridges in use. When the wire does break, the cartridge can be rewound with new wire or the old wire can be spliced and used, if the spliced area is avoided.

Experience with the type of tape units described by J. L. Pike shows that they possess many good qualities. One thing they definitely prove is that it is certainly possible to get fast and reliable start-stop times without complicated and high-power servo systems. These tape drives are also comparatively inexpensive and easy to construct. They require very little maintenance. The part that wears out most quickly is the ball bearing in the jam roller. They are held in place by one bolt and usually last 2 to 3 months. Sometimes the tire

on the jam roller wears and develops flat spots. Since the use of nylon was introduced for these tires, it has been necessary to resurface one tire in about the last six months.

At present, the tapes are being run at 60 inches per second and printing at 110 pulses per inch. The tapes run quite well at 10 feet per second, but at present the computer cannot receive pulses as fast as this would present them. The amount of information that can be put on a tape depends on the manner in which it is recorded. When it is desired that the tape be able to stop between batches of information on it, enough blank space must be left for it to be able to do so. This space is left on in the printing operation by delaying the printing until the tape has had time to move sufficiently. SEAC can print or read, at most, eight words per instruction. If the program calls for more information than eight words at a time, there is no point in leaving this blank space every eight words since the tape is to keep on running. The computer is constructed so that the programmer may state in the instruction whether he wants this space

left or not. We call printing without these spaces 'compressed' printing. Using compressed printing, a 600-foot tape takes 12,000 words; with uncompressed printing, it takes 8,000 words. The entire high-speed memory can be read in or printed out in less than five seconds.

Since SEAC does not check its input-output, it is necessary to put checks in the program. One way to do this is to reverse over the information immediately after printing on the tape, read it back in, and check with what is still in the memory. A shorter way is to have the last word printed be the sum of the previous words. Then each time the information is read in, it can be summed and checked. If the sum shows an error, the computer can back up and try it again with a very small loss of time. This will usually be successful as almost all of our errors are reading errors caused by missing a digit. We have had reported runs of five and six hours with no errors at all. This is with the use of commercially available tape and home-recorder quality heads. There has been a negligible amount of trouble due to flaws on the tape. This we believe is because a

Figure 1. Tape drive unit showing tape supporting projection

1- to 8-inch channel width is used and because of our use of the tape scraping process previously described by J. L. Pike. After the tapes have been scraped, we print them from one end to another and examine them for any bad spots, but we reject very few.

When this type of tape unit was first used, there was trouble with the tape becoming electrostatically charged and sticking to the side of the tank. Radioactive material was inserted in the tank to help the charge leak off. This was an improvement, but was not very effective at speeds much over 3 feet per second. A tape with a conductive coating was tried and this eliminated the trouble completely. In fact, it eliminated it so completely that it now contributes to our present large difficulty involving creases in the tape.

The tape falls to the bottom of the tank so readily that the tape on the bottom is creased by the weight of that above it. These creases cause the tape to be held away from the head, resulting in smaller than normal pulses.

This is by far the worst trouble with the tape units. It has been found to be related to how much tape is in the tank and how long it is left there. At present we are putting only 600 feet of tape in a unit and we find we must replace it in 1 to 2 weeks. Neither of these requirements prevents profitable operation, but it is hoped to improve the situation. The problem is being attacked from two directions: (1) trying to keep the tape from being creased, and (2) improving the ability of the units to read through a crease.

To prevent creases, one of the methods tried was to tilt the unit to about 40 degrees from the horizontal, so that part of the weight of the tape was supported by the sides of the tank. This helped, but not very much. Another method being tried is to put projections in the tank as shown in Figure 1. As may be seen, part of the tape rests on each support and no part of the tape has to bear the weight of very much tape above it.

This helps quite a bit. It is found that tapes can be left in this unit for 3 or 4 weeks as compared to 1 or 2 weeks in the other units. We are also looking for tapes with different types of plastic bases, hoping that one may be found that is more crease-resistant.

To the problem of making the tape unit put up with more severe creases the approach has been to improve the way in which the tape is held against the head, putting more pressure on the tape right at the gap, where it will do the most good. Results on the test bench look quite promising, but it has not yet been put into operation on the computer.

Perhaps a clearer picture of the operational characteristics of the wire and tape units will be obtained from a description of how they are used in the solution of a particular problem. The problem chosen as typical is the finding of a minimum solution of a 50 by 72 matrix, subject to certain conditions. It is solved by the simplex technique, and the same code is used for a matrix of any size up to 50 by 72.

The first phase is a preparation phase. The instructions are read into the machine from wire in about 8 seconds. A cartridge containing the data for the problem is now placed in the wire unit. In a typical problem it contains about 500 nonzero elements. The computer now reads in the data 8 words at a time, transforms them from binary coded decimal to binary, arranges the data in suitable order, and inserts the zero elements. They are now printed out on one of the magnetic tape units and checked by reading back into the computer and comparing with what is still in the memory. Around 4,000 words are printed on the tape. The time consumed by this phase is:

Wire data read in . . . . 2 minutes
Computation . . . . 4 minutes
Print and check tape . . . . 3 minutes
                                              —————
                                               9 minutes

The acutal solution of the problem is done in the second phase. This

consists of processing the data a number of times until a solution is reached. Each data processing performs the following operations: 56 words of data are read in from one tape unit, are operated one by the machine, and then printed out on a second tape unit. The output data from this processing become the input data for the next one. One of these processing cycles takes the following time:

Tape running . . . . 2.5 minutes
Computing . . . . 2.0 minutes
Teletype printing . . . . 0.25 minute
                                          ——————
                                          4.75 minutes

The number of times it is necessary to go through the processing cycle to get a solution depends on the problem. The simplex method of solving approaches the answer progressively. The number of cycles required cannot be determined beforehand.

Assuming that the cycle is gone through 72 times, this phase of the problem takes 72 by 4.75/60, or 5.75 hours. About 52 per cent of the time is tape-running time.

The final phase of the problem is the checking and presentation. The answers are substituted back into each of the 50 original equations to see if they satisfy. Results are changed from binary to binary-coded decimal and printed out on Teletype:

Tape . . . . 1 minute
Wire . . . . 3 minutes
Computation . . . . 3 minutes
Teletype . . . . 7 minutes
                                                ——————
                                                14 minutes

There have been quite a few problems of the type just described actually run on SEAC.

It is the belief of the author that the experience with SEAC described in this paper shows that it is possible to construct from commercially available components some comparatively inexpensive input-output devices which are of somewhat modest performance but reliable and certainly useful for computer applications.

Discussion

W. H. MacWilliams (Bell Telephone Company): I have heard speakers referring to a Dyseac. I assume that this is an automatic computer. Can you tell me what else does it mean?

S. Greenwald (National Bureau of Standards): The reason for the particular term has to do with the sponsoring agencies and the purpose of the computer. It is a new computer that is coming along well. It is built somewhat along the logical lines of

SEAC, but uses the printed wiring described in Miss Haueter's paper. It will be a good deal more powerful than SEAC, in that it will permit input, output, and computing functions to go on simultaneously. It will also be a good deal easier to maintain, we hope, because of the plug-in features.

H. F. May (Teleregister Corporation): What is the technique used to eliminate static charges on the lucite plate in the tape storage unit?

J. L. Pike (National Bureau of Standards): They are coated with a product,

known as Photosweep, which can be purchased in photo equipment houses. The composition of it I know nothing about but, when sprayed on lucite, it eliminates completely static charges and seems to wear forever. We have had no trouble with it.

Mr. MacWilliams: What work have you done on multichannel recording?

Mr. Greenwald: For some time, we have been experimenting with multichannel recording. For this purpose, we have used a Raytheon-type mechanism similar to the one described by Mr. Snyder. In this par-

ticular equipment, we use five channels of information, and one sync channel. We have not considered it a high-priority job, because we felt it was more important to get some of the other equipment working, and working well. However, we do intend to incorporate one of the multichannel units in SEAC in the very near future. We hope it will work out.

C. T. Schaedel, Jr. (Consolidated Vultee, Fort Worth Division): Using the miniaturized printed circuit technique for your components and packages, have you ever had trouble with the component failing during actual computer operations? You described part of your developed circuit technique for your packages. Do you have trouble with reliability of the components for using the printed circuit?

Miss Haueter: I mentioned the fact that the printed circuit package would be used in Dyseac. We are not using it in any of the equipment we now have. The outscriber shown was a hand-wired unit. The situation should not change in printed circuits any more than in hand-wired circuits. We would expect the same failure that is obtained in anything that uses dials, tubes, and transformers.

Mr. Schaedel: Did I understand you to say that you did not remember an error ever having occurred? That would indicate you have had no component failures during the computer operation.

Miss Haueter: I stated that I know of no error that got through our error-checking circuit.

Mr. MacWilliams: A nice distinction.

O. Whitby (Stanford Research Institute): I wonder whether any of the speakers can tell me whether they can distinguish between misreads from the tape due to dust and those due to kinks?

Mr. Ainsworth: We have no way, at the moment, of telling if they are dust or not. When we first hooked up the equipment, we looked for kinks when we had errors; we almost always found them there. I do not think dust would cause as much trouble with the 1/8-inch channel width that we use on the present tape system.

R. C. Boe (Cook Electric Company): Will Miss Haueter elaborate on this method of synchronization?

Miss Haueter: Our basic repetition rate is 1 megacycle. We use the dynamic flip-flops, which means when a flip-flop is turned on, it continues to put out pulses at a 1-megacycle rate, until something turns it off. Therefore, there is no conflict. It continues to put out pulses until something occurs later on, even though what has happened is at a very low rate. The actual synchronizing process which I referred to consists of generating a single 0.5-microsecond pulse from a longer pulse which occurs asynchronously with the clock. This is a somewhat more difficult problem which I had hoped to discuss, but did not have time.

The Uniservo—Tape Reader and Recorder

H. F. WELSH   H. LUKOFF

A PRACTICABLE method of obtaining adequate input-output speeds for digital computing devices is the high-speed tape recording method, but the designing of a good tape system has been, to say the least, extremely difficult. In this paper, the history of the development of Uniservo, the Univac tape transport device, will be briefly sketched.

The need for higher speed input and output devices became apparent as soon as the idea of electronic computing was projected. Among the early objectors to computers, the more farsighted pointed out that, even if a machine could be made, its use would be severely limited by inability to converse with it at appropriate speed. It was realized at the time that a great deal of development work on input and output devices was necessary before a satisfactory commercial computer could be built.

It was fortunate that the first Univac contract was with the Bureau of the Census. The Census problem demands large quantities of conversation and therefore the computer, to be useful, had to have extremely high speed input and output equipment. The final specifications for the future Uniservo were decided upon with the Census problem in mind, yet without making the computer in any sense a single-purpose device.

The most important aim in speeding up input and output operations was to have them interrupt the computer as little as possible. With this established, certain decisions became immediately necessary.

First, it was decided that input and output operations should take place in two separate steps. For input, the preparation of tape takes place apart from the computer, in a Unityper* or card-to-tape converter. Reading of data from tape into the computer takes place at higher speed on a Uniservo. For output the computer records on tape by way of a Uniservo but the printing of the data takes place apart from the computer on a Uniprinter.*

The second decision was to tolerate no speed less than that obtainable with high-density mutichannel magnetic recording. Here was envisaged the Uniservo, a tape transport device recording parallel channels on magnetic tape. The following performance characteristics were predicted:

Speed...............120 inches per second

Pulse density...........100 pulses per inch

Instantaneous conversation rate...........
........12,000 decimal digits per second

The third decision was to make all input and output operations automatic, that is, to have all Uniservo operations initiated by programmed instructions in the computer memory. In view of the fact that the speed of reading and writing on tape is slow compared with the speed of electronic operations, it was decided to include separate control circuits for input-output operations. Consequently, the computer circuits do not have to be tied up all the time the Uniservo is in operation. In fact, there are only two functions which require the cooperation of the central computer control circuits:

1. Instructing a Uniservo to read or write.

2. Transferring from an input register to the memory or from the memory to an output register.

For the input instructions, the logical sequence is to read from tape and then transfer from the input register to the memory, but this would require the com-

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* Reg. U. S. Pat. Off.
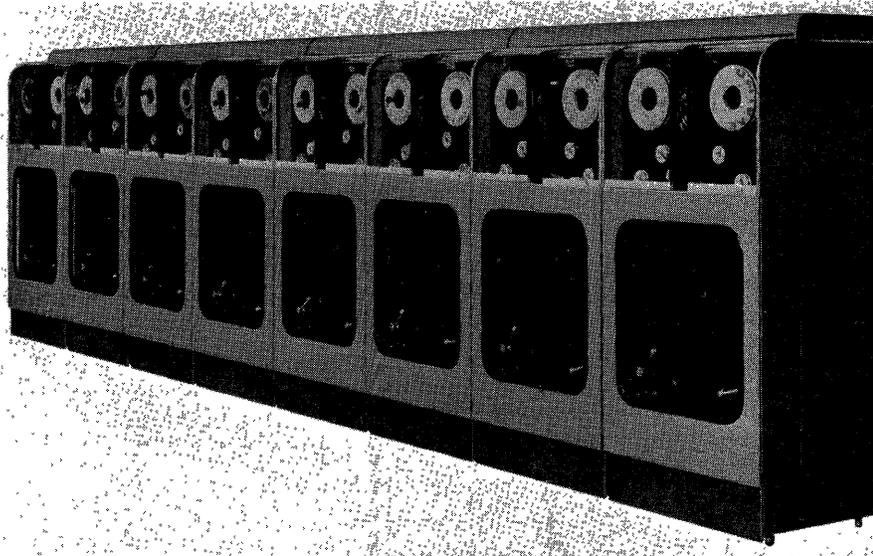
Figure 1. Bank of Uniservos

has several advantages. First, it allows reading, writing, rewinding, and reel-changing operations to occur in parallel. Second, it provides a large low-speed memory. Third, it allows separate storage of program, data, results, lists, or whatever else the problem may demand.

The programmed instruction selects the Uniservo involved in any operation. The instruction, in fact, determines the operation (read, write, or rewind), the Uniservo involved, and the memory location for the data. This uses five digits of the 6-digit instruction, leaving one spare for future use.

Figure 1 shows a bank of Uniservos attached to a computer. The system is designed to take any number of Uniservos up to ten. In fact, two Univac installations use ten Uniservos, and one carries an eleventh as a spare. All Uniservos are lined up side by side under a common wiring trough. They are entirely unspecialized and interchangeable. When necessary, the spare can replace any other Uniservo. The only change necessary is in a plugboard connection in a corner of a computer. The logical positions of all the Uniservos can be arranged in any order at the same plugboard.

The decision to use the tape as a low-

puter to wait for the Uniservo to operate. To avoid this relatively long delay, the initial input instruction reads only as far as the input register. Succeeding input instructions transfer from the input register to the memory, and at the same time call upon a Uniservo to fill the input register once more. By the time the Uniservo has begun to respond, the input register has already been emptied. Effectively, the computer is interrupted only enough to see that the proper Uniservo is set up to do the required job; then the computer proceeds about its own business.

One other important decision was made: to design a system that could use several Uniservos, each one capable of both reading and writing. This arrangement

UNITYPER · 20

UNISERVO · 128
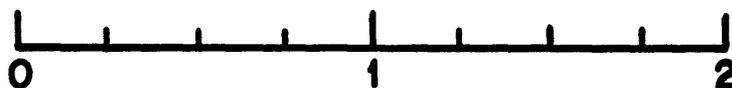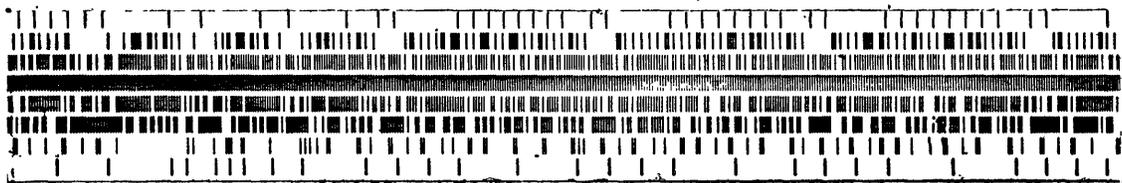
Figure 2. Magnetic tapes

0   1   2

speed memory imposed another characteristic upon the design of the Uniservo. The tape is strictly a serial storage medium without an address system. The only information the Uniservo can read is that which is next in line under the head. So it was decided to design the Uniservo so that it could read backward as well as forward. Now, any amount of information can be written on tape, then read back with the tape moving backward. This makes the tape memory valuable in problems requiring re-use of previously computed data.

This brief sketch provides some idea of the reasoning process by which the necessary characteristics of the Uniservo were determined. But predicting characteristics is one thing, and designing equipment that fulfills them is another. Refining the equipment until it performs reliably is yet a third step, and the hardest of all.

From the outset, the problems were those of severe designing. For example, high speeds demand the highest kind of resolving power in the tape record, and this in turn requires excellent tape. Commercially prepared tapes of the required quality were not available. It became necessary, consequently, to produce locally a tape that would match the requirements of Uniservo.

Metal tape was found to be much superior to plastic at the time of Uniservo development. It still is, although the quality of plastic tape has improved greatly. Plastic tape offers the advantage of being less likely to fold as a result of mechanical handling or to deform as a result of pressure of dirt particles. Metal tape, on the other hand, has better definition and greater resistance to breakage. Metal tape is also superior for long-term storage, because it resists the onslaught of

Figure 3. Magnetic heads
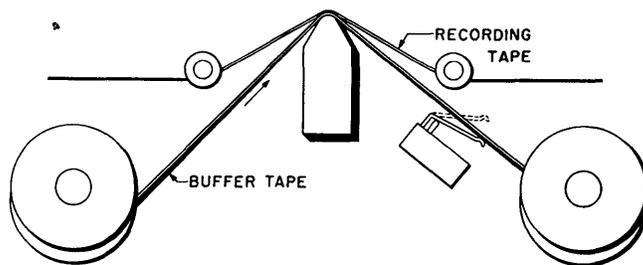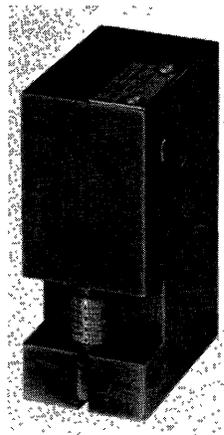
Figure 4 (left).
Magnetic head
close-up

Figure 5 (above).
Tape spacer

unfavorable atmosphere and fire. A fire test was conducted in which six reels of metal tape were placed in a safe along with plastic tape, microfilm and punched cards. The safe was placed in a furnace and the temperature inside the safe allowed to rise to 550 degrees Fahrenheit. Film and cards, of course, were destroyed. Molten plastic tape flowed over the edge of one of the reels of metal tape. The six reels of metal tape were read on a Uniservo without error of any kind, although the oscilloscope revealed that the pulses had suffered a deterioration of about 10 per cent.

Under laboratory conditions, it was simple to produce small quantities of metal tape. But it was a major difficulty to design, build, and operate machinery to manufacture good tape in quantity. Even with careful control, there would occur on the tape areas that either could not hold a strong enough signal, or that produced too much noise.

It became necessary then to develop a method of skipping these bad spots, and to allow splices in the tape. To accomplish this, holes are punched in the tape at bad spots by a tape-checking device, and photoelectric cell detecting circuits are used in Uniservo to search for the holes. All tape devices except the Unityper, which is supplied with perfect tape, use similar bad-spot detecting circuits.

The tape is one mil thick and $1/2$ inch wide. Eight magnetic heads record simultaneously across the width of the tape. Some recordings have been made visible by the use of pulverized iron. Figure 2 represents an image of the pulverized iron lifted from magnetic tape on ordinary transparent tape and mounted in a slide.

The Uniservo records at the highest density, as shown by the bottom tape here. The equipment was originally designed to move the tape 120 inches per second and record at the density of 100 pulses per inch, but it was found that more

reliable results were achieved by decreasing the speed to 100 inches per second and increasing the density. At present, recording is accomplished at a density of 128 pulses per inch, as shown here. This density does not approach the limit of the resolving power of the tape.

Of the eight channels, seven carry a character to the computer in its 7-bit code, which includes a checking pulse. The eighth channel is for a sprocket pulse, used only in the input-output equipment. The sprocket channel is the one which has a pulse in every position.

Actually there is continuous recording in every channel, because the head circuits are designed to record at all times in the erase polarity, except when significant digits occur; then specific heads reverse polarity for a time. Each of the small magnetized areas actually consists of two fine lines, or two concentrations of flux; one occurring at the change from erase to recording polarity, and the other at the return to erase polarity.

A view of a longer piece of Uniservo tape would show data recorded in blocks about 5.6 inches long, separated by empty spaces 2.4 inches long. This is because Uniservo reads and writes in the 720-digit Univac block, and comes to a stop between blocks.

The Unityper does not record as densely as the Uniservo, as illustrated on the slide. Therefore a block of information recorded by a Unityper will take more tape. The Uniservo is capable of reading data at the various densities without change of circuits by counting digits as they are read and stopping when the count reaches 720.

Another fact about the tape is that the pulse combination is not recorded in a straight line across its width, because the pole pieces on the 8-channel head are in staggered array.

Figure 3 shows two magnetic heads. The larger one is very expensive to produce, chiefly because it requires so much precision machine work. So the smaller one, which can be manufactured by much simpler techniques, is being developed to replace it. The final model is not yet in production.
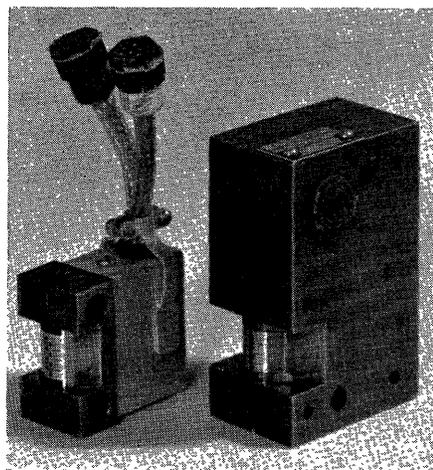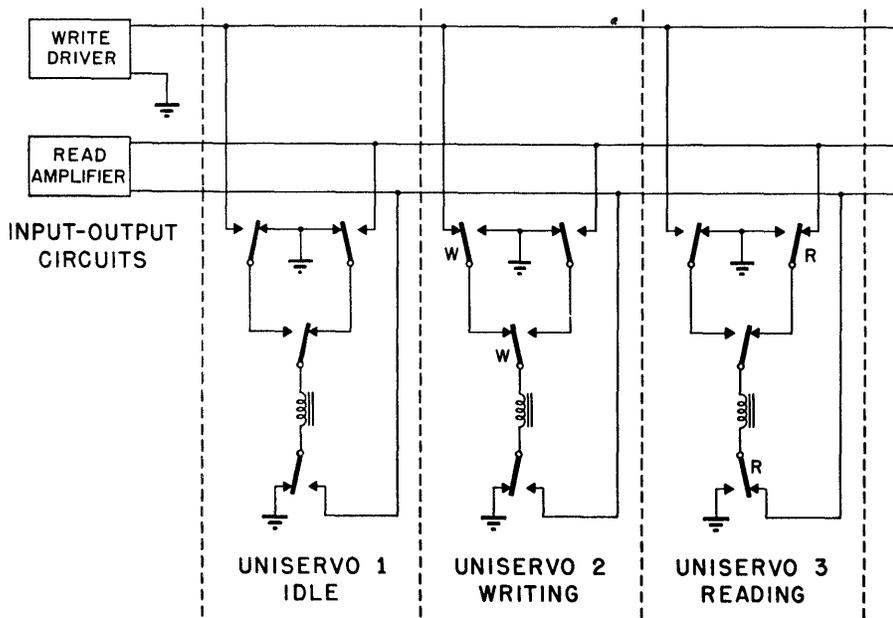
Figure 6. Grounding of relay leads

middle of the reel. It was necessary to reduce tape-to-head friction without making the tape itself slippery, so a spacer was inserted between head and tape, as shown in Figure 5. The spacer is a plastic tape which is reeled across the head like a typewriter ribbon, at a speed of about 10 inches per hour. The spacer moves only when the Uniservo is in action. Results of this system are that head wear is negligible, tape wear low, and friction acceptable.

Because the Univac system writes on only one Uniservo at a time, only one set of eight head drivers is necessary. The outputs of these drivers are connected to all Uniservos in parallel. The input-output control circuits switch the driver output into whichever Uniservo is selected by the computer. Similarly, only one set of reading amplifiers is used, supplied by common read busses from all Uniservos. Every head coil in every Uniservo has a switch capable of connecting it to either a driver or an amplifier.

It is common for the drivers to be writing on one Uniservo at the same time that the amplifiers are reading from another. But the write busses are separated from the read busses by a group of parallel switches only, and because the signals on the read busses are small, crosstalk from the write busses must be kept very low. Banks of mercury relays are used for switching read or write lines into the heads. Their arrangement is illustrated in Figure 6, which shows the common read and write busses for one channel, and their connection in each of three Uniservos. Uniservo 1 is idle. In Uniservo 2, the two write relays have operated to connect the head coil to the write bus. In Uniservo 3, the two read relays have operated to connect the head coil to

Figure 4 shows a close-up view of the array of pole pieces. As shown, the carcass is made of three pieces, providing two gaps. There are four heads bridging each gap, and shields between adjacent heads. The shields help separate the channels and minimize crosstalk. So does the staggered arrangement, simply by separating the recording coils. The staggered arrangement also simplifies the manufacturing process and allows closer spacing of channels across the width of the tape, which permits use of 80 per cent of the tape width for recording. Close spacing is possible because the individual heads are set into slots in a solid, gang-slotted carcass. Tolerances in such a carcass can be kept closer than in a stacked assemblage of individual heads, where errors in machining would be cumulative. Another ad-

vantage of the solid carcass is that it acts as an eddy current shield. For high speed operation no additional shielding of the head is necessary. The space between gaps is $1/8$ inch, small enough that no difficulty has been encountered due to stretching of tape, even when inexpensive plastic tapes have been used.

Certain difficulties were experienced in moving the metal tape at high speeds over the head. Tape and head wear were excessive and friction was high. These problems could be solved by lubricating the tape, and at one time lubricators were mounted right on the Uniservo panel. But lubrication brought about a problem of its own. It reduced the friction between layers of tape on the reels, and when the reel motor accelerated or decelerated violently, adjacent layers were apt to slip and develop folds in the

Figure 7. Input bias levels
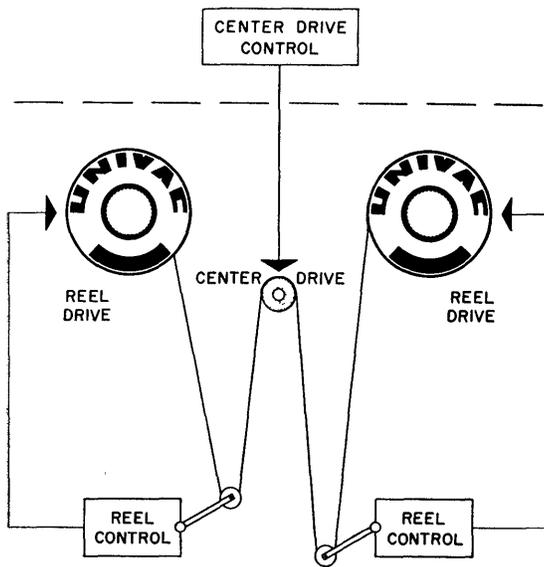
Figure 8 (left). Tape transport control
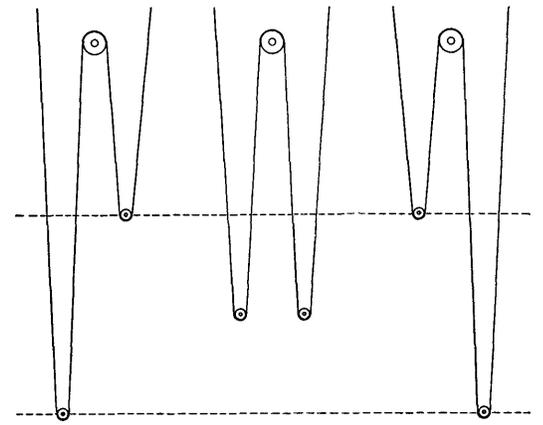
Figure 10 (right). Balance points

the read busses. As the read and write busses come into idle Uniservo *1*, they get only as far as the first relay contact. In every case, the other leads to the relays are grounded. In Uniservos *2* and *3* this condition still prevails; as the write bus or the read bus passes through relays to the head coil, it always sees ground on adjacent relay contacts and leads. This arrangement, together with very careful shielding of the read and write busses, and careful layout of the read amplifiers, keeps the crosstalk problem at a minimum.

During a read operation, signals and noise from the heads pass through the high-gain head amplifiers, then are applied to another bank of amplifiers which are biased to cut out the noise and pass only signal pulses. The bias is set at $^1/_5$ of the standard signal amplitude, which was determined to be the safest possible level. Tapes are tested to assure that minimum signal pulses are considerably above this level and that maximum noise pulses are considerably below, as shown in Figure 7.

If the signal-to-noise ratio degenerates so much that a noise pulse exceeds the $^1/_5$ level and registers a bit of information, or a signal pulse falls below the $^1/_5$ level and drops a bit, checking circuits register an error and prevent the use of the erroneous data. In this case it is often possible to read the marginal data from the tape without error by changing the operating bias. It is possible by switch selection to raise the bias to $^1/_3$ of normal signal amplitude or lower it to $^1/_7$. The $^1/_3$ level passes data with high noise but normal signal, as illustrated by the center wave form in Figure 7. The $^1/_7$ level passes data with weak signals but no more than normal noise, as shown by the wave form at the right. This routine can be accomplished in a few seconds by manually instructing the Uniservo to read the marginal data in the reverse direction at one level and again to read it in the chosen direction at the other level, if necessary. After this maneuver, the tape is back in the proper place to continue the program.

The chief function of the Uniservo itself is that of tape transport. The major requirements of the tape transport system are that it be capable of rapid acceleration and that it move the tape over the head at a constant speed. This, of course, makes necessary separate tape center drive and reel drives, as illustrated in Figure 8.

The center drive has to overcome only the inertia of a few feet of tape and a few light pulleys. The burden of moving the relatively heavy reels is borne by heavier reel motors. Acceleration of the reels can lag acceleration of the center drive because the reels are separated from the center drive by loops of tape which can change size. Control circuits for each reel motor sense the loop size by means of synchro arms and operate to keep the loops at a certain size. Whenever the center drive motor operates and changes the size of the loops, a signal from the loops is sent to the reel motors which servo the loops back to the right size. The system is bidirectional and balanced. Initial motion always comes from the center drive, which can move in either direction. Each reel motor always moves in the direction which will restore its loop to proper size.
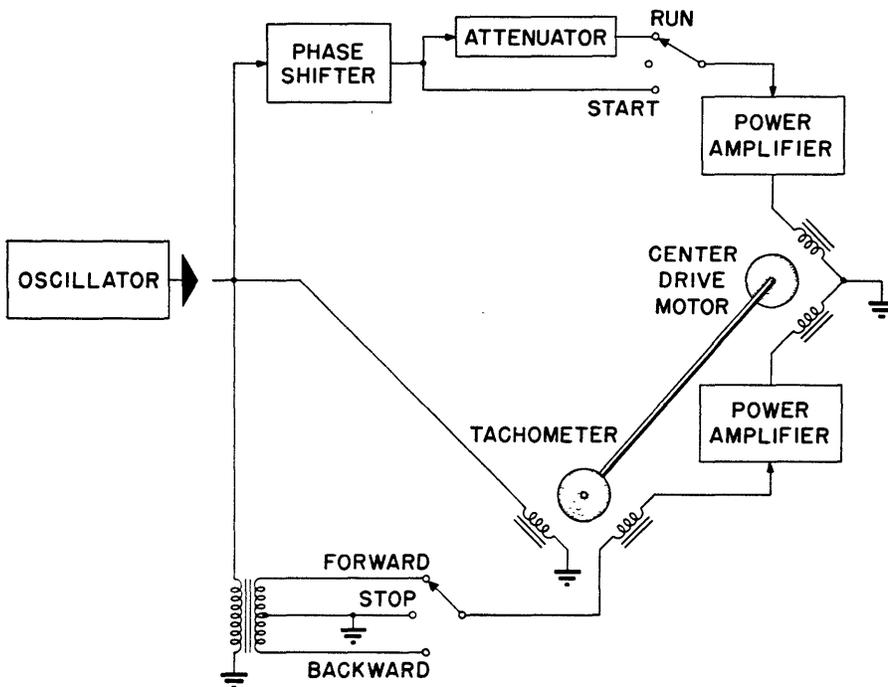
Figure 9. Tachometer-controlled center drive

DETECTOR ← SYNCHRO

SIZE

RATE OF CHANGE
DIFFERENTIATOR → MIXER → REEL MOTOR CONTROL → REEL MOTOR

BALANCE POINT
INTEGRATOR

FORWARD
BACKWARD Ⓐ ← RECTIFIER ← TACHOMETER
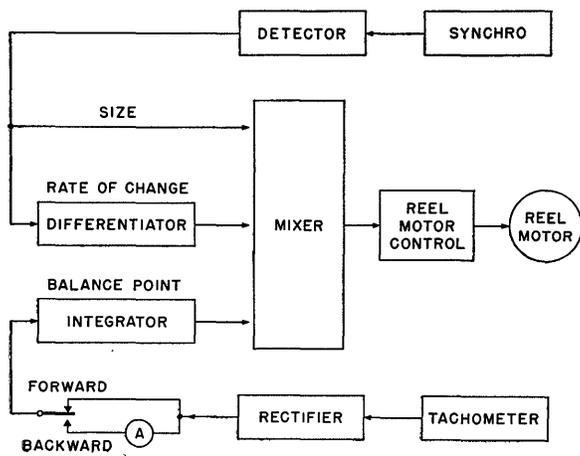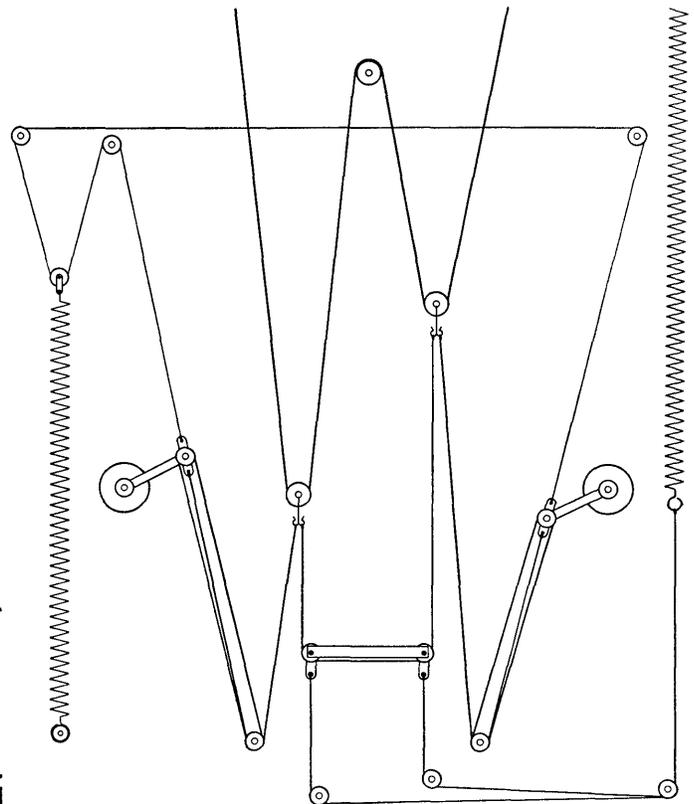
Providing for rapid acceleration and constant speed, therefore, is the function of the center drive system. Figure 9 illustrates the center drive system. It is greatly simplified, like most of these diagrams, to point out the essentials of the circuit. The center drive capstan is turned by a 2-phase motor. The upper winding is supplied with either full or attenuated power, according to relay selection. Power to the lower winding is controlled by a tachometer which is mounted on the same shaft as the motor. The tachometer functions as a transformer whose coupling varies with its speed.

When the motor starts, relays close to apply full power to both windings. As the motor picks up speed, the tachometer generates more and more voltage, which subtracts from the voltage applied to the lower winding until the system balances at a constant speed. This is accomplished in 10 milliseconds. At this time, the attenuator is switched into the circuit and applies reduced power to the upper winding also.

Rapid deceleration is achieved by cutting off the main voltage supply to the lower winding, leaving only the subtractive voltage from the tachometer. This condition tends to stop the motor. The tachometer voltage decreases as its speed of rotation decreases; in 10 milliseconds the system comes to rest. At this time, a relay removes the remaining power from the upper winding.

The constant voltage is applied to the top winding by way of a 90-degree phase shifter. The variable voltage is applied to the lower winding by way of a transformer which provides either 0-degree or 180-degree phase shift. This makes the variable voltage either lead or lag the constant voltage by 90 degrees, and thereby provides control of direction. Reversal of direction also inverts the phase of voltage generated by the tachometer, so that it is still subtractive.

Figure 11 (above).
Reel control

Figure 12 (right).
Uniservo front panel

Another interesting feature of the tape transport system is the balance point of the loops. Figure 10 illustrates three possible loop balance arrangements. It might be thought offhand that, for a bidirectional system, the loop arrangement shown in the center is ideal, because it is ready to move in either direction. The loop arrangements at the sides are biased in favor of motion in one direction, and will not permit motion in the other direction. Provided that the proper direction is chosen, however, the biased arrangements permit twice as much change of loop size as the balanced arrangement. This is a real advantage. It allows, for a panel of a given size, the use of a motor only half as powerful; or for a motor of a given size, the use of a panel only half as long.

This advantage is used on the Uniservo. It requires that the Uniservo always anticipate the direction of rotation, and set its loop balance points accordingly. It also requires that the Uniservo, while moving, reverse its loop balance points in preparation for a stop.

The balance point signal is mixed with other signals applied to the reel motor control circuits, as shown in Figure 11. The action of each reel motor is guided by a mixture of three significant inputs, representing loop size, rate of change of loop size, and balance point. The

system is at rest when a signal of a certain d-c level is supplied by the mixer to the motor control circuits. Increase of this signal causes the reel motor to rotate in one direction; decrease, in the other. The amount of increase or decrease determines the speed of rotation.

The loop size is read by a synchro arm. The detected signal from the synchro is applied to the mixer, and any change in this signal is detected by a differentiator and also applied to the mixer, to boost the response of the reel motor to quick changes of loop size.

The balance point signal is set at either of two d-c levels, which causes the system to balance at different loop sizes. Whenever the center drive tachometer is in motion, a rectifier signal from it inverts the balance point potential, to change the balance point while the tape is moving. This change of signal is integrated so that it will not prevent initial rapid acceleration of the reel. The integrator also minimizes fluctuation of balance point in a close series of operations that move the tape in the same direction.

Some of the most interesting problems on a high-speed tape panel are in connection with the loops. The prototype Uniservo used free-hanging loops. In one design, loop size was read photoelectrically. In another, the metal tape loop hung in a metal box, and the capacity

between tape and box varied with the length of the loop.

In a free-loop system it is difficult to find a satisfactory way to keep the tape tight against the head. This requires that the tape be pulled across the head against a drag or pressure pad. Two center drive capstans are necessary, one to pull in either direction. Moreover, these capstans must be of the pressure-roller type. It was found that such capstans roll dirt particles into the tape and cause weak signals. In the prototype the tape was pressed against a flat head by a pressure pad. It was found that the pad required excessive pressure, wore the head unevenly, and got the tape dirty. In later designs, the whole tape was put under tension by spring-loading the loops and applying a small amount of opposing torque to the reel motors at all times. The head pressure problem was solved by bending the tensed tape around a curved head.

At first, the loops were put under tension by tying long rubber bands, used because of their low inertia, directly to the floating loop pulleys. It was found, however, that the rubber bands deteriorated when the Uniservo was left in the sun on hot summer days.

Figure 12 shows the essential mechanical features of the present tape panel. It was noticed that the equal and opposing motions of the loop pulleys could be tied together. An equalizer bar was made to tie the loops together, and tension was applied to the equalizer bar. With this device, a spring could be used rather than a rubber band, because it was out of the high acceleration system. The spring moves hardly at all, and does not load the center drive.

A block-and-tackle arrangement with a mechanical advantage of three connects each loop with its synchro arm. This reduces a long travel of the loop to a short travel of the synchro arm. It also buffs the inertia of the synchro arm out of the loop system, because the loop sees only one-ninth of that inertia. The motion of the two synchro arms, like that of the loops, is equal and opposing. Like the loops, the arms are connected through an equalizer system.

Some features have been designed into the machine to facilitate the changing of reels. The entire process now takes less than 20 seconds. A tape leader keeps the Uniservo threaded and under tension. The tape is connected to the leader by means of a simple clip joint.

It is not possible to mount a reel backwards.

A master reel system has been designed as a safeguard against the erasure of valuable data. If a master reel ring has been placed in a reel, it contacts a microswitch on the Uniservo. The switch prohibits writing on (and therefore erasing) the tape, but permits reading from the tape.

There were many other interesting problems in the design of the Uniservo, but the limits of this paper prohibit their discussion. It should be pointed out, however, that not all of the circuits discussed are duplicated for each Uniservo. Our aim has been to use the minimum amount of circuitry consistent with reliable operation. The counters which count off 720 digits are in the common input and output synchronizers, not in the separate Uniservos. The bad-spot detector circuits are also associated with the synchronizers. Power supplies are common, head drivers and amplifiers are common, even part of the center drive control circuit is common. Each Uniservo in itself contains little more than a magnetic head, a bank of relays, and a servo-following tape transport system.

Input Devices

L. D. WILSON   E. ROGGENSTEIN

THERE are three separate means for input to the Univac central computer. The first and most direct is a keyboard directly connected to the computer. With this keyboard small amounts of data are inserted into the computer, one word at a time. This direct input is used chiefly for computer operation, maintenance functions, and program alteration.

The other two means for input make use of magnetic tape and the Uniservos. These are the card-to-tape converter described in another paper, and a keyboard-to-tape transcriber known as a Unityper. This latter device, discussed

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in this paper, transfers data directly from source documents onto magnetic tape.

A typist with little special training can operate the keyboard of a Unityper much as she would a typewriter. As she types, digit by digit, the Unityper records the corresponding Univac pulse code combinations on tape. Data on tape are then ready for Univac use as soon as the reel is transferred to a Uniservo.

These principal requirements of the keyboard-to-tape transcription function dictate the basic units shown in the diagram in Figure 1. First, the device must be able to accept random inputs from the keyboard and encode them in Univac code. Second, the digits must be recorded on tape as densely as possible, and uniformly spaced. Therefore,

the tape must step discretely as each character is typed.

Furthermore, since typists sometimes make errors and therefore must erase, the necessity for erasure places the most stringent requirements on the tape transport system. Erasing on tape is accomplished by back-spacing while the recording head records zeros, but this backward step must erase only the incorrect character and must not overshoot into the next previous character. Also, the new character when entered must be positioned on tape exactly where the incorrect character was. Thus forward and backward steps must be equal in length.

The operating cycle starts with a signal from the keyboard. This signal is encoded in a 1-to-8 line encoder which drives the eight channels of the recording head. A secondary keyboard signal also pulses the tape transport system and the tape steps. As the tape moves, the pulse combination is recorded.

In the Unityper, shown in Figure 2,
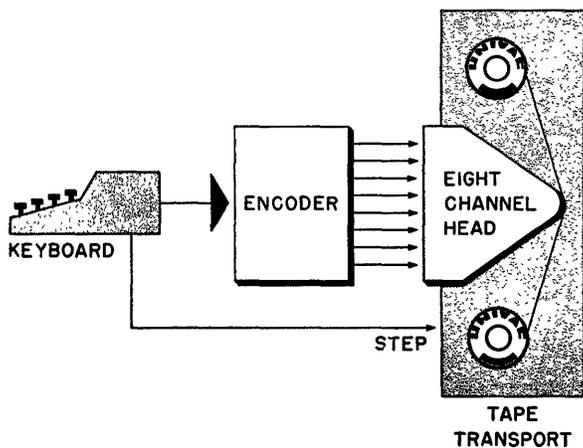
Figure 1. Keyboard to tape transcriber

Figure 3. Loop box

each key operation discharges a capacitor into a resistor matrix encoder, which sets up the combination in eight unit memories. At the same time, a keyboard signal steps the tape 1/20 inch and sets a duty cycle delay flop. This delay flop, a monostable trigger pair, is used to delay the keyboard pulse while recording takes place. Before the tape stops moving, the delay flop recovers and clears the unit memories. As soon as the tape stops moving, the Unityper is ready for the next character.

The data being typed must be arranged in computer format, 60 12-digit words to a block with 2.4 inches of blank tape between blocks. While the typist is entering data it is essential that she know her position within this block. For this reason position-indicating devices, including digit and word counters, and block-beginning and block-ending detectors, are built into the Unityper. The counters are disks appropriately geared to the tape drive. These disks are calibrated to indicate to the typist

the number of the word and digit just recorded. The block-ending and block-beginning detectors are cams driven by the tape drive. These cams operate switches at the beginning and ending of each block.

The block-ending switch lights an indicator lamp and prevents further typing until the space between blocks has been recorded. The block-beginning switch lights an indicator and prevents back-spacing into the space between blocks.

To nullify any attempt to record a second digit before the recording of the first has been completed, a typing rate limiter blocks the normal path of the keyboard pulse and completes a path to the error line for 65 milliseconds after each key stroke. If another keyboard pulse is generated during this period, the error circuit is energized.

This error circuit consists of a thyratron-driven relay. Contacts of the error relay disable the Unityper for anything except an erase operation. Operation
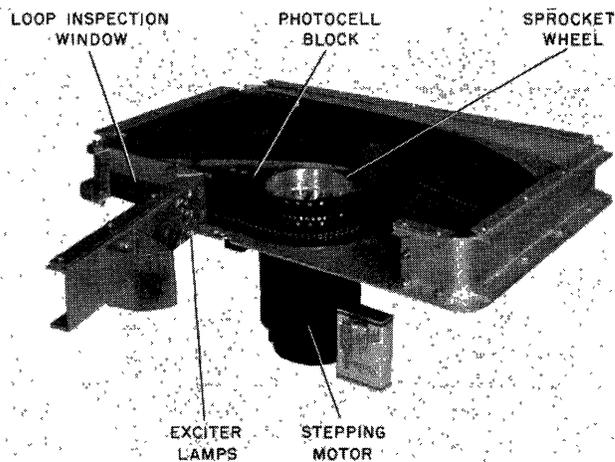
of the erase key steps the tape backward to erase one character and clear the error circuit. Once the error circuit has been cleared, successive operation of either the erase or the back-space key erases the tape, digit by digit. However, it is imperative that erasing be limited to the 60-word block of information currently being typed. For this reason the block-beginning detector disables the back-space and erase circuits and lights a block-beginning indicator lamp after the first digit of the block has been erased.

Typing within a block takes place at normal typing rate. As a time-saving feature, an automatic operator which can execute repetitive operations at 20 characters per second is included in Unityper I. This automatic operator, controlled by the block-ending and block-beginning detectors, provides a recycling circuit for the keyboard pulse.

The first function of the automatic operator is to record on tape the 2.4-inch space between blocks required by the Uniservo. Operation of a blanking key coin-

Figure 2. The Unityper
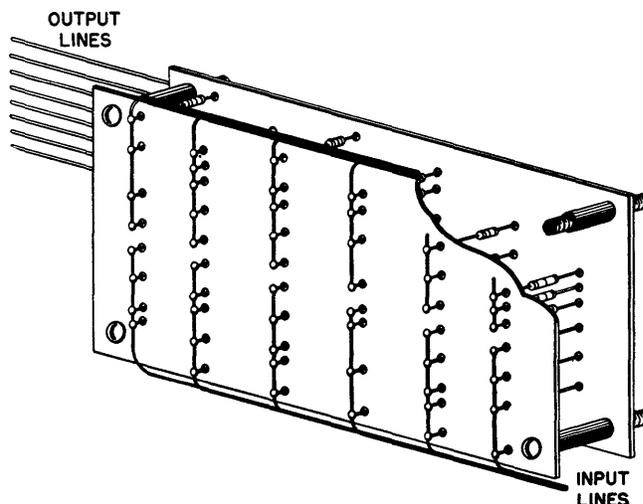
Figure 4. Resistor matrix encoder input side
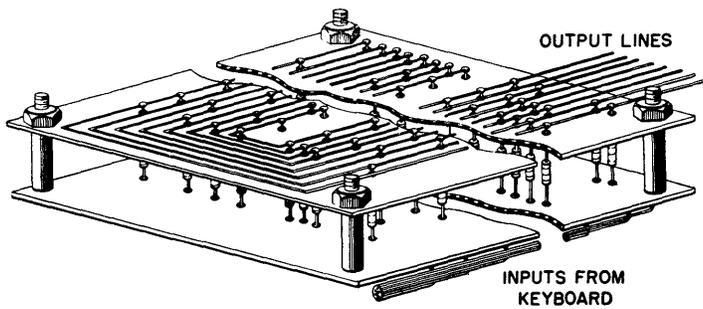
Figure 5. Resistor matrix encoder output side

Figure 7. Unityper tape panel

cident with a signal from the block-ending detector generates a keyboard pulse and inhibits the unit memories. The pulse steps the tape and recycles through the automatic operator to step the tape again. After 48 steps, the block beginning detector opens the recycling circuit to terminate the operation. The block-ending detector inhibits the blanking circuit at all times except at the end of the block. If the typist tries to enter a 721st digit or if she strikes the blanking key prior to the 720th digit, the keyboard pulse is channeled into the error circuit.

A second function of the automatic operator arises in connection with the Computer block length. In case data do not completely fill a block, some Univac symbol must be inserted to fill in the remaining space. Completion of such a block is done on the Unityper by a skip operation. Depressing the skip key starts a pulse circulating through the automatic operator, stepping the tape forward repeatedly as in the space between blocks. But during this operation the Unityper records a digit called 'ignore.' The block-ending detector terminates this operation.

These two automatic features alone provide considerable speed gain over

digit-by-digit operation since they can be performed at a speed of 20 digits per second. However, a study of computer routines and data indicated that more frequent check points similar to block ending would be desirable. Material of this type contains many items of different lengths called fields. The conclusion was that check points inserted within the block length as required by the data would greatly increase the speed and accuracy of the equipment. A check point at the end of a field could prevent further typing if the typist should attempt to type too many or too few characters in that field. Another type of check point similar to block beginning at the beginning of the field could limit erasure to that field.

This extension of the automatic functions was included. It is controlled by a punched paper tape stepped in synchronism with the magnetic tape. The paper tape is photoelectrically examined after each step. Each of the eight possible holes has a different meaning to the automatic operator. The paper tape is prepared according to the needs of each specific program on a special tape-punching machine. The two ends of a given tape are cemented together and the resulting loop is placed in a control-loop

reader as shown in Figure 3. This loop reader is a plug-in assembly containing a motor which drives the tape by means of a sprocket wheel, and photoelectric cells and exciter lamps which search for holes in the paper tape. The loop controls the automatic operator by relays driven by the photoelectric cells.

For example, a typist frequently omits a character from a field or types an extra one. The loop system detects this type of error as follows: A particular hole punched in the paper loop at the end of a field energizes a forced-check relay. As its name implies, this relay forces the typist to check her position. It does this by blocking the normal circuit of the keyboard pulse and completing the path to the error circuit. To proceed, the typist must strike the control bar on the keyboard. In so doing she releases the forced-check relay. If the typist attempts to enter another character without first releasing the forced-check relay, an

Figure 6 (left). Unit memory and head coil

Figure 8 (right). Motor - stepping circuit

MOTOR STEPPING CIRCUIT

Figure 9.   Stepping motor

required between the keyboard and the encoder, while only eight output lines go from the encoder to the unit memories. The encoder should be placed physically close to the keyboard. In fact, it is housed on the back of the keyboard unit in a space $1^3/_8$ by 12 by $6^1/_2$ inches. The eight output lines connect to the rest of the equipment via plug-in cable.

The basic construction is simple. Two predrilled bakelite sheets are mounted on $1^3/_8$-inch spacers. Across the long dimension run 51 input lines from the keyboard. Holes drilled below a given line represent binary ones in the code for the character represented by that line. Both sheets are drilled with the same pattern.

Across the short dimension of the output side of the encoder run the eight output lines. The matrix is wired up simply by placing resistors between corresponding holes, soldering one end to an input line, and the other to an output line. The entire array is folded back on itself to conserve space.

The resulting array is pulsed from the keyboard by discharging a condenser into one of the input lines. A pulse on an output line fires its corresponding unit memory thryatron, as shown in Figure 6. The thyratron anode circuit consists of a voltage-dividing network between 150 and 75 volts. Circuit values are adjusted so that 33 milliamperes normally flows from the 75-volt source through the head to the 150-volt source maintaining the mid-point of the divider at 76.2 volts. This current generates sufficient flux in the head to saturate tape to binary zero, that is, to erase polarity. Firing of the thyratron upsets the voltage divider and drops the mid-point voltage 2.3 volts to 73.9 volts. Under these conditions, current through the head coil reverses to 33 milliamperes in the opposite direction. Resulting flux saturates the tape to the binary 1 polarity. The

error is registered; striking the control bar prior to a forced check point also registers an error.

As already stated, the error circuit can be cleared only by an erase operation. Under control of the loop, erasing is repetitive and continues back through the current field. A stop punch at the beginning of the field opens the recycling path to terminate the operation. Successive fields can be erased by successive erase operations.

Other holes in the control loop provide for various types of automatic recording. A 20-digit field, for example, may be assigned to personal names. Since no tape can be left blank, any unused spaces of the 20 must be filled in with ignores. The ignore symbols can be inserted by the loop when the control bar is struck. The recording is terminated by a stop punch.

To make the loop program independent of computer block length the loop-stepping circuit is inhibited during the space between blocks. Thus a field may start in one block and end in another.

To sum up the automatic functions, the paper loop provides facilities for limiting the erase operation to a known number of characters related to the input data being typed; forced check points provide the typist with milestones as she proceeds through the data; fill-in characters can be inserted automatically as required by the program. Each paper loop is prepared specifically for a given type of input data. However, some copy requires more than one sequence of control punches. Therefore, the loop system was extended to include three separate control loops. The typist can either type in the no-loop condition, that is, free of loop control, or she can call in any one of three loops as required by the data.

Change from one loop to another or to no-loop must be programmed on the loops to ensure completion of the current field before leaving the loop. Therefore, even loop changeover points are governed by the loop.

So far, this discussion has dealt with the problems inherent in the keyboard-to-tape transcription function itself. But, as is usually the case, each such problem when solved generated several more of a new breed. The new generation of problems were specific ones of circuit, mechanical design, and construction. Among these there are a few that warrant description because they represent successful working solutions to problems that face all designers of this type of equipment.

The resistor matrix encoder is of interest chiefly because its construction is ingenious and admirably adapted to sub-assembly production (see Figures 4 and 5). Fifty-one separate input lines are

TO STEPPING
CIRCUITS

2-3

ERROR
LINE

1-4   1-3

T RELAY

KEYBOARD
PULSE

Figure 10 (left).   Binary counter

BINARY
COUNTER

1-1   2-2   1-2   2-1

1   2

NEITHER ENERGIZED ≡ 0
BOTH ENERGIZED ≡ 1

Figure 11 (right).   Tape movement checker

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Figure 12. The Unityper

thyratron is cleared when the duty cycle delay flop recovers and opens the clear relay contact in the cathode circuit.

The logical and the physical conditions imposed on the tape transport system made this unit an interesting design problem. As pointed out previously, the tape must move in discrete measured steps forward or backward in response to random input pulses. Furthermore, in the case of automatic operations, high-speed stepping on the order of 20 steps per second is required.

Obviously, the solution to this problem was not simple. It was necessary to devise a means to accelerate a mass of tape to recording speed, record on tape, and then stop the tape, all in 50 milli-seconds, to achieve the 20-digit-per-second rate.

The first step in the design was to minimize the mass of tape to be accelerated by using floating loops of tape to control the reel motors as shown in Figure 7. As in the Uniservo, the center drive empties or fills a floating loop of tape. The reel motors are both energized during operation. Reel motor brakes are controlled by this loop. A cord runs from each loop pulley through the panel to operate the reel brakes. As the supply loop shortens, it releases its reel motor brake and the reel motor feeds out more tape into the loop. When the take-up loop gets too large, it releases its reel motor brake and the reel takes up tape. Thus the loops are kept at optimum size and the center drive sees only a few inches of tape as its load.

The center drive capstan can be seen

projecting through the tape panel just below the digit counter disk, as shown in Figure 7. Mechanical means for stepping this capstan were first considered. Among the ideas in this connection were the use of Geneva gears and a solenoid-operated ratchet system. But the precision required, the 2-direction stepping, and the random response features made such systems impractical. Wearing of parts in most such systems would have quickly changed the length of the step.

While this problem was under consideration, the General Electric Company brought out a 96-pole permanent magnetic synchronous induction motor for use as a remotely controlled slave motor. It was recognized that this motor, if pulsed correctly, would step from one stable position, with respect to the field, to the next. A circuit was designed to do this in response to a keyboard pulse as shown in Figure 8.

To hold the motor in a fixed position, one of the two fields is supplied with $+90$ volts via a relay contact. In the meantime, a capacitor connected to the other field charges to $+90$ via a second relay contact. Both relays are energized simultaneously when a keyboard pulse sets the first of two delay flops. Unlike the trigger pair used to control duty cycle these delay flops are not used to delay the pulse. Instead, they provide a static output to energize the relays for their delay period. In changing position the d-c relay reverses current through the d-c field, while the capacitor discharge pulses the other field and the armature turns. The relative positions of armature segments and field poles, and the direction of currents, determine the direction of rotation. See Figure 9.

In the static condition, half of the d-c field poles are aligned with armature segments and the other half are aligned with the armature spacers. Since the two halves of the field are excited 180 degrees out of phase, this is a stable position. The capacitor fields are also 180 degrees out of phase, each 90 degrees out with respect to a d-c phase. Furthermore, one set of capacitor field poles leads its corresponding armature segment faces by one-half of a segment, and the other set lags by one-half of a segment. This offsetting of the poles biases the motor to fix direction of rotation. When the relays are energized, there is a reversal of current through the d-c field, a pulse is applied to the capacitor field, and the motor steps clockwise. The capacitor field is disconnected after 8 microseconds and the d-c field is reversed after 12 microseconds. The extra

4 microseconds on the d-c field prevents overshoot.

The reverse stepping problem is solved simply by switching the fields of the motor by means of the reverse relays. In this case, the original d-c field becomes the capacitor field and conversely. This is done by operating the erase or backspace key, either of which energizes the reverse relay and generates a keyboard pulse. However, before the pulse arrives at the stepping circuits, the reverse relay contacts reverse the field potentials, and the motor steps backward one-fourth of a step. Some time later, the keyboard pulse operates the stepping circuits as in forward operation and the motor steps backward one full step. Still later, the reverse relay drops out to restore the original conditions and the motor then steps forward one-fourth of a step to the lock-in position it held before the error was made. This controlled one-fourth step overshoot ensures complete erasure of the incorrect character. Effectively, this system is a high-precision 2-way escapement. Physical wearing of parts is no problem, and the speed of operation can be controlled by delay flop timing.

To avoid superposition of recorded digits caused by failure of the tape motor to step, a tape movement checker (Figure 10) is employed. This checker includes a relay binary counter which changes state every time the motor-stepping circuits are energized, and a relay which changes position every time the motor actually steps.

This latter relay is energized by a photoelectric cell. On the shaft of the center-drive motor is mounted a disk with 24 equally spaced holes. A photoelectric cell searches for holes in the disk. Since the motor steps 1/48 of a revolution per digit the photoelectric cell will find a hole on alternate steps. A change of photoelectric cell output is positive proof that the center drive has advanced. When illuminated, the photoelectric cell output energizes the tape relay. This arrangement is half of the checker. The relay binary counter forms the other half.

The relay binary counter is shown in Figure 11 with all relays de-energized, a condition defined as zero. When the binary counter relay is energized by the motor-stepping circuits, its contact energizes relay 1 in the binary counter circuit. Contacts 1-1 and 2-1 close the holding circuits for their relays. Contact 1-2 prepares an energizing circuit for relay 2. When the binary counter relay drops out, it energizes relay 2. Contact 2-2, when energized, prepares a clearing circuit for relay 1. With both relays ener-

gized the circuit is in its 'one' state.

The next keyboard pulse to reach the stepping circuits energizes the binary counter relay as before. This time, however, its contact clears relay 1 since 2-2 short-circuits the relay coil. When relay 1 drops out, 1-2 prepares a similar short circuit for relay 2 so that the binary counter relay clears relay 2 at the end of the step, and the counter assumes its original state.

Since the binary counter is actuated by the stepping circuits, a change of state of this counter is an indication that the motors should step. Energizing the tape relay is proof that the motor has stepped. Therefore, contacts of all three relays can be arranged into a tape movement checker as shown in Figure 10. This checker is placed in series with the stepping circuits. When the binary counter changes state, its contacts open the path to the stepping circuits. As soon as the tape relay changes position, it cancels this effect by completing a new circuit. Incorrect operation not only prevents further stepping of the motor, but channels the keyboard pulse to the error circuit which lights an error lamp and prevents further typing.

Figure 12 shows a front view of the complete Unityper. The keyboard and encoder are housed together and these fit conveniently on a typist's desk. The remainder of the equipment is housed in a 6-foot cabinet. At the top of this cabinet is the tape transport equipment and the recording head. Below this is the control panel which contains switches and indicator lamps for the error, block-ending and block-beginning circuits. Below this panel are the electronic equipment chassis and power supplies. A printer, which is described in the paper on output devices, can be connected to the Unityper if printed copy is desired. Through the three windows in the control panel, the control loops are visible to the typist. Thus, from her position at the keyboard, the typist has complete control of the transcription process.

Output Devices

E. MASTERSON   L. D. WILSON

THE output demands placed upon an electronic computer vary considerably with the type of problem being performed. In order to achieve the widest possible latitude in this respect, the Univac System incorporates three different output devices, each of which serves its purpose when required. Such a design may at first seem merely a matter of convenience, yet the more important consideration is to avoid the use of higher powered equipment for small-sized tasks. The output typewriter directly associated with the supervisory control desk is used for writing out the smallest amounts of output data. Its principal use is for computer testing, straightening out program routines, for program-to-operator functions where certain directives to the operator are put into the routines for 'on-the-spot' action by the operator, and, in the case of certain special problems, for very limited amounts of actual problem data output.

Next to the control printer stands the Uniprinter, which is the principal output means at the present time. The Uniprinter is a magnetic-tape-operated typewriter and achieves speeds of 10–12 characters per second. This device was intended to be an intermediate device but has, so far, satisfied many situations. If large output is demanded, parallel operation of the necessary number of Uniprinters can always be undertaken.

The high-speed printer represents the third and highest speed output device and, although still in development, is the logical fulfillment of the demands arising in problems where extremely large volumes of output data are encountered. A complete array of output equipment will shortly be available to the Univac user.

When the plans for the Univac output devices were made, it became obvious that certain unit assemblies would be desirable. The first unit was the printer assembly shown in Figure 1 at the right. This unit contains the typewriter, with electrically operated actuators and a relay-type decoder. This unit can be operated from the tape-reading unit, shown at the left in Figure 1, so as to make a Uniprinter or it can be connected to the supervisory control desk where it then serves as the directly connected typewriter-printer.

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Finally, it is basically the same unit which, with the addition of two chassis, can be connected to a Unityper to obtain a printed copy of what has been recorded.

A simplified block diagram of the Uniprinter is shown in Figure 2. The basic operating pattern is cyclic. Operation is started by an initiating pulse from the start switch. This pulse supplies the 'go' signal to the tape drive motor. The tape moves across the 8-channel head at about 2 inches per second. As soon as any combination is detected in the eight unit memories, a signal is generated which passes to the 'stop' input for the tape motor drive system and into the decoding delay. Whatever signals have been set up in the eight unit memories are decoded in a relay-type decoding function table. This function table is a folded whiffletree arrangement which has permitted the decoding of the 6-channel
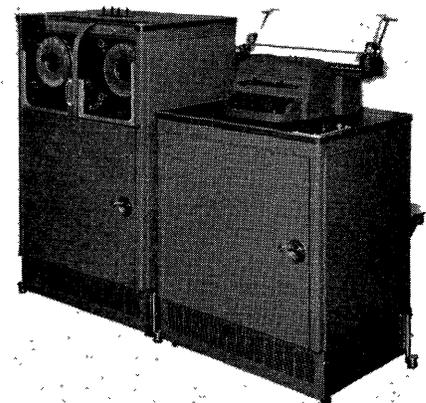

Figure 1. The Uniprinter

Univac code with a total of 11 relays each having six poles. Ten of these 11 relays are connected in pairs so that each pair forms a single 12-pole relay, the remaining relay having only one pole used. Effectively, then, there are six actuating coils, each of which is connected to one of the unit memories corresponding to the six channels of the code. There are 64 possible output lines from the decoding relays of which 51 are used.

The decoding delay is inserted in order to allow time for the relays of the decoder to set up. When the time represented by this delay has been spent, a print pulse is applied to the print circuit. This pulse operates a print relay which applies voltage through the relay decoder and the selected actuator. The print relay is energized for 30 milliseconds. This is sufficient time to trip the mechanical escapement in the typewriter. Although there are only forty-two keys on the typewriter-printer, there are nine additional control functions, each of which is also represented by the coil of another relay, which then performs the required function. If the character selected is a printing character, and not a control function, one of the forty-two type bars responds to the actuator motion by moving toward the platen.

As soon as the actuator has been energized, a pulse is developed, the end-of-print signal, which passes to the clear circuit. Once the actuator has set the typebar in motion, the end-of-print signal starts the search process for the next character. The next character may enter the unit memories before the last character has been completely printed. The effect of such a system is to improve the speed of operation merely by overlapping

operations. The end-of-print signal passes then to the clear circuit. The clear circuit restores the eight unit memories to the cleared state. At the same time this clearing pulse goes into a delay. When the delayed pulse finally emerges sufficient time has elapsed for the thyratrons in the unit memory circuits to reach a stable state. The pulse then proceeds into the 'go' input of the tape panel in order to search for the next character.

The blanking circuit has three different purposes. First, it applies a desensitizing signal to all thyratron unit memories as soon as the motor stops, thereby preventing any spurious signals from triggering the thyratrons once they have been set up. Second, the blanking circuit can also be triggered by a delay flop which has a 150-millisecond delay. If in 150 milliseconds of searching a signal is not obtained, the assumption is made that a space between blocks is occurring. A second delay flop, good for another 250 milliseconds then energizes the blanking circuit for the expected duration of the space between blocks. The third use for the blanking circuit is for bad spots. There is a photocell on the Uniprinter which searches for the indicating holes punched in the tape. When one occurs, a delay flop is set which applies the bad spot signal to the blanking circuit for the 2-second interval of time required for the particular area to pass over the head. If the bad spot exceeds this length, a second hole can reinitiate the bad spot signal for a new 2-second interval.

Thus, proper action of the Uniprinter depends upon having the characters on the tape spaced far enough apart to meet the acceleration characteristics of the center-drive motor, yet close enough to prevent the space-between-block delay flop from triggering. The nominal operating pulse density is 20 per inch.

The principal checking system in the

Uniprinter takes advantage of the odd-even code used throughout the Univac System. All of the actuators associated with the typewriter-printer are divided into two groups: those actuators which represent code combinations carrying a pulse in the checking channel are connected to one bus while the remaining actuators which represent those characters lacking a pulse in the checking channel are connected to the other bus. This system is shown in Figure 3. The checking pulse relay follows the information from the tape. When the print relay applies −90 volts (the other end of each actuator is grounded through the decoder), current flows through the selected actuator only if the odd-even relay is in the right position. Therefore, if the odd-even check fails in any channel there is no through circuit for any actuator coil. Also shown here is the method for generating the end-of-print signal. If the print relay opens after having energized an actuator, the combined inductance of the coil and stray capacity of the circuit produces a sharp positive wave front which is differentiated. If no actuator has been energized, the very high resistance to ground discharges the capacity slowly and the signal from the differentiator is too small to be effective. The Uniprinter, therefore, stops.

One of the problems in designing the Uniprinter circuits was to find a method for obtaining a signal which represented the detection of any one or more pulses in any of the channels. The input signals from the tape, as shown in Figure 4, are applied to the grids of thyratrons. In the anode circuit of each thyratron is the energizing coil of the decoding relay. If a circuit were caused to examine the state of affairs at the anode, it would have difficulty distinguishing between the incoming tape signals and the transients which occur in the anode circuits whenever the
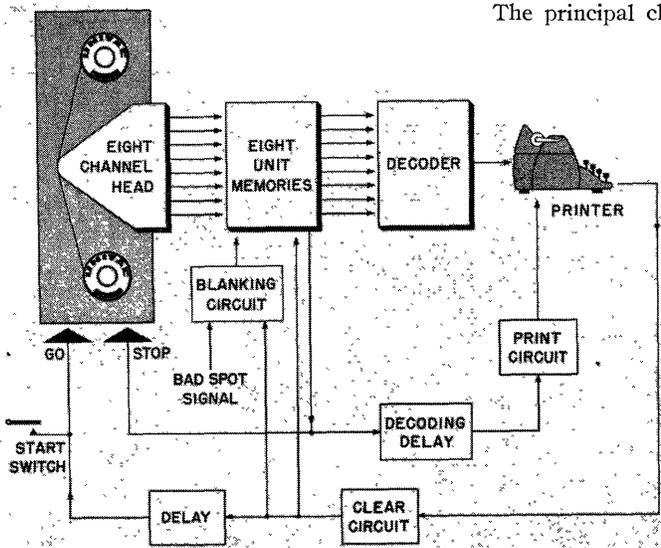
Figure 2 (left). Block diagram of Uniprinter

Figure 3 (below). Common bus for actuators
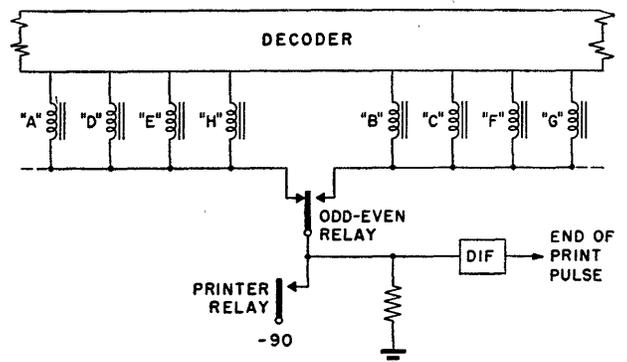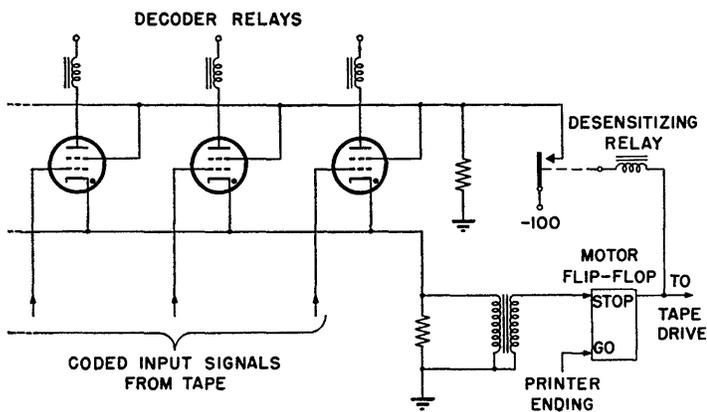
thyratrons are cleared. Therefore, the cathodes were inspected for this signal. As shown in the figure, all the cathodes are connected in common through a resistor to ground. Across the resistor is connected the primary of a transformer. If any thyratron in the group of eight is fired, a pulse is generated across this resistor, and, through the transformer, is applied to the stop input of the motor flip-flop. Extinguishing the thyratrons develops a signal in the motor flip-flop of opposite polarity, and is therefore ineffective.

Another feature of the Uniprinter design also shown in Figure 4 is the desensitizing system. To desensitize the thyratrons a relay is energized which connects the screen grids of each thyratron to −100 volts. The desensitizing relay is energized, as mentioned, during any bad spots on the tape, whenever the motor is stopped and during the space between blocks.

Among the control functions of particular interest, is the carriage shifting arrangement. In the Univac code there is provided a symbol which shifts the carriage and holds it until a second coded symbol occurs which unlocks and releases the carriage to its normal position. These symbols have been called respectively, 'shift lock' (from the conventional key on the ordinary typewriter) and 'unshift.' In addition to these two there is a third symbol which is called 'single shift.' This symbol is decoded to shift the carriage and hold it there for just one character and then to release the shifting mechanism automatically. Thus, the Uniprinter can print a single capital letter through use of two code symbols on the tape, one the single shift and the other the character to be capitalized. Or the Uniprinter can type a whole group of capitalized or shifted characters with the addition of only two extra symbols on the tape, the one for shift lock and the other the unshift symbol.

An elemental diagram of the circuits for the shifting operation is given in Figure 5. If a single shift symbol or shift lock symbol is encountered on the tape, the line from the middle or the line from the left of the function table is energized. These two lines connect together to energize the shift set coil. This coil is one of two coils in the shift relay. As the shift set coil is energized, three poles of the shift relay are connected. The upper pole provides power to the shifting hold coil on the same relay and is the hold circuit for this relay. The middle contact of the relay acts like an end-of-print signal except that it first triggers a delay flop which supplies sufficient time for the carriage to come to rest. This we call the bounce delay flop. The third pole sends power to the actuators which operate the shift key of the typewriter. When the bounce delay flop recovers, it starts the center-drive motor searching for another character. When it is found, it is set up and decoded. When it has been printed, its end-of-print signal is sent to the gate shown. If the original code was for single shift, the gate is not inhibited and the end-of-print pulse passes through to energize the unshift relay which grounds the top end of the holding coil of the shift relay. If the original code was for the shift lock then it also set the lock relay which inhibited the gate. Each end-of-print signal is therefore ineffective. When an unshift symbol finally occurs, it appears from the relay decoder and excites the unshift relay. This action not only releases the shift relay but also the lock relay.

Earlier in this paper mention was made of the control function symbols as distinct from the printing symbols. Of the nine nonprinting symbols, three have been mentioned. The remaining three symbols are 'stop,' 'breakpoint,' and 'ignore.' The stop symbol merely snuffs out the end-of-print pulse while the breakpoint may or may not behave as a 'stop' symbol depending upon the setting of the breakpoint switch. The 'ignore' symbol is so called because it is ignored by the Uniprinter. Although it is set up and decoded, it merely produces an end-of print signal without accomplishing anything else. It is the symbol commonly
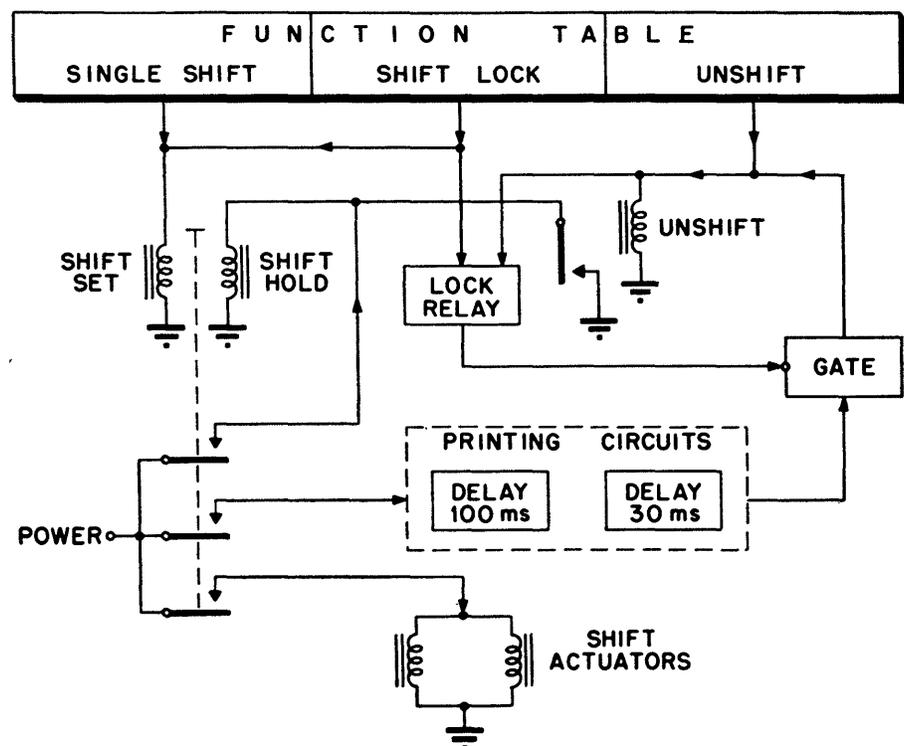
Figure 5. Shift—shift lock detail

used to fill out unused block space in the central computer.

These nine symbols each occupy a digit space on the tape and experience has shown that often it is desirable to obtain a one-to-one copy of the tape codes as printed symbols Rather than add keys to the typewriter for this purpose, we have wired up a control switch which shifts eight of the nine codes (excepting space) so that they are interpreted as printing symbols whenever the control switch is moved to what we have termed 'computer digit copy.' Thus, shift lock prints as a *Z* and unshift as an *8*. Similar substitutions are assigned for the other seven codes. Although this means that certain characters really have two distinct meanings, the context has always been sufficient to distinguish the two. When printing out a tape the carriage is returned automatically by the margin stop. By setting this stop at 120 characters from the beginning of the carriage we obtain exactly six lines per computer block.

At present a high-speed printer system is being developed which will take its place beside the Uniprinter in providing adequate facilities for meeting the exceedingly high demands for printed copy of the results obtained from the Univac. There have been many attempts and proposals for this type of equipment, as is demonstrated by patent literature. Some of these methods lend themselves to an automatic device better than others, and as in many other present-day developments, whatever advances are made will come more from a refinement of the older methods made possible by newer and more excellent tools available to the researcher, than from any basically new concepts.

The requirements of a high-speed printer vary greatly with different applications. High-speed printing problems are of particular importance when new electronic computing methods are applied to business problems. Not only is it necessary to produce great volumes of material at high speed but the output must be very neat in appearance because, in many cases, the results are mailed or sent directly to customers. The accuracy of such a printer must also be of a high order. Requirements for such a printer are, in fact, very like the requirements of the well-known card-fed tabulators. The exception in the case of the Univac printer is the absence of many requirements due to mathematical computations, although several editorial functions can best be done in the printer.

A cursory study of the economics of such a high-speed printer in this application shows quickly that any printing method using sensitized paper would be far too costly. The use of standard varieties of office paper is a necessity. A conventional card-fed tabulator can consume in normal use over $10,000 worth of ordinary paper a year. More than this, the printing method must be able to produce carbon copies. It may be argued that additional copies can be produced by additional runs if the printer is fast enough but, although this may be satisfactory in many cases, numerous business applications demand a carbon copy as the only legal copy.

Another requirement of our high-speed printer is accurate registry of the printed information through use of a control-type paper feed so that the information can be presented on a preprinted form. It is also desirable, in the interest of saving

printer time, to place the paper feed under the control of a paper loop which can advance the paper rapidly over areas where no printing occurs. In addition to provisions for single, double, and triple line spacing, the feed system must be capable of handling a large variety of forms, widths, and thicknesses.

The smallest block of information handled by the Univac is a group of 10 words with 12 characters in each group, making a total of 120 characters. We have decided to use a character size which permits a spacing of 10 characters to the inch. Since a 120-character line has also been decided upon, each line will be 12 inches long. Six lines (one complete Univac block) will be printed in one vertical inch. The 6-channel Univac code makes 63 different characters available to the printer.

In order to conserve the more expensive computer time, several editing functions will be performed in the printer. First, by means of a plugboard, the order of information can be rearranged in any desired manner across the page. Second, a line-printing feature under paper-loop control can subdivide the 120 characters normally printed on a single line into as many as six lines. This feature is valuable, for example, in printing names and addresses. Third, the familiar zero suppression feature will be incorporated, to eliminate 0's to the left of the first significant figure. This function will be under the control of the plugboard wiring. The checking features of the high-speed printer include the odd-even check system. In addition, another check circuit will ensure that all 120 characters have been received from the tape and have caused some form of printer actuation.

Discussion

L. Jaffe (National Advisory Committee of Aeronautics): Will somebody please comment on the difference in pulse density for the three different tapes described?

H. F. Welsh (Eckert-Mauchly Division, Remington Rand Inc.): The Unityper uses 20 per inch, the Uniprinter also uses 20 per inch, and all other data which is to go out onto tapes as intermediate memory, or to go out on tapes and be put into a library for later use in the computer, are at 128 to an inch. The reason for the lower densities on Unitypers and Uniprinters is that the tape must be stopped between every character, and, at 128 per inch, this would be a difficult job, especially at a reasonable speed, if we are to get a decent signal off the tape.

Mr. Jaffe: Is the tape prepared by the Unityper not compatible with the tape used

to insert information to the Univac? It is my understanding that this tape prepared by the Unityper is a manually prepared tape to be inserted in the Univac.

Mr. Welsh: That is correct. The tape prepared by the Unityper can be read by Uniservos in exactly the same way. The Uniservo does not care whether it has tape at 20 to the inch or 128 to the inch. It will read the two equally well. It goes at the same speed (at 100 inches per second) and, therefore, takes longer to read in the 20 per inch but, in general, there is a much smaller amount of information coming through Unitypers than comes through intermediate data. We find the 20 per inch quite adequate speed for tapes coming from Unitypers.

W. H. MacWilliams, Jr. (Bell Telephone Company): Compatibility is in the Uniservo, then?

Mr. Welsh: Yes.

S. Wald (Glenn L. Martin Co.): Can

you tell me what the material of the metal tape is which was especially designed and prepared by the Remington Rand company, about what life is expected, and if you have any difficulty in splicing this tape in case of breakage?

Mr. Welsh: The tape uses a phosphor bronze base and is plated with a magnetic coating. The life of the tape is hard to determine. Our experience, we believe, is very good, but there is no way of keeping track of how many passes a given tape has made, although we assume it to be in the thousands.

The splicing is being done by a pressure-sensitive tape over a diagonal cut. Temporary splicing, of course, could be done with scotch tape. However, permanent splicing of the tape requires the pressure-sensitive tape, and then holes are punched on either side of the splice so that the area cannot be used by the computer, because the splice is likely to cause errors in writing

or reading. Tapes very seldom break, thank goodness!

W. P. Byrnes (Teletype Corporation): Would you like to compare the system of input whereby you go from the keyboard to perforated tape to magnetic tape, with the system whereby you go from the keyboard directly to magnetic tape, as in your Univac?

L. D. Wilson: There are several important differences. First, by introducing a second step, you also introduce more possibility of error. Second, we reuse the magnetic tape. We can erase very easily in case of an error in preparing the tape, and re-record. With a punched tape, the erasure is somewhat more difficult. It is a little hard to put back the pieces. Also, we are not equipped to use the paper tape.

D. Haagens (Control Instrument Company): What is the speed aimed for in the high-speed printer?

Mr. Masterson: Regarding speed, the only thing we can say right now is that the minimum speed will be 200 lines per minute. We are shooting for more than that, but that is all we will guarantee at the moment. This type of printer has type-wheels in it. The paper is struck from the back with hammers. This is not new, but we have devoted quite a bit of study to what it takes to do the job well: to make carbon copies, to produce 10 characters per inch, and to present an appearance good enough to fill business applications.

Mr. MacWilliams: Mr. Wilson, how is the tape stepped digit by digit in the Uniprinter and the Unityper?

Mr. Wilson: In the Uniprinter it is a matter of energizing and de-energizing a low-inertia servo motor. In the Unityper, since we are not interested in following digits already recorded on the tape, but simply wish to space the tape a known distance, we have used what amounts to an electrical escapement mechanism. That is, we have a 96-pole permanent-magnet synchronous motor, which by appropriate circuitry, can be stepped from one-pole position to the next. This provides an error free ratchet mechanism which handles the job adequately.

M. Stein (National Bureau of Standards): Longer stability of storage was mentioned for metal tapes over plastic tapes. Have you actually made any plastic base recordings that yielded inadequate playback after long periods of storage?

Mr. Welsh: We do not know specifically that plastic tape cannot be used for long periods of recording. We do know that metal tape can. Plastic tape may, with some of the newer bases, be satisfactory. Some of the older plastic bases, similar to movie films, require careful treatment. Otherwise, they become weak and fragile. Tests are under way to try to find out whether plastic tapes can or cannot be used.

Mr. Stein: By what factor do you reduce actual pulse packing when using the 1/2 mil spacer between the tapes and the heads?

Mr. Welsh: We are using the same pulse density. We have adequate resolution. Using the 1/2 mil spacer slightly reduces the resolution, but the resolution is still sufficiently good. Even with the 1/2 mil spacer, we use the 128 per inch density.

Mr. Stein: What pulse density could you work with if the tape were in direct contact with the head?

Mr. Welsh: You could undoubtedly work with a higher pulse density from the point of view of the actual resolution of the tape. What led us to use the particular pulse density we were using was not limited so much by resolution as by the problem of what we call skewing. A group of seven bits represents one character. This group has to remain related as a unit, and since they are recorded in various channels across the tape, dimensional problems in manufacture of tapes, the interchangeability of heads, and other similar considerations, led us to select a density somewhat lower than we might otherwise have used. Therefore, the addition of the spacer proved satisfactory.

Mr. Stein: Will you please elaborate on the frequency of flaws on reels of metallic tape, the method of detecting these flaws, and the method by which they can be eliminated.

Mr. Welsh: We run the tape through a machine in which we record, at a somewhat higher density than normally used, a continuous set of pulses on all channels. We then play the tape back in a device which looks for the presence of all these pulses. We also do this at a gain-setting or bias level, which is higher than the level normally used in the computer. That means, if any one of these pulses falls to a level which is lower than the computer needs, it will stop the machine, and permit us to punch the tape with holes so that that portion will not be used by the computer. We also make another pass in which we erase the tape, to make sure that there are no noise signals which may be of an amplitude which could possibly hurt the computer, and there again, we use a sensitivity which is on the other side of what the computer requires. If any noise pulses come through (you might consider these places as unerasable) we again punch the tape in such a way that that area will not be used.

As far as the frequency of these areas is concerned, our chief worry is that we have a certain length of usable tape on each reel. The programmer expects to get a certain amount of information on that tape. We consider the reels we are now using as 1,500-foot reels of tape. Actually, we put on 1,600 feet. The 100 feet extra is allowed for punchings. We keep track of the amount of punching on a tape, and if any tape has punchings which would be more than this extra 100 feet, we would not let that tape go through. Therefore, we know that there are at least 1,500 feet of good data on a 1,600-foot reel of tape.

Mr. Stein: You say you keep track of these punchings? Could you list an average figure for the number of punchings on a 1,500-foot reel?

Mr. Welsh: Each time we use a punching, about a foot of tape is nullified. We do not allow for more than 100 such areas in a 1,600-foot tape.

Dr. C. Swift (National Bureau of Standards): Can a tape that has been used be reinserted in the Unityper after use and be changed or corrected?

Mr. Wilson: The tape can be reinserted in the Unityper, but it can be changed only by completely rewriting the information; that is, we cannot pick out a specific digit or group of digits and change those, except by re-recording the tape completely. What is more important, however, is that we would never need to do this, because it is so simple to correct a few digits by means of supervisory control after the data has been read into the computer.

The Raydac System and Its External Memory

KENNETH M. REHLER

Synopsis: The series of papers on the external memory of the Raydac input-output units is introduced by a brief description of the Raydac system operating parameters.[1-4] Included in this introduction is mention of the built-in self-checking used. The Raydac external memory and its operational performance are discussed in detail.

The Raydac System

NUMBERS AND ORDERS

The Raytheon computer stores and computes with numbers represented in the binary system. Data may be introduced in decimal notation via the problem preparation unit; decimal numbers are represented in the machine in binary coded decimal form. Conversion to binary notation is accomplished by means of standard programming operations. All numbers are represented as proper fractions; that is, with the binary point at the extreme left. All numbers are represented by their absolute values, one digit in each number being reserved for the sign.

Orders for the computer are numerically coded and stored in the memory. No special memory positions are reserved for orders, so they may be arbitrarily scattered among the numbers stored. The basic unit of information, the 'word,' occupies one position in the memory. Since two words are required to express one complete order, each order requires twice as much storage space as a number. A specific word, therefore, may be a number or half of an order. The two halves of an order are always stored in consecutive memory positions.

INTERNAL MEMORY

The internal memory consists of mercury delay lines, and is therefore serial. The basic pulse repetition rate in the memory is approximately 4 megacycles. Each delay line contains 32 normal precision numbers, and there are 32 such delay lines in the internal memory, making a capacity of 1,024 numbers. In addition, there are four special registers, each having a capacity of one number, to which immediate access may be had. There are also four ordinary mercury delay lines associated with the external memory.

Positions of words stored in the internal memory are identified by addresses. An address is a 12-digit binary number, the last five digits of which identify the time associated with the designated memory position. This time indication is required because the memory is serial. Certain addresses belong to special, one-word registers. They require no time indication, and therefore they end in five zeros. Other addresses refer to external memory reservoirs, to be described. The rest of the addresses refer to positions in the regular internal memory. Any memory position except a special one may contain a half-order or a number; numbers only may be stored in special positions. Addresses constitute parts of orders.

MACHINE OPERATIONS

The programmer who uses the Raytheon computer has a wide variety of arithmetic operations at his disposal. The basic operations of addition, subtraction, and multiplication are provided both in single and in double precision, and with and without round-off. Division is a separate operation. Two kinds of branch orders are provided, one of which depends on the exact equality of the numbers being compared.

Numbers may be transferred from one memory position to another with or without signs. Floating point operations are available, in which numbers of arbitrary magnitude may be manipulated by re-expressing them in terms of a fractional number and an exponent. Numbers may be shifted in either direction, the amount and direction of the shift being determined by a control number, or they may be shifted under a fixed program, the amount and direction of the shift appearing as a second result. Digit extraction is also provided.

ORDERS

The Raytheon computer uses a 4-address order. The addresses of the two operands and a code for the arithmetic operation constitute the first half of each order. The second half-order consists of the address to which the result is to be delivered and the address of the next order. Each order requires about as many digits as two normal precision numbers. Each half-order, therefore, occupies one memory position, two halves of the same order being stored in consecutive memory positions in the same delay line. The address of the first half of each new order appears as the fourth address of the preceding order. The second half-order is automatically taken from the succeeding memory position. Orders may be modified in the arithmetic unit using standard arithmetic operations.

OPERATION TIMES

The timing in the Raytheon computer involves a mixture of fixed and variable cycle as well as a mixture of serial and parallel operation. The fundamental unit of time for the machine is called the minor cycle. A minor cycle is the time represented by one word in the internal memory. Each major step in the operation of the computer occupies an integral number of minor cycles. This number, however, is variable. Each arithmetic operation is allotted a fixed number of minor cycles, which varies from operation to operation, but which is independent of the actual numbers being combined. This fixed time refers only to the operation of the arithmetic unit. The time required to obtain information from the internal memory is separate, and depends, because of the serial nature of the memory, on the location of the information. Each memory position to which access is required by any order is selected as soon as it becomes available. The machine then proceeds to the next stage in the operation.

The central control of the computer is primarily concerned with making selections from the memory and is therefore basically a serial unit. The arithmetic unit, on the other hand, is not concerned with the memory except in that it receives operands and delivers results as directed by the central control. It therefore may do its work in parallel and, in the Raytheon computer, it does. The external memory is entirely serial. Its reservoir is synchronized with the internal memory, but it has its own repetition rate for the tapes. Special equipment is provided for synchronizing these
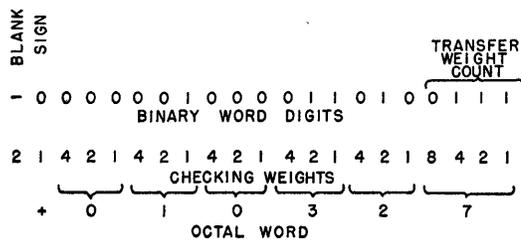
Figure 1 (left). Transfer - weighted count of a hypothetical word

Figure 2 (right). Organization of Raydac external memory
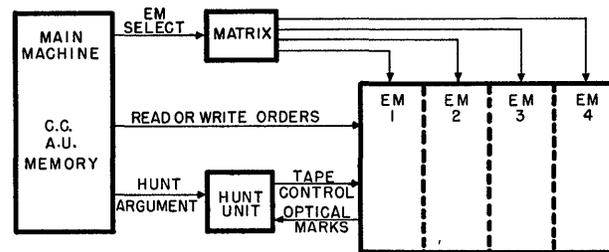
two serial storage mediums during the transfer of information. All of the sequence pulses required for the variable cycle operations are derived from the checking system.

The over-all speed and versatility balance of the machine may be seen by examining the relation between internal memory access time and arithmetic combination time for high-speed operation, and the rate at which information may be obtained from the external memory for computation. Four selections from the internal memory are required for each arithmetic operation. Because of the variable cycle, the time per selection is not fixed. The average, however, is in the neighborhood of 13 minor cycles per selection or 52 minor cycles for all the selections required by an order. The time required for arithmetic computation depends upon the operation, being longest for division and shortest for one of the addition operations. The average is about 12 minor cycles. The average speed of operation of the entire computing system, including access to the internal memory but not to the external memory, corresponds to approximately 1,500 operations per second, or about 650 microseconds per operation.

CHECKING

The Raytheon computer is provided with a completely automatic checking system. The correct selection of mercury delay lines and arithmetic operations on the basis of addresses contained in the orders is verified by means of tags. The circuits which govern the performance of arithmetic operations and which permit transfers to and from the mercury delay lines generate tags which are compared with the codes contained in the orders. Both configuration and duplication checks appear frequently in all units, where they are used to detect a wide variety of possible errors.

Whenever information is transferred in the computer, one type of check, called the transfer weighted count check, is applied. The transfer weighted count consists of a set of digits derived from the main digits of any number or order and stored in the same memory position.

The transfer weighted count is formed whenever a number or order is created, either in the problem preparation unit or in the arithmetic unit. This weighted count is compared with a new weighted count derived from the number itself whenever the number is used in any operation of the machine, thus checking for mistakes. From Figure 1 it is apparent that this check number consists of the four low-order binary digits corresponding to one plus the sum of the octal digits. A zero word carries a weight count of one.

The arithmetic weighted count, which is analogous to casting out nines in decimal arithmetic, is used for checking arithmetic operations. A check number is associated with each operand and each result, and defined as the sum of the digits of the number represented in binary form to the base 32. The algebraic sign of a number is not included in this weighted count since signs are checked by another method. An auxiliary arithmetic unit uses the three basic identities.

$$[(X)_c+(Y)_c+(Z)_c]_c=31 \quad \text{(Addition)}$$

$$|(\mathbf{X}_c Y_c)_c+(Z)_c]_c=31 \quad \text{(Multiplication)}$$

$$\{ [(Z_c Y_c)+(\mathbf{X})_c]_c+(R)_c\}_c=31 \quad \text{(Division)}$$

where

subscript c indicates the arithmetic weighted count of the quantity to which it is affixed

X and Y are the operands

Z is the result

R is the remainder

The boldface $\mathbf{X}$, $\mathbf{Y}$, and $\mathbf{Z}$ represent the complement on $(1-2^{-30})$.

Dr. Louis Fein presented a complete paper on the Raydac checking system.

External Memory Operation

DESIGN PHILOSOPHY

The fundamental properties of an external or low-speed memory system are its type, capacity, speed, mode of access, and versatility. External memory devices of large capacity may depend upon magnetic tape, paper tape, punched cards or, occasionally, magnetic drums. The capacity depends upon the volume of the storage medium and upon the density with which information may be packed in

the medium chosen. The speed likewise depends upon the medium chosen, devices involving electronic reading providing high speed. On the other hand, almost all large capacity storage devices require mechanical movement, so that the speed is fundamentally limited by the rapidity with which mechanical operations may be carried out.

Various modes of access to the external memory are possible. For example, information from the external memory may be inserted directly into the computing parts of the machine, such as the central control unit or the arithmetic unit. On the other hand, information may be drawn from the external storage medium directly into the internal memory under control of coded commands. Finally, it is possible to have elements, called reservoirs, which are intermediate in nature between the internal and external memories. If these reservoirs are provided, and if they are appropriately designed, it is possible to transfer information into one of the reservoirs from the external storage medium at its low speed at the same time that information is being taken out of the reservoir at the high computing speed of the machine.

Since the external memory is large in capacity and low in speed, the problem of obtaining information from it cannot be solved by the same methods that are used in obtaining information from the high-speed storage mechanism. Usually special computer operations must be provided for locating information and for making it available to the arithmetic unit. One type of operation sometimes provided is a hunting operation whereby the external memory is directed to locate a particular piece of information. Occasionally the hunting process is simplified to an instruction simply to locate one end or the other of the external storage medium. An additional order is usually provided, directing the external memory to proceed to the next information in sequence, without hunting.

In the design of the external memory, attention must be given to the convenience of the programmer as well as to the simplicity and the reliability of the equipment. The speed and type of the exter-
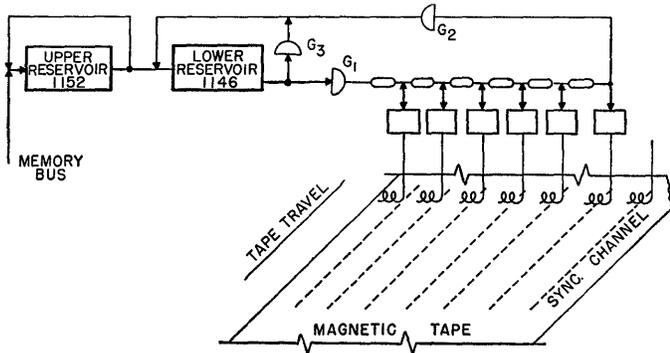
Figure 3. Buffer system to magnetic tape

nal storage medium determine the rate at which data may be fed to the computing parts of the system and the rate at which results may be recovered. At the same time, they are important in determining the internal balance of the system. It frequently happens in a long and complicated program that the capacity of the internal memory is exceeded. If this happens, the programmer must store intermediate results in the external memory. The external memory must therefore be fast and versatile enough so that the high speed and versatility of the computing parts of the system are not wasted.

EXTERNAL MEMORY UNITS

The external memory is the large capacity storage unit of the Raydac machine. It has to store words, accept words from, and deliver words to the high-speed part of the machine, and provide the sequence signals required by the various orders. The location of information in the storage medium has to be checked, as well as the correctness of individual words as they are transcribed. The external memory is the only unit of the machine to

which the coder may send conflicting instructions; the unit must, therefore, provide interlocks to guard against such conflicts.

Each of the four external memory units of the computer can store 100,000 information words of 36 binary digits in length. These units function as input devices to supply numbers and orders to the machine, or as output devices to record intermediate and final results. Approximately 500 words per second can be transferred between one tape and the remainder of the machine. If the mean rate of call for new words from a single tape unit does not exceed 500 words per second, then no time is lost as a result of a tape reading or writing process; and the machine effectively possesses a high-speed internal memory capacity of several hundred thousand words.

The storage medium is magnetic tape 1/2 inch in width. A cellulose acetate backing carries a film of red oxide magnetic material, which results in a tape thickness of 0.0022 inch. Minnesota Mining number *111* and Audio Tape number *1251* or their equivalent have proved satisfactory. Words are recorded

on the tape in six parallel channels with a seventh synchronizing channel. A whole tape is divided into blocks which are numbered serially from the beginning of the tape. The time required to read or record one block is about 64 milliseconds.

In Figure 2, the sequence of operations in the external memory involves a hunt for the desired tape block, a read and a write process between tape and electronic circuitry, and checking of these operations. A single hunt mechanism can locate any tape segment when starting from a random tape location without first rewinding to the start of the tape. In addition, the machine's central control can select and sequence one of the four external memories. In this case, control of the process is local with each external memory unit. During a hunt, read, or write operation, the balance of the machine can perform its own functions.

Since the machine computation rates may be irregular, and to minimize tape acceleration time, information is transferred through the external memory units in groups of 32 words. Storage on each tape is divided into 32 word blocks, each identified by a block-hunt tag or address. The use of this block address in the hunting process will be described. In Figure 3, the upper reservoir is a mercury acoustic delay line. It is equivalent to an extension of the main high-speed memory. One or more words may be drawn from or entered into each upper reservoir in any order.

Upon receipt of a write order, it is desired to take the contents of the upper reservoir and deliver it to the tape in parallel groups of one-sixth of a word at a group repetition rate suitable for the relatively slow tape. A 3-kc group repeti-
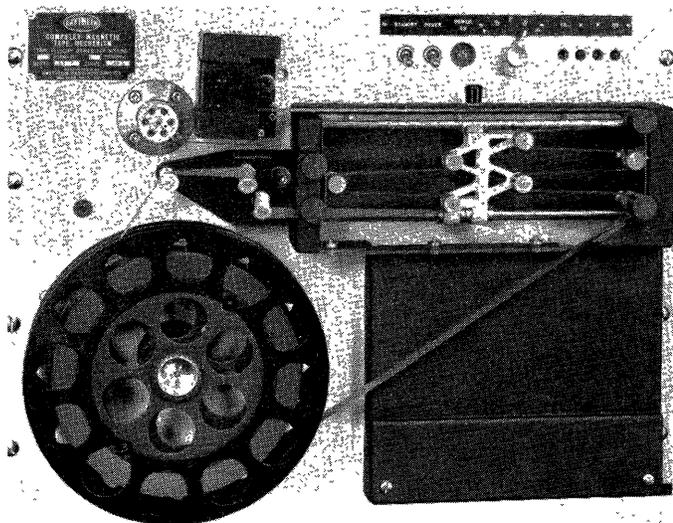
Figure 4. Raydac high-speed tape mechanism, front view
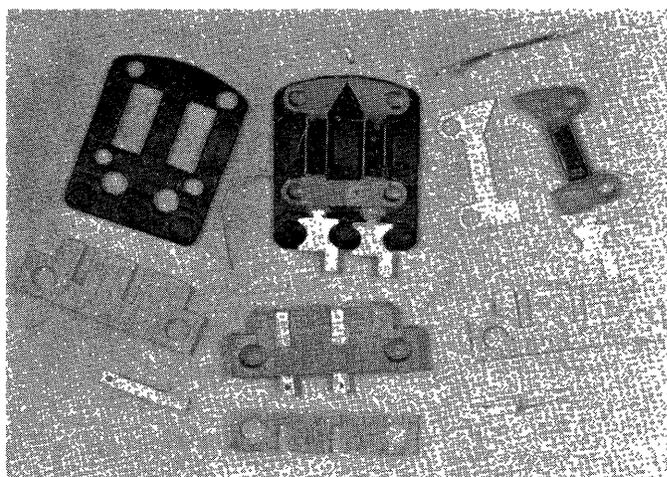
Figure 5. Raydac magnetic head, exploded view
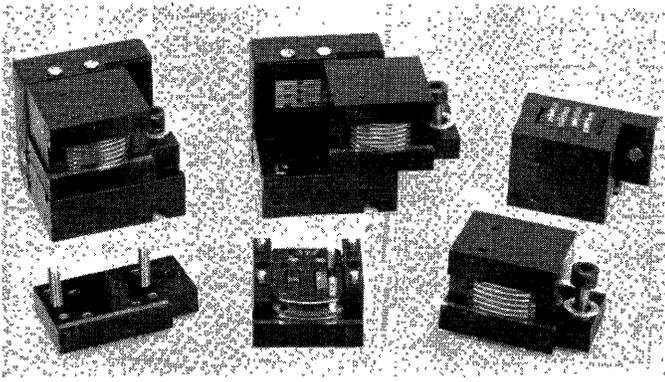
tion rate is commensurate with the tape speed. With a 4-megacycle synchronous pulse rate, every 1,152nd pulse is also approximately a 3-kc per-second rate. Thus, if a 6-channel parallel group is delivered to the tape once for each circulation on a storage path of 1,152 digits, the group repetition rate would be suitable. Naturally, for each parallel group delivered to the tape, the remaining information must advance in time by six digit positions so that successive parallel deliveries to the tape represent new information.

The buffer system shown in Figure 3 accomplishes this 4-megacycle rate change to a 3-kc rate change in the following manner. A write order serially transfers the contents of the upper reservoir to the lower reservoir where the 1,152 digits circulate through a lower reservoir, gate $G1$, six digit times of tapped electrical delay line, and finally through gate $G2$. Gate $G3$ is closed. This acoustic and electrical delay path obviously has a total storage capacity of 1,152 times. Assuming that a constant frequency reference pulse is defined which occurs every 1,152 digit times, the first of these reference pulses will occur in time when the foremost digit in the circulating train is at the right end of the electrical delay line. The second digit resides at the next tap to the left, and so on. Note that digit number 7 has not yet left the lower reservoir acoustic storage medium. If now the first reference pulse momentarily opens output gates, a parallel group of six digits will be sent to the tape for recording thereon.

Simultaneously with this parallel dropout from the electrical delay line, gate $G2$ is closed and gate $G3$ is opened. Digit number 7 and those following pass through open gate $G3$ and make one circulation through the shortened delay of the lower reservoir. Notice that its storage capacity or delay is only 1,146 digit times. Thus, the lead digit, in this case digit number 7, leaves the lower

reservoir at the first reference time, passes $G3$ and is delayed, 1,146 digit times in the lower reservoir. Gate $G3$ is now switched closed, while $G1$ is still open so the lead digit, number 7, is electrically delayed six more digit times, when it reaches the right end of the electrical delay line. The reference pulses are spaced by 1,152 digit times. Also, digit 7 and five others have been delayed since the first reference pulse by 1,152 digit times and now appear at the electrical taps, in time with the second reference pulse. Thus, the second group of six pulses is dropped out of the electrical line and sent in parallel to the tape. This process continues until 192 groups of six digits have been sent to the tape, at which time one block of 32 words has been written. This process has been termed precession, in that the word train is advanced in time by six digit positions each time a synchronous reference pulse senses the digits residing at the six taps of the electrical delay line. Figure 3 emphasizes this parallel delivery of six channels of information to the magnetic tape.

At the start of a tape-read process, the lower reservoir of Figure 3 is empty. Parallel groups of six digits, read magnetically from the tape, are to be collected in the lower reservoir for serial delivery as a group of 32 words to the upper reservoir. The input points now are the taps on the electrical delay line. The parallel groups from the tape are introduced by the same synchronous-reference pulse. They pass the gate $G2$,

which is open, as a serial digit train and enter the shortened 1,146 delay of the lower reservoir, find gate $G1$ closed, and pass through the open gate $G3$. Six digit times later, these six digits will have just re-entered the lower reservoir at the time the second synchronous reference drops another group of digits into the electrical delay line. This second group will enter the lower reservoir and add on directly behind the first six digits. Thus, a 12-digit serial train starts a second short precession delay. This continues until 32 words are accumulated in the lower reservoir. In general, on a tape read order none of the gates shown are synchronously switched.

Since the linear speed of the magnetic tape may vary slightly, it is necessary to place magnetic digits on the tape at a pulse repetition rate which is asynchronous with the main machine. A repetition rate slightly slower than the synchronous reference pulse already described is used. The square boxes of Figure 3 thus represent buffer devices to compensate for the synchronous-to-asynchronous change in operation. Because of this difference of frequency, occasionally the reference pulse exists before information has been sensed at the tape. In this case, there is no information available for transfer to the lower reservoir. Therefore, the precession of the lower reservoir that is used to prepare room for the incoming sets of six digits is halted for one 1,152-circulation time.

Owing to the fact that the magnetic heads are not precisely aligned, these boxes also contain circuits to insure that the reference pulse does not call for information before all six digits have been sensed by the magnetic heads. This correction for any skew in alignment of the magnetic head gaps is accomplished by short-time storage in six flip-flops.

Figure 4 shows a front view of the high-speed magnetic tape drive used in Raydac. At the upper left is the high-performance capstan. It can accelerate the tape from rest to operating speed of 30 inches per second in 3 milliseconds, or 3/16 inch of tape. Reading and writing are performed with one direction of tape travel
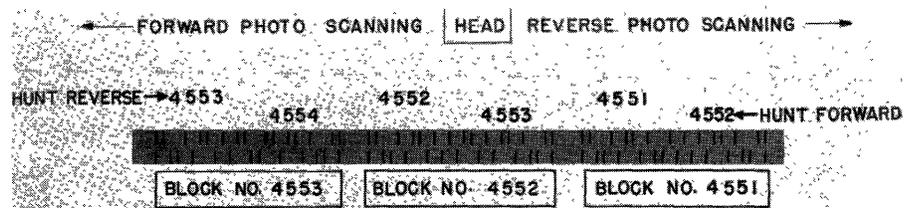
Figure 7. Raydac sample section of magnetic tape showing optical block markings
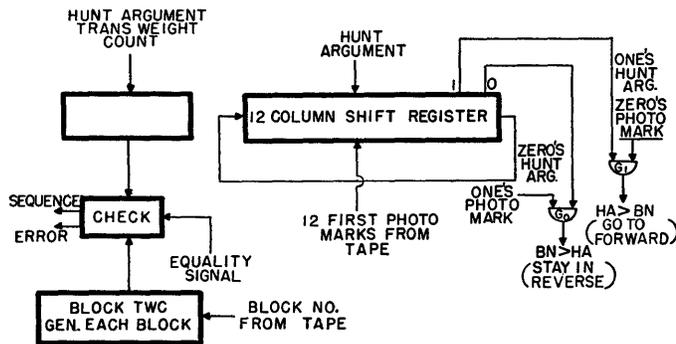
Figure 8. Checking and equality sensing Raydac hunt unit
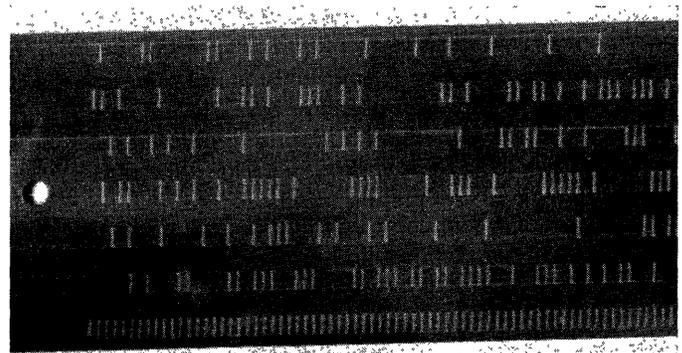
Figure 9. Sample of Raydac magnetic tape showing actual magnetic poles of digital information

at this operating speed. Rewinding is accomplished at 60 inches per second. The 7-channel parallel magnetic head is the upper rectangle next to the capstan. A surplus of tape is threaded over the idlers of the slack absorber carriage at the right. This unit isolates the reel inertia from the capstan and supplies the high tape demand of the capstan during the time the reels are accelerating. The reels are independent, one behind the other, and are quick-change units.

The dimensions of the Raytheon *RX2953* magnetic recording heads used in Raydac are:

Height.....................1³/₈ inches
Width......... .. ..1 inch
Thickness.......... .....about 5/64 inch

The core is made up of two stacks of nine laminations each of 0.003-inch mu-metal. One hundred and ninety winding turns are used, the approximate flux rise time is 3 microseconds, and the air gap is about 0.0007 inch. As used in Raydac, seven heads stacked side by side are a comfortable fit for 1/2-inch-wide tape.

A writing current of about 25 milli-amperes' peak and about 20 microseconds, duration is used. The pulse density per channel on the magnetic tape approximates 90 per inch. On playback, poles of this type result in open circuit head signals of from 1 to 2 millivolts. An exploded view of a Raydac magnetic head is shown in Figure 5, while Figure 6 shows several assembled heads.

THE HUNT UNIT

In using the tape drive, information is recorded in 32-word blocks, and optical block numbers are printed on the reverse side of the tape. These are detected with a dual channel photoelectric head located just below the magnetic head. In Figure 7 is shown a typical piece of optically marked tape. This tape marking provides several features: the optical marks are not subject to erasure, so visual indexing is available; no sync channel is needed since ones are in the upper row and zeros are in the lower;

two 12-digit binary addresses are used per block, differing from each other by one. These two numbers per block allow hunting to start at a random location and proceed either way for the shortest tape motion. Only the first address of twelve binary columns encountered is used, so, since the two numbers differ by one, the point of stopping between blocks is independent of the direction of tape travel.

In Figure 7, assume that block 4552 (octal notation) is being hunted in the forward direction. While passing over block 4551, the photoelectric head reads 4552 and stops the tape with the head in the blank space between blocks 4551 and 4552. It is now in the correct position to operate on block 4552 when started in the forward direction. If hunting in reverse, then 4552 is detected from block 4552 in such a way that the tape stops at the identical point.

Start and stop markers define the limits of a block and are distinguishable since they occur simultaneously in both channels. The block length is about 2.7 inches, while the dead space is 3/8 inch. This indicates the tape utilization factor.

When an order arrives at the hunt unit to hunt for and locate a particular information block on one of the magnetic tape units, the following process should result: the tape is started in reverse (an arbitrary decision in the designing); the optical block marks on the back of the tape are scanned, and a decision is made as to the direction on the tape of the desired information block; if reverse is the wrong direction to reach the desired block, the tape changes direction and the time to cover one block only is wasted; next, the desired block is found and successfully checked; and finally, a hunt-completed signal is sent out. If an error takes place either in the hunt process or in the final transfer weighted count check made on the optical marks, an error signal is sent out and the machine stops.

The heart of the hunt mechanism is

the equality sensing circuit which decides which way along the tape the desired block lies, and also tells when the desired block has been reached. In Figure 8 the arrival of a 12-column hunt argument initiates the hunt process. The start mark from the first tape block resets the hunt circuitry. The first twelve optical marks, whether ones or zeros, will shift the hunt argument once around the shift register with the highest order digit travelling first. Between each shift the right-hand register column controls gates $G0$ and $G1$. $G0$ is open if this register column contains a zero, while $G1$ is open if the column contains a one.

Simultaneously with this shifting, the ones of the block number are applied to gate $G1$. It will be recalled that the tape is always started in reverse; that is, scanning toward lower order block numbers, and also that the first block number is random with respect to the hunt argument. However, the equality sensing circuit will determine the required tape motion at the first photomark scanned in the following example. Before the first shift of the shift register, the high order, or 2^{12} digit position, of the hunt argument controls Gates $G0$ and $G1$ in this figure. Assuming that this column holds a zero, then $G0$ is open. If the first or 2^{12} optical mark from the tape is a one, a signal passes $G0$ and signals that the tape block number BN is greater than the hunt argument HA. This is true since 2^{12} is larger than 2^{11}. Thus, the tape is moving correctly in the reverse direction. If the converse is the case, namely, a one in the 2^{12} column of the hunt argument and a zero as the 2^{12} mark from the tape, gate $G1$ passes a signal, and the tape is stopped and restarted in the forward direction.

Incidentally, any further tape reversals beyond the one just described are detected, and an error is indicated. Thus it is not proper for this hunt mechanism to oscillate about a final stop posi-

tion or to hunt in the sense usually applied to dynamic systems.

If the highest order position of the hunt argument and the block number agree, neither gate $G0$ nor $G1$ passes a signal and the next highest digit position comes under this comparison scrutiny. The first inequality signal controls the tape motion as already described.

Since there are 24 photo marks in each block, a counter-of-12 makes the hunt circuitry sensitive only to the first 12 marks. The first inequality signal delivered from the equality sensing circuit resets this counter to zero and causes the remaining block marks in that block to be ignored. Successive blocks are handled similarly.

When equality between the hunt argument and the block number occurs for all 12 columns, neither gate $G0$ nor $G1$ will have passed a signal. Instead, the counter-of-12 will finally produce an output signal. This is the equality signal and means that the correct block has been found or an error made. This equality signal senses the check circuits and opens a gate so that the stop marker at the end of the block can stop the tape.

To obviate the requirement of rescanning the block marks of the desired block, once it is found, the transfer weighted count of each block number is generated as it is scanned photoelectrically. The start marker of the next block resets this generated transfer weighted count. In the equality case, the generated weighted count is statically compared digit by digit against the weighted count transferred from the machine with the hunt argument. This is a positive check in that a pulse must pass this check comparison to initiate the next external memory operation.

The static sensing of equality between the two transfer weighted counts is a powerful diagnostic aid since neither transfer weighted count is destroyed in the event of an error. It is important to note that during the time of a hunt operation, the remainder of the machine except one of the four external memories can be performing its own functions.

The Magnetic Tape Medium

TAPE TRACKING

Of all main units of present electronic digital computers, certainly the input-output units enjoy the poorest reputation with regard to information handling and life reliability. This should be so, since it is difficult to wed electromechanical and magnetic devices to electronic circuitry. The external memory design
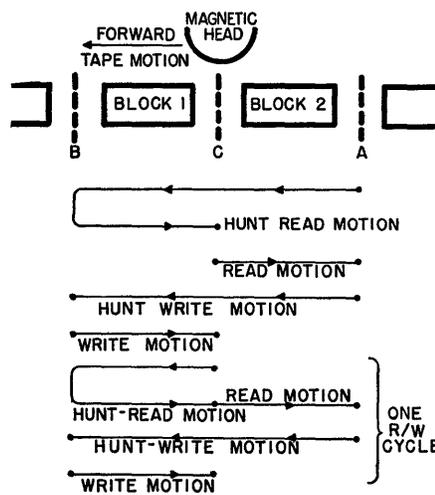
Figure 10. Tape motion during test cycle

engineer enters the fray with more of the physical world arrayed against him. He must face humidity, abrasion, and the problems of his high-speed medium such as cracking, flap, skew, slippage, and curl. One physical example will suffice to bring these thoughts into focus. During the system testing of the Raydac external memory, a certain persistent problem occurred at random on one rack and even wandered daily from rack to rack. All indications pointed to electronic circuit difficulties. About six man-weeks were spent to investigate this problem only to lead to the discovery that the tape itself was the culprit. In Raydac the tape passes the head gap inside of a slot which is precise in width. Depending on the way a tape and its tape-handling mechanism decided to act, the tape at random, following accelerations, would curl one edge slightly away from the magnetic head and effectively lose pulses. The problem was solved by more careful adjustment of the tape-tracking process.

One investigator[5] has found a relationship between the decrease in read-back signal with increase of tape-to-head spacing. This exemplifies nonelectronic problems that are faced in input-output work. It is not intended here to convey the meaning that magnetic tape storage is impractical or unreliable, but merely that input-output design thinking must be careful, and carried to a greater degree than is perhaps necessary in all-electronic computing circuitry.

MAGNETIC TAPE DEFECTS

A comprehensive study[6] into the nature and effect of defects in the surface of magnetic tape was undertaken during the development of Raydac. Recently, tape manufacturers have made such improvement in their product that the chief

cause of information loss lies in the formation of clumps on the tape surface.

These clumps are very small, and dextrous use of small implements will remove them. Abrasive scrubbing of the tape with steel wool effects a marked improvement in the number of troublesome defects. However, a guaranteed corrective method is necessary in digital use.

In Raydac, these defects are located magnetically on unmarked tape and their location indicated. Later, in the process of producing the optical marks, such defective zones are placed in the dead spaces between tape blocks. This results in a few dead spaces being longer than usual. With present tapes averaging about 12 defects per 1,000-foot reel, this has represented a very effective solution. Other computers are using or have investigated the use of multiple channels, or some method of prepulsing the tape so that good areas only are used but on a pulse-by-pulse basis.

Most clump defects average 0.012 inch in length and width but are of irregular outline. Their height averages 0.0005 inch. With magnetic poles on the tape of 0.005 inch in length spaced at 0.010 inch, one might expect a typical defect to alter only one or two read-back digits. Such is not the case, since the elevation of the defect moves the tape away from the head and produces leading and trailing shadow areas. These shadow areas yield definite amplitude alteration of the read-back digits. In some observations, as many as eight digits markedly deviated from normal amplitude.

In one case encountered during a test problem on Raydac, an intermediate result failed consistently to read back into the machine correctly. The transfer weighted count check stopped the reading at a certain word. Magnetically raising the digits near that word showed a defect in one channel only with two shadow areas encompassing nine digits along the tape. This defect was a foreign particle imbedded in the tape surface after magnetic inspection.

Figure 9 shows a 1-inch segment of 1/2-inch-wide magnetic tape with the magnetic poles raised into view by dipping the tape in a solution containing carbonyl powder. No defect is shown, but the pulse density and definition are clear. The lowest channel contains sync pulses, while the remaining six contain variable digital information. The first six sync pulses at the left indicate the six frames across the tape which contain the first word. This word in octal notation is +0103205120 (transfer weighted count of 15).

Accidental stripping of the magnetic material from the tape backing and splitting of the tape edges represent another class of defect which would render the tape unusable in an unchecked computer. However, one program was corrected on Raydac at a saving of over 1 day, even though one tape block had magnetic material missing for part of two tape channels. Reliance was placed on the check circuits to stop any erroneous reading. When such stops occurred, the tape would be backed up one block, and the work would then continue.

OPERATING PRACTICES WITH MAGNETIC TAPE

Careless handling of tape or the introduction of foreign particle defects can render a tape useless. Incorporated on the tape drive panel is a holder for lens tissue, not shown in Figure 4. This wipes the magnetic side of the tape and effectively removes such particles as dust. In addition, a dust cover encloses this front panel. In Raydac certain physical practices allow long trouble-free use of magnetic tape. Some of these are:

1. Cleaning the magnetic head every week.

2. Checking the tape tracking process every week.

3. Checking the tape tension daily.

4. Removing at least two layers of tissue from the wiping pad daily, or when a tape is changed.

5. Storing tapes in film cans immediately after use.

6. Wearing white, lintless gloves when handling the main body of a tape.

7. Cleaning the capstan and idler surfaces every month.

External Memory Performance

In most of the papers one hears and the articles one reads, the lack of any discussion concerning the procedures used to get a large-scale electronic computer operating is quite apparent. In a system like Raydac, which employs 5,200 tubes and about 18,000 germanium diodes, the subunit and system test phases represent a considerable amount of time. In the design of Raydac, the philosophy was followed that built-in facilities to cycle independently each of the major units would be invaluable. To this end, the arithmetic unit can conduct independent count problems to check out rapidly many of its operations. In addition, to ferret out such problems as duty cycle sensitivity, these count problems can be sequenced externally at variable repetition rates. It was indicated earlier that Raydac contains a main arithmetic unit

and a check arithmetic unit. In addition to manual controls available to assist checkout of the central control, however, a third type of arithmetic unit is available. This consists merely of a coaxial cable, and a segment of delay which allows the central control to cycle certain orders as though it were tied to the arithmetic unit.

Most pertinent to the present discussion is a description of the powerful testing procedures represented by the external memory self-cycling routines. For purposes of development, trouble shooting, and life testing, these routines allow all combinations of external memory operations to be performed cyclically and totally independent of the balance of the machine.

A hunt operation is performed manually with the use of controls provided for this purpose. By means of a few additional signal lines, this hunt sequences external memory in simulation of the normal command signal. The simulated signal is stored by the regular interlock which has been provided until completion of the hunt operation. Immediately upon completion of the hunt, the external memory operation is performed and this, in turn, sequences the hunt unit to do another hunt operation. This command is likewise stored until completion of the external memory operation, whence the cycle repeats automatically without any further intervention by the operator.

Three modes of cycling are possible:

1. Read cycles—hunt-prepare-to-read followed by read.

2. Write cycles—hunt-prepare-to-write followed by write.

3. Read-write cycles—hunt-prepare-to-read followed by read followed by hunt-prepare-to-write followed by write.

In addition, more than one external memory can be interlaced with the hunt unit to provide versatile life test cycles. The internally determined rates of these automatic cycles are:

1. Read cycles—3 cycles per second.
2. Write cycles—5 cycles per second.
3. Read-write cycles—2 cycles per second.

Using these automatic cycles, it is possible to obtain some very interesting life-test and performance data. For example:

1. Since the optically marked side of the magnetic tape passes over certain idlers on the slack absorber, one may investigate the life of these optical marks.

2. Since contact recording is used on a plastic-based medium, one may determine the life of a restricted portion of tape passing over the magnetic head or the wearing of the magnetic head itself by the tape.

3. Once a test engineer feels he can rely on the transfer weighted count check circuits of external memory, he can then initiate any of these test cycles, sit back and wait for an error, and thus determine the long-term, error-free, data-handling capabilities of such a unit. In addition, these cycling methods have proved very valuable in improving the engineering design and operating margins of the external memory.

To evaluate the type of life-test data obtained, consider a typical test run using a fully automatic read-write cycle at 2 complete cycles per second. In this test, the tape might start at position A in Figure 10. A hunt-read order would move the tape back to B, where the balance of the hunt order would move the tape to C performing a read of block 1, such that block 1 then resides in the lower reservoir. The previously stored read order would transfer the block 1 information into the upper reservoir, move the tape from C to A, thereby reading block 2 into the lower reservoir. During these reads, the 64 words in both blocks are individually transfer-weighted count-checked. The information in the upper reservoir came from block 1 of the tape. Termination of the reading of block 2 automatically initiates a hunt-write process which again moves the tape from A to B. The termination of the hunt initiates the stored write so that the external memory moves the tape from B to C, thereby writing the contents of the upper reservoir on block 1 while simultaneously erasing what had previously existed on block 1. Thus, only block 1 is rewritten in each cycle, but its 32 words are again individually transfer-weight counted. It is important to note that twice each second, the upper reservoir information is erased and replaced with tape information, and, twice each second, the block 1 tape information is erased and replaced with upper reservoir information. Thus, if at any time even one digit alters, it is irrevocably altered and the check circuits stop the cycle immediately when the alteration occurs.

This test cycle has been operated for up to 1 hour without error or failure. From Figure 10 it is apparent that block 1 is passed over the magnetic head 8 times per second while block 2 passes 4 times per second. In only 30 minutes of such operation, block 1 has performed without error magnetically or photoelectrically for about 15,000 abrasive traversals of the magnetic head. The photo marks have been wrapped around idlers and straightened an equal number of times without deleterious change. In the same 30 minutes, nearly 10,000,000 bits have been read from the magnetic

tape and about 5,000,000 bits have been written on the tape without a single error or, indeed, any indication that the process might not continue for another hour. It should be pointed out that these performance figures pertain to a composite subsystem of the Raydac computer which contains magnetic tape, photoelectric readers, electromechanical units, electronic circuitry, relays, and a mercury acoustic medium. It is dependent upon the correct operation of over 650 tubes and covers a range of operating frequencies from a few hundred cycles to 18 megacycles.

In view of the performance indicated by this one test, it can be concluded that:

1. Built-in testing methods for major units of large-scale electronic systems represents a very valuable design philosophy.

2. The transfer-weighted count checking employed in the Raydac computer is a most valuable piece of system test equipment, and guarantees to a high degree that intermediate and final computational results placed on the magnetic tape are correct.

3. The designers of Raydac feel that these two items, together with sound engineering design practice, have resulted in a reliable and versatile, high-speed external memory.

Design Recommendations

Experience has shown that certain features existent in Raydac appear worth while for incorporation into new designs. The built-in testing facilities have been mentioned. In a serial 4-megacycle machine, internal logical checking should be considered even at the expense of some additional equipment. The facility for automatic duplication of a tape, now built into two of the Raydac external memory units, should be considered in the future. At a small cost of down time, this allows the use of one tape for printing out of intermediate results while the second tape permits the problem to continue.

In some parts of these units where margins are now adequate, these margins could have been increased or the logical requirements eased by a change in fundamental design. For example, instead of performing precession by manipulating the 4-megacycle information, the bandwidth of this precession circuitry could be lowered by precessing the 3-kc control reference pulses This principle has already bettered the minimal design of certain of the new arithmetic elements.

On the research side, the tracking of wider tape at higher speeds should be studied. Reading and writing techniques for a magnetic medium should point toward better tape utilization. Even in the absence of a defect-free magnetic material, operationally perfect tape can be attained by means of new simple techniques.

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Raydac Input-Output System

WALTER H. GRAY

RAYDAC, Raytheon's digital automatic computer, is a large-scale electronic machine capable of solving any problem in the field of numerical mathematics. It consists of seven major units, as well as two separate auxiliary units, a problem preparation system, and an output printer.

Although an operator may transfer information to and from the central computer by means of the operator's console, the normal means of communication with the computer is through the external memory section. Since magnetic tape is the storage medium in this external memory, the problem preparation system provides a means of writing input information on the magnetic tape

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and the output printer is used for writing out information from the tape.

Problem Preparation System

The problem preparation system consists of two modified Teletype units with paper-type punching equipment and paper-tape-to-magnetic-tape conversion unit for recording information on magnetic tape for use in the external memory.

The process of recording suitably programmed information on magnetic tape for insertion into the external memory is accomplished in three steps. First, an operator enters data and order words on a Teletype machine which prepares a perforated paper tape. Then a second operator enters the same data and orders in a second Teletype machine and prepares a second perforated tape. To guard

against human error, the first perforated paper tape is read simultaneously with the preparation of the second tape. Should the operator making the second tape strike a key that is not in agreement with the corresponding character on the first paper tape, the Teletype machine will lock. If a conflict should occur, the operator checks the first paper tape with the text, makes the necessary corrections, and proceeds to complete the second paper tape. The information is then taken from the second, error-free, paper tape and recorded on magnetic tape.

PAPER TAPE PREPARATION

A modified model 19 Teletype set, shown in Figure 1, is used to prepare the perforated paper tape. Numbers, which may be in either decimal or octal notation, and half-orders in octal notation, are typed out, one at a time. While the operator is typing a number or half-order word, the unit prepares a transfer weighted count which is automatically appended to the word and punched on the tape to be used for checking throughout the machine. The unit prints a copy of
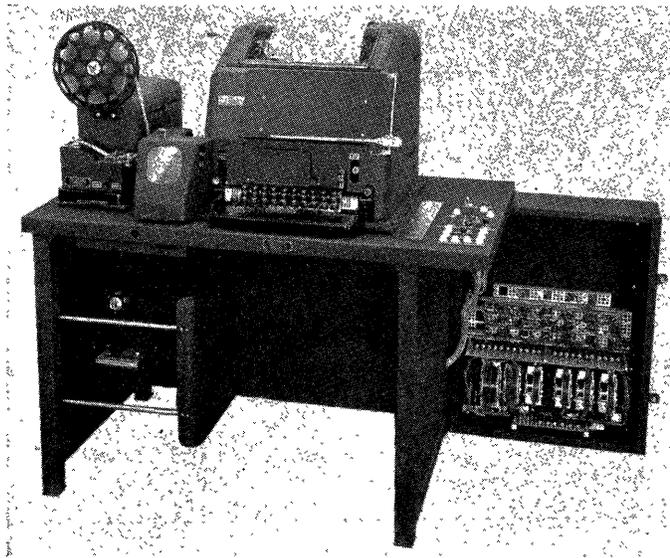
Figure 1. Paper tape preparation unit

the information which is being typed, and can also print the weighted count of each word, if desired.

Information is punched on paper tape, one frame at a time. Each frame holds an octal or decimal digit, the transfer weight count, and a sign, or a block-marker. An octal word consists of the sign, 10 octal digits, and their transfer weight count; and occupies 12 frames of paper tape. A decimal word has nine frames: the sign, seven decimal digits, and their transfer weight count. The transfer weight count of either type of word may be any quantity from zero to 15. The remaining code, the block-marker, denotes the end of one block of information and the start of a new one, and is used in the transfer of information from paper tape to magnetic tape.

The Teletype equipment used in the Raydac input and output equipment has been modified considerably. All electrical and mechanical parts not necessary in performing needed functions were removed to provide space for many added items. The 5-place coding was altered to correspond with the binary-coded decimal notation used in the machine. This required new selector bars and keytops for the perforator keyboards, and new code bars, function bars, and type pallets for the printer units. It may be noted that the numbers 10 through 15 appear on the keys. However, it was necessary to build these codes into the perforator keyboard so that transfer weighted counts could be punched in paper tape, and so that the six keys involving these codes were allowed to remain in the keyboard. A switch is included for sensing the carriage position to ensure that the typing units are in the figures-shift position when handling information for or

from the computer. The carriage return function of the printer unit has been altered so that it combines with it line feed, thus often saving one character in operation. The other functions retained are line feeding, spacing, and tabulating, the last being a standard Teletype modification.

The main purpose of the Teletype equipment in the paper-tape preparation units is to produce punched paper tape. The printed copy, which is produced simultaneously, may be used for checking the paper tape against the original programming sheets. The perforator keyboard is then of primary importance. Special selector bars, shown in Figure 2, are used to close the punch switch only when a positive or negative sign, a number from zero to 15, or a blockmarker (apostrophe) is typed. The printer unit carriage must be in the figures-shift position or the punch will not operate. The remainder of the figures-shift and all letters-shift characters can be typed, but will have no effect on tape preparation.

The selector fingers, connected to the

keyboard selector bars, in addition to setting up the code combination to be punched, operate a set of five switches, shown in Figure 3, which act as sensing devices for any code combination, to furnish the addends for the transfer weight count adder and to check what is being typed against what appears in the first tape.

Four punch selector fingers are fitted with solenoids, shown in Figure 3, actuated by external circuits to permit the automatic punching of transfer weight counts at the end of every word. A reset solenoid is provided to zero the selector fingers before the weight count is inserted.

Normally, all keys of a Teletype keyboard operate a universal bar which trips a pawl which, in turn, allows the transmission shaft clutch to close for one revolution of the shaft. In the Raydac units, the universal bar operates a clutch-actuating switch as shown in Figure 4. When a key is depressed, this switch energizes an added clutch solenoid through a step function relay. This change was made so that sufficient time delay could be provided electrically between the pressing of a key and the actuation of the clutch to allow for comparison operations.

The pressing of a key mechanically sets up the selector bars and punch selector fingers. The transmission (or cam) shaft goes through one revolution, thus supplying, by means of contact levers, a serial electrical code to the printer, and causing a printing cycle. During the shaft revolution, a cam closes a switch which operates the punch and transmitter-distributor magnets, provided the punch switch is closed and the printer unit is in the figures-shift position. When the punch magnet is operated, the code set by the selector fingers is punched in paper tape.

Part of the transmitter-distributor function has been changed. The distrib-
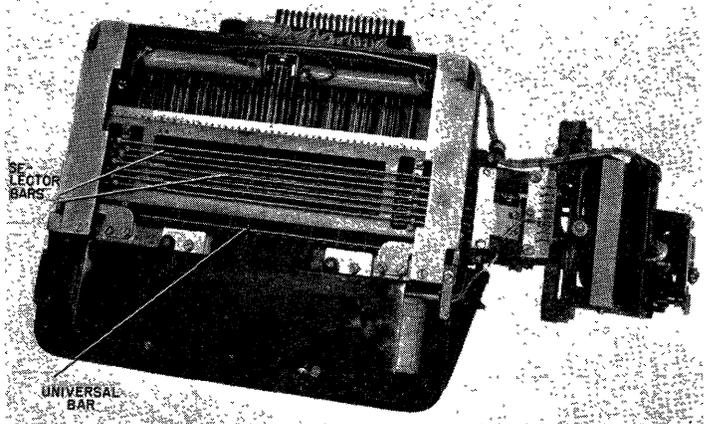
Figure 2. Perforator keyboard, bottom view

SELECTOR BARS

UNIVERSAL BAR
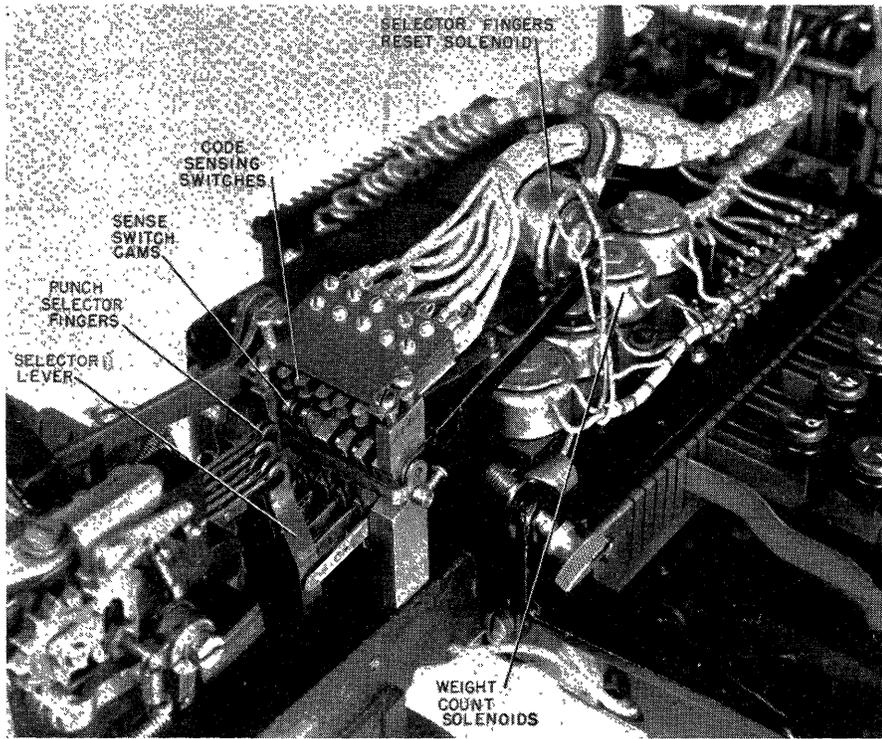
Figure 3. Code sense switches and solenoids

utor disk is no longer used as a parallel-to-serial converter but as a source of timing pulses. However, the paper tape reader is used as intended.

Step switches are used to provide sequence control for octal and decimal words, advancing one position for every significant character typed. Thus, for an octal word, a step switch advances 11 positions, and for a decimal word eight positions, arriving at the 12th and 9th positions respectively, which automatically initiate the transfer weight-count-punching cycle.

The first step in weight count insertion is to zero all five punch selector fingers by actuating the reset solenoid. Then the four weight count insertion solenoids are appropriately actuated, setting the punch selector fingers to correspond to the quantity stored in the transfer weight count accumulator, just as though they were set mechanically by the action of pressing a key. After the selector fingers have been set, the clutch solenoid is operated. From this point on, the operation is the same for keyed and automatic cycles.

Four step switches form the transfer weight count adder-accumulator. The addend is derived from the switches operated by the selector fingers. For octal operation, the addition is simple. Considering the octal code as three binary digits labelled *1*, *2*, and *4*, all digits labelled *1* are added with weight *1*,

all *2*'s added with weight *2*, and all *4*'s with weight *4*. For addition, then, the three digits are supplied to three relays which form the addend register, and thence to three step switches of the adder, which are so wired as to represent alternate *1* and *0* steps. If the operation is decimal, however, each frame contains four binary digits, which are separated for each frame of the word into their appropriate weight positions. Since the adder accepts only three digits at a time, two additions are necessary. Timing pulses for digit position switching and adding are supplied by the transmitter-distributor disk.

The first and second paper tapes are prepared on identical units. Both in-

clude a paper tape reader, which is part of the transmitter-distributor. The first tape is supplied to the tape reader and indexed. The operator then types the same information again. As each key is depressed, comparison with the corresponding character on the first tape takes place and the printer, punch, and weight count adder are actuated only if the characters agree. It should be noted that the first paper tape is one step ahead of the operator so that each character is read and stored for comparison before the operator punches the corresponding character on the second tape.

The comparison circuit consists of the switches linked to the keyboard punch selector fingers and corresponding relays holding the character read from the first tape. If the positions of any corresponding switches and relays do not agree, a circuit is completed which prevents punch, printer, transmitter-distributor, and weight count adder from operating, and locks the keyboard. The operator must clear the error before proceeding. If the error is made in typing, a button is provided to release the unit but the comparison feature remains effective. If the fault lies on the first tape, the comparison feature must be bypassed for one character by operating another button. Transfer weight counts are also subjected to comparison. In the event that a typing fault lies on the first tape and is corrected in making the second tape, it can be expected that the machine will lock at the point of automatic weight count insertion for that word. Removing the comparison feature allows the proper weight count to be inserted and punched on the second tape.

MAGNETIC TAPE PREPARATION

The second paper tape, which is assumed to be free from error, is then supplied to the paper tape reader of the
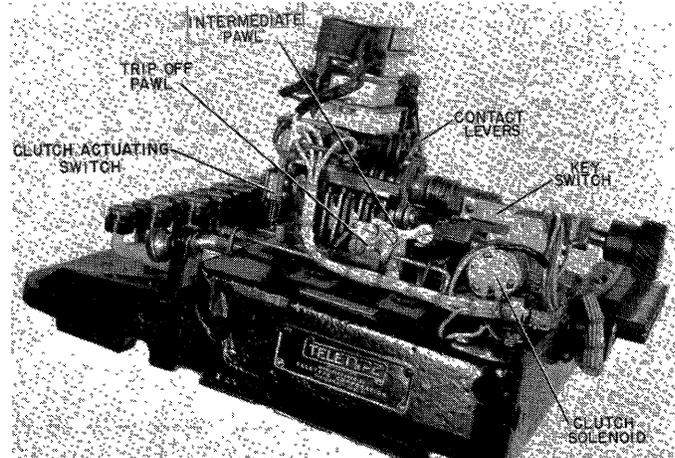
Figure 4. Perforator keyboard, side view
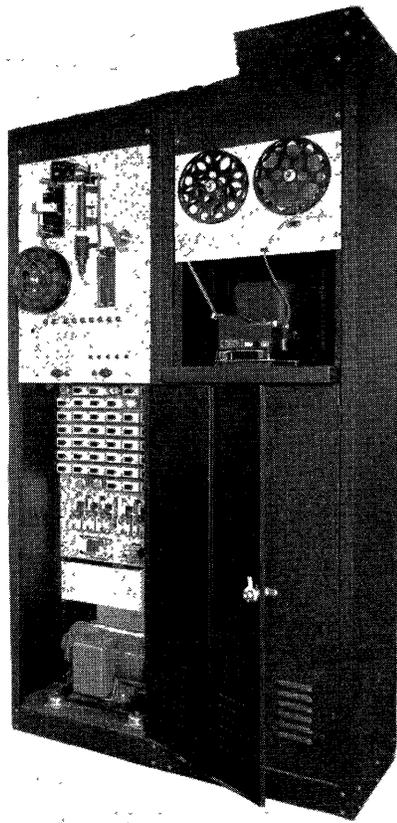
Figure 5. Paper-to-magnetic tape conversion unit

paper-to-magnetic tape conversion unit shown in Figure 5. The reader reads one frame of paper tape every time the transmitter-distributor is actuated by a pulse supplied through a step switch. This step switch controls the sequence of operations in transferring information from paper to magnetic tape. Since each frame of paper tape contains a sign, octal or decimal digit, weight count, or blockmarker, while each frame of magnetic tape holds six binary digits, part of the circuitry is devoted to sorting the binary digit positions so that they may be read one to four at a time and written six at a time on magnetic tape. The sequence is shown in Table I. The sign is contained in digit position *2;* the weight count in positions *33* to *36.* Pulses are supplied to the step switch at a constant rate so that equal frame spacing results on the constant speed magnetic tape.

A transfer weight count is generated in the paper-to-magnetic tape conversion unit from the digits read from paper tape and compared with the weight count punched in the paper tape. Any disagreement halts the transfer process. Agreement allows the generated count to be inserted in its place at the end of the word on magnetic tape.

The arrangement of digits for writing tape and for weight count addition is different for octal and decimal words. An additional reading pin, shown in Figure 6, has been installed in the transmitter-distributor reader in the fifth channel to distinguish between the two word types. Only signs and block-markers have fifth channel perforations. By virtue of the difference in the number of paper tape frames for octal and decimal words, a reading pin located 12 frames behind the normal reading station indicates that the word about to be read is octal.

Another part of the transfer circuit is affected by the blockmarker on paper tape. When a blockmarker is read, if 32 words have not been counted since reading of the block began, the unit writes zero words with legitimate weight counts on tape until 32 words are contained in the block. After 32 words have been written, all operation is halted until two successive holes in the magnetic tape have been sensed by the photoelectric reader. The holes denote the end of one block space on the magnetic tape and the beginning of another. The second hole starts the transfer operation again, after a delay sufficient to permit writing to begin well inside the block space. The magnetic tape on the transfer unit moves continually at a very low speed (1.63 inches per minute). Consequently, holes are punched between the coincident printed optical marks to permit sensing with chopped, transmitted light rather than reflected light. The photoelectric cell output can, therefore, be amplified in an a-c circuit, and a large hole-to-no-hole signal ratio may be obtained.

The paper tape is positioned in the reader so that the first blockmarker on the tape is read. The sign of the first word of the first block will then be read. The magnetic tape drive is started, but no information transfer takes place until a photohole is sensed, denoting the start of the first block space on magnetic tape. After a delay, the transcription process, which consists of reading paper tape and writing magnetic tape, begins.

A check is performed to ensure that a sign or blockmarker is read at the correct point in the cycle. Failure to read a sign or blockmark at the prescribed point stops the unit, as does reading either one at an incorrect point. A word counter keeps track of the words transferred in each block. If less than 32 words are read from paper tape, zero words are generated. If more than 32 words are placed between blockmarkers on paper tape, an error is indicated.

The Raydac acceptance test routines and problems required the preparation of about 700 blocks of data and program information. The paper tape preparation equipment was operated for a period of about 100 hours, during which time some 20,000 words were typed and their transfer weighted counts generated. One hundred thousand digit-by-digit comparisons were made in the preparation of the second paper tape. The value of punching a second tape was demonstrated by the fact that no error in the transcription from written pages to magnetic tape was noted, even though the same operator prepared both paper tapes, making several errors during the typing of each.

Two sets of magnetic tapes were prepared for the acceptance test, requiring approximately 50 hours of magnetic tape writing. The reliability of operation of the paper-to-magnetic tape converter,

Table I. Sequence of Transfer Operations

	Digit Positions Read												Digit Positions Written						
	Octal Word						Decimal Word												
Pulse	Channel	1	2	3	4	5	Channel	1	2	3	4	5	Channel	1	2	3	4	5	6
1	2					2*	2												2*
2	5	4	3																
3	8	7	6				6	5	4	3			2	3	4	5	6		
4																			
5	11	10	9				10	9	8	7									
6	14	13	12				14	13	12	11			7	8	9	10	11	12	
7																			
8	17	16	15																
9	20	19	18				18	17	16	15			13	14	15	16	17	18	
10																			
11	23	22	21				22	21	20	19									
12	26	25	24				26	25	24	23			19	20	21	22	23	24	
13																			
14	29	28	27																
15	32	31	30				30	29	28	27			25	26	27	28	29	30	
16																			
17																			
18	36	35	34	33			36	35	34	33			31	32	33	34	35	36	

* Both positive and negative signs have a 5th-channel perforation. The sign is defined by the first channel.
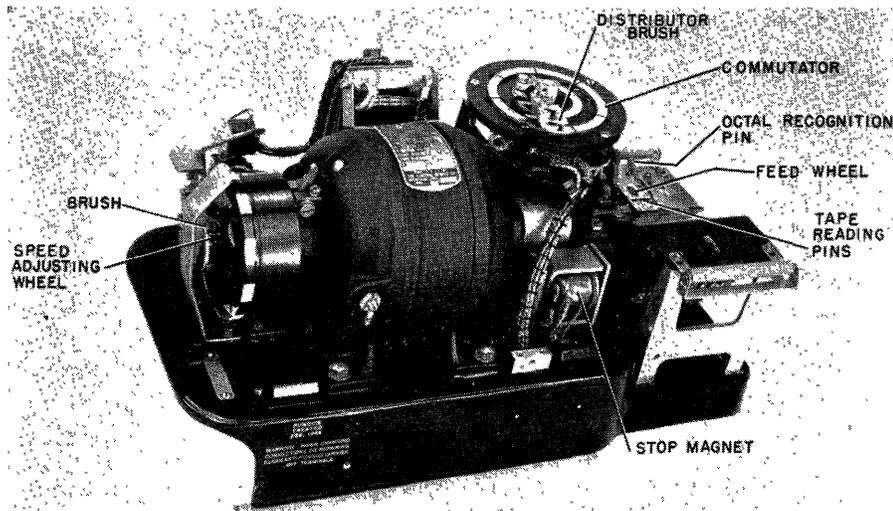
Figure 6. Transmitter-distributor

and its compatibility with the external memory are indicated by the fact that no error was made during the acceptance test in reading information into the external memory.

Experience with the problem preparation system of the Raydac indicates that typing comparison and checking features should be considered in new designs, as should the possibility of preparing magnetic tape directly during the retyping process to save time and tape handling.

Output Printer System

The output printer system, shown in Figure 7, prints the contents of the magnetic tape written by the external memory units of the Raydac. The primary function of the unit is to print, in a directly readable form, the binary-coded decimal words which are normal problem results. Printing in octal notation is also included to permit checking the contents of a tape prepared by either the external memory or problem preparation system.

Since the system is not intended primarily for operation in octal notation, no elaborate format is provided for printing in this mode. The octal word is printed as a sign and 10 digits. Once the number of columns on the page and the number of lines between extra line feeds have been set, no further control of the printing operation is possible. Except for sign printing, where the vane check described later applies, the only check performed is that involving the transfer weight count.

In the decimal modes, however, the programmer has great latitude in the format he may provide. Although the information is read from magnetic tape

as a series of 32-word blocks, each word consisting of a sign, 30 binary digits, and the weight count, it is printed in a form almost entirely free from the arrangement of information on the type. Words may be combined into multiprecision or floating-point numbers; decimal points and cut-off may be varied at will. Meaningless zeros at the high end of the word are dropped. Thus, the results on the printed page may be read without need for further interpretation.

One section of the output printer is concerned with reading the information from the tape into a one-word register, and another section with interpreting the information in the register according to the format requirements. The format section acts as the clock of the unit. Information must be available in the register when required.

Tape Reading Section

Each block of information on tape contains 32 words of 36 binary digit places each, each word being a square array of 6-by-6 digit places. There are then 192 frames per block, each frame consisting of six information channels and a sync channel. Since it is desired to handle only one word at a time instead of storing an entire block, the tape reading circuits must scan a block 32 times, each time picking out the next word in order, and supplying it to the storage register. Figure 8 is a simplified block diagram of the tape-reading circuits.

The reading cycle is initiated by the format circuit, which emits a read-next-word pulse, starting the tape drive in the forward direction. The next stimulus is the photoelectric reading of the coincident optical marks, which indicate the begin-

ning of the block and open the reading circuit of the sync channel. The sync pulses are supplied to a 6-counter, which in turn feeds a 33-counter. At the start of a block, both counters are set so that the first sync pulse provides an output from the 33-counter, which opens the read-in circuits of the six information channels. The 6-counter also operates a matrix which switches the information channels to appropriate stages of the one-word register as the count advances. When six sync pulses have been read, the entire word is stored. The seventh sync pulse produces a 6-counter output which shuts off the information channel read-in circuits and advances the count in the 33-counter. At the end of the block, 192 sync pulses have been read and the 33-counter contains a count of 32. Coincident optical marks, denoting the end of the block, shut off the sync channel reader, stop the tape drive and, after a delay, reverse the tape drive. First the end-of-block optical marks are sensed, then the beginning-of-block marks stop the tape drive and prepare the circuits for the next pass over the block.

The reading heads are now poised at the head of the block, the register is reset, and a second read-next-word pulse arrives, initiating the next scan. Now, however, the 33-counter must receive two inputs from the 6-counter before the information channel read-in circuits are opened and the second word of the block will be read into storage.

The subsequent scannings are similar. The 33-counter precesses once for each pass, so that the third word is stored on the third pass, and so forth, until all 32 words of the block have been read. After
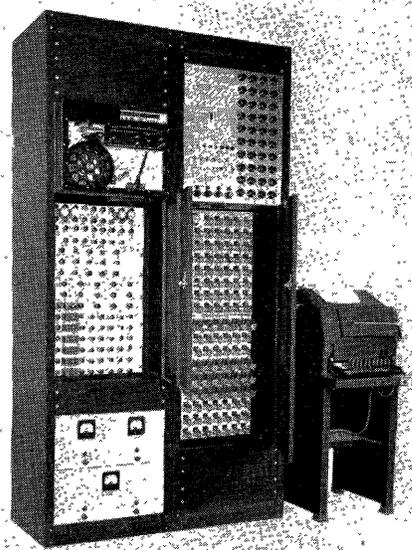
Figure 7. Output printer system
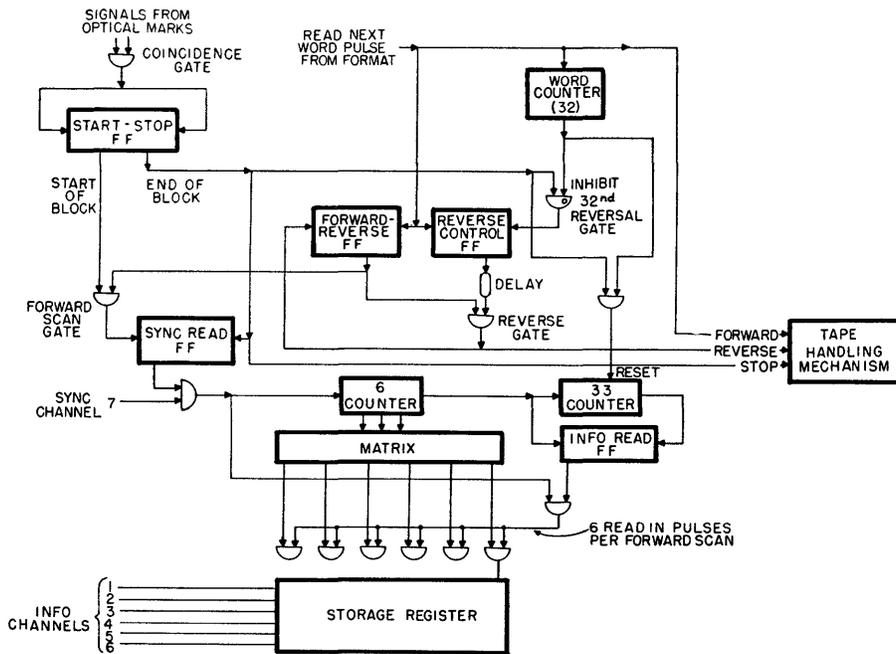
Figure 8. Tape reading circuits simplified, block diagram

32 forward scans of a block, the tape drive reversal is inhibited so that scanning will proceed to the next block and the circuit is in the same state as it was at the beginning of the first block.

The static register contains 35 binary digit positions, since the first digit position of a word is always blank. These may be grouped as the sign, 10 octal digits, and weight count; or as the sign, 7-decimal digits, weight count, and two binary digits for format instructions.

FORMAT CONTROL SECTION

The format controls of the printer consist of five parts. Each part governs one phase of the format for one column of printed results. When a number is printed, a control circuit steps ahead to the next group of controls to derive the format instructions for the next column. Up to 10 columns may be printed on a page and the format of each column is separately controlled.

The first set of controls has four positions which control the mode of printing. A decimal word may be printed with its sign, as a single precision number or the first part of a multiprecision number. Or a decimal word may be printed without sign, as a later part of a multiprecision number or as an absolute value. No more than two decimal digits of a word may be printed as a decimal exponent with its sign, and appear located between parentheses. An octal word may also be printed with its sign. If the control calls for a sign, a negative number is printed with a minus sign and a space is

used instead of a plus sign for positive numbers.

The second set of controls specifies the position or absence of the decimal point in the corresponding column, effective only for the sign and no-sign modes of printing. The eight possible positions of the decimal point, with respect to the 7-decimal digits of the word, plus the absence of the decimal point, are the nine positions of this control. When the decimal point is printed, all zeros occurring before the first significant digit which lies to the left of the decimal point are dropped. If the first significant digit occurs to the right of the decimal point, all zeros to the right of the decimal point are printed and a zero is printed immediately to the left of the decimal point. The sign is placed immediately before the first digit printed. The deci-

mal points of all numbers printed in the same column appear in a vertical line regardless of the number of insignificant zeros dropped from each number.

To accomplish the dropping of insignificant zeros, notice is taken of any decimal digit which might be zero. It is then possible to determine how many digits to drop and how many spaces to move before printing the sign. A relay matrix, controlled by the word stored in the register, accomplishes this by controlling the manner in which code relays are operated by the sequence circuit.

The third set of controls determines the point in the word beyond which digits are cut off. The setting may be made to cut off anywhere from after the first digit to after the seventh. Cut-off is effective only for the sign and no-sign modes of printing.

The fourth set of controls specifies the carriage action of the printer following the printing of each column. Each control may be set to space, tabulate, carriage return, or take no action at all, as in the case of printing multiprecision words. Just as a carriage return ends the printing on a line, since the line feed function is combined with carriage return, so the setting of a switch to carriage return marks the last group of switches which controls the printing operation. Thus, if the format is set so that carriage return follows the printing of the third word on a line, only the first three groups of format controls affect the format.

Since only a carriage return can follow printing in the 10th column, no carriage control is included in the 10th group of switches. In its place, an extra line feed control provides for an additional line feed after every 1 to 9 lines of printing, or for no extra line feeds, depending on the setting.
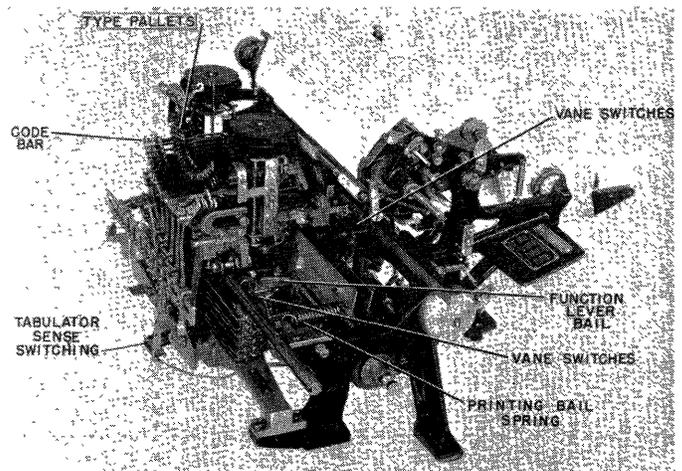
Figure 9. Output printer typing unit

One way in which the word itself affects the format has been mentioned in the matter of zero drop-off preceding the first significant digit. The format is affected by the word in two other ways.

Each group of four binary digits, specifying a decimal digit in the binary-coded decimal notation, can legitimately represent zero to 9. Any configuration from 10 to 15 will not be printed, but will cause the printer to space.

The two binary digits available for format instructions at the register are used as follows. If both are zero, the word is printed according to the controls set for it. If either or both are not zero, the word is not printed at all, but the carriage may be instructed to tabulate, carriage-return, or take no action, in which case the format remains in the same column. If the format is in the last column of a line and tabulation is ordered, a carriage return is substituted. By the use of these codes in the word, the programmer may provide for the skipping of words and manipulation of the carriage when the strict columnar format provided by switches is not sufficient for the problem.

PRINTER

A Teletype model-15 printer is used with the output printer system. Since Teletype printers are designed primarily for ruggedness and reliability, speed of operation is not high. Used as input devices, machine speed is not a serious handicap, since the input rate is dictated by the proficiency of the operator. However, in output printing, the printer mechanism is a definite limitation. When used in connection with the Raydac, the effective speed is still further re-duced, since a vane check operation has been incorporated in the operating cycle.

Several modifications have been made to the Teletype machines, in addition to the coding change. Switches have been stacked between the five code vanes of the printer to indicate the code combination set up as shown in Figure 9. Switches have also been added to the carriage and tabulator to sense when the carriage is at the left and when tabulation is completed. These switches are necessary since the time consumed by the carriage to complete its action depends upon its position along the line when carriage return is ordered, and upon the distance tabulated. A switch has also been added to sound an alarm if the printer should be in the letters-shift position. The keyboard is furnished with the printer so that the unit may be used to record pertinent data on the result sheets.

The printer operates from a serial code, while the output of the format circuits is a parallel code. The disk of a transmitter-distributor is used for parallel-to-serial conversion and the paper tape reader of the unit is not used. The codes supplied by the format circuit are for printing digits zero to 9, minus sign, decimal point, and parentheses; and for ordering the space, tabulate, carriage-return, and line-feed functions.

A check is performed for each character to ensure that the printer vanes set up the proper code. Although performance of this check slows down slightly the effective printing speed, since the vanes must all be set up before the check is performed, it ensures conclusively that the information appearing on the printed page agrees with the information re-siding in the register. A transfer weight count check is performed on each word by comparing the weight count on the tape with the weight count generated by a parallel adder connected to the register holding the word. Assurance that the printed information is correct is therefore given, since the failure of either the weight count check on the register contents or the vane check stops the printing process.

All acceptance test magnetic tapes were proofread at least twice by the output printer to show that the information on the tapes was correct, using octal printing. The printing time for this operation was about 35 hours.

It should be noted here that the printing time of a word varies with the form and content of the word printed. The maximum time, excluding time for completion of carriage action following the printing of a word, is 2.8 seconds, required for an octal word or for a decimal word printed with sign, decimal point at the left and no digits cut off. A word printed as a decimal exponent requires 1.8 seconds of printing time and a coded word to order no carriage action requires 0.6 second of printer time for processing.

The output printer system of the Raydac has handled over 20,000 blocks of magnetic tape, representing more than 400 hours of system operation. Experience indicates that the designer of new output printing systems should consider checking both the information read from tape and the information printed. These checks provide excellent diagnostic indications during the test period and provide comforting assurance during operation that correct information is being printed.

Operating Experience with Raydac

FRANKLIN R. DEAN

THE RAYDAC acceptance tests were run from June 4 to July 19, 1952, in five sessions of 3 days each. The tests were divided into three phases. Phase 1 consisted of programmed test routines which caused each unit of the computer to go through its various combinations of operations. This included tests of the terminal equipment, central control, and internal memory; the arithmetic unit; and the external memory. Phase 1 also included an exhaustive test of all checking and error-detecting circuits. Phase 2 was a single mass data-handling problem calling for large volumes of input and output data with relatively little actual computation. Phase 3 consisted of the solution of a full-length physical problem to which a reliable numerical solution was already available.

Phase 1

TERMINAL EQUIPMENT TESTS

The terminal equipment tests involved the operation of the problem preparation unit, the output printer, the control console, and the directly connected printer.

Problem Preparation Unit. This test routine consisted of orders and data which were punched on paper tape and transferred onto magnetic tape by the conversion unit. To determine whether the preparation unit performed correctly, the magnetic tape was then put on the output printer, and the information printed out. Agreement between the printed listings and the original manuscripts was to be considered a demonstration of satisfactory operation. The original manuscript consisted of 32 orders and 160 numbers.

Three attempts were required before this test was passed. The first attempt failed because the speed of the transmitter-distributor governing the preparation of the first paper tape was set at an incorrect speed, through an oversight of maintenance personnel. This caused transfer weight count check errors to occur while preparing the second punched paper tape. The second attempt failed as a result of malpositioning of the magnetic tape on the paper to magnetic tape converter unit. The third attempt passed successfully without error.

It was also demonstrated that all combinations of errors occurring in the problem preparation unit were detected by the transfer-weight-count-error detection system.

Output Printer. This routine was designed to test the output printer and its several modes of operation, using a variety of formats and numbers. Specific instructions for the setting of the output printer controls were given on a master tabulation sheet which showed the form and contents of the printed results. Agreement between these results and the tabulation sheet was to be considered satisfactory performance for this test. Various formats were tested by separately adjusting the controls of the 10 printed page columns. This routine was completed without error on the first attempt.

Control Console. This routine was designed to test the use of the major operating switches and keyboards on the operator's console, together with the operation of the directly connected printer. Forty-three words (orders and numbers) were inserted in the internal memory through the use of the order and word keyboards and the manual controls. The directly connected printer automatically printed these orders and numbers as they were entered. The orders and numbers entered comprised a routine which was started by the normal start routine of the computer. The computer performed this routine and, during its course, 16 numbers were printed on the directly connected printer using both decimal and octal printing modes. This test was performed successfully on the first attempt with no errors. It took approximately 1/2 hour to insert the information manually in the internal memory, and approximately 1 minute of computation time. It was also demonstrated that errors in the control console and directly connected printer were detected by the transfer weight count and printing error detecting systems.

CENTRAL CONTROL AND INTERNAL MEMORY

This test consisted of 15 separately coded routines which tested the variables that effect the processing of an order by the central control. These variables are the type of address (regular addresses of the internal memory, special addresses

of static registers and void addresses) and the time of selection of these addresses. Orders consisting of all combinations and permutations of the different types of addresses were programmed. The time of selection was varied by deliberately placing the operands in certain relative word positions. In the course of the routines all internal memory positions were read from and written into at least once. The program of these routines was such that, upon completion of the last routine, the first routine was inserted again. One cycle of the routine took approximately 36 seconds. To pass this test, the computer was to operate continuously for at least 5 minutes without error. The test was completed successfully on the first attempt, running for 26 minutes and 45 seconds. The machine stopped at this time as a result of an arithmetic unit error that was detected by the arithmetic weight count check. It was also demonstrated that all operational and transfer weight count error-detecting circuits in the central control performed properly.

EXTERNAL MEMORY

This routine was devised for the express purpose of testing the external memory of the computer in its several modes of operation. The four external memory orders; hunt-prepare-to-read, hunt-prepare-to-write, read, and write, were used in a variety of combinations. Program checks were inserted to verify the correctness of the machine's operations. Hunting, reading, and writing were performed on the magnetic tapes of all four external memories. The test was self-cycling, requiring no operator intervention at any point. To pass, the computer was to operate continuously without error for a period of 5 minutes. This test was passed successfully on the first attempt, running without error for 1 hour and 23 minutes. It stopped as a result of a transfer weight count error of one of the operands transferred to the arithmetic unit. During this test, approximately 7,000 36-bit words were written on and 6,300 36-bit words read from the magnetic tape. After the completion of this test, it was also demonstrated that all operational and transfer weight count error detecting devices operated satisfactorily.

ARITHMETIC UNIT

The variables in the arithmetic unit test routine were the 26 operations and

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the known configurations of the operands. There was a separate test for each of the arithmetic operations. For example, more than 1,000 additions and 1,000 subtractions were performed. If each routine was processed correctly, its operation code number was printed by the directly connected printer. If the operation being tested was not being performed correctly, the machine would stop shortly after the performance of the incorrect order. The test was self-cycling, requiring no operator's intervention at any point, and took approximately 3 minutes for one complete cycle. To pass, the computer was to operate continuously without error for a period of 5 minutes. The test was passed on the first attempt. It ran without error for 1 hour, and 52 minutes, during which time approximately 11,000,000 operations were performed. It stopped as a result of a transfer weight count error in the external memory. After the completion of this test, it was demonstrated that all operational, transfer weight count, and arithmetic weight count error circuits in the arithmetic unit operated satisfactorily.

Phase 1.2

Two supplementary tests, designated phase 1.2, were added to phase 1 for the purpose of producing conclusive evidence of everything tested, mainly by printing results on the directly connected printer. The first routine was designed to test the ability of the arithmetic unit to perform each of its built-in operations, the ability of the machine to transfer data from one random memory position to another, and the ability of the internal memory to retain data. This was accomplished by performing each of the built-in operations of the arithmetic unit using operands designed to test the circuits as exhaustively as time permitted and, in general, printing from the directly connected printer the operation code, the two operands, and the result of the operation. All lines and word positions of the internal memory and the upper reservoirs were used to transfer randomly, using each different kind of transfer to do this. The word was printed before and after it was transferred. Fifteen minutes after the last printing, the transferred numbers were reprinted to demonstrate the ability of the internal memory to retain data. This test was programmed to last 1 hour and 13 minutes when performed without interruption. The directly connected printer was the limiting factor in this case. Approximately 1,657 words were printed. The test was passed

with two errors occurring during the operation. Both of these errors were due to loss of information in the internal memory and were detected by the transfer weight count error check. In each case, the information was restored by transfers from the operator's console, and the test restarted at a previous point in the routine.

The second part of phase 1.2 was designed to test the selectivity of the central control. The Raydac selection circuits provide for the selection of the address that is available first, for the immediate selection of special addresses, and for bypassing the selection of void addresses. Ten separate tests were performed to demonstrate the ability of the central control to make address selections in this manner and in the exact time stated. Each test was timed for a specific length of time. The calculated number of operations was then checked with the actual number of operations performed.

For instance, to demonstrate an average time of selection of operands, one order consisting of four regular addresses was cycled for 6 minutes. This order, which was a counting order, was performed at the rate of approximately 1,640 operations per second. At the end of 6 minutes, the order had been performed 589,553 times, as contrasted with the calculated number of 589,824 times that it should have been performed. This small discrepancy can be attributed to the time lags in relation to starting and stopping the machine, and starting and stopping the stop watch.

To demonstrate a fast selection of addresses, 5 orders which contained a number of void addresses were cycled. This was also programmed so as to count the number of times the routine was performed. The orders were performed at the rate of approximately 8,200 per second. At the end of the $5\frac{1}{2}$ minutes, the five orders had been cycled 541,239 times as contrasted to the calculated number of 540,672. More than 2,700,000 operations were performed in the $5\frac{1}{2}$ minutes.

Phase 2

Phase 2 was a problem which called for the evaluation of a rational algebraic function of two independent variables for an uninterrupted period of 5 minutes. The function was of the type $Q=f_1(x,y)/f_2(x,y)$ where f_1 and f_2 were both polynomials. The values of the independent variables were generated in advance of the test by the computer, and recorded on magnetic tape. Eighteen hundred blocks consisting of 28,800 pairs of values

of x and y were recorded. The results, along with the values of the independent variables, were recorded on tape. At the conclusion of the problems, values were chosen at random and then printed from the tape by the output printer. The results were checked by hand computation. This test was passed on the first attempt with no errors, all selected values agreeing precisely with the hand calculated values.

Phase 3

Phase 3 consisted of a problem of 14 simultaneous nonlinear differential equations. Solutions of the 14 dependent variables and their derivatives were computed and recorded on magnetic tape for many values of the independent variable. During the course of this problem, approximately 660 numbers were printed out on the directly connected printer. The results were to agree within 3 per cent of those which were produced on another machine. There was no limitation regarding machine error except that the problem was to be successfully concluded within an 8-hour period. This problem was solved on the first attempt in 1 hour and 3 minutes without error or interruption.

Error Diagnosis

In the design of the Raydac, considerable emphasis was placed on circuits and methods for providing self-checking. This was done to minimize the number of undetected errors, and to provide means for error diagnosis. As a result, the operator's console contains a large number of error indicators, status lights, and controls for obtaining diagnostic information.

When an error occurs, computation is automatically stopped. The operator can immediately determine the order being processed and the point in the order at which the error occurred. In most cases, the operator can simply push the reset and then the normal start button. This starts the computation with the same order in which it has failed. If the error was of a transient type, the problem might proceed normally. If the error reoccurs, the operator should try to determine the cause of the error and the circuit involved. Some of the means of obtaining information available to the operator for error diagnosis is as follows:

1. Twenty-eight error lights which indicate the circuit or unit causing the error.

2. A group of lights which indicate the status of the central control, including the half-order being processed, the addresses

that were selected, and the tag of the last address selected.

3. A group of lights which indicate the operation and, in the case of compound operations, the suboperation being performed.

4. A group of lights which indicate the status of the arithmetic unit. These lights indicate the exact step in the arithmetic processes at which the error was made.

5. A group of lights which indicate the status of the external memory; that is, if they are in a read or write state and if a hunting operation is in progress.

6. A monitor oscilloscope by which it is possible to read the contents of all internal memory addresses and all special address registers. Thus it is easy to determine such information as the order being processed, the previous second half-order that was processed, and operands of the order, and the content of the arithmetic unit registers.

To assist in determining the cause of an error, be it due to a component failure or some other factor, there are also available many manual controls for operating specific units of the computer. For example, it is possible to cause the central control to cyclicly process a whole order or even a half-order without requiring the use of other major units. Also, such circuits in the central control as the transfer weight count adder and selection circuits can be operated individually. A typical error occurring in central control might be a selection error. Selections are checked in the Raydac by dividing each address processed in central control into its spatial and temporal parts. These parts are then compared with tags delivered by the matrix and the clock indicating the selections actually made. Disagreement between any corresponding digits of the address and the tags is indicated as an error and the computer is automatically stopped. If this error occurs, the operator can determine from the central control status lights the address selection that failed, and the tags that were delivered for this address selection. He can then look up the order residing in the central control and compare the address of the selection that failed with the tags. Agreement indicates a failure in the checking circuits. Disagreement indicates a failure of either the temporal or the spatial selections. Further to isolate the failure, a built-in routine for cycling an address selection can be used.

It is possible to step the arithmetic unit manually through each of its suboperations and thus analyze the status of the arithmetic unit after each step. A switch arrangement is provided which shifts the control of the arithmetic unit over to special test equipment. This permits any operation to be cycled with any pair of operands.

The arithmetic unit status lights previously mentioned represent the nine stages of progress in the arithmetic unit operation. The first stage indicates that the arithmetic unit has been properly prepared for the operation. Stages 2 and 3 indicate that the two operands were delivered properly and that their transfer weight counts checked. Stages 4 to 6 indicate the progress of the main and check arithmetic unit computations. Stage 7 indicates agreement between the main arithmetic unit's result and the check arithmetic unit's weight count identity. Stages 8 and 9 indicate that the valid weight count has been appended to the result and that the central control has been sequenced. Failure in any of these steps prevents the transmission of the signal which would initiate the next step of the operation. Other check circuits prevent the arithmetic unit from beginning an operation if the central control has not completed all of its checks, and prevent the central control from beginning a new operation if an arithmetic unit error has occurred.

When the console indicates an arithmetic unit error, the operator first notes from the status lights whether the error occurred before or after the arithmetic unit began an actual computation. A typical failure before computation might be indicated by the arithmetic unit transfer weight count error light, and with the status lights indicating that only one valid operand was received. The operator can look up the operands in the memory by use of the monitor scope, and check the transfer weight count tags of these operands. If the stored tags are incorrect, he knows that this information in the memory has been garbled. If they are correct, the operator should check the tags of the operands as delivered to the arithmetic unit registers. If the transfer tags are incorrect here, the operator has isolated the trouble to the read-in circuitry and transmission path. If the tags of the operands in the arithmetic unit are correct, trouble is isolated to the transfer-weight-count checker.

A typical failure occurring during the arithmetic computation might be indicated by an arithmetic check error light, with the arithmetic unit status lights indicating that all main arithmetic unit computation was completed. In this case, the operator would look up the operands in the memory, manually perform the arithmetic unit operation, and check this result against the contents of the arithmetic unit result register. From this, the operator will determine whether the main or the check arithmetic unit was in error.

In general, the contents of the result register and the check register will also enable the operator to determine which digital column is responsible for the error and whether the error was due to a failure in the sequencing or the computation circuits.

Controls are provided for cycling the external memory with the hunt equipment through various cycles involving hunting, reading, and writing.

Although all failures are not as easy to diagnose as those given in the preceding examples, it has been found that an experienced operator can locate the cause of most errors in a matter of minutes, and that the problem very seldom has to be restarted from the beginning after an error occurs.

Conclusion

In conclusion, it would be fitting to quote a summary from the report on the acceptance tests on the Raydac by Professor Francis J. Murray of Columbia University. Professor Murray was the chief examiner for the Navy during the acceptance tests. He wrote:

"The Raytheon computer acceptance tests were run from June 4 to July 19 in five sessions of three days each. The computer passed all its tests, some in a brilliant manner. The percentage of 'down time' for the computer during these tests was reasonably good if one takes into account the fact that this is a new computer. Except for a transient difficulty in the phase 1.2 test, all tests were completed perfectly. The phase 3 test was particularly notable since the machine did in 1 hour and 3 minutes, without error or interruption, a computation which previously had required 20 hours on an automatic sequence calculator.

"The checking features of the Raytheon computer were demonstrated in a very convincing manner. The computation procedures are simplified and the effective computing ability of the machine is greatly increased. The external memory input and output equipment are very effective pieces of equipment because of the combination of this feature and well-engineered construction.

"Other aspects of the design of the Raytheon Computer probably should be judged on the basis of actual use. I believe the machine is certainly in a state as good as any large scale electronic computer at the start of its computing life."

Discussion

G. N. Patterson (Burroughs Adding Machine Company): Would you be willing to forecast future trends in methods to eliminate human errors in keyboarding data, that is, the use of check digits, double verification, and so forth?

Mr. Gray: I think that whenever it is important to have no error whatsoever in the preparation of data for feeding a machine, it would be advisable to continue the use of a double preparation system, that is, where the actual data is prepared twice, such as program information. In cases where the amount of input information is large, I suppose it does not matter too much whether an occasional digit or character is dropped or picked up, in which case this would not be necessary. Certainly for program information and possibly for some kinds of data, I believe this should be continued.

R. D. Bronson (Consolidated Vultee Aircraft): Would you give more details on magnetic tape flaws, and indicate the trend in manufacturing techniques, and the possibility of eliminating essentially all defects? What minimum test equipment would the user require to confirm the tape quality, and how does a good splice joint affect the record?

K. M. Rehler (Raytheon Manufacturing Company): That is a good broad question. I will make my answer a little bit safer by saying that some of it is purely conjecture. We have studied defects quite a bit on the plastic base medium. We feel sure that a defect of the type I showed in the slide is magnetic material; it is a hump which resulted from a surrounding area shrinking down in thickness so that the center has become a small hill. You can scrape these off, as I said in my paper, but the question is how to overcome this defect. The tape manufacturers are co-operating with us. We did some work, I believe, with Minnesota Mining to investigate particle size of the magnetic oxide and the material used for the colloidal suspension when they build a film on the plastic base backing. They have achieved very good improvement in the past 2½ years. In the future, assuming that a plastic base magnetic tape might still have 10 flaws in 1,000 feet, how does one get rid of these flaws? Pre-pulsing techniques, in the future, may become more important. I believe the Bureau of Standards is working on this quite successfully. This requires that the sprocket or sync channel be permanently written, and never rewritten. Therefore, if a sprocket pulse exists somewhere, it indicates that all pulse locations across the tape are free from defects. This is a very good solution.

For those who have a computer with some time available, the computer probably represents the best minimum test equipment both for inspecting tape and perhaps preparing prepulsed tape. The minimum tape inspection equipment used at Raytheon inspected 7 channels simultaneously and involved about 28 tubes. The effect of a splice joint is difficult to evaluate since, among other things, it is a function of the magnetic background, or erase, used.

C. V. L. Smith (Office of Naval Research): Do you ever have trouble with the magnetic tape units losing information due to random dust particles on the tape?

Mr. Rehler: At one time, we did. That kind of problem is one that occurs after all the easy-to-find electronic troubles are overcome. We have a dust cover over our tape drive, and a wiper of lens tissue.

J. Earshen (Cornell Aeronautical Laboratories): I understand you do have some means for polishing the tape. Is it a specific device developed for that?

Mr. Gray: As far as polishing the tape is concerned, we have made it a practice to run a tape reel a couple of times before recording anything on it. It sometimes helps in smoothing down the bumps a little (the magnetic defects or clumps). It also helps, on occasion, to wipe the entire tape.

D. Haagens (Control Instrument Company): What is the speed of output with the Teletype equipment? Was any thought given to higher output speed printing equipment?

Mr. Gray: The output speed varies, as I mentioned in the last part of the paper. The longest printing time for a word is 2.8 seconds. The shortest printing time for a word is 0.6 second. As to going into higher speed printers—yes, we would like to, but we did not. We stayed with the Teletype digit-by-digit printing system. This offers one advantage, notably, that we obtain a check on each character that is printed on the page. This, we feel, is a very worthwhile feature.

W. S. MacDonald (W. S. MacDonald Company, Inc.): Has Raytheon done any work on metallic tape?

Mr. Rehler: We have seen it, but we have not had operational experience. We are doing some experimenting with plastic base tape, trying new ideas which look very promising.

Mr. MacDonald: What is the absolute magnitude of the crosstalk in the multiunit heads?

Mr. Rehler: There are 7 channels in a head with mumetal shielding between each core stack. We run about 20 to 25 decibels down on crosstalk, which is more than adequate, as seen by the electronic read circuit.

Mr. MacDonald: Is that between read and write?

Mr. Rehler: No, that is between two channels of, say, reading. If one of the digits being read is a 1 and the other is a zero, the latter will be 25 decibels below the former.

Mr. MacDonald: Then it is not possible to read in an adjacent channel to one being written?

Mr. Rehler: There are several people, with whom I have talked, who are doing this successfully. We approached that problem, but dropped it for certain reasons. It can be done successfully, but not just in the present head structure. There must be something equivalent to a duplexer, so that the channel which is read is protected from the writing blast in a near-by head, and is blocked only sufficiently so that it has time to recover before the next pulse is to be read. This is being done successfully in two places that I know of, with minimum circuitry.

E. S. Rich (MIT Digital Computer Laboratory): In recording on your external magnetic memory, I understand that the precessing tank controls the spacing of the pulses on the tape. During the reading, it appears to me that both this tank and the magnetic tape have their own timing systems which must be more or less the same. You mentioned that in case the tape goes more slowly and the arriving pulse is late, there is no trouble. Do you have provision for taking care of the tape where the pulses come too early in the tape?

Mr. Rehler: This was taken care of in the design stages. This cannot happen because of the known variation of speed on the tape, and the known variation of the pulse frame rate that is written. You did make one statement which is incorrect. The mercury pulses have nothing to do with the tape rate. This is controlled from a separate oscillator source. There are pulse dodging interlock systems.

Mr. Smith: I think we are all impressed by the ease with which the test was passed, and by the fact that if you kept working on the test routine, any operating error finally was picked up readily through the weighted counter system. I, however, was impressed by the fact that in several cases, the breakdown occurred only after a moderately long computing time. Would Mr. Dean care to comment on what kind of system apparently gave the most trouble, and if it was found possible to make improvements?

F. R. Dean (Raytheon Manufacturing Company): Most of the trouble occurred on the transfer weight count checker, or because of garbled information in the memory. This occurred in the phase 1.2 test. It happened twice during the test, and we had to restore that information manually from the console. We did nothing about the correction of that particular mercury line at that time, because it was not serious enough to stop further computation. In other words, we just restored the information and kept our fingers crossed, and it stayed there long enough to finish the problem. After that problem was over, we investigated that particular line and found that the gain control on that line on the circulation amplifier was set low (marginal). From then on, everything was in good working order.

Mr. Gray might want to comment on something that happened in the problem preparation unit test. I classified it as a human error. Perhaps he can elaborate this.

Mr. Gray: The error that Mr. Dean spoke of in the problem preparation unit went something like this: the night before the acceptance test, we carefully looked over the machines, made all final adjustments, and then hoped that we would go through all right. In making one of the adjustments, we got the speed of a transmitter distributor off by a factor of 2. This had been 'carefully' checked by the strobotac. This is why we classified it as a human error.

John W. Brean (Massachusetts Institute of Technology): Do you find that, psychologically, the double paper tape typing system influences the accuracy of the typist? This question is in reference to the time consumed by typing errors.

Mr. Gray: We have never had two different operators on this equipment. In this particular case, realizing that it is troublesome to correct errors, it was the operator's interest to make sure that she did not make too many.

However, I should suspect that if operators were interchanged, one operator making the first tape and then switching over to make the second tape, they would be very careful.

Engineering Organization of Input and Output for the IBM 701 Electronic Data-Processing Machine

LOUIS D. STEVENS

THE International Business machines Corporation (IBM) type-701 electronic data-processing machine is to be a general-purpose high-speed electronic calculator utilizing the Williams type of electrostatic storage. The binary system of notation is used internally with a word size of either 36 bits (a full word) or 18 bits (a half word): transmission is parallel throughout the machine except to and from magnetic tape. Instructions are of the single-address type with 32 possible operations, and a maximum address capacity of 4,096 half words; each instruction occupies one half word of storage capacity.

In addition to the high-speed electrostatic storage with a maximum capacity of 2,048 full words, the machine is provided with a slower access time magnetic drum storage of 8,192 full words, and a completely integrated and flexible input and output system consisting of one card reader, one card recorder, one alphabetic printer, two twin magnetic tape reader-recorders, and manual input and output by means of the operator's control panel.

A more detailed description of the general characteristics and of the organization of the machine has been presented previously.[1,2]

Input-Output System

The input-output system of type 701 is so designed that the use of an input or an output device by the calculator is accompanied by the performance of five distinct functions:

1. Selecting. An input-output unit to execute either a reading, a writing, or an auxiliary operation such as rewinding a tape.

2. Interlocking the operation of the selected input-output unit with the execution of the calculator program.

3. Copying data to and from the electrostatic memory and the input-output units.

4. Synchronizing the signals between the input-output unit and the calculator.

5. Disconnecting the input-output unit

from the control of the calculator after the operation for which the unit was selected (and connected) has been completed.

These five functions are performed in such a manner that the inactive waiting periods normally associated with the use of an input-output unit may be utilized for useful operations by the calculator. This is accomplished by allowing the calculator to continue with the execution of its program during these otherwise inactive periods, and to converse with the input-output equipment only at those times when these devices may be in a position to transmit or receive data in full-word increments to or from the electrostatic memory. The following general description of the use of an input-output unit by the calculator will make the operation clear.

An input-output operation is initiated by the execution of a Select instruction (read or write) which places the desired unit under calculator control and sets the unit into motion to perform the function required. After the execution of select instruction the calculator may continue with its program, until the selected input-output unit has reached a position where it requires a word to write or a place to store a word which has been read. Just previous to this point, the calculator must have executed an instruction which is known as copy and skip or simply as copy. This instruction provides an address in electrostatic memory at which a word to be written may be located or at which a word that has been read may be stored.

Upon reaching a copy instruction in its program, the calculator will delay the execution of further instructions until the selected input-output unit has reached a position that will allow the memory address associated with the copy instruction to be utilized. Since most transfers of data between the storage and input-output units consist of more than a single word, successive copy instructions are required, one for each word to be transferred. These successive copy instructions only need be available just previous to the time an input-output unit may

utilize the storage address, thus making the time between successive copy instructions available for useful operations.

From the foregoing it can be seen that the copy instruction not only supplies the necessary storage address for data transfers between the storage and input-output but also provides a synchronizing and interlocking function between the slow-access input and output devices and the faster access electrostatic storage. The skip function of the copy instruction will be described later as part of the discussion of the card reader and magnetic tape reader and recorder.

Since the calculator may continue with its program after an input-output device has been selected for reading or writing, it is necessary to provide an interlock, which will remember that a unit has been selected, and should the program arrive at another select instruction, its execution will be delayed until the previously selected unit has completed its operation. This interlock is known as the input-output interlock. It is turned on simultaneously with the selection of an input-output unit and will remain on as long as the selected unit is in operation. It will remember the unit selected and the function (reading or writing) for which it was selected. The need for this is due to the manner in which information is transferred to and from the electrostatic storage and the input-output devices. The storage address is supplied by a copy instruction, and the direction of information flow is determined by the setting of the input-output interlock.

Information transfer between the electrostatic storage and the input-output equipment is always routed through the multiplier-quotient register (M/Q). These transfers of information take place in single full-word increments and one copy instruction is required for each full-word transferred. Figure 1 shows, in block diagram form, the interconnection of the various units with the M/Q register of the calculator.

Each time a selected input-output unit is in a position to transfer information, the program must have arrived at a copy instruction just previously, to supply the required storage address. Should no copy instruction be available when required, a disconnect signal will be generated which will turn off the input-output

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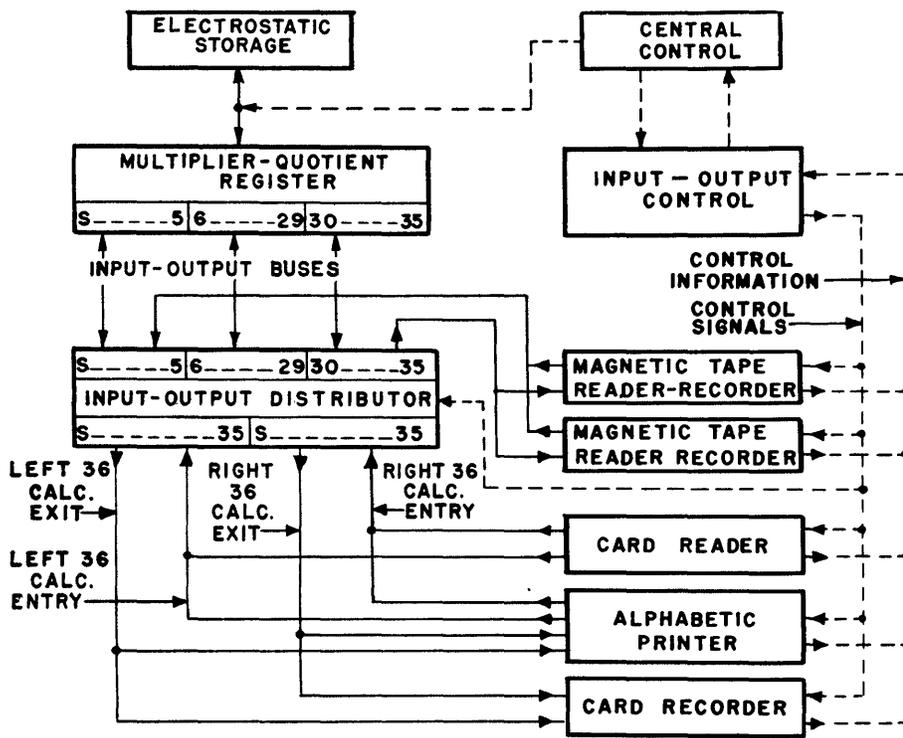
Figure 1. Input-output system information and control signal paths

interlock and prevent any further information transfer. In this manner an input-output unit will be disconnected from the system automatically, simply by not supplying it with information to write or not taking the information which it might read. Should an attempt be made to transfer information by giving a copy instruction with none of the input-output units connected, the machine will recognize this as a mistake and light a copy check lamp on the operator's control panel.

Card Reader, Card Recorder, and Alphabetic Printer

The card reader, the card recorder, and the alphabetic printer are referred to collectively as type-*701* card machines, since each of these devices is a development from a prototype punched card accounting machine. The reader was developed from a type-*402* card feed, the recorder from a type-*517* (*523*) card punch and the printer from a type-*407* accounting machine. Each of these machines retains many features of its well-known prototype but some new functions have been added to make them more suitable for use as input-output by type *701*.

The card reader and card recorder accept standard IBM cards nine's, edge-first, and are capable of feeding these cards at the maximum rate of 150 cards per minute in the case of the reader and

100 cards per minute for the recorder. The printer has no facilities for handling cards, and is supplied with information directly from electrostatic storage, by way of the M/Q register and the input-output distributor. It is capable of printing 120 characters per line at the maximum rate of 150 lines per minute. Since the printer is designed to print from a conventional card, the information which the calculator supplies it from elec-

trostatic storage must be in the same form as that obtained from cards. Information can be stored in electrostatic storage in such a manner that it resembles information punched on cards. A group of full words required to do this is referred to as a card image. The manner in which a card image is formed and used by the card machines will become clear later.

Reading, punching, and printing proceed on a card row-by-row basis as each machine goes through its mechanical cycle. For example, when reading a card, each card row is handled by the calculator as if it were composed of two full-words of 36 binary digits each, and since there are twelve rows on a card, each complete card is considered as 24 full-words of 36 binary digits per word. If the 24 words of information from a card are considered as a card image when these words are stored in electrostatic storage, it is possible to read conventional card punching (or any other system of punching) and translate the resulting card image to binary information which is usable by the calculator. Conversely, it is possible to translate from binary to an appropriate card image in the electrostatic storage so that any desired punching or printing, either conventional or special, will result.

Since a single copy instruction can supply only one storage address, and a maximum of one full word can be located at any such address, it is necessary to supply two copy instructions for each card row of reading or punching, and for each line of printing. The time at which these copy

Figure 2. Functional diagram of card reading
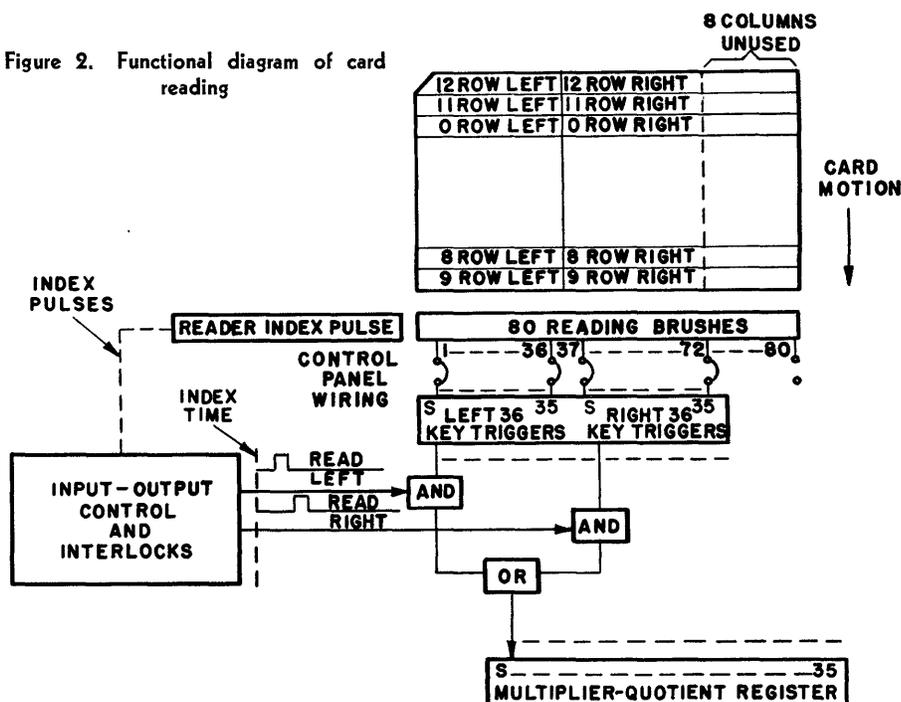
instructions are required is determined by 'index pulses' from the card machine in operation. The index pulses from each machine are derived from electromechanical contacts and are used to indicate to the input-output control each time a selected card machine has arrived at a position where an information transfer to (or from) storage, and thus a copy instruction, is required.

Card Reader

Figure 2 indicates in functional form the manner in which card reading is accomplished. The card reader is set in motion by the execution of a read (card reader)-select instruction. As each row of the card comes under the reading brushes, the data punched in that row (two words) will cause appropriate ones of 72 key-trigger circuits located in the input-output distributor to be turned on. These key triggers are of a special design and are not used for the purpose of storing information but to provide reliable electronic signals from the electromechanical contacts of the reading brushes. Appropriate signals from the card reader and the calculator will cause the data to be transferred from the input-output distributor, one word at a time, by way of the M/Q register to a specified address in the electrostatic storage, in the following manner.

Shortly after the key triggers have been set by a card row coming under the reading brushes, an index pulse will be emitted by the card reader to indicate to the input-output control that two words are available for reading. The control will then send out a read-left-word pulse to sample the left 36 key triggers and place this word in the M/Q register, providing that a copy instruction had previously been executed by the calculator to make available a storage address for this word. If such is the case, then the word will be stored at the address designated by the copy instruction.

The calculator will then be allowed to continue with its program, until the control emits a read-right-word pulse at which time another copy instruction must have been executed, or else the word cannot be stored. Repetitive copy instructions and reading may continue as described for each of the 12 2-word rows punched in the card. However, should a copy instruction not have been executed previous to any read-left or read-right pulse, a disconnect will be initiated and will prevent the reading of further information from the card.

However, if 24 copy instructions are executed, thus storing the 24 words from
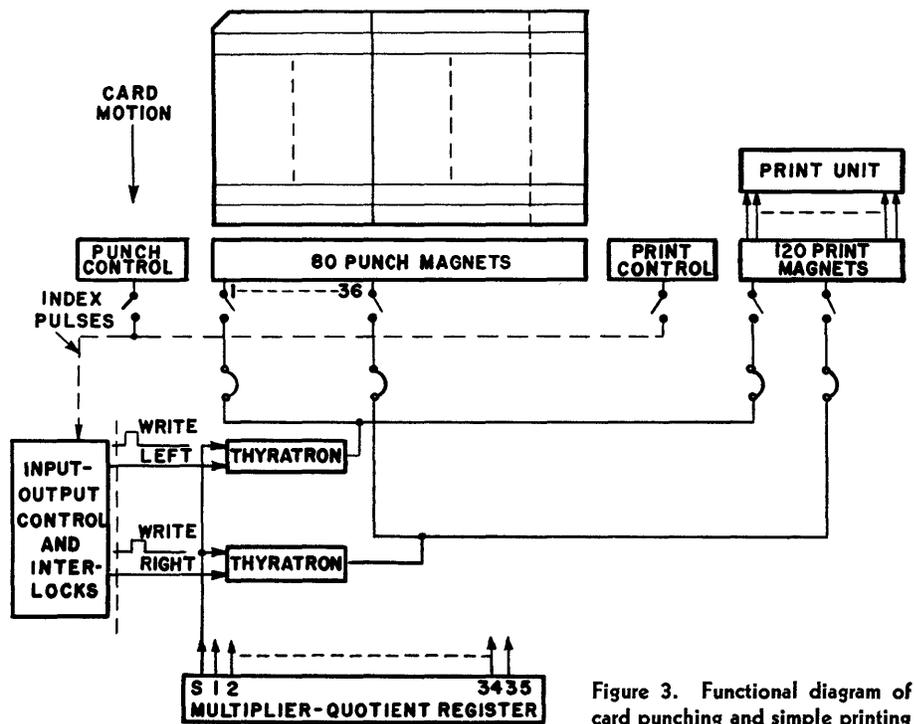
the 12 card rows, then a 13 index pulse will be emitted by the card reader. This signal is called the end-of-record indication since it indicates that a complete unit record of information has been accepted by the calculator. The execution of a copy instruction after receipt of an end-of-record signal by the calculator will cause the next two instructions following the copy to be skipped, thus providing a simple and automatic exit from a repetitive procedure which may be supplying the successive copy instructions.

When all the cards in the hopper of the card reader have been read, the operator may either stack more cards in the hopper and continue as if the file of cards had been continuous, or he may end the file by depressing the start button on the reader with the hopper empty. When this is done, an end-of-cards interlock within the reader is set, and upon the next selection of the reader a signal will be emitted which indicates that the card reader had finished reading a file of cards. The execution of a copy instruction after an end-of-file signal from the reader will cause the next instruction in the program following the copy to be skipped. This provides a distinction between end-of-record and the end of last record (end-of-file).

Card Recorder

The card recorder operates in a manner similar to the card reader in that at each index pulse (each card row) two copy instructions are required. These copy in-

structions are used to obtain the information which is to be punched from the card image in electrostatic storage. Figure 3 indicates in a functional manner the method used in punching cards. The card recorder is selected by the execution of a write (card recorder) instruction and as each card row comes under the punching station an index pulse to the input-output control will cause a write-left and then a write-right pulse to be generated. If the M/Q has been filled with a word by a copy instruction previous to each sample pulse, any of the left and then the right 36 output thyratrons will be fired when a binary one is in the corresponding M/Q register column. Should the M/Q not have received a word as a result of a copy instruction at either write-left or write-right time, a disconnect will be initiated and further punching in that card will be impossible. Similar action occurs at each of the 12 card rows, and thus it is possible to punch a card in any desired system by merely assembling the appropriate card image in electrostatic storage before punching is initiated.

Alphabetic Printer

The 48 different characters which may be printed in any of the 120 print positions of the alphabetic printer are shown in Figure 4 (A) along with the corresponding card image code required to select each character. The printer is selected to write by the execution of a write (printer) instruction, in which case the func-

Figure 3. Functional diagram of card punching and simple printing

ZONE → / DIGIT ↓	NO ZONE	12(R) ZONE	11(X) ZONE	ZERO ZONE
BLANK	*	+(¢)	—	0
1	1	A	J	/
2	2	B	K	S
3	3	C	L	T
4	4	D	M	U
5	5	E	N	V
6	6	F	O	W
7	7	G	P	X
8	8	H	Q	Y
9	9	I	R	Z
8-3	+(#)	.	$	,
8-4	—(@)	◻	*	%

(A)

```
                          →| |←WRITE
 9  8  7  6  5  4  3  2  1   0  11  12   INDEX POINTS FOR
 ▮  ▮  ▮  ▮  ▮  ▮  ▮  ▮  ▮   ▮  ▮   ▮    WRITING (SHADED)

 INDEX POINTS    8-4 8-3 9  8  7  6  5  4  3  2  1
 FOR READING     ▧  ▧  ▧  ▧  ▧  ▧  ▧  ▧  ▧  ▧  ▧
(CROSS HATCHED) →| |←READ
```

(B)

Figure 4. (a) Printer symbols and code for card image used in printing

(b) Printer index points showing overlap of writing and reading when checking printing with echo impulses
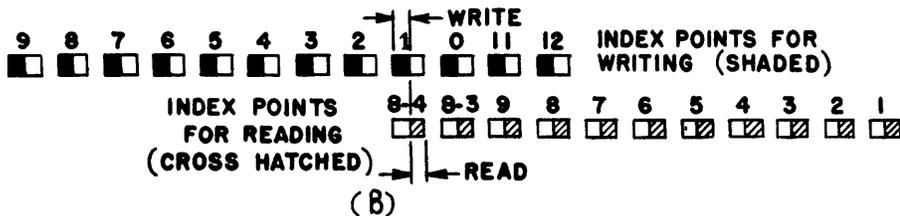
tional operation of the system is similar to card recording, and will not be described again. When a type wheel on the printer has been selected for printing a certain character, a timed echo impulse representing the digit portion of the selected character will be available for reading later in the print cycle as indicated in Figure 4 (B). Provision has been made to take advantage of these echo pulses to check the accuracy of printing. For writing with checking, the printer is selected by the execution of read (printer) instruction (the write instruction provides for writing only). The echo impulses are read into electrostatic storage in much the same manner as a card is read on the card reader. However, the situation is complicated by the fact that four of the echo impulses overlap with the last four index times during which printing is still being set up. This situation is shown in Figure 4(B), and during these overlap index times it is necessary for the input-output control to interpret the four required copy instructions per index pulse so that two of these instructions are used to write and the next two used to store the returning echo impulses.

In addition to the checking facilities, the printer is supplied with an automatic tape-controlled carriage similar to that on type 407. However, by use of special outputs from the calculator and a special input to the calculator, the tape control of the carriage may be combined with automatic control from the calculator program.

Magnetic Tape Reader and Recorder

In addition to the card reader, card recorder, and alphabetic printer, type 701 is provided with four magnetic tape readers and recorders. A view of one of the tape units is shown in Figure 5. Notice that each unit is composed of two tape drive mechanisms. Each of these mechanisms is an independent tape unit as far as its functional use with type 701 is concerned, and they are combined in one cabinet for compactness and economy of construction.

The tape unit has many unique mechanical and magnetic features which are described in other papers in this volume and the comments here will be restricted to the functional connection of the tape unit to the 701 system.

Long-term high-volume storage with a reasonably short access time to the next unit record is provided by the magnetic tape unit. The access time to the next unit record on tape from the stopped position is set at 10 milliseconds, and the reading and writing rate of unit records is 1,250 words per second. The information density on the tape of 200 words per foot corresponds to a bit density of 100 bits per inch in each of seven parallel tracks. The tape is plastic back with red oxide coating. Six of the seven tracks contain six bits of one 36-bit word, the seventh track contains a check bit which is used to check the correctness of reading and writing in the other six tracks. Since a full word is 36 bits, six groups of six bits

each are required for a full word on tape. Transmission of information to and from the tape is done in a partially serial fashion, each group of six bits with its check bit being transmitted in parallel and the six groups of a word occurring in serial sequence. The M/Q register is used as a buffer between the serial-parallel tape and the parallel calculator in both reading and writing operations. The information paths from the M/Q register to the tape are indicated in Figure 6.

A word to be written on the tape is placed in the M/Q register by the execution of a copy instruction in much the same way as in writing on cards or printing. Exit from the M/Q register to the tape is by way of the right six (30-35) places of the M/Q. The word to be written on tape is shifted in total to the left, serially, around the ring shift path, until the first six bits of the word (S-5) have been displaced and arrive at the location (30-35) of the M/Q register. The six bits of the word, now located at (30-35) are transferred in parallel to the tape together with the check bit. The check bit to accompany the six information bits is determined by counting the binary ones in the 6-bit group to be written and making the check bit either a one or a zero so the total of binary ones in the 7-bit group is an odd number. In this manner, for each copy instruction supplied by the program a complete full-word is written on the tape as six groups of six bits each (with a check bit for each group). The tape will continue to run as long as copy instructions are available to supply new words. Thus a unit record on tape is not limited to any specific number of words
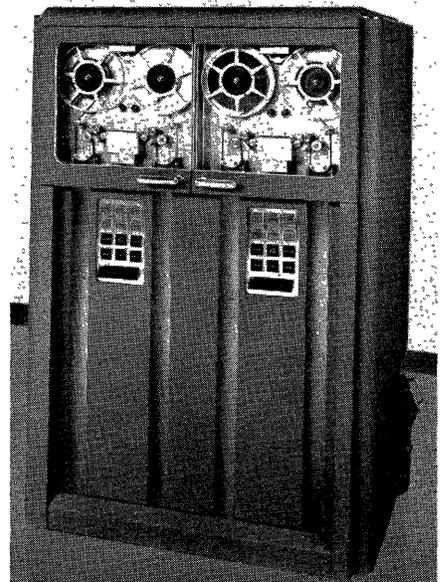
Figure 5. Tape unit
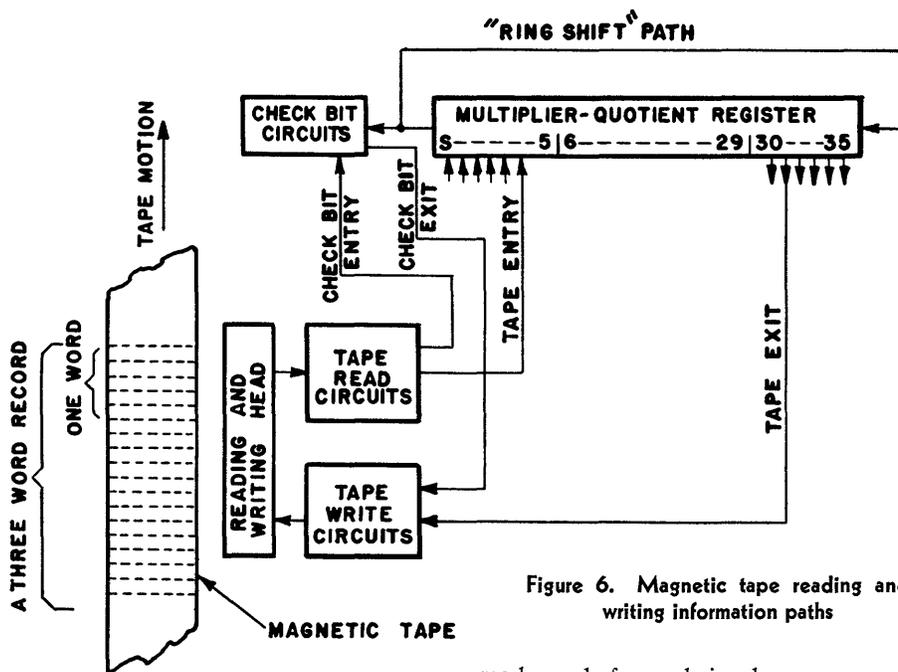
Figure 6. Magnetic tape reading and writing information paths

and may be any length from one word to the limit of the available space in the electrostatic storage.

The M/Q register is used in a similar manner when reading from the tape, except that the register is used to arrange the six separate groups into a complete fullword before the information is stored by a copy instruction. Each group of six bits is entered into the M/Q columns S-5 as shown in Figure 6, and then ring-shifted left in steps of six places. During the shifting operation, the group and its check bit are inspected to determine if the check bit corresponds to the correct one. If this check fails, a tape check light is turned on. After six groups have been entered into the M/Q register from the tape, the complete word is stored by execution of a copy instruction.

When reading, the tape unit will run the tape through a complete unit record, once it has been selected by a read instruction, and it is not necessary to store any of the information from the record unless desired. Thus it is possible to step the tape along in search of a particular unit record merely by supplying read instructions. The end of a record on the tape is identified by the tape unit by the large gap in the information. This gap is caused by the clean tape which is used in accelerating and decelerating the tape at the start and at the end of writing a unit record on tape. The sensing of this gap in information is used not only to stop the tape from feeding but to supply a signal to the input-output control to cause an end-of-record skip of two instructions following the next copy, in much the same manner as the functioning of the card reader end-of-record signal.

In addition to the end-of-record signal, the tape unit will also emit an end-of-file signal when it has read the last record on a reel of tape. This signal is generated when the tape unit is selected to read another unit record and, after a specified length of time finds no information available. In addition to stopping, the tape will set up an end-of-file skip in the program much the same as a card reader end-of-file. The extra long gap at the end of a file of information on tape is obtained by the execution of write-end-of-file instruction that cleans tape for a specified length past the last record.

In addition to the functions described in the foregoing the tape unit is capable of reading tape while the tape is moving in the backward direction, as well as being capable of completely rewinding a reel under program control.

Manual Input and Output

One function of the operator's control panel is to provide a means of manual input and output. This input-output function is provided as a part of the over-all function of manual machine control which will not be discussed here. Manual input is provided to the left 18 bits of the M/Q register from keys on the operator's panel. Appropriate instructions may be executed manually to store the contents of the M/Q register. The contents of any storage location may be inspected by means of neon lamps on the operator's control panel. These neons are connected to all major registers within the machine. It is necessary first to execute manually an appropriate instruction, which will place the contents of the desired storage location into an appropriate major register.

In addition to the manual information input facilities, manual control inputs have been provided. These control inputs consist of six switches located on the operator's control panel. Each of the switches has an address which may be used with a sense instruction. When a sense instruction with the appropriate address is executed, the position of one of the switches is sampled. If the sampled switch is off, the program continues in normal sequence, but if the switch is on the instruction immediately following the sense instruction will be skipped. The sense switches thus provide manual control over the course of a program, a function which has been found very useful.

In addition to the six sense switch inputs, four sense outputs have been provided. These outputs consist of neon lamps connected to trigger circuits which may be turned on by the execution of a sense instruction with the appropriate address. The sense outputs have been utilized for all types of indications, but their widest application has been in indicating the cause of error stops in programmed checks of machine operation.

Conclusions

The input and output system for the IBM type-*701* electronic data processing machine has been described along with the functional operation of the system. It is believed that this input-output system will represent something new in the field of high-speed electronic data-processing equipment. Previous machines of this type have been seriously hampered by the lack of adequate input and output facilities of one type or another. The *701* system is composed of the most suitable of the input-output devices of each type which are available today, and these devices have been arranged into an integrated system. When the *701* is released it may well be one of the first machines to exemplify a new era of data-processing machine development, in which much of the effort previously concentrated on the development of storage and control systems will be devoted to the development of more suitable input and output equipment and techniques.

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IBM Magnetic Tape Reader and Recorder

W. S. BUSLIK

THE purpose of the magnetic tape reader and recorder, as the name implies, is to record digital information onto magnetic oxide tape and to read it. Reuse of the tape also requires erasing before recording. The erasing, recording, and reading occur at the magnetic head which is described elsewhere with its associated circuitry. This paper will be confined to a description of the methods employed in handling this tape for most efficient use.

Most efficient use of the tape means conformance with the following requirements. Tape is to run at 75 inches per second in both directions. Rapid starting and stopping of the tape are to consume not more than 5 milliseconds from the time the start or stop signal is given. Uniform speed is to be reached in that interval of time. The tape should be capable of reversal in 10 milliseconds. These requirements apply to the piece of tape in the immediate vicinity of the recording station. The bulk of the tape can be handled much more leisurely. Reels are 8 inches in diameter and carry a maximum of 1,400 feet of tape.

Control of the tape functions is either from the calculator or from a control panel at the tape reader. In addition to these specific requirements, some less well defined points have to be considered. Speed should be as uniform as possible. Tape wear should be reduced wherever possible. Because the seven bits of information across the tape form a group, it is essential that the reading of these seven bits be completed before any of the seven bits belonging to the next group come into the reading position. This then requires that the tape be held as close to the same position as possible, from machine to machine as well as from forward to backward speed.

Machine Layout

With these points in mind, the machine layout in Figure 1 was conceived. This shows the record-erase head in a shield in a central location, easily accessible, approximately 4 feet off the floor. To either side of it is a series of pulleys and capstans, constituting the drive mechanism for the portion of the tape near the head.

The tape passes through this section essentially horizontally. It then makes a 90-degree turn, entering the two vertical vacuum columns. These serve as buffer storage between the drive mechanism and the relatively sluggish reels which are located above the rest of the mechanism at a convenient height off the floor. The reels are easily detachable from their shafts, which are each driven by a set of three magnetic powder-type clutches.

Reel Clutches

These clutches are shown in more detail in Figure 2. One of the three clutches (the one in front) is stationary and serves as a brake. The other two are driven in opposite directions and, when energized, rotate the reel so as to supply tape to the vacuum column or remove tape from the vacuum column. All three are mounted on a common shaft with three rotors keyed to the shaft. When a clutch is energized, a rigid connection is established between its rotor and housing. A single clutch unit is shown in Figure 3. The innermost part is the bell-shaped rotor whose hub is keyed to the shaft. Its rim is surrounded by a mixture of magnetic iron powder and graphite. As long as no magnetic field exists, the rotor rim can move freely in this iron-graphite mixture, or the clutch housing can rotate freely around the rotor on the two ball bearings that locate it on the shaft. The clutch housing carries a coil which can establish a magnetic flux in the iron surrounding it. This flux, passing through the rim of the clutch rotor and the magnetic iron powder mixture, will solidify the latter, forming a torque-transmitting medium between the clutch housing and its rotor and shaft. Due to the inductance of the coil, current in it builds up gradually and, since torque transmitted is proportional to current (and flux), a rather smooth acceleration is produced. This is essential because shock in the reel will cause slippage of the tape on the reel and eventual breakage. The magnetic powder clutch was selected here for its ability to produce rather smooth accelerations and large torques with relatively small control currents.

Its wear characteristics are very favorable because there are no linings or friction materials to be replaced. The iron-graphite mixture will not wear the clutch parts, only tending to polish them. To contain the iron-graphite mixture in the vicinity of the flux gap, a series of labyrinth-type ridges was designed into the clutch parts. These utilize centrifugal forces to return the powder back to the magnetic gap.

The entire clutch assembly as shown in Figure 2 can be removed from the machine after loosening four screws in front and disconnecting it by pulling a 15-position plug. Individual clutches are then easily replaced.

The clutches, and thereby the reels, are controlled from the tape in buffer storage. Each set of three clutches and associated reel and vacuum column represents an on-off servo system, which is completely independent of the motion of the tape in the vicinity of the head.

Vacuum Column Storage

The vacuum columns are vertical columns of rectangular cross section, just wide enough to accommodate the 1/2-inch tape. The front face of the vacuum column is transparent so that tape can be observed at all times. The top of the vacuum column is open; the lower end is connected to a manifold and thence to a vacuum pump which maintains a vacuum of about 10 inches of water. The tape is inserted so as to follow the sides of the column, forming a semicircular loop at the bottom. Vacuum is thus maintained below the loop and atmospheric pressure above it. This pressure difference is used to control the reels. Two holes in the back of the column are drilled at about one-third of the length from either end and are connected to pressure (or vacuum) switches, which effectively sense whether the loop of tape is above the holes or below them. Thus, the length of column is divided into three regions and the vacuum switches can sense in which of these the loop of tape is located at any time. Now, if the loop is in the region between the two switches, the brake clutch is energized and the reel stands still. If the loop is below the lower vacuum switch, the take-up clutch will be energized, turning the reel in the direction in which it will pull tape out of the vacuum column until the loop reaches the center again. If the loop is in the top third of the column, the reel is rotated to supply tape into

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TAPE
SENSING ARM (2)
FILE REEL
THREAD HANDLE
MACHINE REEL
MAGNETIC
HEADS
REEL RELEASE
SWITCHES
TAPE
VACUUM
SWITCH (4)
VACUUM
COLUMNS
VACUUM PRESSURE
SAFETY SWITCH
VACUUM PUMP
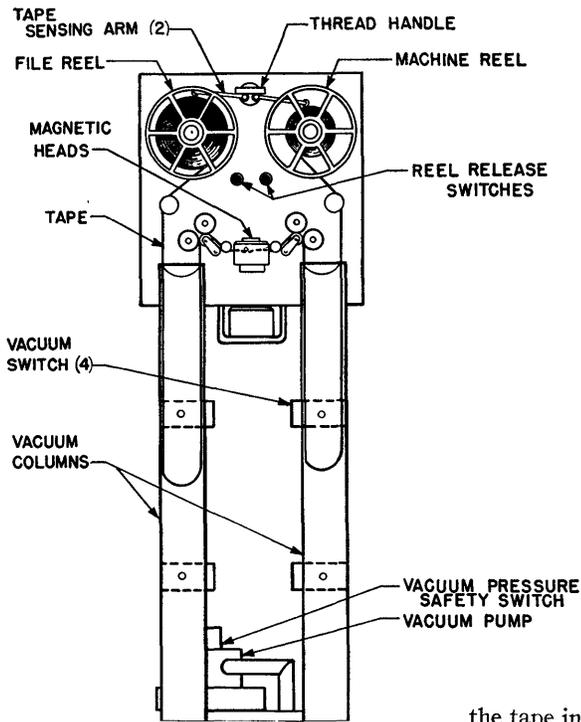
Figure 1 (left). Machine layout
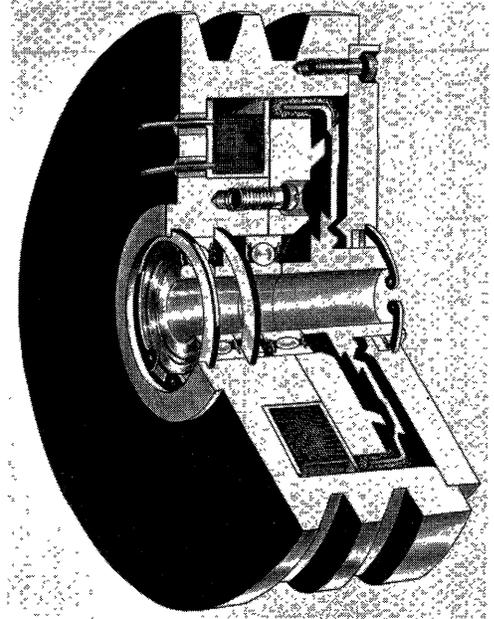
Figure 3 (right). Magnetic clutch

the column until the loop is lowered into the center region again. By the proper arrangement of the switch contacts no relays or tubes are required in the control circuit.

The vacuum switch used is shown in cross section in Figure 4. The heart of this switch is the diaphragm which compresses a return spring when vacuum is applied and thereby transfers an electrical contact. For reliability's sake, two sets of contacts in parallel are used, and after a year of operation no failures have been reported.

The vacuum in the column does not serve the clutch control alone, but also provides sufficient tension to wind a tight reel. Besides, it maintains tension on

the tape in the drive mechanism, preventing the formation of loops when starting abruptly.

Start-Stop Mechanism

Fast starting and stopping is accomplished by the mechanism shown in Figure 5. This figure shows the main plate of the machine transparent, and the items behind it are shown somewhat lighter than the parts in front of it. The magnetic head is omitted here. The drive is symmetrical except for the reverse magnet (1) which is off to the left of the center line. There are two constantly rotating drive capstans (2) and two fixed stop capstans (3). All four are rubber-covered and ground concentric. A light nylon idler (4) mounted in fork (5) moves between the stop and start capstans and

may be pressed against either one by the linkages behind the main plate. The tape runs oxide-side down under idlers (6) over nylon idlers (4) and vertically down into the vacuum column. The right drive capstan turns counterclockwise and the left one clockwise. Therefore, the tape can be moved forward (left to right) by bringing the right nylon idler (4) to bear against the right drive capstan (2); and right to left by squeezing it between the left nylon idler (4) and the left drive capstan. As indicated, the tape is always pulled away from the head when starting. Similarly, when stopping, the tape is stopped after going from left to right by being squeezed between the left nylon idler and the left stop capstan, and conversely. The linkages in back of the main plates do not permit both nylon idlers to make contact with a capstan simultaneously, thereby tape breakage is prevented. These linkages are actuated by the moving coil (8) which through rod (9) provides vertical motion of link (10) and by the reverse magnets (1) which impart a horizontal displacement to link (10). Thus, the reverse magnet biases the mechanism into forward or reverse status and the moving coil puts it into start or stop condition. The moving coil suspended in the magnetic field of a permanent magnet (11) makes it possible to obtain very short start and stop times. Actual transfer time of the mechanism from start to stop, or from stop to start, is 2 milliseconds, which includes current rise time in the moving coil. This coil is connected in a bridge circuit with four (5687) tubes making reversal of coil current possible in a fraction of a millisecond.

Figure 2. Reel clutches

ATMOSPHERIC SIDE

VACUUM SIDE   DIAPHRAGM

Figure 4. Vacuum switch

Figure 6. Split-idler pulley
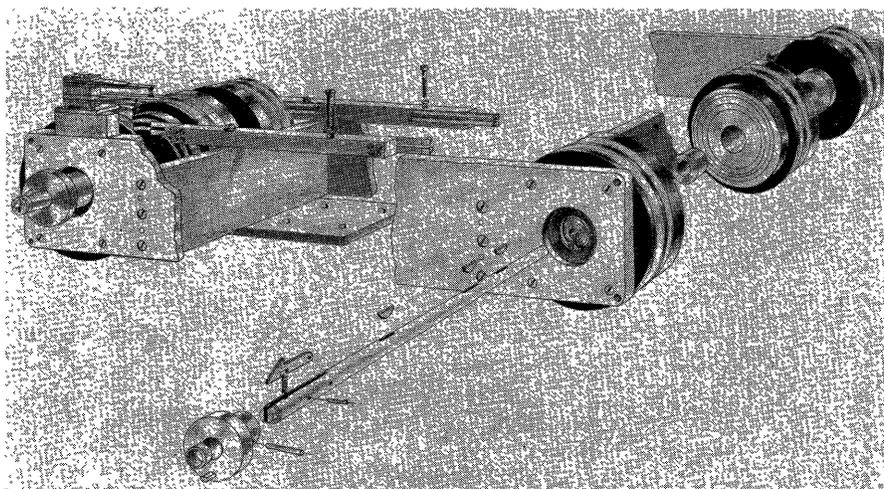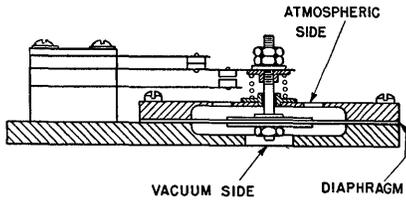
Forces required for rapid acceleration of the tape are rather large. Approximately 10 pounds pressure is required between the nylon idler and the capstan. This in turn calls for about 5 pounds at the moving coil. To obtain this force about 200 milliamperes have to flow through the 800 turns of number 40 wire on the moving coil. This large current can be maintained only for a short period of time (about 12 milliseconds) at starting and stopping. During steady running or stopped condition only a small current (60 milliamperes) flows, because only a small force is required to keep the tape moving, once it has been brought up to speed.

To achieve these rapid starts and stops, all displacements in the start-stop mechanism have been kept small. The nylon idler, for instance, moves not more than 0.004 inch when transferring from stop to start condition. This leaves just enough air gap between the rollers for the tape and a splice to run through freely, even if splices should occur on both sides simultaneously. Adjustment of this mechanism is therefore fairly important. Adjustments are made at the reverse magnet and the stop capstans, which are

eccentric and may be rotated to open or close the gaps between rollers. They can be locked in place by means of a screw (7).

Tape Alignment

To maintain proper alignment of the tape, the split idlers (6) are used. These have to hold the tape parallel to the main plate and also keep the tape a fixed distance from it, both regardless of variation of width of the tape. To avoid too complicated an alignment system, it was preferred to maintain the alignment of one edge of the tape only and let the other move freely. Figure 6 shows how this is done by the split idler. The left edge of the tape is held a fixed distance from the plate which is set by grinding a little spacer to the proper thickness. The right-hand half of the idler is pushed to the left by a spring and at all times assures contact between the rim of the left half-idler and the left edge of the tape. When the tape expands in width, it spreads the split idler. The track farthest away from the guided edge of the tape is therefore most subject to misalignment when the tape expands or contracts laterally between the time of recording and the time of reading. If the distances of two split idlers from the main plate are the same, a minimum of skew can be expected. Measurements have shown that split idlers can be very effective in reducing skew to a minimum; also, that alignment between machines can be very closely controlled. In addition to the split idlers, guides are provided directly at the head to keep the tape in line laterally. These
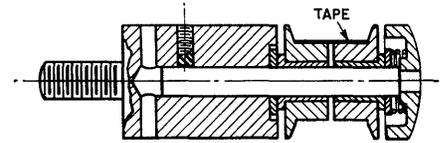
guides are fixed and are an integral part of the head assembly.

Magnetic Head

The head itself is mounted inside a shield, which can be opened manually for inspection of the gap and threading of the tape. A push button located just above the head releases the head shield cover and lets it open upward. Figure 7 shows the magnetic head assembly approximately as the operator would see it. The shield consists of three layers of mumetal, copper, and mumetal, to provide both electrical and magnetic shielding. The erase head is visible to the left of the record-and-read head. This implies that tape moves from left to right when recording. The surface of the record-and-read head shows longitudinal slots which run almost the full length of the head, but are filled in the center portion by intertrack mumetal shields. These slots are no longer cut the full length, as shown, and thereby some dust and oxide accumulation is avoided.

The head cover is constructed on the 3-layer principle again and shows the pressure pad at the cantilever end of a leaf spring. Pressure is adjusted to
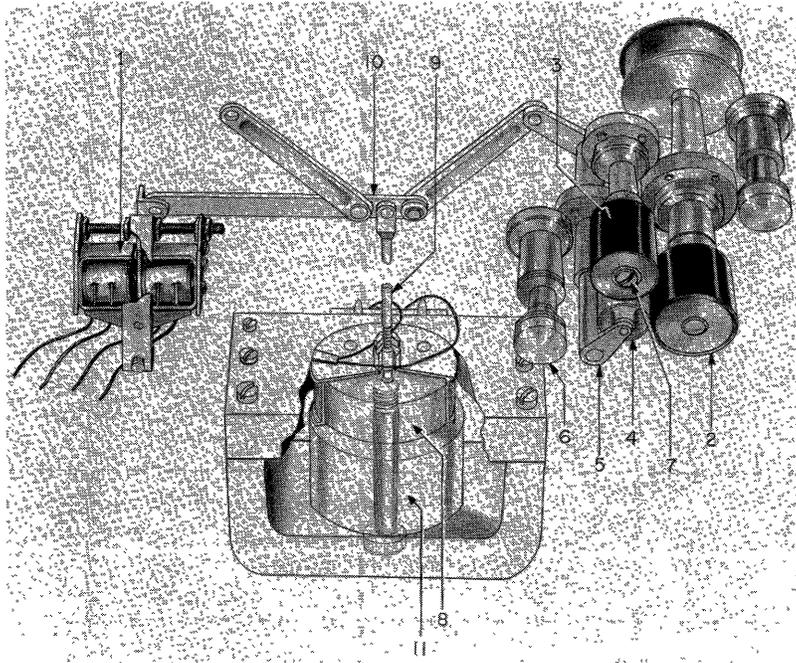
Figure 5 (left). Start-stop mechanism

Figure 7 (below). Magnetic head assembly
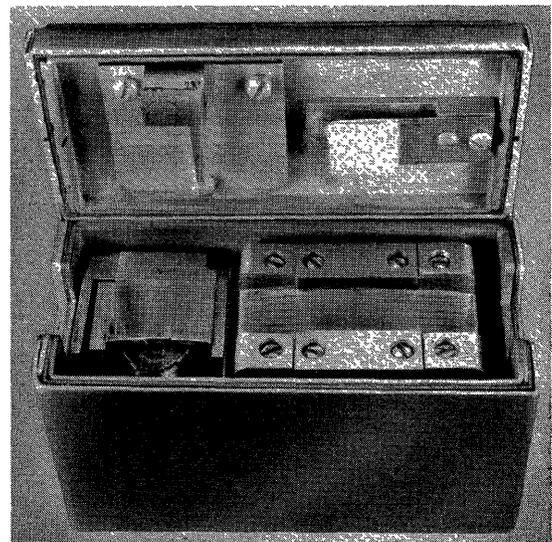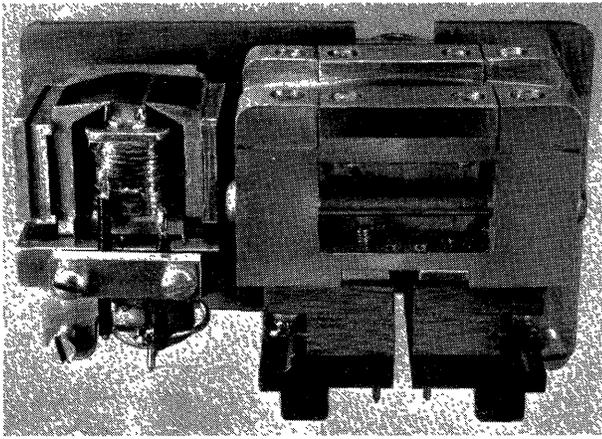
Figure 8 (left). Head assembly (shield removed)

Figure 10 (right). Typical stop picture

about 6 ounces by carefully bending or shimming the leaf spring. Since the top surfaces of the head form a 12-degree angle at the gap, which is rounded off to a radius of 1/16 inch or less, the pressure pad exerts maximum pressure at the gap. The pressure pad is displaced slightly to the left of center to give more pressure to the tape as it approaches the gap than when it leaves it. To the left of the pressure pad is the depressor rod. This is made of glass to withstand wear and cause a minimum of drag. It is located between the erase and the record-and-read head, and drops down below the head surfaces when the head cover is closed. Thus, it insures proper contact of the tape all along the head surface. Figure 8 shows the shield removed from the head assembly. The two heads are mounted to a common plate. This plate may be rotated about a vertical pin for alignment purposes. The hole that receives this pin is clearly visible behind the gap of the read-record head and in line with it. Alignment rotation is controlled by two screws at the bottom right and left corners of the mounting plate. As one screw is loosened, the other is tightened up, thus giving a positive lock. Adjustment is made while reading a master tape on which information has been recorded in the two outside tracks on a line perpendicular to the edge of the tape within 0.0002 inch. In this picture, some construction details are apparent. The head is essentially made of two symmetrical halves which are held together by horizon-

tal studs in front and back. The two halves are held in alignment by dowels. The only parts not halved are the intertrack shields and the tape guides. Even the male plug at the underside of the head is made in two pieces. Therefore all electrical connections can be made before the two halves are joined.
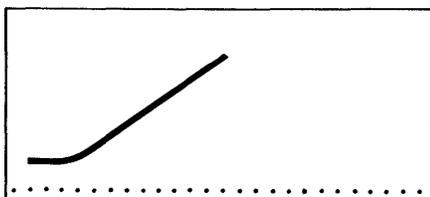
The d-c erase head is of much simpler construction but it is also laminated. The small and large gaps of this head as shown in Figure 8 are the effective erase elements. The small gap saturates the tape in one direction and the leakage flux from the large gap is just large enough to return the oxide to zero magnetization. A small connector is mounted to the underside of this head.

Operation

Just above the head and close to each reel, two push buttons release the reel shafts so they can be rotated manually when loading a fresh reel of tape. Normally, the left or file reel would be replaced, whereas the right or machine reel would remain on the machine. To sense end-of-reel, a steel leader dimensionally similar to the tape is used at the bottom of each reel. This steel leader is grounded through the reel and the reel shaft. As the tape comes off each reel, it runs over an insulated aluminum roller and as the steel leader reaches it, a signal is transmitted to the machine. A typical operation when changing file reels (left reels) would be as follows. Tape is rewound from right to left. When the steel leader at the bottom of the right reel comes off and touches the right aluminum roller, the machine stops. After the head shield has been opened manually, the steel leader may be run beyond this position clear past the head by pushing a button, and it will come to rest again as it reaches the left aluminum roller. There, the tape is disconnected from the steel leader and
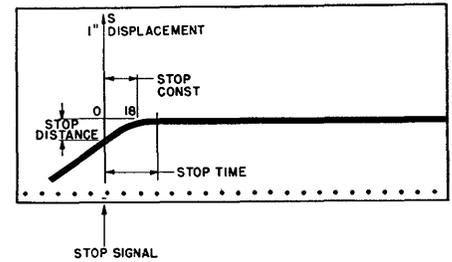
the file reel removed. When a new reel is connected to the steel leader and a load button pushed, the tape is pulled by the steel leader through the mechanism up to the right aluminum roller, where it will stop. The head cover may then be closed and recording of information will start a safe distance from this point.

Performance

Performance of the production prototype has been very satisfactory. Since the unit has been operating largely in an air-conditioned room, problems arising from dimensional changes of the tape have been minimized. Precautions, as described in the foregoing, have been taken to allow for lateral expansion of the tape.

Stretching of the tape under tension is another potential source of trouble. This occurs most noticeably when accelerating the tape. At that time about 2 pounds of pull is exerted on the tape at the capstan. Consequently, the piece of tape between the capstan and the read station is stretched. When the tape has reached its nominal speed, the tension in the tape has become reduced and the stretched piece of tape may assume its original dimension. This contraction gives rise to a nonuniformity of speed at the read station. By keeping the capstan close to the read station, this effect can be minimized. Plastic tape shows this to a much larger extent than the stiffer paper tape.

In conclusion, some performance data should be presented. A nominal start time of 5 milliseconds has been attained. Start time is defined as the time from receiving a start signal to the time when the tape has reached its nominal speed of 75 inches per second without further speed variations larger than those normally encountered during steady running. Measurements of start time were made with a single dimension camera. This camera takes pictures of a point on the tape through a slit parallel to the motion of the tape, on film wound on a rotating drum whose axis is also parallel to the motion of the tape. In this way, a time-versus-displacement diagram is obtained on the film. A crystal-controlled timer pro-

Figure 9. Typical start picture

vides a dot on the edge of the film every millisecond, and also a mark is made on the edge of the film when the start pulse is given. Figure 9 shows a typical start picture taken at a higher tape speed, 130 inches per second at the head. This higher speed accentuates the previously mentioned tape stretch. It indicates

that the tape begins to move after 2 milliseconds, reaches full speed after about 3 milliseconds but, due to contraction of the tape at that time for a millisecond or so, it exceeds the speed at the capstan. The starting time for this picture according to our definition would be about 6 milliseconds. A corresponding stop picture is

shown in Figure 10, also at a higher tape speed. Tape stretch will appear as a slight overshoot here but this is hardly noticeable. Stop time is 4 milliseconds. To get a more accurate picture of tape stretch during a start, dynamic tension measurements were made which confirmed the speed overshoot seen here.

Magnetic Tape Recording Techniques and Performance

H. WILLIAM NORDYKE, JR.

THE MAIN purpose of this paper is to present technical characteristics and performance data on the recording methods and equipment used in the production prototype-*701* Electronic Data-Processing Machine magnetic tape units.

Recording Techniques

The recording head longitudinally magnetizes the red oxide, plastic-backed magnetic tape in either of two saturated magnetic states. A binary information bit therefore changes the polarity of tape magnetization either from a positive saturation condition to a negative saturated state, or conversely. Figure 1 shows the relationship just described, where the y axis is the recording head magnetizing flux, and the x axis is time. This method of non-return-to-zero recording permits a greater output and a greater number of bits per inch on the tape than in systems using a return-to-zero method of recording.

Figure 2 shows how the computer information pulses are converted to changes of flux reversals in the recording head. Successive pulses flip the binary-connected trigger and alternately raise and lower the potential of point A. This change in voltage is sufficient to allow the switch tubes to be either on or off. If switch tube 1 is conducting, flux exists in a direction in the magnetic head as indicated. The core will continue to have

this direction of magnetization until the next pulse is applied to the input of the binary-connected trigger. At this instant, the trigger flips, switch 1 is cut off, switch 2 conducts, and the direction of magnetization in the head core is reversed. Switch 3, which is a set of relay points in type *701*, is for the purpose of switching both tubes 1 and 2 off. Under the off condition, switches 1 and 2 act as open circuits, except for tube capacitances, thereby permitting the same coil windings to be used for reading. The time required for switching tube 1 off and 2 on is of the order of 2 microseconds. The fringing of the head gap is such that $d\phi/dx$ is relatively independent of tape speed. Here

$x =$ distance along tape
$\phi =$ remanent fringing tape flux

Each switch tube, when conducting, permits approximately 10 milliamperes of current to flow through the head windings. This results in a magnetizing force of 4.3 ampere-turns. This magnetomotive force is sufficient to saturate

the tape even though it is separated from the recording head gap by as much as 1 mil. The inductance of the head is 20 millihenrys per coil at 1,000 cycles per second.

Figure 3 illustrates the block diagram of the read amplifier together with clipping and shaping circuits. The same coil windings are used in reading as in writing, and points C and D are the same points as shown in Figure 2. At the standard tape speed of 75 inches per second, this head develops an output voltage of 75 millivolts peak-to-peak across two coils in series, each having 430 turns of number 42 wire. This gives an output of 87 microvolts per turn for the standard 32-mil track width. For lower tape speeds a transformer is used to couple the head to the amplifier input and thereby keep the voltage to the amplifier input relatively constant.

The input pulses at points C and D have a pulse width of approximately 20 microseconds if measured at the standard tape speed of 75 inches per second. This corresponds to a distance along the tape of 1.5 mils if measured at a pulse amplitude equal to 20 per cent of the maximum amplitude. If measured at the 10 per cent point, the pulse width becomes about 35 microseconds or 2.5 mils along the tape length. If reduced amplitude writing currents are used, considerably narrower pulses may be obtained. However, in view of present operating condi-

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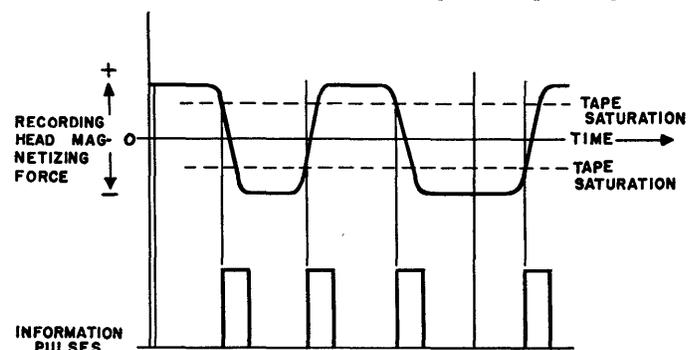
Figure 1. Non-return-to-zero reading
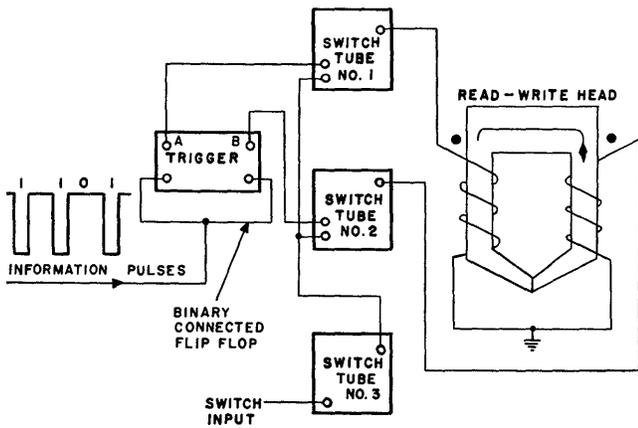
Figure 2. Write circuit block diagram
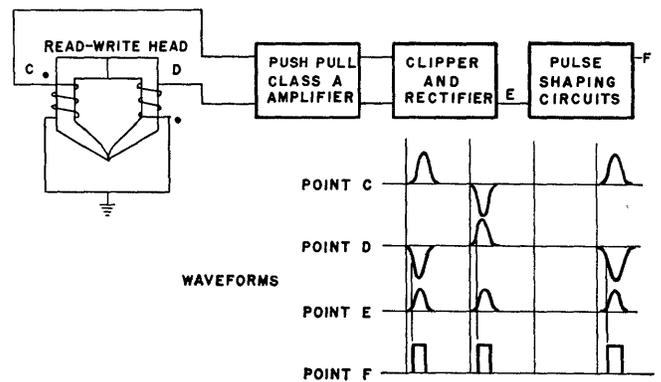
Figure 3. Read amplifier block diagram

tions, there is no real need for a narrower pulse, particularly when it is necessary to sacrifice the feature of tape saturation.

The push-pull amplifier characteristics were used primarily to reduce the effects of power supply variations on amplifier performance. This feature also tends to reduce any in-phase noise components introduced either in the head magnetic circuit or its associated lead wires. Owing to the mechanical configuration of the tape drive unit, the first amplifier stage must be located about 3 feet from the head because of physical limitations on the placement of components. This is one of the factors limiting the maximum head impedance level.

The amplifier upper frequency half-power point was chosen to be 38 kc per second. This was a compromise value partly depending upon the allowable noise frequency spectrum on one hand and the desired pulse shape on the other.

As will be shown, the information signal from the tape may drop to 50 per cent of the average peak signal level for a period of time which may be as short as 50 microseconds. Such a change in the instantaneous information signal will subsequently be referred to as a dropout.

It will also be shown in this paper that an interfering signal or pulse may occur with amplitude as high as 10 per cent of the average peak information signal level. It may therefore be seen that an amplitude-discriminating device must be used to differentiate between the information signal and the interfering signal. Clipping-circuit techniques are used to produce this effect and at the same time rectify the output of the class A push-pull amplifier. The resulting wave forms are seen in Figure 3 at point E. It is important to note that no interfering pulses occur at point E. It is therefore possible to apply conventional pulse-shaping circuits to produce the output pulses shown at point F.

It has been found both theoretically and empirically that for most tapes the most desirable point to adjust the clipping level is the 20- to 25-per-cent value. This means that all interfering signals below approximately 20 per cent of the average peak information signal level will be rejected and all information signals above the 25-per-cent level will be accepted.

The leading edge of an output pulse corresponds in time to a clipping point as determined by the clipping voltage. Variations in amplitude of the pulse at points C and D may cause the leading edge of the output pulse to shift as much as 10 microseconds. At present, this effect has not become a serious problem as the density is relatively low, being 100 bits per inch. Later, should this effect prove a detriment, tests show that the time shift of the leading edge may be reduced by sensing the peaks of the pulses at the output of the amplifier.

Tape defects which usually consist of foreign matter or irregularities in the tape surface cause dropouts by moving the tape away from the recording and play-back head. The recorded wave length is such that if the entire tape is separated from the head by 1 mil, the read voltage pulse amplitude will drop to about 30 per cent of the average peak information signal. In practice, since the information bit recorded on the tape is 32 mils in width, a small portion of the bit may be moved as much as 4 or 5 mils away from the head without dropping the information signal amplitude below the 25-per-cent point, at which the clipping circuits are set.

Interference pulses are generated when a magnetized portion of the tape is moved rapidly away from the head gap. It is the rate of speed at which a portion of the tape is moved away from the head that is important as far as the amplitude of interfering pulses is concerned. It may, therefore, be seen that in addition to the defect size, the shape and contour of the surface irregularity is also important. In practice, we find that generally
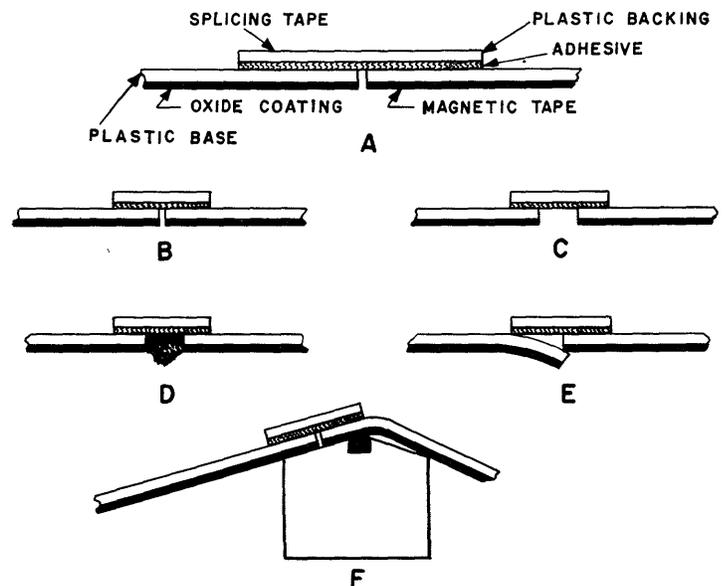
Figure 4. Magnetic tape splices
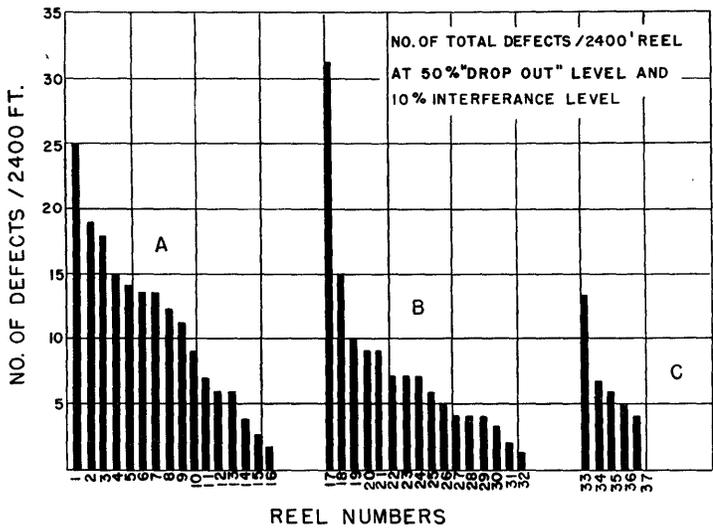
diagonal cut, and to ooze adhesive at the ends of the splicing tape and in the gap between the ends of the magnetic tape. This may be seen in Figure 4(A), 4(B), 4(C), 4(D), and 4(E). Many apparently successful methods were tried, but all caused stiffening of the tape to such an extent that large dropouts were noticed even with a high pressure exerted by the pressure pad and special reduced curvature head surfaces, as shown in Figure 4(F).

Finally, a method was developed which met the requirements of tension, temperature, adhesive ooze, and flexibility. As fairly short lengths of tape are used on type *701*, namely 200 and 1,200 feet, very little splicing, if any, will have to be done on tapes used with this machine. However, if lengths of tapes longer than 1,200 feet are needed, it will be necessary to use the improved splicing technique.

Tape Performance on Tape Test Equipment

It is interesting to examine the total defect count of tape supplied by various manufacturers. Figure 5 shows a comparison of different tapes all tested under the standard conditions mentioned previously. The reel numbers along the abscissa are merely our identification numbers and have no other significance. It should be observed from Figure 5 that the number of total defects for a 5-to-1 signal-to-interference ratio varies widely among tapes supplied by each manufacturer.

Figure 6 shows the results of a defect removal technique which considerably reduces the number of defects per reel. This technique was not applicable to tapes of earlier vintage, but as quality control in tape manufacturing increased

the spots which cause dropouts do not cause interfering pulses, although this is not always the case. It is important not to confuse the interfering pulse with the more commonly encountered noise characteristics of magnetic sound tape.

Tests of tape received directly from different producers showed that not all tapes from any one source met company specifications as to the ratio of information signal to interfering signal. A routine test procedure was then established for all incoming tape. It was found that small lengths of tape were available with a 10-to-1 signal-to-interference ratio. Additional tests showed that greater quantities of tape could be salvaged and conditions made more compatible with actual machine performance by testing for a 5-to-1 signal-to-interference ratio.

All magnetic tape for use in company equipment is now tested for no

dropouts below a 50-per-cent level and for no interference pulses above a 10-percent level. A special test machine was developed for this purpose so that all tapes could be tested at a standard speed of 75 inches per second. The test machine automatically stops the tape when a defect is located. By this means data of considerable extent which will be presented later in this paper have been collected on tape characteristics. During the early stages of the tape testing operation, many defects were found which limited the useful lengths of tape unless a way of marking or splicing out the defect could be perfected. We chose the latter method. It was soon discovered that the usual splices would not withstand machine-operating conditions and storage conditions. Splices using the conventional splicing tape, no matter how carefully made, showed a tendency to pull apart along the
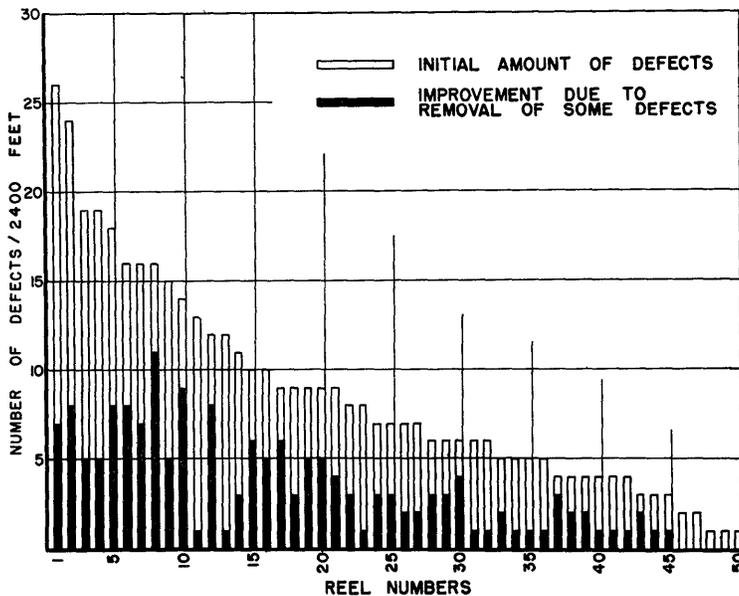
Figure 6 (left). Defects per reel of 1/2-inch plastic tape

Figure 7 (below). Error-free tape per various lengths
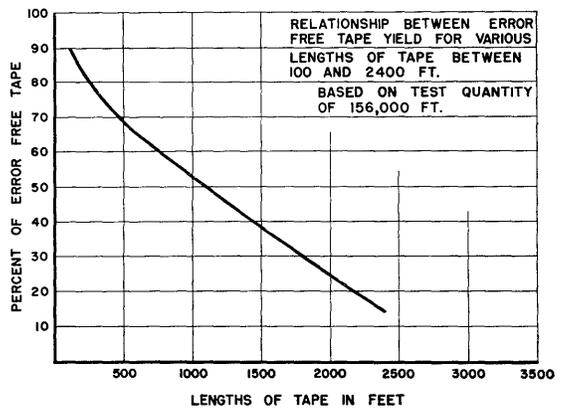
the class of defects changed from the tape-coating or deeply embedded types to surface or adhering-foreign-particle types, that could in many cases be brushed off the tape or carefully removed with a small knife blade. Both the defect removal technique and better manufacturing quality lowered the defect count from approximately 10 or 11 per 2,400-foot reel to about 3 or 4, and practically eliminated the splicing or accompanying wastage of tape to secure long error-free lengths. In order to be°classified as error-free, the tape must have passed the standard 5-to-1 signal-to-interference ratio test.

Figure 7 shows the relationship between the percentage of available error-free tape and various lengths of tape for each 100 feet of length between 100 and 2,400 feet. It may be seen that at least 15 per cent of the tape tested will yield lengths of 2,400 feet with no defects large enough to interfere with the standard 5-to-1 signal-to-interference ratio. In other words, approximately 15 2,400-foot reels of error-free tape without splices may be obtained from a given lot of 100 2,400-foot reels of untested tape. At the other extreme it is seen that 90 per cent of the tested tape will be available without splices in lengths of 100 feet from this same lot.

If instead of 100-foot lengths, 200-foot lengths are considered, it may be seen from Figure 7 that a tape yield of about 82 per cent may be expected.

As mentioned previously, type *701* has two standard-length tapes, 1,200 feet and 200 feet. Figure 7 shows that approximately 46 per cent of the tape tested is available in 1,200-foot lengths, the remaining 36 per cent is available in 200-foot lengths. It may be seen therefore that with the tape specifications as used in type *701* that an over-all tape yield of 82 per cent can be obtained with no tape splicing.

It is interesting to analyze in more detail the nature of defects as received on recent shipments of high-quality red oxide magnetic tape. Table I shows data on defect classification as obtained on 28 reels of 2,400-foot tape.

Item 1. Oxide flakes may cause both information signal errors and interference signal errors, depending upon the size and shape of the particle. Usually this type of defect may be removed without any damage to the underlying oxide surface. Fifty per cent of the oxide defects were found on only 10 per cent of the tape upon which this classification was based. This would tend to indicate that this trouble, which was·probably caused by

worn slitting knives or trouble in the vendor's winding mechanism, could be almost entirely eliminated.

Item 2. While crystalline and powder deposits generally cause signal dropouts rather than interfering pulses, tests and an analysis of these defects are underway. It is believed that they are formed by deposits from the acetate tape backing and from small particles of felt from the pressure pad. The current theory, supported by laboratory tests, is that the heat generated between the tape and pressure pad tends to combine the small particles caused by friction effects into larger ones.

Item 3. Oxide nodules once were the most prevalent type of defect. Splendid co-operation and effort on the part of tape manufacturers has reduced this type of defect occurrence to an almost insignificant amount.

Item 4. Metallic particles usually cause interference signals rather than signal dropouts. Some of these particles may be removed by previously mentioned techniques. Others, however, become firmly embedded in the oxide dispersion and cannot be removed without causing a greater defect.

Item 5. Fibers and other foreign material may cause either a signal dropout or an interference pulse. Practically all of these defects are too firmly embedded in the surface to be removed without resulting damage. It seems that the number of the defects may be reduced by greater precautions during manufacturing with regard to cleanliness and quality control.

Item 6. A group of holes will cause a signal dropout. This group-of-holes effect should not be confused with the occasional 1- or 2-mil diameter hole that may be seen on the oxide surface. The latter imperfection causes only about a 6-per-cent decrease in signal level, and as such, does not cause a dropout.

It seems that the group-of-holes effect may be caused by removing some types of foreign particles.

Item 7. Miscellaneous defects include items as acetate particles; also brown, gummy lumps; black particles; and other unknowns.

Machine Performance

To obtain more data on machine and tape performance, a test procedure was devised which duplicated almost exactly machine operating conditions. Records were written consisting of 100 groups of bits, with a spacing between groups of 0.010 inch. The number of records per tape varied depending upon the test desired, and the inter-record space was adjusted for 1 inch. Each tape contained 5,000 records. During reading, the test equipment checked each group of bits recorded on the tape. In addition, the tape stopped between records for approximately 1 millisecond and then accelerated back to the standard 72-inches-per-second speed. If any errors were present, the tape was automatically stopped, and the portion of tape containing the error was inspected.

Table II shows the percentages of different types of identified defects as obtained under the conditions described, which represented a total tape operating time of 167 hours. Splices were not necessary but were introduced primarily to test the improved splice under typical machine start-stop and wear conditions.

During the same period of time, five errors were attributed directly to the machine. These consisted of tube failures, part breakages, and one case of power failure.

Maximum tape life is difficult to estimate. Tests on short lengths of tape, that is, a 100-group record, indicate that over 100,000 passes may be read, error-free. In this series of tests the tape was read first in one direction and then in the other.

Table I. Classification of Defects as Found on 28 2,400-Foot Reels of High-Quality Red Oxide Magnetic Tape

Type of Defect	Percentage of Total Defects
Oxide flakes	30
White crystalline and powder deposits	11
Oxide nodules	2
Metallic particles	21
Fibers and other foreign material	19
Groups of holes	6
Miscellaneous	11
Total	100

Table II. Classification of Defects Which Caused Errors During Machine Performance

Type of Defect	Percentage of Total Defects
Oxide particles or dust	48
Metal particles	19
Fibers or white powder	7
Tape breakage	17
Splices	9
Total	100

Longer lengths of tape do not yield as many error-free passes. As an example, the best results obtained with a 300,000-record tape showed only 356 consecutive error-free passes. The error terminating this run was caused by an accumulation of white powder on the tape. After brushing off the powder, the tape ran an additional 144 passes with only one error, an oxide particle. After 500 passes, the test was terminated for other reasons.

The maximum tape unit machine-operating time without error, neglecting tape errors, was approximately 528 hours.

Discussion

D. Mayer (Philco Corporation): I should like to ask what the pulse densities on tapes are, that is, how many binary digits per inch?

L. D. Stevens: A similar one records a pulse density of 100 bits per inch in each track, and there are seven tracks.

Mr. Mayer: How do you convert information to and from tapes without using the computer, that is, do you have a separate converter for that, a separate reader and writer in both directions?

Mr. Stevens: At present, there is no other machine available to do this. The tape was designed as an intermemory, or high-volume memory, for the 701, which receives most of its input information from punched cards.

Lt. R. S. Weinberg (Air Materiel Command, United States Air Force): Are you in a position to venture an estimate of when the first 701 systems will be made available to your customers?

Mr. Stevens: I am not prepared, at this time, to answer the question.

Mr. H. Lukoff (Eckert-Mauchly Division, Remington Rand Inc.): An erase head was shown which consisted of two gaps, one saturate, and the other return-to-zero. What is the purpose of the second gap, and how can you be sure that it does return to zero?

Mr. Nordyke: In this system, the second gap does not actually have to return the magnetic tape to a zero magnetic state. It can be off quite a bit because we use a non-return-to-zero recording technique, and tape saturation recording. This makes the machine more versatile, as we can use a narrower pulse width, that is, write at lower current if we so desire, and also we obtain less pulse distortion or time displacement when the tape shifts by means of this second gap.

Mr. J. L. McPherson (Bureau of the Census): Mr. Nordyke, you said over 1,000,000 passes of tape is not impossible. Do you have any idea of the number of passes it would take to wear the tape out physically?

Mr. Nordyke: We have run some tests on this, though not extensive ones. The tape will continue to work for many passes, but the frequency of errors increases. Therefore, to establish a definite tape life, it is necessary to say what frequency of errors and occurrence you are going to have. In general, 1,000,000 passes of this type is not too reliable. That is why I mentioned a more conservative figure of 100,000 passes for short tape lengths or about 350 passes for longer tape lengths.

E. D. Schreiner (Underwood Corporation): I notice that you are using the pulse envelope system of recording, but I do not notice any sprocket channel on the tape. I am curious as to how you propose to separate one bit from another? Suppose, for instance, that they are identical.

Mr. Nordyke: That is a very good question. Essentially we use an OR circuit to combine the pulses. The first pulse sets off a gate, or a counter; this acts for a prescribed interval of time, at the end of which all the pulses have entered the register. The process is then ready to repeat for the next group.

In the usual pulse envelope method, the polarity of the flux shifts on the tape between a one and a zero. We shift the polarity when we desire to record a binary one; we do not shift the flux polarity when we record a binary zero.

Mr. Schreiner: If two successive digits are exactly alike, as I understand your system, there will be no change in flux along that area of tape.

Mr. Nordyke: No. If we have a successive series of ones along any one channel, we will have a series of output pulses. If we have a series of zeros, we will obtain no pulses. The code is set up so that we always have a prescribed minimum number of pulses in any one group. You could never have a case of all zeros in any one group time.

Mr. J. R. Cartwright (British Tabulating Company, Ltd.): Will you explain how the machine converts decimal to binary? As I understand it, what you have described so far is virtually putting a picture of the card onto the machine storage.

Mr. Stevens: That is correct.

Mr. Cartwright: If that card is punched, for example, in decimal or in pounds, ten hundredweight and quarter, you will still have to convert that to binary before the machine can attack the problem?

Mr. Stevens: The first problem is for the programmer to decide in what system he is going to punch the cards. If he punches them in decimal, or if they are standard IBM-punched cards, there is a standard input-output subroutine which will convert the cards to binary automatically. However, if he punches in a system other than decimal, he must provide his own subprogram to do the conversion. The conversion is done within the arithmetic unit of the calculator.

Mr. May: I should like to combine the questions of George E. Clark, from the Glenn L. Martin Company, and H. L. Tholstrup of Commercial Controls Corporation. They refer to the construction of the multichannel magnetic recording and reading head, and they refer to the detail by which interchannel interference is reduced, and what the magnitude is of the interchannel interference.

Mr. Nordyke: The interchannel interference is reduced primarily by the utilization of a mumetal magnetic shield between the adjacent channels. The magnitude of the interference is a voltage ratio of about 50 to 1. At this time, there is no reason to increase the ratio, but it can be done easily if needed.

W. Wolfson (Raytheon Manufacturing Company): I presume non-return-to-zero magnetic inscription on the tapes has been employed by reason of resolution difficulties and pulse densities used. Would you describe the method of sync channel inscription, and the method of reading used with the non-return-to-zero system?

Mr. Nordyke: We do not use a sync channel as such. It is a self-synchronizing system. Because of the nature of the code, the first pulse of each group acts as a sync pulse and produces the same effect as a sync pulse.

R. D. Bronson (Consolidated Vultee Aircraft Corporation): Do you break down the tape defects by actual number of defects rather than percentages, and do you have that information?

Mr. Nordyke: I have the approximate number, but I should like to check it before giving the answer.

H. S. Duncan (Remington Rand Inc.): In your opinion, what factors influence the ultimate density of recording on magnetic tape?

Mr. Nordyke: I presume you mean in the longitudinal direction. There are quite a few factors involved and it is a problem influenced by how the tape is going to be used. For example, it is possible to obtain much higher reliable densities with single-track recording than with multiple-channel recording. Skewing of the tape is probably the main factor in limiting the density of recording in multiple-channel operation. Skewing of the tape occurs because we have to guide the tape mechanically. A variation of about 1 per cent occurs in the tape width as a result of humidity changes, and a cutting tolerance variation in tape width has to be added in, also. These factors all contribute to the decrease of the maximum safe density that can be used. In a single track, resolution of over 1,000 bits to the inch can be obtained.

H. F. Welsh (Remington Rand Inc.): When a reel is removed from the system, is it necessary completely to unthread the tape for the system, or do you have other means for changing tapes?

W. S. Buslik (International Business Machines Corporation): The steel leader, which serves to indicate the end of a reel, may be pulled through the drive mechanism to the left reel, which is to be replaced. The tape may be detached from the steel leader when a new reel is remounted. The beginning of the new tape is attached to the steel leader, and thus automatic threading is obtained.

Mr. Welsh: How is the tape attached?

Mr. Buslik: It is attached with a splicing tape, at present.

Mr. K. M. Rehler (Raytheon Manufacturing Company): Apparently, the matter of the 1,000,000 passes· of tape has raised

another question as to whether the 1,000,000 passes were over one tape area or if different areas of the tape were used each time.

Mr. Nordyke: The tape was read over the same area of tape which was of the order of 20 inches. Again I want to emphasize that this is a high figure even though we have obtained it. The total number of passes on a longer length of tape, or a tape in which there are weak spots, is much lower, although you will still get reliable tape operation.

L. C. Hobbs (Radio Corporation of America, RCA Victor Division): You mentioned tape stretch during the rapid start-stop. Could you elaborate on this as to the magnitude of the velocity overshoot, and any steps taken to overcome it, aside from not using the tape during that time?

Mr. Buslik: At the present speed of about 75 inches per second, I do not think the overshoot in speed is as serious as we have shown in the slides. The overshoot is approximately 10 per cent, but that can be modified by the distance between the reading station and the point where the tape is actually being driven. When I said that we have accomplished a 5-millisecond start time, it does not mean that we are starting to read or record at that time— we have also incorporated a safety factor in the start and stop time. Also, we feel that by the use of other backing materials that are somewhat stiffer than the present acetate tape, this stretching can be reduced.

J. L. Hill (Engineering Research Associates, Inc.): It is apparent that there is some slippage between the capstan and the tape, both in acceleration and deceleration. To what extend does it damage the tape? Have you observed any accumulative effects of stopping in the same place?

Mr. Buslik: We have no accurate records because, as the tape is rewritten, the start and stop processes may not occur at the same place, but we have run tape, started, and stopped it, for many hours without being able to notice abrasion on the tape surface. I might point out that the rubber surface of the capstan is located so as to accelerate the tape from the backing, rather than from the oxide side. We have run tests at several times the speed that we are now using, and at those speeds we could notice some abrasion of the tape during starting and stopping.

High-Speed Printing Equipment

L. ROSEN

THE Synchroprinter was developed to provide a rapid means of printing out data from electronic computers. Although the development was motivated by a very specific application in the United States Government Department of Defense, after attainment of the original objective it became clear that a much broader field of application was available.

The Synchroprinter is shown in front view in Figure 1. The essential elements of the printing mechanism visible are the type wheels, or type roll; the sync pulse generators; and the drive motor.

The principle of operation can also be described by reference to Figure 2, although generally in electronically controlled operation another system, to be explained later, is actually used. As an example, let us assume that we want to print a 3 in column 1. The type roll and sync pulse generator are rotating continuously and a voltage pulse is generated in each sync pulse generator coil as the pulse generator rotor passes it. When we close switch 3, the pulse from coil 3 of the sync pulse generator reaches the thyratron grid and, firing it, allows it to unload the capacitor $C1$ through the print hammer coil, thus actuating the print hammer, at the correct instant to print a 3 in column 1. Of course, inked

ribbon and paper are placed so that an impression is transferred to the paper when a type hammer strikes the print wheel character. Separate selection circuits and thyratrons serve the other print hammers; however, a common sync pulse generator triggers all the thyratrons.

Figure 3 illustrates a more common method of controlling the printer. Here each print hammer has an electronic counter as well as a thyratron associated

with it. These counters are usually of the binary type but may take almost any form. The only requirement placed on them is the ability to count and produce a carry pulse after receiving 10 counts when operating with a numeric printer. Now to print a 3, the counter is preset to 3 either by counting or other means, such as a simultaneous set pulse to the appropriate sides of the binary units. After the counter has been set, the printer is signalled to print out by closing switch B. When the rotor of the start pulse generator passes the zero coil a pulse unblocks the gate and allows pulses from the sync pulse generator to reach the counter. After seven pulses in our example, the counter carries and its output pulse triggers the print hammer thyratron

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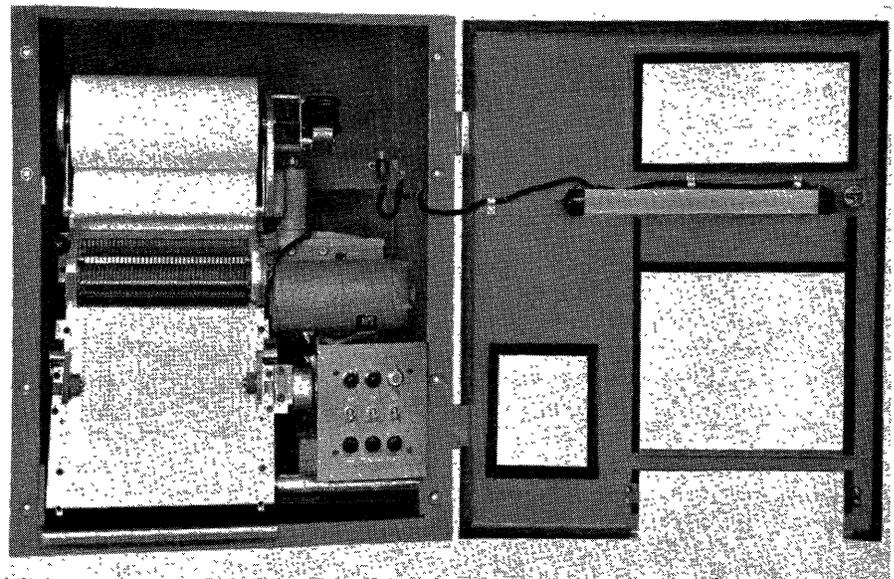
Figure 1. Front view of the Synchroprinter
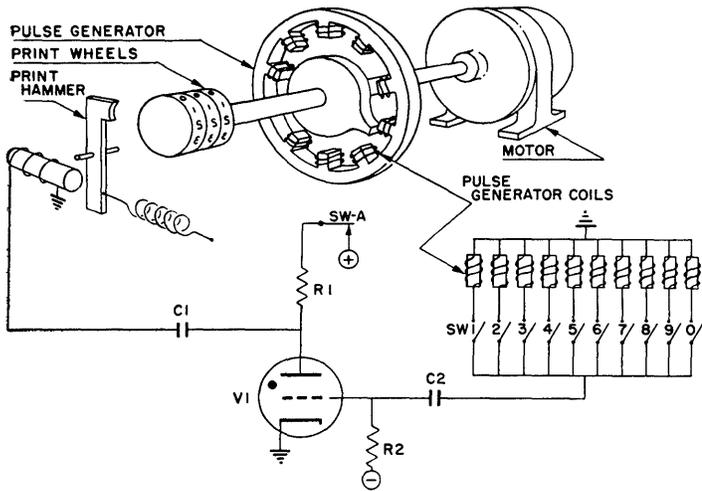
Figure 2. Operating schematic using circuit closures for control

Figure 3. Operating schematic using electronic counters for control

Figure 4. Typical print hammer thyratron circuit
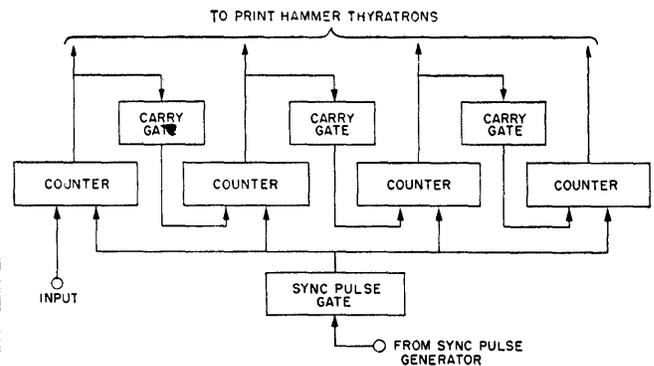
Figure 5. Counter-printer control circuit
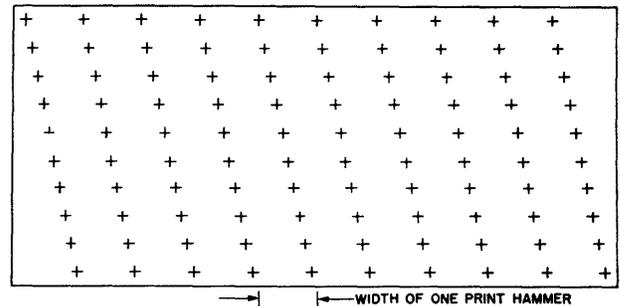
Figure 6. Plotter print roll

which actuates the print hammer. The print roll is engraved in such a way as to have the 3 appear on it seven sync pulses after the zero.

During this printing cycle, the print roll rotated continuously, while the paper was not moved. The print cycle occurs during one revolution of the print roll, or 1/30 of a second. When printing of a line is completed, an independent signal is sent to the paper advance mechanism, which causes the paper to be advanced one line during the next revolution of the print roll. Thus the printer is capable of printing and line feeding in 1/15 of a second or a line rate of 15 per second. This means 600 characters per second for a 40-character line, or 1,200 per second for an 80-character line, or 1,800 per second for a 120-character line.

Figure 4 illustrates a satisfactory circuit for the thyratron driver for the print hammer.

Figure 5 illustrates an arrangement which allows the same electronic counter to be used both for controlling the printer and for counting data. During the counting cycle, the carry gates are unblocked and the sync pulse gate is blocked. The counter now operates as a decade scaler. When the count cycle is completed, the carry gates are blocked and the sync pulse gates are unblocked. Pulses now flow to the counter from the sync pulse generator as described previously. If the counters are not reset before each count, the printer of course prints subtotals, while resetting the counters after the print-out gives the total. The counter here described might be the counter of an analogue-to-digital converter of the type where the number of pulses produced corresponds to an incoming voltage amplitude or time length.

In addition to the features already described, the Synchroprinter can be equipped with column markers. These are small metal arms which can be flipped into active or inactive position. When the column marker solenoid is actuated, the active column marker arms draw a vertical line between characters, thus separating columns or indicating decimal points.

The printer specifications are given in Table I for a 40-column, 10-character unit known as the N-1. The A-1, or alphanumeric unit, has about the same per-
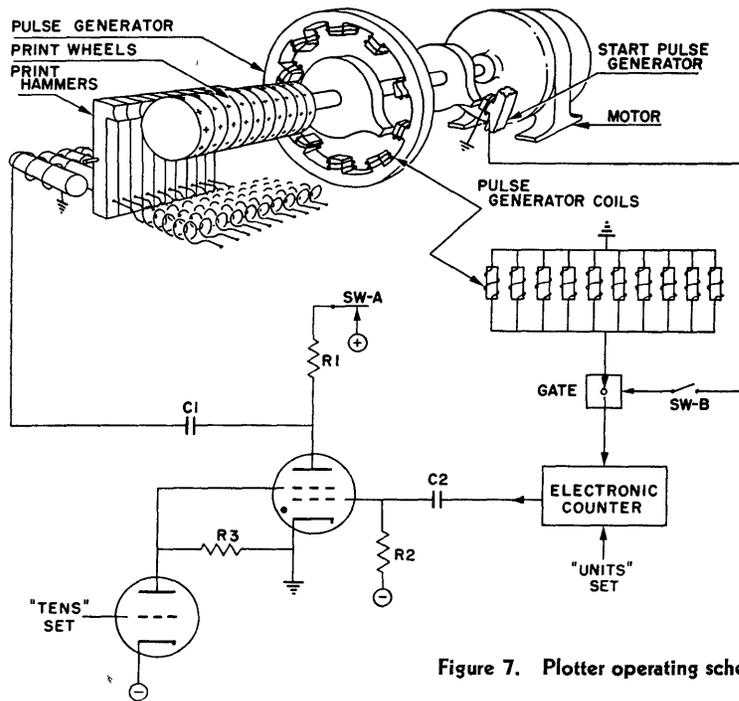
Figure 7. Plotter operating schematic

formance characteristics, except that 36-character type wheels are used.

One of the interesting features of the printer is its construction in building-block form. Assemblies are removable as integral units for repair or replacement, while the whole unit can be removed from its dust case and operated out in the open for purposes of inspection or adjustment.

An interesting adaptation of the printer mechanism to plotting data which is in digital form has been proposed. For purposes of explanation let us assume we wish to plot points ranging from 0 to $10^2 = 100$. In this case, 10 of the type wheels of the printer would be engraved as shown in Figure 6, which is a devel-oped view of the periphery of the type roll. Now, if we select the print hammer by means of one digit and the position of the character to be printed by means of the other digit as shown in Figure 3, the printer is capable of selectively printing any one of the 100+ marks. Thus we can plot one point of a curve in 1/15 second. The remaining 30 type wheels can also be converted to plotters or can be retained as character printers.

By converting 32 type wheels and using 2^5 or 32-character type wheels we will be able to plot 2^{10} or 1,024 points.

An interesting feature of the plotting arrangement is that the accuracy of the ordinate of the point printed is determined entirely by the accuracy of the engraving on the type roll. One advantage of this plotting mechanism is that its full-scale transit time is only 1/15 second.

Various alternative paper movement mechanisms of course suggest themselves for operations requiring either accurate abscissa displacement or paper movement in both directions.

Summary

We now have a tested and dependable printing mechanism capable of printing 15 lines per second. This mechanism can be paralleled to any reasonable number permitting the printing of large quantities of data at high speed. A simple modification of the mechanism permits plotting digital data. The printing mechanism is designed for control by electronic means and therefore can be applied wherever the data to be printed can be reduced to digit form.

Discussion

W. P. Byrnes (Teletype Corporation): Have you determined how many carbon copies you can produce on the Synchroprinter?

Mr. Rosen: We have produced up to three copies that I would consider legible. I must admit that I dislike carbon, because it makes a mess, but we have produced four carbons. The unit shown does not have a paper guide mechanism capable of handling unjointed carbons. We have used the Teletype roll, paper and carbon held together loosely in a roll, in our experimental work, but the present paper drive will not pull these carbons. With a relatively simple modification we can pull the kind of carbon that is glued on the edge, or on the top and bottom.

D. Haagens (Control Instrument Company): Can you tell us something about the speed and the price of the alphabet printer?

Mr. Rosen: The alphameric unit is capable of operating at the same speed; nominally, at 50 revolutions per minute. I say nominally because at present we do not have a synchronous motor. I will answer the second part of the question after the meeting (it is no secret, but I do not think this is the proper place for it).

C. T. Schaedel, Jr. (Consolidated Vultee, Fort Worth Division): Will you please restate the number of characters available in one line?

Mr. Rosen: The present unit is 8½ inches wide, or really 7⁷/₁₆-inch paper with 1/2-inch margin on each side. We have 40 characters in the unit. The printing control is substantially like salami, you can slice off what you want in building it. There is an ultimate limit where the shaft becomes so long that it is no longer practical.

J. J. Earshen (Cornell Aeronautical Laboratories): You showed the method in which the information is read out of the electronic counter, but do you have to use some sort of complement code because of the fact that you were using roll-out pulses there?

Mr. Rosen: It is rather difficult to answer the question in a simple way. The only thing that you must do is to make sure that the print hammer thyratron is energized at the right time. We will engrave whatever character you want at that position. The equipment does not have to be operating in the way shown in the slide. Another possible setup is where there is a comparison of the code set up in the

counter and a code generated by electronic equipment driven by the printer. When the two codes compare, the hammer is energized. The important thing is to get the print hammer thyratron fired at the right time. As long as the sum total of all the operations you do beforehand achieves that, you get the right character.

Lt. R. S. Weinberg (Air Materiel Command, United States Air Force): Can you relate something of the service experience of the printer so far?

Mr. Rosen: Not extensively because of security problems. I can tell you this. In our experimental work the print hammer mechanism was tested to a life of 200,000,000 operations without showing any detectable wear.

The earlier units have been in use over a period of about two years, but I cannot tell you how much of that time they were actually used. We have made one batch of replacement parts. The implication is that there hasn't been much replacement.

A Survey of Analogue-to-Digital Converters

HARRY E. BURKE, JR.

A GOOD many years ago Aesop told a story about a grain miser whose horde was raided by ants that silently crept through cracks into his warehouse to extract his store, kernel by kernel. It is easy to picture the frustration of this wretched man, opening his granary doors one day to find his treasure gone. Today, engineers and scientists are frustrated by a reverse situation—they want to empty their storehouses of raw information, but succeed in doing it only "kernel by kernel," or point by point. Raw data continue to pile up at such a rate that research laboratories and test facilities are overflowing with unreduced information. Manometer tube photographs, theodolite records, frequency-modulated carriers on magnetic tape, galvanometer deflections from recording oscillographs, strip-charted pen gyrations, and so forth, are gathering dust despite a frantic effort to reduce them to useful engineering conclusions.

There is now available a technique to help break this bottleneck, and to accelerate the tedious data reduction process to a point where it at least approaches the speed at which raw data can be generated by modern instrumentation. This technique is that of analogue-to-digital conversion, and it has already reached a point far beyond mere engineering curiosity. A wide variety of instruments has already been designed and used to prove the value of this approach.

The term 'analogue' is used here to describe a dependent parameter that varies by some ratio in the same manner as does some independent parameter.

For instance, the voltage generated by a thermocouple is analogous to the temperature differential experienced by the couple, and is hence an analogue voltage. In the same manner, the deflection of a galvanometer, the shift of a carrier frequency, or the rotation of a shaft can be continuously proportional to some other varying physical quantity, to become analogue functions. Figure 1(D) is a curve describing some such function, and is essentially an analogue plot. Analogue functions are characterized by being continuous in nature, with an infinite number of values.

The term 'digit' implies discontinuity, that is, the presence or absence of some finite symbolism describing the phenomena. Figure 1 illustrates a typical function by means of an analogue plot and by certain digital presentations. Figure 1(A) describes the function of Figure 1(D) by means of familiar Arabic symbols, while Figures 1(B) and 1(C) are typical binary records of the same information. Roman numerals or Egyptian pictures could have been shown with equal significance. The term 'binary' (or 2-state) here means the presence or absence of one type of symbol in a geometric location coded to some special significance. For instance, a hole may be punched in a card. This hole is a binary mark, in that either there is a hole or there is not a hole. This hole can then be made to take on a decimal-digital form by its location on the card. If datum points are to be assimilated by the human brain with the minimum of effort the presentation should be in a tabular Arabic form, as this best matches the brain's previous training. On the other hand, machines do not have the versatility of the brain, and they can best work on a binary signal. Machine assimilation of data is therefore usually carried out through some binary-coded data-handling system.

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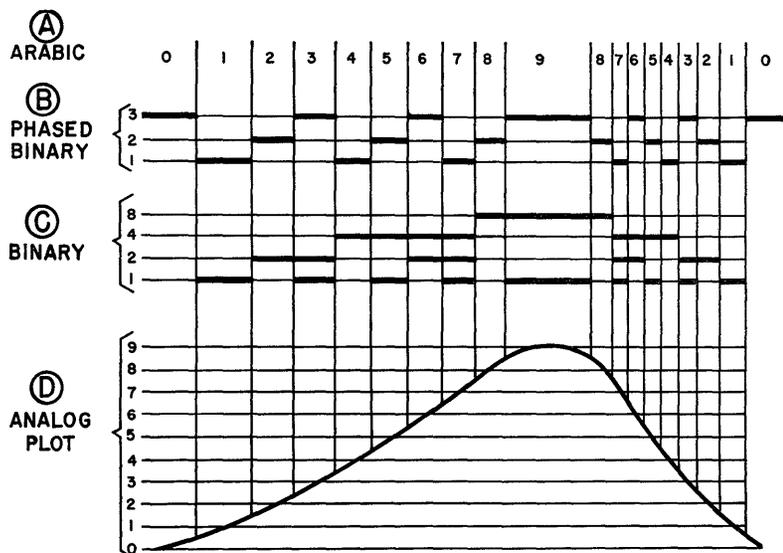
Figure 1. Typical digital presentations

(A) SLOTTED DISK

θ=f (INDICATED COUNT)

(B) MAGNETIC INDUCTION

Δ= SIDE DISPLACEMENT OF ONE SET OF CONDUCTORS IN RELATION TO THE OTHER

Δ=f(INDICATED NULL COUNT)
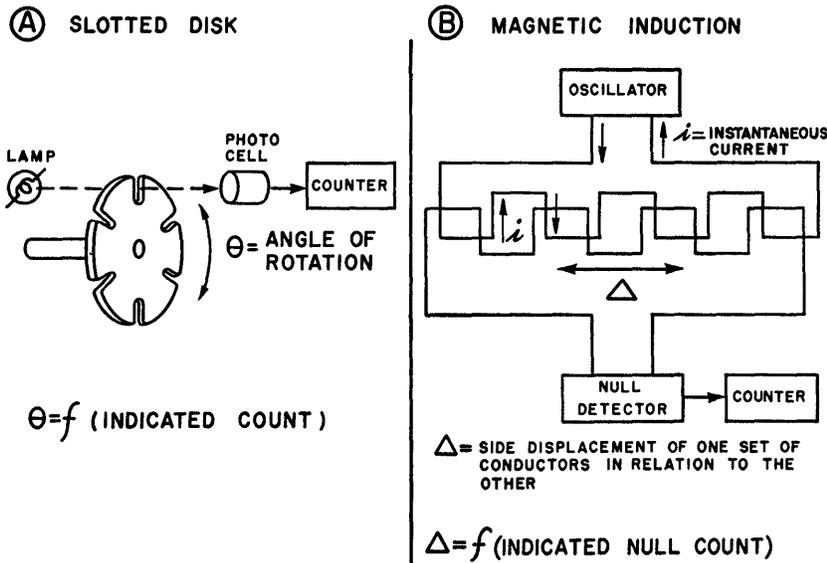
Figure 2. Direct-counting techniques

The analogue-to-digital converter is a device interposed somewhere between the analogue input information and the tabular, or binary-stored, output information. Digits result in uniform, rapid, and accurate data processing. In the past, engineering data have often been considered to be accurate only to ±1 per cent of the full-scale capabilities of the data-handling system. A good part of this feeling has arisen from the knowledge that an analogue system tends to shed some accuracy each time the data is processed, or each time it passes from one instrument in the system to another. One-per-cent system accuracy is then about all that can be economically attained in an extensive analogue system. Digital information, however, can be processed and reprocessed with no loss in accuracy, and systems capable of handling data accurate to ± 0.1 per cent of full scale can be economically assembled. The accuracy of a digital system is almost entirely a function of the accuracy of the creation of the original digits, and once the digits are available, the problem of processing is a relatively minor one. Digital information is being transmitted now over radio links, through computers, into recording devices, and the like, with excellent reliability. The key to such a system is, then, the analogue-to-digital converter.

Characteristics

A survey of analogue-to-digital converters shows that many exceedingly ingenious ideas have led to the development of useful instruments. A casual examination of these instruments might

lead to the impression that they share few features in common, but there are certain characteristics that apply to all of the converters discussed here.

The measurement of an unknown quantity generally establishes its relationship to some known standard reference quantity. The process of analogue-to-digital conversion is essentially a measurement, so somewhere in every converter there must be a standard. Of necessity, this standard will have the same physical characteristics as has the quantity to be digitized. Precision components such as resistors or condensers, precise units of distance or rotation, and standard voltages are all used as references where appropriate. Some functions are more readily standardized than others, so they

are probably easier to digitize. No converter will perform with more accuracy or stability than is demonstrated by its standard.

The output signal of all of these converters falls into one of three categories. The first of these is that of mechanical coded-contact closures. This is exemplified by the type of signals produced by relays or commutators. The advantage of such a signal form lies in its universality, as there is generally no problem of synchronization, impedance matching, or signal level matching between the converter and the device accepting the digits. For higher speed applications, one disadvantage is that it takes more time to operate a mechanism than it does to energize a purely electronic device. The second category is that of coded busses. Here a vacuum tube can control the presence or absence of a signal on a bus wire. This sort of system has speed advantages, but requires careful matching of the output signal into the receiving instrument. The third category is that of a pulse code, such as is used by telegraphers to transmit information of all kinds. Here, simplicity of transmission equipment is important but the transmitted signals must be stored somehow before they can be decoded. The first two coding techniques might be considered to be space codes, while the third is a time code.

All of the converters described on these pages operate from some form of binary signal, that is, a contact is closed, or it is not; a bus line is energized, or it is not; a specific period of time is occupied by some event, or it is not. The presence or absence of a particular binary condition in space, time, or space and time is then

(A) MULTI-CONTACT DISPLACEMENT INDICATOR

Δ = DISPLACEMENT

Δ =f (HIGHEST INDICATED NUMBER)

(B) STEP-MATRIX VOLTAGE INDICATOR

e = INPUT VOLTAGE

e=f (HIGHEST INDICATED NUMBER)
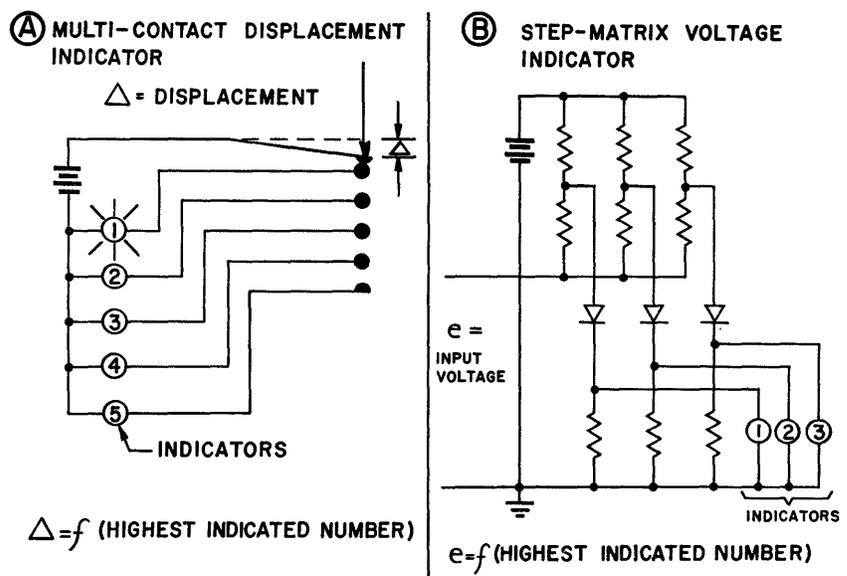
Figure 3. Incremental step techniques
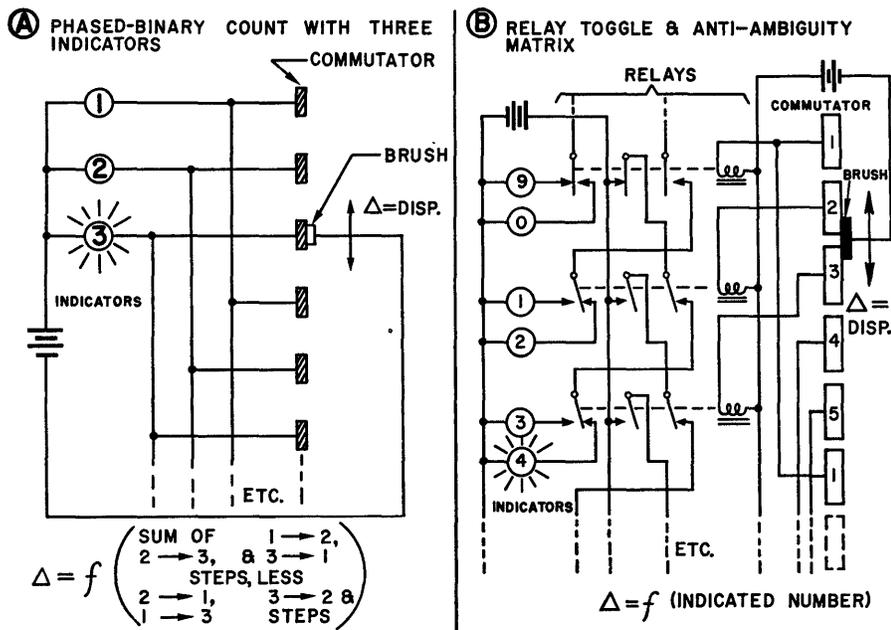
Figure 4. Commutator and brush techniques

arranged to have the intended significance. If Arabic decimal information is desired, it can be accomplished by binary coding 10 bus wires in such a way that only one of 10 is ever designated at one time. These bus wires are then used in some manner to energize the proper Arabic symbol. This action is typified by the operation of a typewriter keyboard, where the binary pressure (there is either pressure or there is not) on a key produces the number engraved on the type bar. Figure 1 includes two examples of the many possible binary codes. Figure 1(B), labeled Phased Binary, is coded to indicate incremental steps in either the plus or minus direction. This is a space-time code where the change of signal from line 1 to line 2 (also 2 to 3, and 3 to 1) indicates a plus step, while the change from line 3 to line 2 (also 1 to 3, and 2 to 1) indicates a minus step. The important information of such a system lies in the sum of the number of plus and minus steps that transpire in describing the analogue equivalent. Figure 1(C) is a fairly common system, often called binary, where the code spaces are allocated significance in the order 1, 2, 4, 8, 16, 32, and so forth. In this system, combination codes fill in the numbers between the designators. Figure 1 is intended to illustrate the term 'digit' and certainly does not give every possible example of a digit. The number of possible codes seems to be limited only by the total imagination of all of the instrument designers.

The term 'digit' is inextricably coupled with the term 'toggle.' It has already been pointed out that a digital system is a dis-

continuous one, and it is usual that some kind of toggle action provides the required discontinuity, or the rapid change from one state to another. Relays, vacuum tubes, detents, and so forth, can be used to furnish this required toggle action. If the analogue input signal changes in value over one full unit, the digital output signal should flip, or toggle, from one digit to the next at some point during this change. This toggle action is one of the factors that prevent ambiguity in the number read from the converter, as only one number should be readable at any one instant. Toggle action is required for each digit-to-digit step but in a decimal-digital system it is also required at a carry point, such as experiences in changing from a count of 99 to 100 or from 30 to 29. Here the toggle action becomes more complicated, as several digits

must correctly toggle if correct read-out information is to be available. In a decimal system, carry-toggle action of this kind is accomplished by an interchange of information between the decimal digits.

A description of an analogue data-processing device usually includes some discussion as to its frequency response characteristics. This method of comparing similar devices is so useful that attempts are often made to couple the terms 'frequency response' and 'digit' together. In defining the frequency response of such a system, the number of samples required per cycle to describe the input signal must first be determined. It has been shown that only two samples per cycle, at the highest frequency of interest, are actually needed, but there is a general feeling that more than this is usually desired. It is suggested that the term 'samples-per-second' be used in reference to devices of this type, instead of applying a cyclic caption to a sampling process. Some analogue-to-digital converters are constructed so that they can actually follow an input signal through its various changes with time, if the changes are not too rapid. Under these conditions, it is possible to sample the signal each time it changes by one digit, or to sample in equal time intervals which are short enough to give the information desired. Another type of converter searches the entire range of possible values for the correct answer, and requires the same period of time for any sample of the analogue signal, regardless of its value. If comparisons are made between converters as to their maximum sample rates, it should be noted whether this is a rate based on the digit-to-digit speed or on the zero-to-full-scale speed.
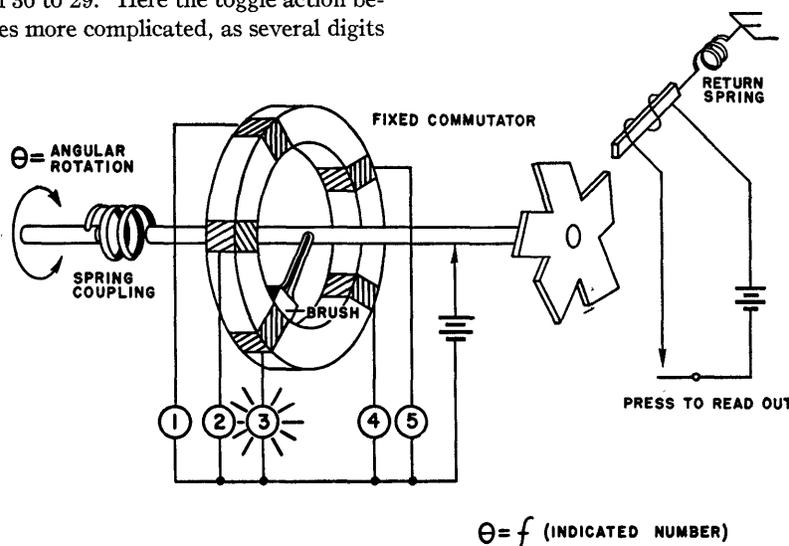
Figure 5. Forced nonambiguous techniques—star wheel

Accuracy, stability, linearity, and resolution are all subjects that apply to the process of analogue-to-digital conversion in much the same way that they apply to an analogue process. For this reason it it not felt that they need be discussed in detail here, except in connection with two special cases. Assuming that a converter has been constructed so that the input and output signals are reasonably compatible, the stability and resolution of the conversion process will be about one-half of one digital step. This ambiguous half step, combined with the toggle action which occurs between steps, usually means that the output reading of an analogue-to-digital converter is accurate to no better than ±1 digit in the number of digits read out. For maximum accuracy, it is then desirable to digitize the analogue input signals as near to the system full scale as is possible. If noise is present in the analogue input signal, the problem of conversion may be extremely difficult. Some converters are completely useless in the presence of cyclic noise because of their inability to stabilize on any single reading. Others will read out the sum of the signal and the instantaneous noise, while still others will read the peak or the average noise plus the signal. In any case, for maximum accuracy, frequency components in the analogue input signal that exceed the maximum frequency that can be digitized must be damped to the point where they do not interfere with the digital conversion.

Examples

At present, developmental effort in the field of analogue-to-digital conversion is quite intense and very fluid. It is prob-

able that over 100 different devices have been demonstrated in breadboard form in the last 3 years, although very few of these have reached the stage where they can be purchased commercially. This survey covers about 50 of these devices in particular, and it is believed that the ideas expressed here would also describe the majority of those not included. Seventeen techniques have been chosen as illustrations. Although these are grouped together as nine different figures, for convenience as much as anything else, it is not felt that this is necessarily the best classification. Perhaps devices competing for the same application would have made a more interesting grouping, but the problems of explanation would have been much more complex. The reason for this is that many specific analogue-to-digital

converters are, or could be, combined with an analogue-to-analogue converter in such a way that all techniques could be essentially competitive.

Two direct-counting techniques are shown in Figure 2. For this application, the converters are arranged to generate some kind of repetitive event which can be counted. The revolution angle of a shaft can be broken into finite segments by slotting a disk attached to the shaft. With reasonable machining care, one revolution can be digitized to an accuracy of plus or minus one count in several thousand counts. The slots can be sensed magnetically or photoelectrically, and counted in an electronic counter. Special arrangements of the sensing device can be used to detect the phase of the count, and the counter can be made to count up or down, depending on the direction of the rotation. The instantaneous count in the counter is then the digital measurement of the shaft position in relation to its position at a zero count. In much the same way, the relative motion of the two conductor grids generates nulls and peaks in the detector circuit which can be counted. This technique tends to average the dimensional location errors and may be potentially the more accurate of the two. The output signal from both of these converters is a time code.

Figure 3 describes two incremental-step techniques. The step-matrix voltage indicator is essentially the electrical equivalent of the multicontact displacement indicator. In this device a crystal is biased at each of the desired voltage increments. When the input voltage is equal to one of the bias voltages, the current through that circuit will suddenly
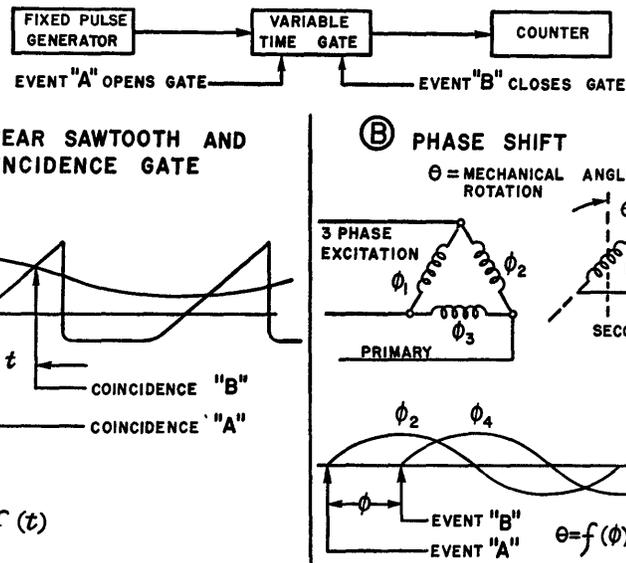
Figure 7. Chronometric techniques
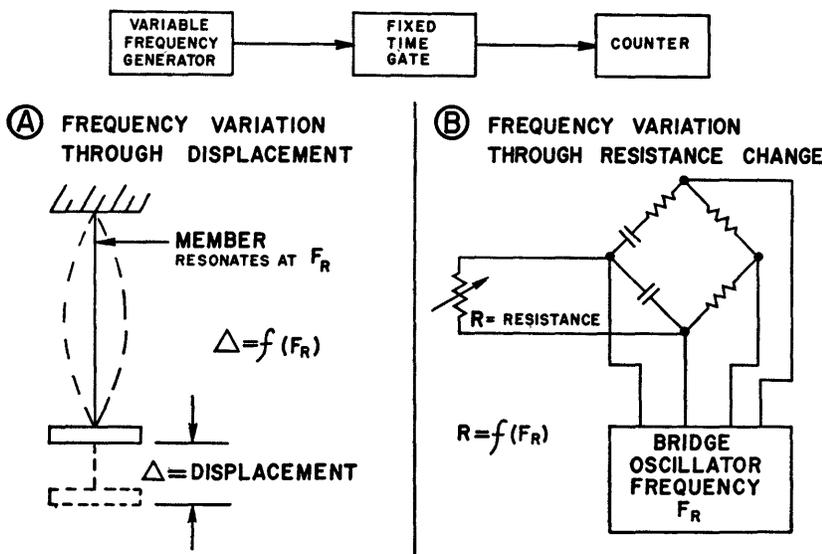
Figure 6. Fixed-interval techniques

(A) BINARY-CODED DISK

PHOTO CELLS

DISK

$\Theta=$ ANGLE OF ROTATION

$\Theta = f$ (CODE)

(B) FLYING SPOT WITH CATHODE RAY TUBE

COLLECTOR RASTER

e=ANALOG INPUT VOLTAGE

SAWTOOTH VOLTAGE GENERATING "FLYING SPOT"

$\Theta = f$ (RASTER PATTERN)

OUTPUT RASTER CODE
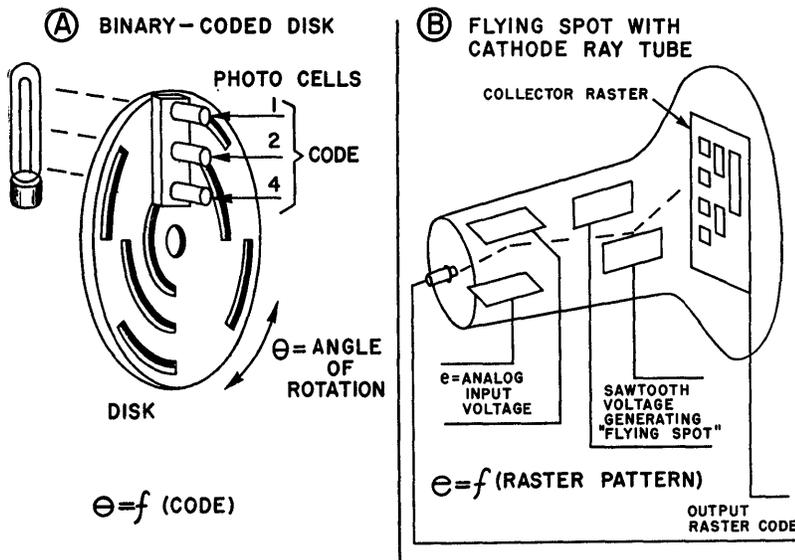
Figure 8. Raster techniques

change, and can be used to actuate an indicator. It is probable that this technique can have the highest possible speed of response, as the speed limitation is primarily a function of circuit capacitance. Each of these converters produces a space code.

Figure 4 demonstrates some of the things that can be done with a commutator and a brush. The phased-binary presentation of Figure 1(B) is producible by bussing every third commutator bar to actuate three indicators in a space-time code. It is not even necessary that the brush span the distance between two bars, as the absence of a signal can carry significance in this case. An ambiguous space code can be prevented if the commutator bars are spaced very close together and the brush is equal to one half the width of one bar. In this case a relay matrix can unscramble the code into decimal significance, as is shown. One other commutator-brush converter has an exceedingly clever method of actually toggling the brush itself so that it jumps from bar to bar, and never stops on or between two bars.

The principle illustrated by Figure 5 is a relatively simple one, but it requires a rather complex drawing, so only one example is shown. In this case the analogue input information is in the form of a shaft angle. . A star-wheel-and-commutator combination is elastically coupled to the shaft, so that its position duplicates the shaft angle until read-out is desired. Just before read-out, a solenoid-operated plunger forces the star wheel to align the brush directly onto the nearest commutator bar, which then provides the desired digital signal.

. If the oscillations of a frequency-

modulated signal are counted for a fixed period of time, the count can be made to describe the modulating function. Figure 6 shows two well-known methods for changing the frequency of an oscillating system. The vibrations of a wire under tension can be sustained at the natural frequency, or some harmonic, by magnetic-electronic means, and the frequency can be varied by changing the tension. In much the same way, changes of resistance, capacitance, inductance, or voltage can be made to change an electronic oscillator's frequency. These methods are generally nonlinear, and require some technique of zero suppression, but can be made to give useful results.

Figure 7 describes the converse of Figure 6. Here chronometric pulses are generated, and gated into a counter by

one event, and the counter is stopped by another event. The resulting count in the counter is a measurement of the elapsed time between the two events. A linear saw-tooth voltage, coinciding with a zero signal and an input voltage, can be made to digitize the input voltage. In much the same way the phase relationship between two alternating signals can be measured. This is a very old approach and has been used in ballistic studies and in timing races.

Figure 8 shows two ways in which a raster can be used to provide the digital signals. Example A makes use of holes in a disk to control the passage of light from a source to a group of photoelectric cells. The holes and photoelectric cells are then mutually coded to give a space binary code. This device would not actually work very well as shown, because the particular code used has a tendency to become ambiguous if there is any instability in the system. Other codes have been used that will accurately divide one shaft revolution into several thousand parts. The same raster is capable of producing a time code if the so-called flying spot is used to develop a time axis. Example B makes use of the beam in a cathode-ray tube driven by a saw-tooth voltage on the horizontal axis. The verticle voltage is then digitized by the interruptions of the beam caused by that part of the raster over which the flying spot passes. A galvanometer driven with a saw-tooth current and a single photoelectric cell could accomplish the same effect with the coded disk of example A.

Two methods using continuously rotating drums are pictured in Figure 9. In

(A) DRUM, GALVANOMETER, PHOTOCELL & FLASH TUBE

OPERATION OF PHOTOCELL TRIGGERS FLASHTUBE

PHOTO CELL INSIDE DRUM

FLASH TUBE

i INPUT

GALV.

LAMP

$i = f$ (FLASHED NUMBER)

(B) MAGNETIC DRUM SHAFT ANGLE INDICATION

READING HEADS

$\Theta=$ ANGLE BETWEEN HEADS

DRUM

READING HEAD ON MOVABLE SHAFT STOPS COUNTER

CONTINUOUS CLOCK PULSES

COUNTER

ZERO PULSE (RESETS COUNTER)

$\Theta = f$ (INDICATED COUNT)
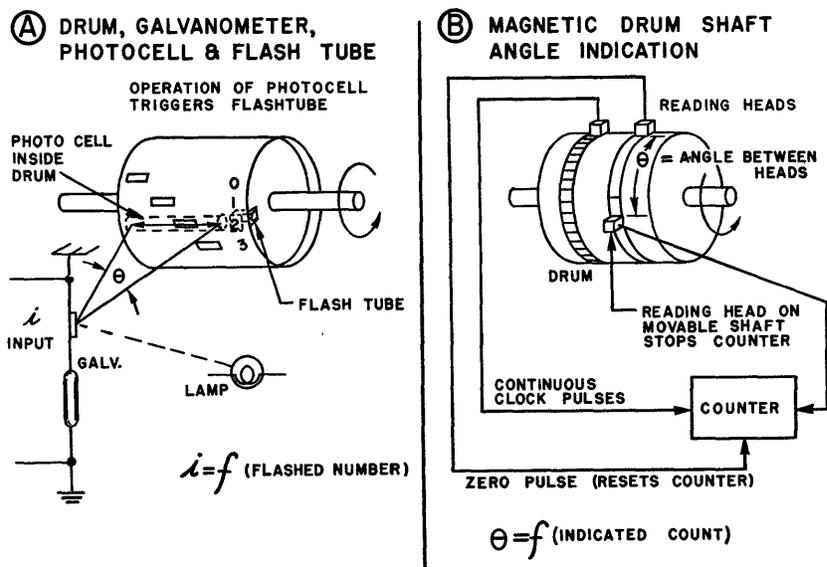
Figure 9. Synchronous drum techniques

both of these examples there are two information areas on the drum that are mutually synchronized by their physical locations. Example A requires a hollow drum whose cylindrical surface is perforated by two types of symbols. Inside the drum, in back of some small slits, is a photoelectric cell, while in back of the appropriate Arabic numbers is a flash tube. The photoelectric cell and flash tube do not rotate with the drum. If light ever impinges on the photoelectric cell the flash tube will be energized and the number that is currently passing in front of the flash tube will be illuminated. The slits are then arranged around the circumference of the drum in such a way as to synchronize with the proper symbol, and along the axis of the drum to break up a linear distance into incremental steps. If the spot of light from a galvanometer's mirror is then reflected onto the area of the drum which includes the slits, it will fall on only one of the slits per drum revolution and only one number will be illuminated, indicating the galvanometer's deflection. Example B makes use of a magnetic drum on the periphery of which are recorded two pulse tracks. The first of these has a multiplicity of pulses which break up the circumference of the drum into the desired number of digits. The second pulse track has only one pulse recorded on it. There is a fixed head reading each of the two tracks and a movable head reading the single pulse track. An electronic counter can then be used to count the number of pulses on the drum between the

A   ANALOG-TO-DIGITAL CONVERTER
B   ANALOG AMPLIFIER
C   X-Y PLOTTER
D   DIGITAL-TO-ANALOG CONVERTER
E   PROGRAM UNIT
F   CARD PUNCH DATA STORAGE UNIT
G   TABULATOR
H   REMOTE CONTROL UNIT
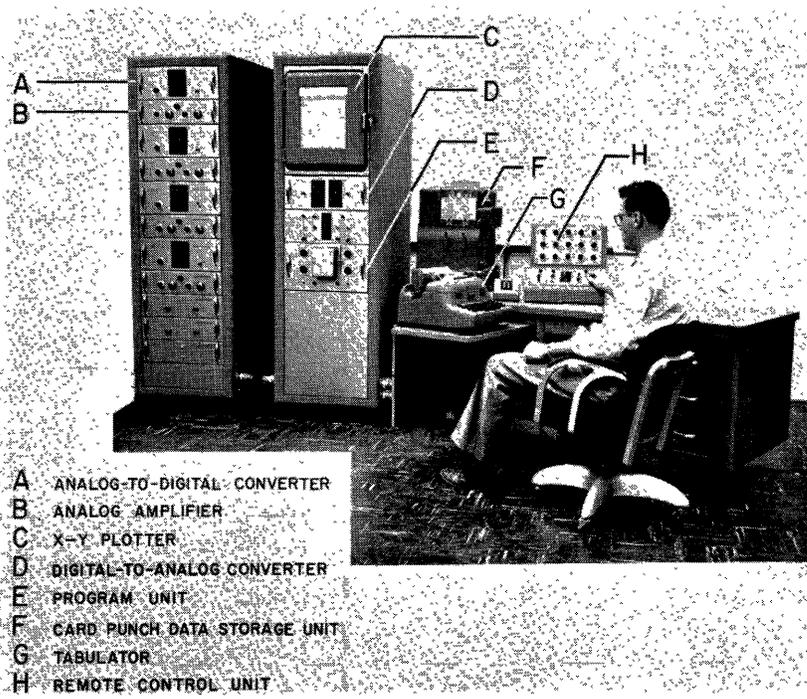
Figure 11.   Analogue-to-digital conversion

fixed head and the movable head in such a way that the angular distance between the two heads is indicated.

Figure 10 includes two self-balancing or null-detecting techniques. The first of these is nothing more or less than a standard self-balancing potentiometer with the slide wire replaced by a Thompson-Varley decade. In this particular example individual plus-minus stepping switches operate on each decimal-digit to achieve the maximum speed of balance.

The second example might be considered to be an electronic equivalent of a self-balancing potentiometer. A phase-sensitive detector, working from the difference between the input voltage and the voltage generated by an adder circuit, controls the flow of pulses to a toggle counter, which in turn controls the voltage of the adder circuit. The circuitry of such a device becomes rather complex, so symbols are used here, but it should be understood that all of the indicated functions can be done electronically for maximum speed of response. The Thompson-Varley output signal consists of coded-contact closures from the stepping switches, while the electronic counter circuit produces a bus code from one side of each toggle.

All of the analogue-to-digital converters described here have been reduced to their bare essential features for the purpose of this discussion. This was done so that lengthy descriptions of each device would not be necessary. Most of the successful instruments are considerable elaborations on these basic ideas.

Systems

Analogue-to-digital converters are useful devices in themselves, but they demonstrate their greatest worth when they are incorporated into a system. Figure 11 is a typical digital data-processing system. For the sake of identification, this might be called a multichannel quasi-static system, where quasi-static means that the input signals change only at the discretion

Figure 10.   Null detector techniques

of the operator. For example, in the collection of data from a wind tunnel, the operator initiates the data-handling cycle when he is satisfied that the model is adjusted properly, and that conditions in the tunnel are stabilized to the point where data of some significance can be taken. After the data have been collected, the conditions in the tunnel are changed and the cycle is repeated. This particular system is chosen as an example because it contains all of the essential features of a 'complete' system.

The system illustrated consists of four channels of analogue-to-digital conversion equipment, a remote control unit, a plotting unit, a tabulating unit, a storage unit, and a program unit. After this system is set up, adjusted, and calibrated, an operator at the remote control point can examine the input channels, decide on their reasonableness, freeze these data, and initiate the readout cycle. The data collected by the system are then automatically tabulated, plotted, and punched into the cards.

For the sake of this illustration, it might be assumed that this system is operating from the output signals of four strain gauge bridges attached to a model in a wind tunnel. The analogue voltages generated by the strain gauges are amplified and converted to their equivalent digits by the action of individual digital self-balancing potentiometers. The coded-contact closure signals from these potentiometers indicate the balance points accurate to three decimal places, the polarity of the balance points, the attenuator settings, and whether or not there is an actual balanced condition in each channel. The calibration of this system will include simple analogue computations in the input amplifiers, which change the significance of the digits to some desired linear function. Zero suppression (addition or subtraction) and scale factor adjustment (multiplication or division) controls are available on the front panel of each amplifier.

The remove control unit includes 15 rotary switches that allow the introduction of arbitrary fixed constants into the tabulator and card format. These constants can be used to indicate dates, model configuration, test numbers, and other information that does not change

as a result of the test. The program unit controls the flow of information from the converters and the fixed-constants on the control board into the tabulator and the card punch, and from the digital-to-analogue converter to the X-Y plotter. A plug board is provided to allow flexibility in the program and information format. A run number, generated each time the program completes a cycle, is recorded along with the other digits. A possible format might be as shown in Table I. The same information would be punched into the cards, with one card for each tabulated row. These cards can then be used to control a computer for complete data reduction.

The digital-to-analogue converter can receive two 3-digit numbers, and pass equivalent analogue signals to the plotter unit for control of the X and Y plotting axes. These digits can be programmed automatically, introduced by hand at the remote control point, or read from the punched cards, as circumstances dictate.

If the operator has control of only the start of the test and must take data at fixed intervals of time thereafter, the required system might be called a dynamic data-processing system. An application example would be that required for processing data during a rocket's flight. Here, high-speed conversion and control equipment are required, with perhaps a recording oscillograph replacing the electromechanical plotter and a magnetic-tape recorder replacing the card-punch unit. Tabulation and computation could be done at the end of the test by playing back the magnetic tape at a reduced speed. Dynamic data-processing systems usually generate a great deal of unwanted data to assure the collection of the desired data, so some method must be available for separating out the useful information at the end of the test; otherwise, the system philosophy is not much different from that of the quasi-static example.

It has been shown that an analogue-to-digital converter can be a very important part of an automatic data reduction system. Of course, such instruments are not the complete answer to all of the data reduction problems, as they furnish but one step in the process. Plotters, tabulators, storage devices, matching equipment, and computers must all be considered as a

part of such a system, and the characteristics of the analogue-to-digital converter must be compatible with their characteristics as well as those of the analogue signal. At present, an analogue-to-digital converter is considered something of a novelty, but in the future its use will become commonplace. Applications that are imminent, if not current, include wind tunnels, engine test stands, telemetry, static structural tests, industrial process control, computer inputs, and so forth.

Appendix I. Information Sources

Company Brochures

Arthur D. Little, Inc.
Atomic Instruments Company
Beckman Instruments, Inc.
Benson-Lehner Corporation
Berkeley Scientific Company
Clary Multiplier Corporation
Consolidated Engineering Corporation
Electronic Engineering Company of California
Engineering Research Associates, Inc.
Institute of Inventive Research
Melpar, Inc.
Metrotype Corporation
Potter Instrument Company
Streeter-Amet Company
Taller and Cooper, Inc.
Telecomputing Corporation
Westinghouse Electric Corporation
Wright Engineering

Sources of Projects Not Yet Published

Benson-Lehner Corporation
Consolidated Engineering Corporation
Cornel Wind Tunnel Instrumentation Group
Electro Circuits Company
Massachusetts Institute of Technology, by Sisson and Susskind
National Advisory Committee of Aeronautics, Lewis Laboratory
National Bureau of Standards Survey, by G. G. Bower
Naval Research Laboratory, by A. M. Rothrock
Office of Naval Research Survey, by N. M. Blachman
Tally Register Company
Telecomputing Corporation
Wallind-Pierce Corporation
Wright Field Wind Tunnel Instrumentation Group

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2. MATRIX TELEMETERING SYSTEM, N. R. Best, *Electronics* (New York, N. Y.), volume 23, number 8, 1950, pages 82–5.

3. HIGH-SPEED RECORDING POTENTIOMETER, Ralph B. Bowersox, Chester G. Hylkema. *Memorandum Number 20-69*, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif., January 16, 1952.

4. DIGITAL DATA RECORDING AND TELEMETERING INSTRUMENT, F. H. Davis. *Navord Report 1219*, Naval Ordnance Test Station, Inyokern, Calif., November 16, 1949.

Table I

Test	Date	Run	X	Y	Z	Number 1	Number 2	Number 3	Number 4
21	1-21-52	01	0 10 0	15 1	00 1	−251 2	354 1	791 4	−697
21	1-21-52	02	0 10 0	15 2	00 1	−264 2	300 1	988 4	−501
21	1-21-52	03	0 10 0	15 3	00 1	−281 2	265 2	525 4	−275

5. Automatic Data Reduction, E. Donath. Applied Science Corporation of Princeton, Princeton, N. J., December 6, 1951.

6. Step Multiplier, E. A. Goldberg. *Electronics* (New York, N. Y.), volume 24, number 8, August 1951, pages 120–24.

7. A Five-Digit Parallel Coder Tube, Harrington, Spencer, Wulfsberg. Massachusetts Institute of Technology, Cambridge, Mass.

8. A Dial-Reading Translator for Digital Machine Inputs, Arthur L. Klein, Kenneth P. Gow. *AIEE Transactions*, volume 71, part II, 1952, pages 137–44.

9. Anodige, an Electronic Analogue-to-Digital Converter, M. L. Kuder. *Report Number 1117*, National Bureau of Standards, Washington, D. C., August 24, 1951.

10. A High Precision Analog-to-Digital Converter, B. Lippel. Signal Corps Engineering Laboratories, Fort Monmouth, N. J.

11. Electron Beam Deflecting Tube for Pulse Code Modulation, R. W. Sears. *Bell System Technical Journal* (New York, N. Y.), volume XXVII, number 1, (pages 44–57).

12. The SADIC, A Precision Analogue-to-Digital Converter, R. L. Sink, G. M. Slocomb. Consolidated Engineering Corporation, Pasadena, Calif., August 1951.

13. Telemetering by Pulse Code Modulation, B. D. Smith. Melpar, Inc.

Discussion

H. F. May (Teleregister Corporation): What speed can be achieved with 0.1 per cent accuracy in converting a voltage to digital value?

Mr. Burke: This is dependent on the signal. Voltage in itself can extend all the way from a very low to a very high level. I would say that it is possible to digitize something less than 100 volts to 0.1 per cent accuracy. This is based on the Miller sweep, which is capable of sweeping over this range to an accuracy of 0.1 per cent or better.

In the case of a millivolt, I would be very doubtful. This goes back again to the necessity for matching the analogue-to-digital converter to the system in question.

In the case of strain gauges or thermocouples, I doubt if the Miller sweep can get a 10 per cent accuracy. Let us say, for less than 100 volts, two or three times a second is quite easy. For something in the order of a millivolt, once a second is possible. The reason for this lies with the problem of amplification and identification. At these low levels the only thing I know of that will do it is the mechanical chopper. There are only two choppers that I know of that will do the job; one is capable of 400 or 500 motions a second, achieving several times a second; the other, 60 times a second. The chopper determines the carrier frequency, and the carrier frequency determines the speed response of the system. Generally, the speed response is considered to be approximately 10 per cent of the carrier, but this is a holdover from 1-per-cent systems. When talking of 0.1 per cent, it is not possible to approach that high percentage of the carrier; for example, a 60-cycle carrier gives a 1-cycle response.

J. S. Fondrik (General Electric Company): I am very much confused by your first slide. You have a nonuniform sampling rate. It looked to me as if you were not converting from analogue to digital, but really from analogue to some other analogue.

Mr. Burke: There are several conversion techniques possible. One technique is to convert digitally so many times a second. The other is to convert digitally at such-and-such an increment of the analogue signal. The slide purposely showed the latter, because most people think in terms of the former. This was a conversion that changed at increments of signal level, not in timing.

Mr. Francis A. Collins (Atlantic Refining

Company): Has any work been done on converters for old or dead data which are available only as a graph?

Mr. Burke: Yes, there has been a lot of work. One technique which has been used for a long time has an operator adjust a set of cross-hairs on a projection of the graph and then convert the cross-hair position. In two cases I know of, this system has been used. It is almost like the flying-spot technique, where the position of the flying spot coincides with the graph, and triggers some other circuit; the zero position of the flying spot can open a gate and the coincidence uses the signal on the graph to close the gate, becoming a conversion like the photomagnetic technique shown by the slide.

Capt. R. W. White (Air Development Center, Wright-Patterson Air Force Base, Dayton): Would you care to comment on which of the many techniques you described best lends itself to a high accuracy, that is, a large number of digits for any given range?

Mr. Burke: I would rather not comment. Part of this reading again depends on what is being digitized. For instance, in my opinion, shaft position is the easiest thing to digitize because the reference is some scribe mark on the shaft bearing which can be quite precise. I have heard terms bandied about all the way from 1,000 counts to 1,000,000 counts. I have never seen anything over 3,000. I am not in this area, so I don't know the whole story.

W. D. Deutsch (General Electric Company): It is apparent that in applying the techniques of analogue-to-digital conversion to any type of engineering or scientific test, the equipment chosen must satisfy the type of testing that is being carried on, since digitizing analogue data represents a sampling of the analogue information. The sampling periods in samples per cycle or in samples per second must be well chosen in order to represent as true as possible a picture of the analogue information.

In any type of test work, each test will have its own time rate for such things as stabilization and transient conditions. These considerations will be important in proportion to the type of test which is being performed. Consequently, the selection of equipment must be guided by the test performed as to the necessary speed of the equipment, the accuracy required, and as to whether or not digitizing the information is warranted.

In many cases, analogue presentation of the data in the form of graphs, and so forth,

represents the desired end point in a test. In other cases numerical results are called for, and we should look into these cases in particular for the application of analogue-to-digital conversion techniques.

As Mr. Burke has pointed out, it is possible either to parallel (space) code or serial (time) code a digital word. It should be noted that for high-speed work, space coding is definitely required because time coding will reduce the available amount of time for each digitizing operation, and hence result in less possible samples per cycle than could the space-coded method.

In the seminar discussions, it was noted that for large-scale fixed slow-speed tests such as running wind tunnels and in engine development, relatively low speed digitizing equipment could be applied, and this equipment might be of a fairly large and heavy nature. In other words, chair-borne equipment. However, for flight testing, it is obvious that much lighter and smaller equipment would be necessary. It was generally agreed in the seminar that at present, analogue techniques are far superior to present-day digitizing techniques for the telemetering of parameters such as temperature and pressure. Therefore it would seem that the most promising solution for high-speed data from flight testing would be to telemeter analogue data and to make the conversion of the data after they are once recorded and correlated to reduce redundancy.

For that reason, equipment is required for the conversion of already recorded or dead data to the digital form. Equipment of this type, should it be developed, would find wide use in the missile test field and in flight test of manned and unmanned aircraft.

It should be remembered that for optimum utilization in any specific type of testing where data is to be digitized, the conversion system should be designed as a system, not as a series of unrelated black boxes or gadgets which, taken together, will work, but not as effectively as a properly designed co-ordinated over-all system.

Of the 33 people who attended the Thursday evening seminar on the subject of digitizing scientific and engineering data, some 10 were manufacturers, and it is hoped that these people will return to their laboratories and produce the desired and necessary equipment for the fulfillment of the requirements of those who are performing such tests.

Survey of Mechanical Printers

J. C. HOSKEN

BY THE time computers become really sophisticated, they will communicate their findings to other machines in machine language and they will only produce the most concise progress reports in typescript. However, until this comes about, it is unfortunately necessary that computers shall have large outputs which their masters must read. By the time clerical machines are really well-developed they will produce bills in machine language which we shall put directly into our private check writers which will then prepare the checks and address the envelopes for us in machine language suitable for the automatic accounting machines and the automatic mail-sorting machines. But until that time we shall need high-speed printers to deal with the enormous output of clerical machines.

Many people have ideas about how high-speed printers might work but there are not many of these desirable devices available in the hardware stores. Because we all have more things to read than we can possibly cope with, I have been instructed to prepare a short and easily digestible summary of the high-speed mechanical printers now available or in embryo. The subject of this paper is mechanical printers in which, generally speaking, something solid hits a piece of paper to transfer ink to it. Lt. R. J. Rossheim is to deal with flying ink spots, magnetic powders, electrical and chemical discolorations, and photographic devices.

Requirements for High-Speed Printers

Consider first the form of the input, then the form and speed of the output required from a high-speed printer. Then look at the various classes of printer which have been developed. Table I illustrates the approach.

The kinds of input which most concern us are typescript, punched tape, punched cards, magnetic tapes, and drums, and pulse signals directly from computers. The ouptut required may be tabular, address labels, forms of various sizes used for bills, orders, notices or reports; and any number of copies may be required.

The speed requirement varies widely. The output from a computer may be

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small and intermittent. This can obviously be dealt with by storing the information on a magnetic tape and feeding the tape slowly but continuously into a relatively slow printer. On the other hand, it may be necessary to tabulate for reference a large amount of information, as in census work, or in mathematical tables. Clerical machines may have an enormous output of bills, premium notices, orders or reports and the speed-limiting factor may be the movement of the paper or the speed at which the input can be sensed. A punched tape can be read at 200 characters a second, a magnetic tape at 10,000 or 12,000 characters a second. Punched cards can be read at 10 or 15 a second which means about 1,000 characters a second. Continuous paper feeds of 20 or 30 feet per second are used in newspaper printing, so continuous paper speed is not a serious limitation; but intermittent paper feeds are limited to the order of 15 or 20 lines or controlled movements a second. There are probably few cases where continuous output speed greater than 15 or 20 lines a second is warranted. For very large outputs it is always safer to have several relatively small units rather than one very large one which, if it fails, holds up production completely.

Printers Developed to Fulfill These Requirements

Five general kinds of mechanical output printer have been developed so far:

1. The single-action typewriter variety with solenoid or pneumatic control.

2. The line-at-a-time printer used for printing calculators and punched card tabulators.

3. The on-the-fly machines with continuously revolving type wheels and accurately timed hammers.

4. The matrix machines which form characters by selective operation of a matrix of dot-producing hammers.

5. The bar and helix machines which use the same principle as facsimile devices.

SINGLE ACTION

These printers usually consist of typewriters controlled by solenoids or pneumatic bellows. Ten characters per second is the usual speed limit, though Underwood claims 20 characters per second

for the typewriters used as the output for the Harvard Mark III computer. Several firms have fitted solenoids to standard typewriters and the Autotypist and Robotyper use a conventional 'Pianola' mechanism with a motor-driven crank.

For many years Teletype machines have been made using typewriter mechanisms operated from punched tape or line signals through mechanical decoders. The principal makers are Teletype Corporation and Kleinschmidt Laboratories. Teletype Corporation is now bringing out a new kind operating on a rather different principle but still single-acting and in the same speed range of 10 characters a second. In this, their model *28*, a light, rectangular type box containing separate pallets for each character, is substituted for the regular type basket. The type box provides the shift function so that the normal typewriter carriage carrying the platen is not needed.

The Flexowriter is in the same speed range but its design provides greater flexibility for uses outside the normal communications field. It consists of an extra rugged International Business Machines (IBM) electric (that is, electric motor-driven mechanical) typewriter with various optional units attached. These include a tape punch, a tape reader, a mechanical encoder, a mechanical decoder, and justifying equipment (with this attached it is called the Justowriter). The tape used can be 5-, 6-, 7-, or 8-hole, and the encoder and decoder can be easily changed to any code needed.

Line-at-a-time printers were developed for desk computers and punched card tabulators. Most use a type bar with a complete set of pallets opposite each character position in the line. In the usual mechanism the type bars are mechanically returned to the home position and then allowed to rise under spring tension as far as a set of individual stops actuated by the signal through a mechanical decoder. A set of hammers strikes the pallets against the paper which is held on a platen roll. For greater speed, type wheels are used instead of type bars. Type bars are used in IBM and Remington Rand tabulators and Engineering Research Association (ERA) printer. Type wheels are used in the IBM type-*407* accounting machine and the Bull tabulator. These tabulators are designed around punched card input and include a number of mechanical devices necessary in punched card accounting systems. The decoding systems are tied in with the particular punched card codes used. Electrical or mechanical patchboards are used to enable information

Table I

		INPUT							DECODING	ARRANGING		ENCODING	TYPE				PAPER			SPEED (PER SEC)	
		KEYBOARD / PIANOLA ROLL	TYPE	PUNCHED TAPE	PUNCHED CARDS	MAGNETIC	DIGITAL COMPUTER		INPUT/CHARACTER	SERIAL/PARALLEL LAYOUT		ACCUMULATING	NUMBER OF CHARACTERS	CHARACTERS PER INCH	LINES PER INCH	CHARACTERS PER LINE	DRIVE	WIDTH	COPIES	CHARACTERS	LINES
SINGLE ACTION	KEYBOARD	TYPEWRITERS X											84	12	6		FPi	7		10	
		ADDING MACHINES X										M									
	SOLENOID CONVERSIONS	UNDERWOOD	X										12	12	6		FPi			20	
		BENSON-LEHNER	M										12	12	6		FPi	7		10	
	PIANOLA	AUTOTYPIST X X											84	12	6		FPi	7		10	
		ROBOTYPER X X											84	12	6		FPi	7		10	
	MECHANICAL DECODING	FLEXOWRITER X	X						EM				84	12	6		FPi	7		10	
		TELETYPE X	X						EM				42				F			10	
		KLEINSCHMIDT X	X						EM								F			10	
LINE-AT-A-TIME	TYPE BARS	IBM			X				EM	EM	EM	M	37	6.5	8	88	Pi	7			
		RR			X				M		M	M	37	6.3	6	100	Pi	7			1½
		ERA			X				EM	EM											1
	TYPE WHEELS	IBM			X				EM	EM	EM	M	48	10	6	120	Pi	15	7		2½
		BULL (RR & FERRANTI)			X X				EM			M	36	6.3	6	92	Pi	5			2½
ON-THE-FLY	SINGLE WHEEL	POTTER			X X			E	E	E Ph	E	47	10	6	80	FPi	4		10	
		WHEATON			X X			E		IP							F			15	
	MULTI-WHEEL	ANELEX X	X X X					E	E	IP			5	4	40	F	8½		15	
		SHEPARD			X X			E	E			55	6.3	5.3	120	Pi	20	4		10	
		UNIVAC (RR)			X				EM				63	10	6				6		3½
MATRIX BAR & HELIX	SIMULTANEOUS	IBM X		X					M				37	12		80	F	PC	1	25	
		CIC/BURROUGHS		X									8	6	36		Pi	4		15	
	SCANNING	EK-		X X X X				E	E		E		10	5	V	Pi	V	3	350 V	
	OPTICAL SCAN	EK/AM X							Ph				11V	5.3	25V		Pi	3½	2		8 V

E = ELECTRONIC   EM = ELECTRO MECHANICAL   F = FRICTION   IP = INDUCTION PULSE GENERATOR   M = MECHANICAL   V = VARIABLE

PC = PUNCHED CARD   Ph = PHOTOCELL   Pi = PINFEED

from any part of the card to be printed in any location or locations on the form or forms. Mechanical accumulators fit in very well with this kind of tabulator and are built in. These tabulators are therefore highly specialized devices and not necessarily adaptable to electronic computer needs. One machine of this type was built by ERA for a government job. It had an electrical input. A tabulator is made in France by Ste. des Machines Bull. It is handled in the United States by Remington Rand, and a modification of this tabulator is used with the Ferranti Computer.

The output of these tabulators is normally pin-fed forms and the speed limit of the type bar machines is about 1½ lines per second. The type wheel machines can operate up to nearly twice this speed. The ERA machine operates at one line per second. Owing to the bulk of the mechanism, there are limitations on the closeness of the characters. For instance, the Remington Rand tabulator prints about 6 characters per inch.

Figure 1 (below). Teletype model-28 printer

Figure 2 (right) Flexowriter translator

SEEKER

PERMUTATION BARS TRANSLATER SLIDE

COIL

ARMATURE

PRINT LINE

PRINTING PLUNGER

CONTACT DRUM

STOP PAWL
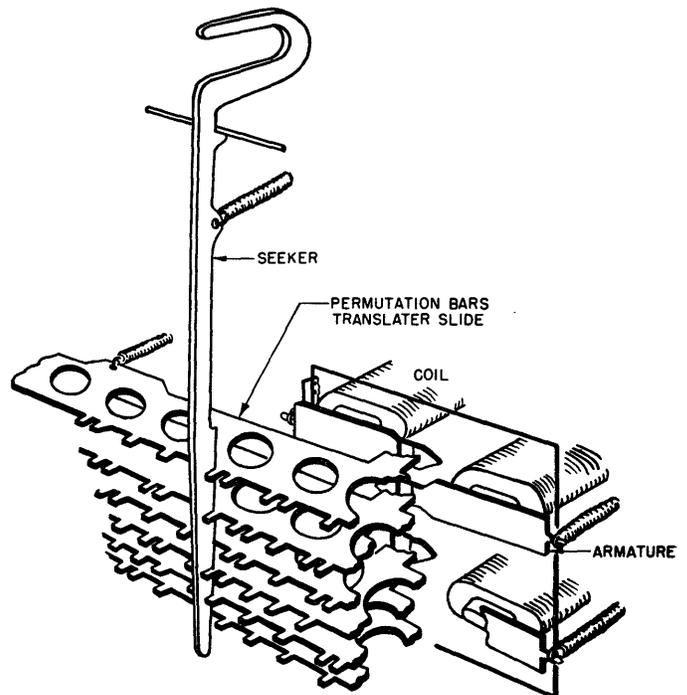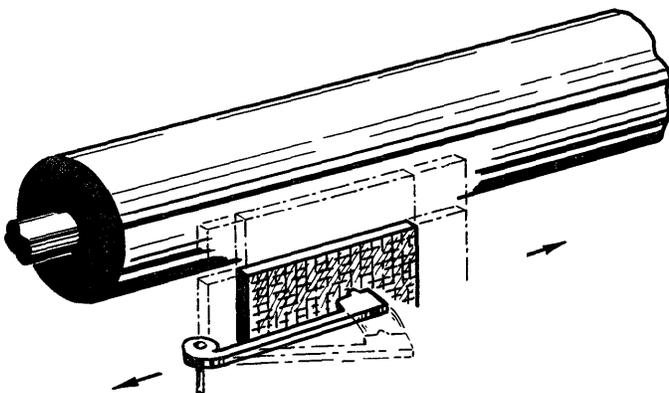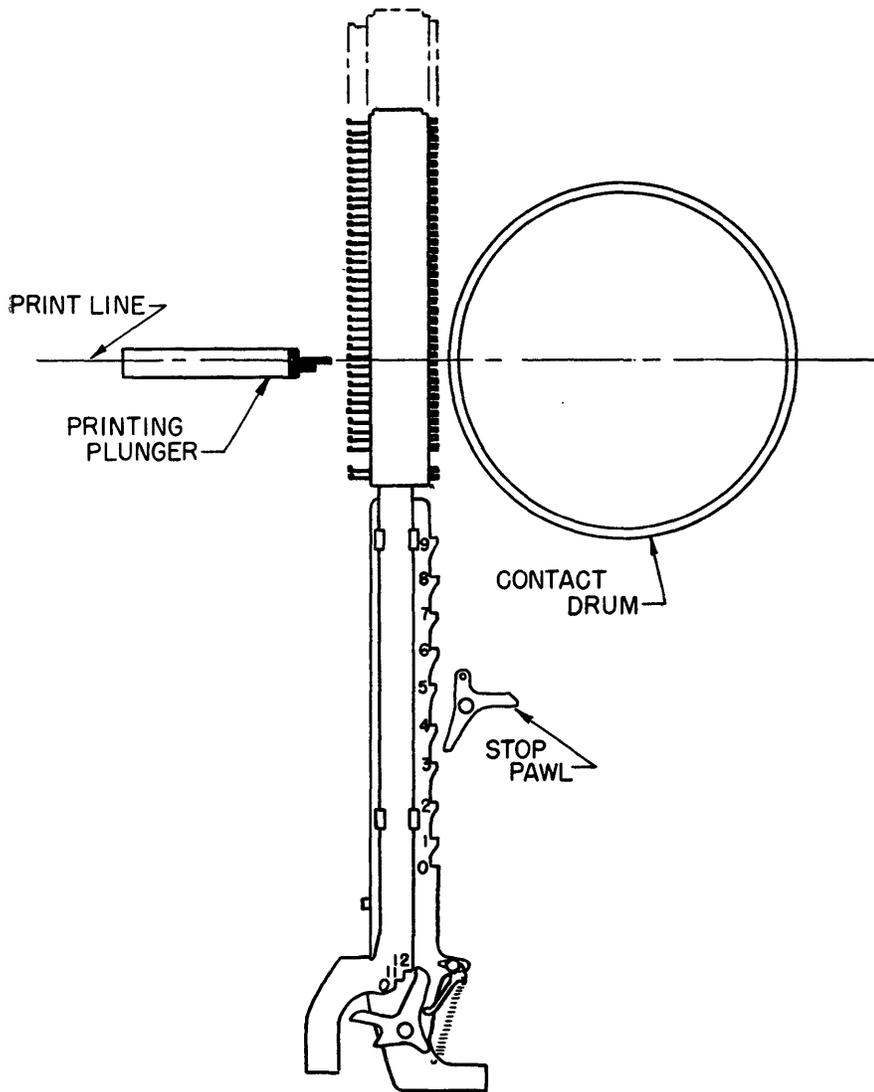
Figure 3. IBM type bar
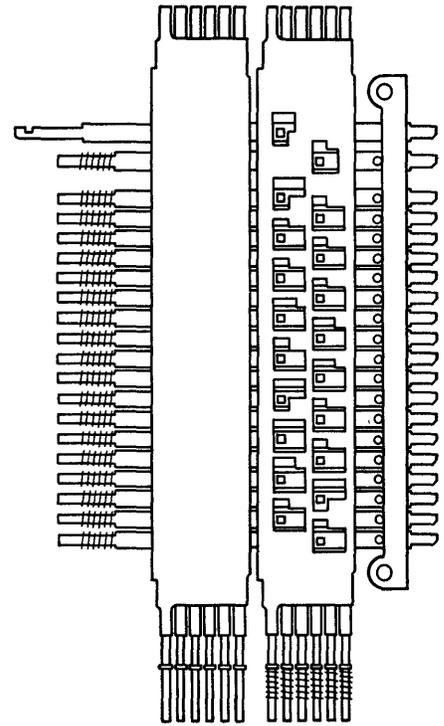
Figure 5. Remington Rand decoder

On-the-Fly Printers

A logical development from the intermittent-motion print wheel machines is the on-the-fly printer in which the print wheel rotates continuously and a light fast-acting hammer presses the paper against the wheel at the moment the required character is in position. Shortly after World War II the Armed Forces Security Agency let a contract for the development of such a printer. The first one was made by Wheaton Engineering Company and printers of this kind are now available from ANelex Corporation and Shepard Laboratories. These have one print wheel per character position. The new Univac printer is to be of this type.

A printer of this kind requires not only a decoder to translate binary signals into individual character signals but also a character timing encoder and a temporary memory for each character position. The encoder is needed to delay the signals to the hammers until the correct character arrives. The memory is required if the input is serial, as from a magnetic or

PRINT CLUTCH DOG
TYPE WHEEL HANGER
TYPE WHEEL
PRINT CLUTCH REAMER
PRINT CAM
PLATEN
SELECTOR CLUTCH REAMER
SELECTOR CLUTCH GEAR
SELECTOR CLUTCH DOG

Figure 4. IBM type wheel

PULSE GENERATOR
PRINT WHEELS
PRINT HAMMER
MOTOR
PULSE GENERATOR COILS
SW-A
R1
C1
SW 1/2/3/4/5/6/7/8/9/0
V1
C2
R2

Figure 6. ANelex synchroprinter

Figure 7. Print wheels and mechanism of ANelex synchroprinter

Figure 8 (above). Shepard printer

Figure 9 (below). Potter flying typewriter

punched tape, because the information has to be put in parallel form before it can be used. In the case of the mechanical tabulator the memory is the mechanical latch system, triggered from the incoming signals which may be serial or parallel. In the case of the ANelex the memory is a series of electronic registers. Just as a mechanical tabulator can print totals by the use of racks on the type bars which rotate mechanical decade counter units back to zero, so the on-the-fly printer can print from electronic counters driven on to zero by mechanically timed pulses derived from the print wheel drive system.

The ANelex printer is relatively small and fits into a standard relay rack. It provides 40 characters per line and operates at up to 15 lines per second. It is described in detail in another paper.

The Shepard printer works on the same principle but is generally larger, having 120 characters per line. It operates at up to 10 lines per second and uses 1,100 tubes.

Another on-the-fly system is the Potter 'flying typewriter' which uses only one print wheel, instead of one per character in the line. In this case the hammer impulse timing depends on both the required character and the position of the character in the line, since the characters on the one wheel have to be used by all the hammers. The first Potter machine with 80 characters per line had a speed of 5 lines per second and used 1,200 tubes. A later model uses two sets of characters round the print wheel and has twice the speed (10 lines per second). It uses a small magnetic drum memory in place of

900 of the tubes. The general principles of operation have been explained elsewhere.[1] Briefly, the electronic system consists of 80 6-binary-digit shift registers, one for each character position. Binary

character codes can be fed into these in a serial or parallel form. When the registers have been filled, photoelectric cell signals from slits in a wheel coupled to the drum are fed into the registers. As

TYPE FONT
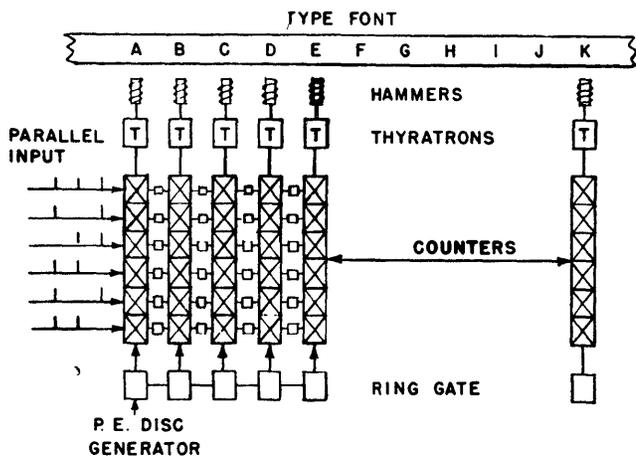
Figure 10. Potter counter type storage and parallel loading

each register comes to the final carry, it pulses the corresponding hammer. To allow for the fact that each type slug reaches each line position in turn, each register gate is held off until the previous one has received a pulse.

MATRIX PRINTERS

The main limitation to the speed of most high-speed mechanical printers is the time needed to get one type slug out of the way before the next can be positioned. The matrix system avoids this difficulty. Although a 5-by-3 matrix is enough for intelligible figures, a 7-by-5 matrix is usually used for alphanumeric systems. There are two methods of using the matrix principle. In one the paper remains stationary during printing by a selection of 35 pins. The IBM printing card punch type *26* is one example of this. Another is the Control Instrument Company (Burroughs) printer which seems to have defied the laws of nature and returned to the egg stage. The other principle makes use of one row of pins only, each character being generated by a number of impressions from selected pins. For high-speed operation the paper moves continuously past the pins. An example of this system is the Eastman Kodak printer described in another paper.

The obvious difficulty with a matrix system is the fact that, while 6 bits of information are enough to specify a character, 35 bits of information are used in operating a 7-by-5 matrix of needles. If each needle is operated by a solenoid and electronic amplifier, and if a line at a time is to be printed, an 80-character-per-line printer will use nearly 3,000 amplifiers and solenoids, which is rather far from efficient.

The IBM printing punch gets over the difficulty very neatly by operating the flexible needles with a printing-code plate, the mechanical analogue of a switching matrix. The punches operate interposers which move the code plate in two co-ordinates, in units of 20 mils. The

Figure 11 (left). Potter flying typewriter

Figure 12 (below). IBM printing punch, model 26

Figure 13 (left). In embryo
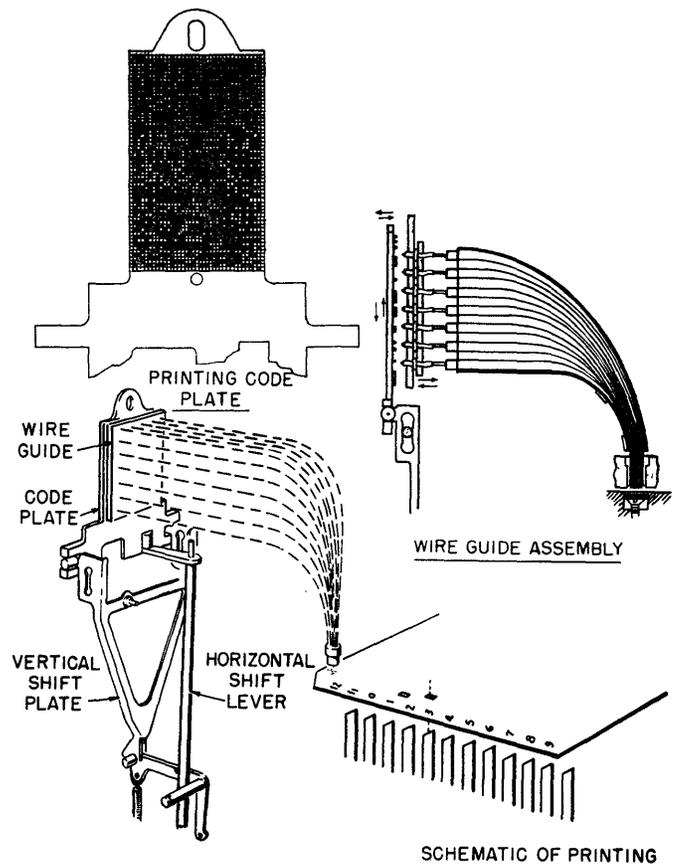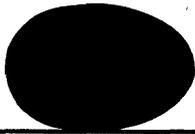
printing and punching speed is 25 characters a second. In this particular application only one character is printed at a time and therefore the space problem is not very serious.

Unfortunately, I do not know how the Control Instrument Company's printer gets over the difficulty of operating 36 matrices in parallel.

The Eastman Kodak printer uses the scanning matrix technique, printing one line of dots at a time on fast moving paper. A gating tube is used for each of the 35 dots in the matrix but only five or seven output channels and electro-mechanical hammers are needed for each character. In this case the operating speed is so high (about 350 characters per second) that it is practicable to feed forms through the machine sideways, using only one head per line instead of one head per character per line. For instance, a form containing five lines of 36 characters could be printed with 5 heads in about 1/10 second, which is equivalent to about 50 lines a second.

BAR AND HELIX

While the bar-and-helix principle is commonly used in electrolytic facsimile systems, there seems to be only one printer of immediate interest using a mechanical bar and helix, that designed by Eastman Kodak and manufactured by Addressograph-Multigraph. This printer was designed originally for copying typed names and addresses from punched cards on to dick strips, but it can also be used
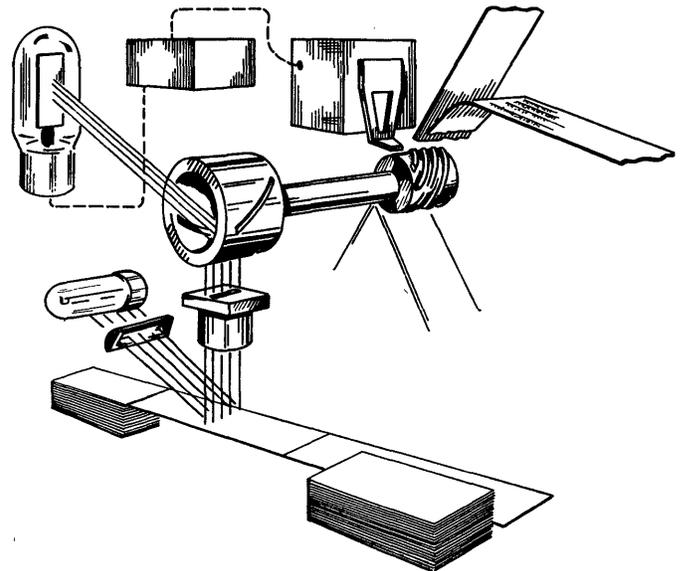
Figure 15 (right). Eastman Kodak addressograph - multigraph printer

on preprinted forms. Most models print four lines at a time and scan up to two normal addresses a second. Among the newer high-speed printers this one is remarkable in that nearly 100 have already been made.

The Illustrations

Figure 2 shows the Flexowriter translator. One permutation bar is used for each possible hole in the code. All bars are initially to the left. When a code is read, the bars corresponding to holes are allowed by the armatures to be pulled to the right by springs. Projections on the bars are so arranged that only one of the seekers is opposite a slot in each bar and can be pulled back by its spring. An operating bar parallel to the translator bars engages and pulls down this seeker thereby operating only the corresponding

typewriter key.

Figure 4 shows the IBM type wheel. The two reamers turn throughout the cycle. Their motion is transmitted only after the clutch dogs are released. Timing of the two clutch dogs represents the positions of the two holes in the code. The selector drives the print wheel counterclockwise. When the print cam pushes the type wheel hanger to the right, the type wheel is given a clockwise component of rotation. At the moment of impact the two components cancel and the letters are printed without smudging.

Figure 5 shows the Remington Rand decoder. The double pressed steel unit shown converts two parallel 6-bit codes to latch selections to stop two rising type bars. (Only the left-hand permutation plates are drawn in detail.) Permutation plates corresponding to the code are pushed from below against the springs

OUTPUT TUBES
CONTROLLING HAMMERS
COUNTER CHAIN
GATING
TUBE
MATRIX
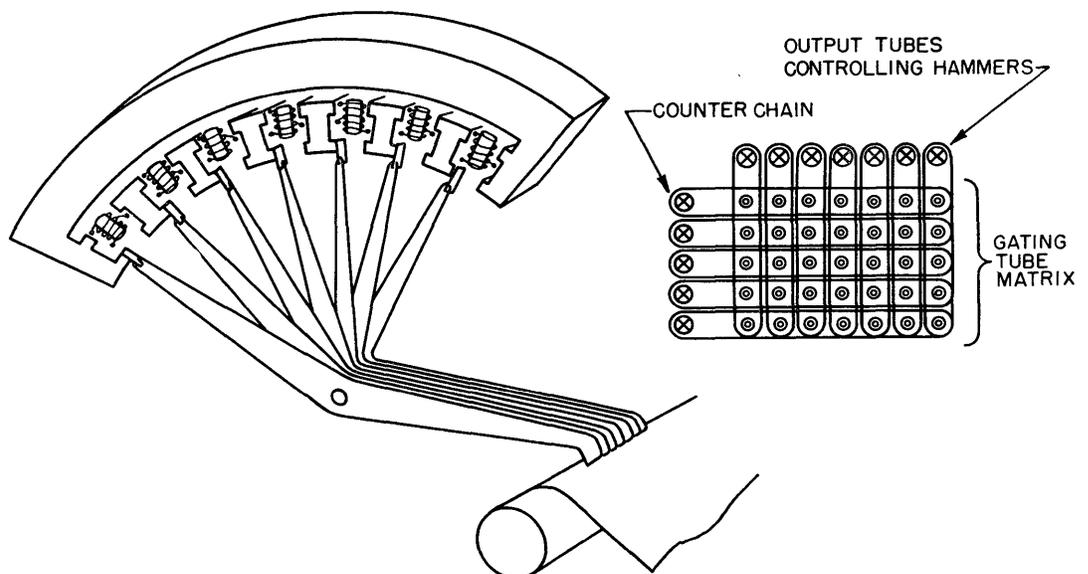
Figure 14. Eastman Kodak matrix printer
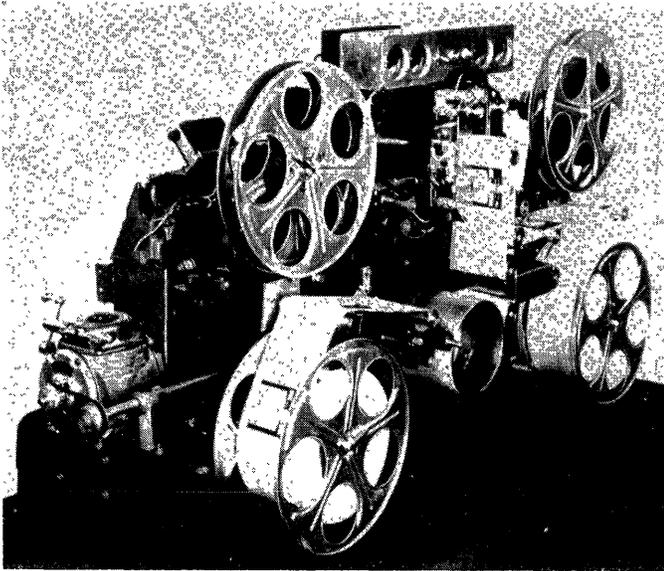
Figure 16. Eastman Kodak addressograph - multigraph printer for narrow forms

above. The slots are so arranged that they hold the projections of all but one latch which is pushed to the left by a spring when the common control bar moves to the left.

Figure 6 shows the ANelex synchro-printer. The pulse generator produces a pulse in each character wire as that character on the print wheel approaches the hammer. That character is printed which corresponds to the switch which is made.

Figure 14 shows the Eastman Kodak matrix printer. A single permanent magnet maintains a flux across a series of actuators like polarized relays. A hammer is operated by the gating-tube matrix whenever both the character gate, con-

trolled by the character encoder, and the counter gate, controlled by paper position, of one of its associated line of gates are open.

Figure 15 shows the Eastman Kodak Addressograph-Multigraph printer. The illuminated typed matter on a punched card is viewed by a photoelectric cell through a mechanical scanner coupled to a mechanical bar and helix printer.

Conclusion

To summarize, various machines for typewriter speeds are available, the most versatile of which is the Flexowriter. For parallel inputs like punched cards, line-

at-a-time tabulators are available through IBM, Remington Rand, and Bull, to operate up to nearly three lines per second. In addition to printing, these machines have internal accumulators and very flexible devices for rearranging the input information into a suitable layout. These machines can be modified to accept digital computer information, as has been done for the Ferranti computers.

For higher speed straight tabular output on-the-fly printers are suitable up to about 15 lines a second. Potter, ANelex, and Shepard machines are being produced. The electronic equipment necessary for use with these is quite complicated. The only general-purpose simultaneous matrix printer known to the author is that of the Control Instrument Company (Burroughs) which is apparently still in embryo. The fastest mechanical printer is the Eastman Kodak scanning matrix printer. By the use of a large number of heads, several hundred lines a second could be printed at a large cost in electronic complication. Very high speeds still are possible using one head per line on short forms or address labels. The Eastman Kodak Addressograph-Multigraph bar-and-helix printer is the only one available for copying type information on to dick strips and short forms at a high speed.

Reference

1. HIGH-SPEED PRINTER FOR COMPUTERS AND COMMUNICATION, John J. Wild. *Electronics*, New York, N. Y., volume 25, number 5, May, 1952, pages 116-20.

Discussion

W. P. Byrnes (Teletype Corporation): What speeds are available for the matrix, for the bar, and for the helical type of printer?

Mr. Hosken: The control instrument device does five lines of 36 characters,

and it will print forms at about 2 or $2\frac{1}{2}$ a second. I can tell you nothing further about this device. As far as the Eastman Kodak printer is concerned, in the next paper there will be a great deal of detail about this subject. There is a bar-and-helix device on show here in the building, that does about two addresses per second.

F. H. Shepard, Jr. (Shepard Labora-

tories): In defense of the 1,100 tubes in the Shepard Laboratories printer, I might say that no crystal diodes are used; they are all thermionic.

E. Masterson (Remington Rand): In defense of the Remington Rand printer, it was mentioned in your paper in the wrong category. It is of the ANelex and Shepard type.

Nonmechanical High-Speed Printers

R. J. ROSSHEIM

TO SURPASS the speed limitations of more conventional approaches to printing digital information, which commonly involve hard type faces coming in contact with the recording paper, some essentially nonmechanical methods have been investigated. The fundamental characteristic common to these systems is that character selection, positioning, and formation are accomplished without mechanical motion or contact. The next limitation, and a problem which appears to be of the same magnitude as high-speed character formation, is the permanent recording of the images once they have been formed. This does involve physical motion and related mechanical problems. In the following are described several systems which were brought to the attention of the Office of Naval Research during a recent survey.

The Atomic Instrument Company has produced a high-speed direct-recording printer called the Dataprinter; see Figure 1. Developed in conjunction with an analogue-voltage-to-digital-pulse converter and a digital-pulse counter, the printer is capable of recording 3-digit decimal numbers in a column at rates from 10 to 500 per second.

The decimal number representation is of the dot-array type, the dots being formed by sparking tungsten-filament wires through Western Union type-L Teledeltos paper. This is a multilayer paper used in facsimile work and contains beneath the light-gray reading surface a pitch-black layer which is exposed in the sparking process. The paper, 16 millimeters wide, is run from one reel to another during the recording period, passing beneath a row of 11 tungsten wires. One wire is used to provide timing marks, one is for sign indication, and the remaining nine are divided into three groups of three wires per digit. Pulses may be delivered to some or all of the digit wires up to five times for a given digit; thus a 3-by-5 array is available to represent all digits. The motion of the recording paper from reel to reel during the printing process is continuous at speeds which may be varied to suit the information input rate. When recording 500 3-digit numbers per second,

R. J. ROSSHEIM, Lieutenant, United States Naval Reserve, is with Office of Naval Research, Logistics Branch, Washington, D.C.

the tape moves at about 100 inches per second, and the 800-foot reel will last $1^1/_2$ minutes. The cost of this reel of paper tape is $1.40. Ten-wire inputs are provided for each digit position. It is necessary to maintain the input signal to the selected wire until printing of the digit is completed. The printer requires 47 tubes, 4 diode matrices made from Harvard selenium diode boards, and 8 power-control relays. The equipment occupies 37 inches of standard rack panel, and consumes approximately 500 watts.

The electrical marking process as developed in the Dataprinter appears to be quite fast, and quite acceptable for some applications. In the samples seen, the marks made by the wires are sharp and evenly spaced. With some practice the 3-by-5 dot decimal representations are easily recognizable. The contrast between marks and background is not as great as in common printing. The form of the printed output in the unit produced has been largely determined by the particular application. The advantages of reels of narrow tape moving at constant speed have made possible a comparatively simple and inexpensive unit. The manufacturer is considering a page printer utilizing the same principles, and will build models with 5-by-5 or 5-by-7 dot arrays to suit the application.

A system of data recording based on the properties of shaped magnetic fields has been partly explored by the General Engineering Laboratory of the General Electric Company. The basic process, named Ferromagnetography, (Fig. 2), consists of three steps, as follows. First, a latent magnetic image is produced on a permanently magnetizable surface. Second, the transfer medium consisting of finely divided charged particles is placed in contact with the surface containing the latent image, adhering to the magnetized areas and thus making the image visible. Third, the surface now containing the visible particles is brought in contact with the final recording medium, perhaps a paper treated with an adhesive, and the image in the form of the visible particles is transferred to the final paper surface. By repeating steps 2 and 3, multiple copies can be made from the latent image resulting from step 1.

A pilot model has been constructed

which indicates the details of a printer utilizing Magnetography and suggests quantitatively what might be expected from such a system fully developed. The equipment to produce the latent magnetized image consisted of a shaped core piece (the shape chosen was a figure 7) mounted on the surface of a rotable drum. A second core piece was mounted facing the drum in such a position that the shaped piece passed directly opposite each time the drum revolved. Around the second core piece was wound a low-inductance coil, forming an electromagnet capable of being energized by a very rapid pulse (about 30 microseconds). Between the opposing cores ran a magnetic tape on which could be recorded a latent image shaped by the character core piece mounted on the drum. In order to trigger the pulse which creates the magnetic recording field, a pulse-generat-
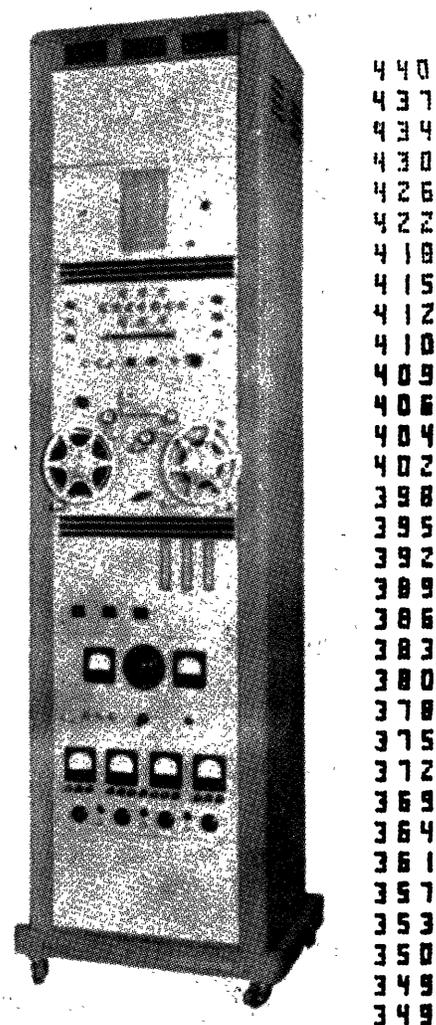

Figure 1. Atomic Instrument Company Dataprinter model 10ABC (left); top half of rack contains voltage-to-decimal converter. Sample output (16-millimeter tape) from Dataprinter (right)
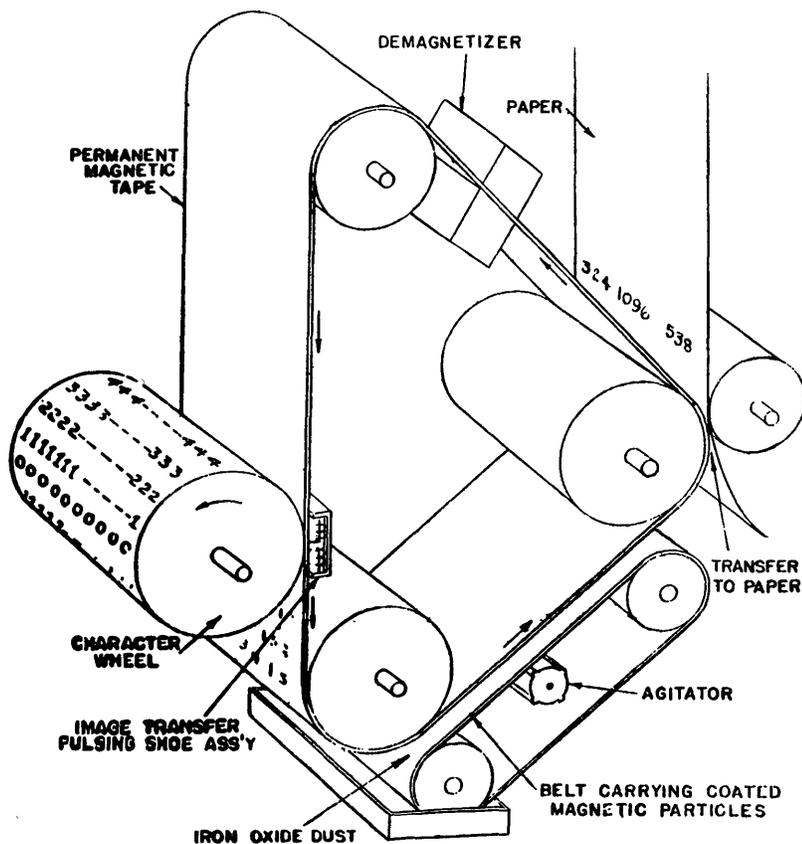
Figure 2. Diagrammatic representation of General Electric Ferromagnetography

ing ring was mounted on the same shaft as the drum. A trigger pulse was generated each time the cores were exactly opposite, so that one character was recorded each time the drum revolved. The drum speed was 2,400 rpm. The resultant speed of this single-character single-column image recorder was 40 lines per second.

The proposed complete system involved passing the permanently recorded tape in the form of a closed loop through three successive processes. The tape with its recorded latent character images would be passed close to an agitator belt bearing loose electrostatically charged iron-oxide particles. The dust would adhere to the magnetized portions of the tape, making visible the character patterns. Next the dust patterns would be pressed against adhesive paper which would retain permanently the recorded images. Finally, the magnetic-tape loop would pass through a demagnetizer which would erase the former images and allow the tape to be recorded again with new data, thus completing the cycle. If multiple copies were required, the erasing process would be omitted. Diagrams of the proposed system do not indicate that the problem of moving the magnetic recording tape in discrete steps rather

than continuously has been attacked. It appears that this start-stop tape advance would be necessary when different characters are arranged around the drum circumference, since all characters must be presented to the same tape position before a recording cycle is completed. There is no indication at present that a finished product using Magnetography principles for digital-computer output is being developed by General Electric, although other laboratories have indicated interest in pursuing similar approaches.

Several groups have explored the possibilities of cathode-ray tube display of alphanumeric information with high-speed printing in mind. Engineering Research Associates, Inc., in 1950 delivered to the National Bureau of Standards an equipment called the Magnetic Numeroscope Printer designed to avoid restrictions on the use of digital computers by the limitations of output printing devices; see Figures 3 and 4.

The system is comprised of three basic parts, a set of magnetic drums, a cathode-ray tube, and a motion-picture camera mounted to record permanently the output data. Two narrow magnetic drums have mounted around their peripheries permanent recordings of the deflection voltages needed to make the electron

beam in the cathode-ray tube trace the desired characters. One drum contains the horizontal deflection recordings, the other contains the vertical. Of the 40 spaces for different character recordings around the drum peripheries, only ten representing the decimal digits are used in the experimental equipment. The deflection recordings are made on magnetic-surfaced inserts which are screwed to the drum surface. The third drum carries positioning pulses needed to select a specific character, and clock pulses which determine the displacement of successive characters on the cathode-ray tube screen. Only ten pickup heads are arranged around the character-signal drums, although once again there is room for 40 on a full-scale model. Provision has been made to select the set of pickup heads under which the desired recordings will next pass after the coded signal from the computer has been received. With ten sets of pickup heads, the maximum access time to any character is therefore one-tenth of a drum revolution. With a full complement of 40 heads, this would be reduced to one-fortieth of a drum revolution. Access time to the character signals is the fundamental speed limitation in this part of the system.

To display a character on the 5-inch cathode-ray tube, it is necessary only to unblank the electron beam, position it in the line of printing, and apply to it the horizontal and vertical deflection voltages selected from the recordings on the drums. Finally, to record permanently the instantaneous displays on the cathode-ray tube, a 16-millimeter Bell and Howell microfilming unit somewhat modified has been used. It is assumed that the printing rate will be reasonably uniform so that the film transport is continuous at 0.2 inch per second. To compensate for the displacement of characters in a line of printing caused by this continuous motion, the characters are skewed proportionally in the opposite direction on the screen of the cathode-ray tube.

Both a manual keyboard input unit and an electronic keying unit have been built, the latter to accept short-duration voltage pulses such as would come from the output of a computer. The selection and gating circuits of the unit utilize the full capabilities of the printer. The printing speed of the decimal printer model with a drum speed of 3,000 rpm is 500 decimal digits per second, 100 characters per line. As has been indicated, a full complement of 40 pickup heads would increase this speed by a factor of 4 by reducing the drum access time, and it is claimed that an increase in drum speed

an 8-by-8 character array. It appears that by using the methods described in the foregoing, characters may be selected and displayed at speeds up to 10,000 characters per second. Work is under way to perfect and build a complete Charactron-Xerographic printer.

In still another cathode-ray-tube display method, magnetic cores are used to provide the character-signals. The high-speed magnetic core output printer, Figure 6, has been developed by the Laboratory for Electronics, Inc., for data-processing and computer applications which might require rapid data conversion and either visual display or permanent recording capable of being directly read.

The purpose of the magnetic-core device is to produce a dot-modulated signal which is used to intensity-modulate the grid of the cathode-ray display tube. The technique employed to produce dot-modulated character signals is as follows. Magnetic cores are arranged in a 2-dimensional array, seven cores wide by eight high. Each core may be considered as representing a dot in a rectangular array of dots from which is selected a set to indicate the desired character. To determine the form of a particular character, a read-out wire is passed through those cores in the rectangular array cor-

by a factor of 2 to 4 is within reach. Thus using these techniques, 8,000 characters per second seems to be possible. The characters have the appearance of line drawings rather than conventional type, but they are quite legible and distinguishable. Additional processing of the exposed film is necessary, of course, but the total cost of hard copy is estimated at 5 cents per square foot.

The Charactron developed by the Consolidated Vultee Aircraft Corporation (see Figure 5) is an entirely different approach to cathode-ray tube display of information. The heart of this system is a specially designed tube. The electron beam in this tube must pass through a set of character selection plates, through a beam-shaping metal stencil, and finally between a set of deflection plates, before it travels to the fluorescent screen. The function of the selection plates is to choose the desired character from the array of character shapes cut out of the metal stencil mounted in the tube between the electron gun and the screen. Emerging from the stencil, the character-shaped electron beam is then positioned with respect to the tube screen so that the character selected will fall in the proper position in the line of information. The Charactron principle depends on focusing the electron beam in such a way as to form a relatively large beam, large enough to cover an entire character opening in the stencil. Character stencils may be prepared with characters and symbols to fit the application. Arrays as large as 10

by 10 are considered practical. When the beam emerges in the shape of the desired character, it is gradually enlarged until it impinges on the screen.

For computer printing applications the designers of the Charactron propose to use dry photographic methods to copy successive displays from the face of the tube, permanently recording them on paper. Such a process, called Xerography, will be described in the following.

Of interest in computer applications is the fact that a binary code may be easily decoded into the horizontal and vertical voltages needed to select characters from

Figure 5. Consolidated Vultee Aircraft Charactron-Xerographic high-speed printer

Figure 6. Laboratory for Electronics, Inc., magnetic-core printer. Simplified block diagram

responding to dots in the display image. By interrogating or pulsing the cores in the array one by one in systematic sequence, it is possible to make each core in the array change from its zero state to its one state. A pulse is generated on the read-out wire each time a core through which it passes changes state, and the result is a signal unique to each read-out wire which may be used to intensity-modulate the grid of the cathode-ray display tube. If the electron beam in the tube is synchronized in its scanning with the order of interrogating the core array, the line described by the read-out wire will be reproduced by a series of dots on the tube screen. In practice all the read-out wires, one for each different character, are run through a single set of cores. By interrogating the cores in the array continually, character signals are produced on all of the read-out wires and it is necessary to choose only the one corresponding to the input code in order to display the proper character. The display tube must, of course, have additional control over horizontal and vertical placement of the dot image in order that it be in the correct position relative to the other characters.

A unit is being built which will be capable of displaying approximately 8,000 characters per second. It is intended to use either wet or dry photographic techniques to record the displayed information, depending on the application. The designers note that, using 1/8-inch characters, up to 6,000 characters could be displayed on a single 15-inch tube.

A somewhat different display system has been breadboarded by the Naval Research Laboratory, involving the use of a monoscope for generating the signal used to modulate the intensity of the writing beam in a cathode-ray display tube. The monoscope is a special cathode-ray tube which produces an output current proportional to the electrons reaching the screen of the tube. By placing in the tube a mask containing the characters which are to be used in the output display, and by scanning the small rectangle in the mask containing the desired pattern, a unique character signal is generated. If this signal is then used to control the intensity of the electron beam in the display tube, the mask pattern will be reproduced. Character selection takes place in the monoscope, while characters are positioned and appear in the display tube. A mask of 4-by-4 patterns would be used in a monoscope for the Naval Research Laboratory computer which works with codes representing decimal digits 0 through 9 and letters A through F.

Speeds comparable to the other electronic methods could be attained by using the monoscope. No work has been done on a copying process, since rapid display is the primary requirement, but the foregoing methods would apply here as well.

There are two other schemes which have been diagrammed and which may be further developed in the future. The Austin Company would make use of a high-speed electrical marking process involving Alfax paper. This paper is chemically treated and when thoroughly moist may be permanently marked by the passage of a current pulse through a brush in contact with it. The brush must be of ferrous material since there is a chemical action between the brush and Alfax paper when current is applied. The brush material is consumed gradually in the process and would have to be periodically replaced. The marks on the paper are distinct and of sufficient contrast, which improves as the paper dries out. The paper is not light-sensitive nor can it be marked accidentally in routine handling, but its sensitivity is dependent on its moisture content. Unless there were rigid moisture and humidity control, the intensity of the markings might vary considerably.

The technique which the Austin Company envisages would depend on the bar-helix system to form the characters.
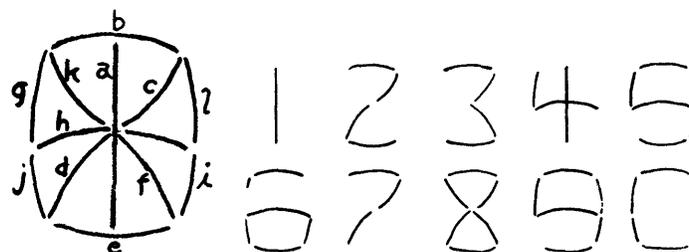
Figure 7. Hogan Laboratories decimal digits and the basis of their formation

They estimate that the present specifications of the recording paper would permit speeds of 20 lines per second.

Hogan Laboratories, Inc., have proposed a high-speed electronic digital recorder using a product called Faxpaper. This paper was developed for the Hogan Faximile System and is marked by passing current through it between two electrodes in contact with it. It is planned that the decimal digits would be formed by specially shaped electrodes in an array of segments roughly forming a rectangle with center lines and diagonals. There would be a set of these marking electrodes for each column of printing. If a data source, such as a computer, supplied digits serially, switching from column to column would be electronic and would involve applying the output of a 44-rectifier encoding matrix to the appropriate set of marking segments. It is estimated that 500 to 1,000 characters per second could be permanently recorded using this scheme, although apparently no work has been done on a suitable paper advance to keep up with the recording speed.

From the foregoing it is clear that the cathode-ray-tube type of display is both practical and flexible when used for high-speed character formation. Use of the cathode-ray tube implies a further process if the information is to be permanently recorded. Photographic methods can be utilized for this purpose, and dry processes are particularly attractive in those applications requiring immediate and legible results.

Such a process is Xerography developed by the Haloid Company. The central element of the system is the xerographic cylinder which in a revolution passes the information to be recorded permanently through a succession of processes. The initial recording of the cathode-ray-tube display depends on the photoconductivity of a thin film which is the surface of the cylinder. Just prior to recording, the surface is charged, and a latent electrostatic image is formed when the light pattern from the cathode-ray tube is projected on the surface. The charge is transmitted through the film in the illuminated areas only. In the next step the electrostatic image on the cylinder is brought into contact with developing powder of opposite charge. The powder particles adhere selectively to the cylinder surface. The powder image is then transferred to the final paper base by pressing the paper against the cylinder and at the same time placing an electrostatic charge on the paper of such polarity as to attract the powder image away from the cylinder.

The image is fixed on the paper by heat treatment which fuses the powder and makes it adhere to the paper base. The final copy is ready at this point and it is necessary only to brush any residual powder from the cylinder surface to prepare it for the initial process again.

The upper speed limit of this process is determined by the use of the cathode-ray tube as a light source. Present materials indicate a drum peripheral speed of 2 inches per second, which, using typewriter-width paper and typewriter characters, corresponds to 1,000 characters per second. If the intermediate process of microfilming is used, the light intensity during xerographic recording may be increased and a writing speed of 2,000 characters per second is attainable.

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3. Magnetic Numeroscope Printer, Final Development Report, **H. I. Daniels, J. W. Hogan.** Engineering Research Associates, Inc., April 1950.

4. THE CHARACTRON, **J. T. McNaney.** Consolidated Vultee Aircraft Corporation, March 1952.

5. A HIGH-SPEED MAGNETIC-CORE OUTPUT PRINTER, **B. M. Gordon, R. N. Nicola.** Laboratory for Electronics, Inc., September 1952.

6. HIGH-SPEED ELECTRONIC DIGITAL RECORDER (brochure), **Alfred F. Deuth.** Hogan Laboratories, Inc., New York, N. Y., December 1950.

Other Data Sources

Atomic Instrument Company, Cambridge, Mass.

Naval Research Laboratory, Washington, D. C. (D. H. Gridley)

The Austin Company, New York, N. Y.

The Haloid Company, Rochester N. Y.

Discussion

H. F. May (Teleregister Corporation): In the matrix printer of the Laboratory for Electronics, Inc., when 8,000 characters per second are used, will the matrices have as many dots as you showed here, or will there be fewer dots? Apparently there were approximately 56 dots in that matrix.

Lieutenant Rossheim: That is correct.

H. F. Lanier (Goodyear Aircraft Corporation): Has continuously printing Xerograph apparatus been put into operation.

Lieutenant Rossheim: I believe it has. I do know there is someone here from the Haloid Company and, presumably, he would be glad to talk about this with you.

D. W. Davies (National Physical Laboratory, England): Does the proposed Charactron Xerographic printer produce a negative picture of the printed characters? I understand that the image produced on the paper is negative since the light acts by discharging the paper. Does that mean

that the numeroscope can produce a negative picture on its screen, or that the paper is to be a dull paper and white powder is applied?

Lieutenant Rossheim: I did not have time to go into the details of the process, but the powder which is used to develop the latent image can be charged in either direction electrostatically, depending on the form of the powder, and therefore either a negative or a positive image may be developed.

B. S. Benson (Benson-Lehner Corporation): In the first work described, I think you spoke of converting to 3 decimal digits at a rate up to 500 per second. Does this mean that the direct-current-to-decimal converter also keeps pace with this, or was it just the actual printing mechanism?

Lieutenant Rossheim: I do not know the details of the development, but I would guess that the printing speed attempted to keep up with the data conversion.

T. M. Berry and **J. P. Hanna** (General Engineering Laboratory): In the oral presentation of this paper two statements were made concerning Ferromagnetography which require correction or clarification. First, it was stated that the latent magnetic images were developed or 'inked,' using electrostatically charged particles. This is incorrect. The latent images are developed or made visible with a finely divided ferromagnetic powder such as magnetite which is held by magnetic attraction.

Second, it was stated that the permanent magnet tape in which the latent magnetic images are formed or the type-set must be stepped or notched line by line to obtain all different characters on the same straight line across the paper. This is not the only way of obtaining all the characters in a straight line. It is also possible to have the recording tape driven continuously and synchronously with the character drum at the proper speed ratio. A pulsing shoe is used, the height of which is equal to two line spaces, and the time occurence of the recording pulses is shifted by the amount necessary to compensate for the motion of the tape from character to character. In this manner all zeros in a given line would print at the top of the pulsing shoe. All ones would print lower on the pulsing shoe by the amount the tape had moved in the time required for the character drum to move from the zero's row to the one's row. This process would continue until finally the nine or the Z or whatever the last character row might be would print at the bottom of the pulsing shoe and still on the same line across the recording tape as the zero's.

Thus, for high-speed printing applications where a continuous flow of information to be printed exists, the recording tape and paper could be continuously and rapidly driven to utilize fully the very high magnetic 'typesetting' speeds available. Paper-notching mechanisms need not limit the printing speed of these applications.

Finally, it might be added that equivalent tabulating speeds for decimal information of 200 lines per second have been demonstrated with the simple magnetic 'typesetting' device. A current pulse of about 10-microsecond duration was used. Also, the recording tape used is of a durable metal with mechanical properties similar to those of spring steel.

The Eastman Kodak Multiple-Stylus Electronic Printer

R. G. THOMPSON   C. E. HUNT, JR.

THE Eastman Kodak multiple-stylus electronic printer prints, at high speed, outputs from electronic computers, insurance premium notices, utility bills, addresses on magazine labels, addresses on cards and envelopes, and so forth. High-speed printed communication is also a field for this printer, as it can be operated by remote control, without synchronization.

This nonphotographic electromechanical printer operates from a coded signal, supplied from any suitable source, such as from the holes in automatically fed punched cards, film, perforated tape, magnetic tape or magnetic wire, radio, coaxial cable, electronic computer, electronic storage, and so forth. The coded signal releases a predetermined sequence of operations to print the entire built-up rectangular-dot character, automatically, from a 5- by 7-dot rectangle, made up of 35 rectangular dots, five rows of seven dots each for serial print, or seven rows of five dots each for parallel or columnar print, as shown in Figure 1.

Every character is connected permanently into a 35-switch electronic matrix printing storage which operates the printing styli. The number, variety, and form of characters desired are provided for in the electronic decoder and electronic matrix connections. Current models have single-case billing-type letters and numerals and special characters.

The printing is done by a single row of five or seven styli, each stylus being operated by an independent polarized relay to print or not print (yes or no) rectangular dots, in accordance with the predetermined pattern of the amplified signals released from the electronic matrix. These styli strike impact blows on carbon paper to print rectangular-shaped carbon dots, row by row, on the paper under the carbon paper, for the character signaled, as the paper and the carbon paper at one-fourth the paper speed, pass between the anvil and the styli. Heat fixes the carbon impressions.

Current models print on ordinary paper, 0.003 inch thick in 4,200-foot-long rolls of the desired width, which is run

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continuously at speeds up to 50 inches per second under the printing styli assemblies. One-time carbon paper from a separate roll is run between the styli and the paper. Thick cards and thick paper, or sheets, can also be printed.

The printing speed is 300 to 400 characters per second for each printing assembly, as much as 20 times the maximum speed of automatic typewriters. Six hundred 4-line address labels, of 96 characters each, can be printed per minute.

Adding printing heads increases the output proportionately as follows:

Number of characters per minute = Number of printing heads × 400 × 60

Printing Heads	Characters Per Minute
1	24,000
4	96,000
6	144,000
100	2,400,000

Patents have been allowed, without any references, covering the multiple-stylus printing and the electronic matrix control.

The multiple-stylus electronic printer can be made in various forms and combinations for the particular performance and service required; for serial or parallel printing, different numbers of lines or columns, different signal sources, and so forth. The electronic printer described in this paper is now in process for the Eastman Kodak advertising department, where it will be used to print dick strip for publications and direct mail.

General

The multiple-stylus electronic printer prints dick strip from the signals received from the holes in punched cards at the rate of 36,000 to 42,000 addresses per hour. There are two separate principal units, the printer, and the electronic unit, connected by cables. These two separate units are built into two metal cabinets, shown in Figure 2.

The printer consists of two sections, driven by the same motor, through a variable-speed transmission. One section, the end-card feed and card reader, is a spe-

cial, positively operated card feed with the addition of a photoelectric reading station, to read all the holes in all the columns of the tabulating card. The signals from the holes in the card are transmitted to the electronic unit by cables. The other section of the printer prints the tape in accordance with the grouped signals received from the electronic unit, and consists of the styli-printing assemblies, the dick strip paper rolls, carbon paper rolls, feeds, controls, and so forth.

The electronic unit stores the signals received from the cards, rearranges them in the proper sequence for printing, then decodes the signals, and translates them in predetermined combinations and sequences of signals for the printing styli to print the corresponding characters, as shown in Figure 3.

The pluggable connection panel provides considerable flexibility in the location of the printing from any one of the columns. An additional feature is a receptacle for a fixed card which may be plugged in to print the name of a city or state, or any other information common to a large number of cards.

The entire 4-line address is punched in one card, or this may be divided so that the first three lines of the address are carried on the address card, and all or part of the fourth line on the fixed card, and so forth.

Checking circuits are incorporated so that if a signal is lost in the machine, through the malfunctioning of a tube or other component, an error signal will be generated which will light a lamp and shut down the machine. Further, instead of printing an incorrect letter or number at this point, an unmistakable mark will be made on the tape to indicate the location of the error.

Printer

The printer unit, shown in Figure 4, consists basically of the multiple-vibrator and printing-styli assemblies, shown in Figure 5, the paper and carbon paper feeds, with associated supply and take-up reels, mechanically coupled to the special card feed and card reader.

The whole unit is driven by a master variable-speed drive. The card feed is directly coupled to the drive, but the printer section is driven through a Warner magnetic clutch brake, which is engaged after the first card is in position and disengaged when the last card runs out, or when the cards are lifted to stop feeding the cards, in order to print dick strip with no blanks.
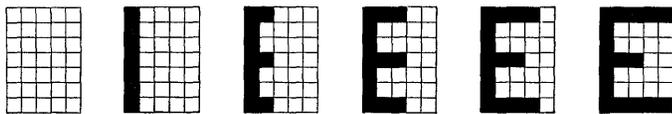
Figure 1 (above). Designs for printed characters

Figure 2 (right). Printer unit and electronic unit

Additional features are the individual take-up torque motors for paper and carbon paper, flying punch for piercing holes in the paper between address labels, drying lamps for setting the carbon print, and suction for disposing of paper punchings made by the flying punch. The speed can be varied within reasonable limits by adjusting the master speed ranger. Relays and controls for the printer are mounted underneath, inside the cabinet.

The printing is done by a single row of seven styli, which are actuated by the polarized multiple-vibrators, as shown in Figures 5 and 6. There is one vibrator for each stylus, seven styli for each line, and the multiple-vibrator is assembled as a single unit, with one permanent magnet which furnishes the magnetic field which passes through the air gaps of all the vibrators in series. Thus, the permanent field direction is the same on both sides of the movable armature. Current passing through the coil of a unit induces a field which travels through the stationary core to the movable armature, then through the air gaps, and back through the laminations to the stationary core.

Thus, the field from the coil is in opposite directions on each side of the movable armature. On one side it will assist the permanent magnet field, and on the other side it will oppose it. This creates an unbalance which will pull the armature to one side. Reversal of current in the coil will reverse its field, assisting the permanent field on the opposite side, pulling the armature in the opposite direction. The individual vibrators for each stylus have two adjustments. Each individual blade has adjusting screws, and the frame for each unit of seven can be raised or lowered as a group.

The punched cards are stacked in a hopper, or feeder magazine, about 700 at a time. The card is fed positively, sideways, by two mechanical pushers, from the bottom of the stack in the feeder magazine, into the cross feed, where the card is fed endwise by a mechanical pusher to engage rollers which pass the card through the 24-photoelectric-tube reading section, consisting of four reading stations of six photoelectric tubes each. A 50-candlepower auto lamp provides light to pass through the holes in the card to energize the photoelectric tubes, to produce electric-code signals for the holes punched in the cards. The columns are sensed sequentially.
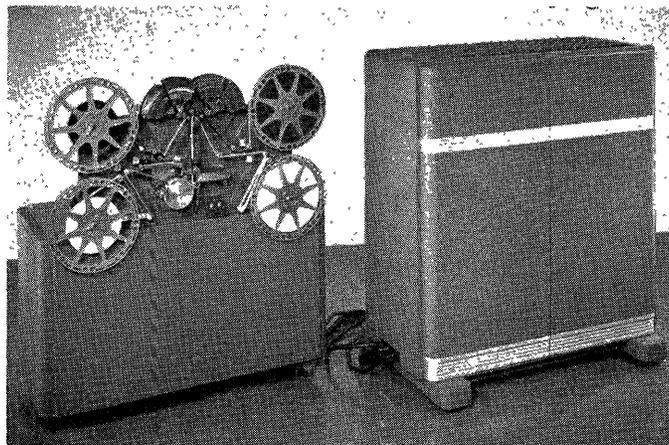
A toothed wheel is driven in front of an additional photoelectric tube to supply timing pulses for each card column. Another toothed wheel is mounted on the
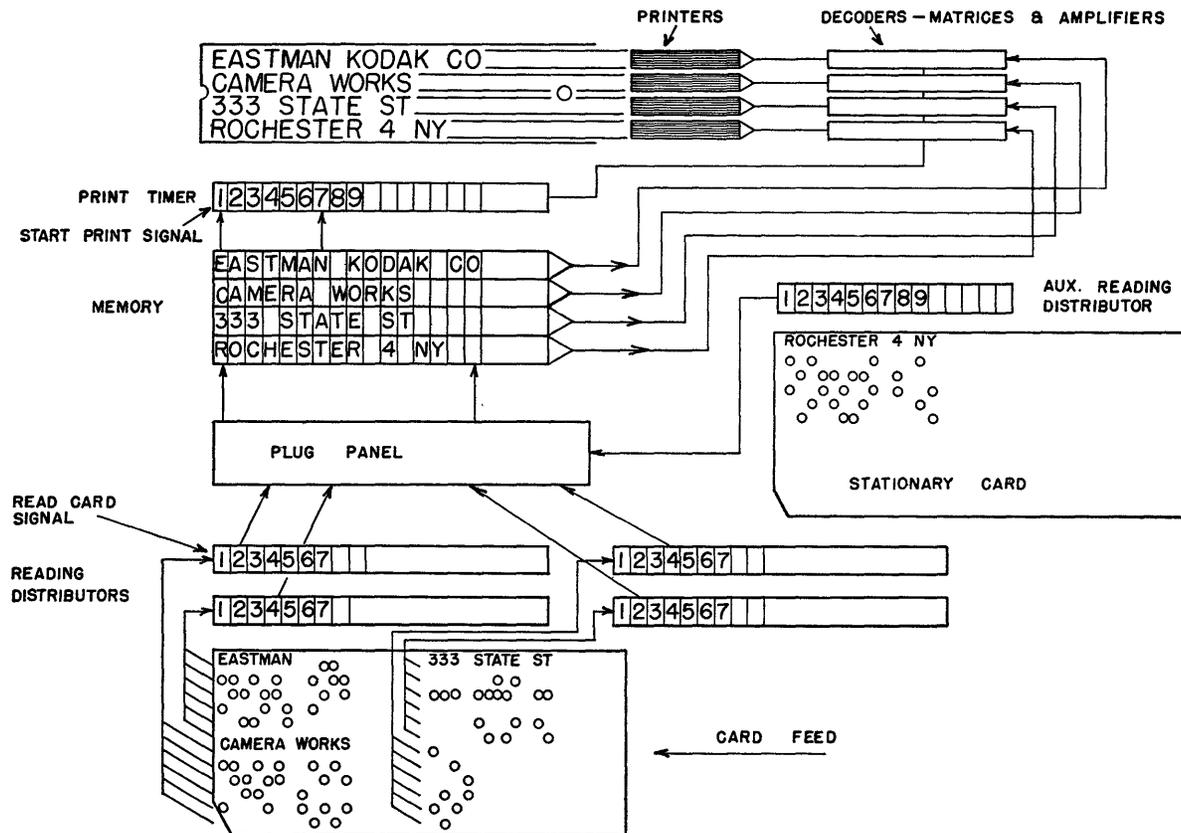
Figure 3. Block diagram for Eastman Kodak multiple-stylus printer
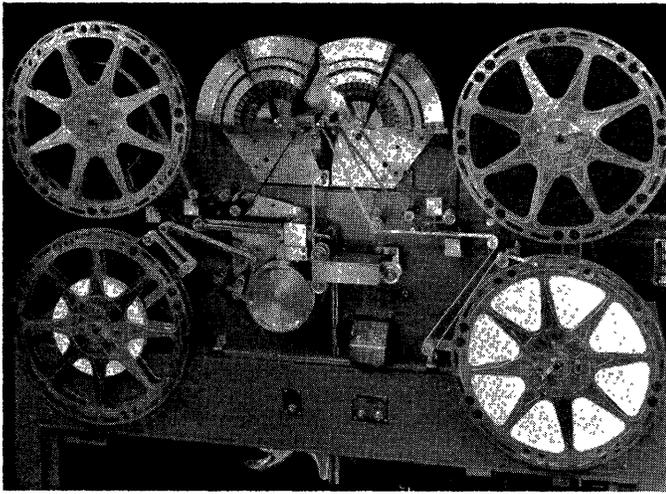
Figure 4. Printer close-up
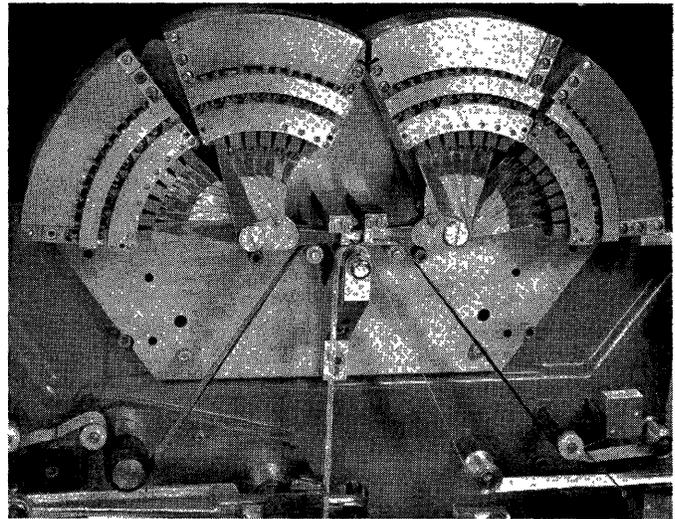
Figure 5. Vibrator assemblies

printer and is driven by it, to supply pulses for printing.

A feature of this system is the fixed-card reader, a stationary unit entirely separate from the card feed itself, in which the fixed card for the city and state for a given group of cards is placed, manually. This fixed card for the city and state remains in the fixed-card reader for printing the fourth line of the address during the time that all the cards in that area are read.

Pins, actuated by springs, pass through the holes in the city and state section of the card, for the fourth line, and these signals from the fixed card are correlated with the signals from the automatically fed 3-line address cards for the first three lines of the address, to print the entire 4-line address.

Electronic Unit

The electronic unit, shown in Figure 7, is contained in a separate cabinet, and initiates and controls all printing operations. All signal switching in the unit is done electronically, relays being used only for power supply switching, interlocking, and motor starting. A great deal of flexibility is incorporated by means of a plug panel, which allows the printing position of any card column to be shifted at will.

Each of the four reading stations located on the card feeder sends out a group of from none to three signals from its six photoelectric tubes as each column of card passes. A toothed wheel, rotating in synchronism with the card feed, sends out pulses by means of a photoelectric tube and light source, each pulse coinciding with the reading of a card column. The card signals are amplified and gated with the toothed-wheel pulse signal, assuring

exact synchronism. The card signal pulses go to four rows of sockets, one for each reading station, located on the plug panel. An electronic ring circuit is stepped along by the toothed-wheel pulse, in synchronism with the card reading, and suggestive pulses are sent to the four rows of sockets. A series of plugs on the panel are wired to a group of memory units, one unit for each possible letter in an address label, or 96 in all. Each memory unit consists of seven magnetic memories, each capable of storing a single signal. Each memory unit plug can be inserted into a socket corresponding to the card column desired printed in that position, so that when a group of pulses is received from a card column, the memory unit whose plug is connected to the socket pulsed by the ring circuit at that moment is activated. Six of the memory unit's magnetic memories are used for this. The seventh is activated by an auxiliary device which gives out a pulse only if the card signal has an even number of pulses. The result of this is that the signal content of each memory always consists of an odd number of pulses. This fact is used later to determine whether any signals have been lost.

Another toothed wheel run by the printer unit generates a series of pulses at the rate of seven for each character to be printed. An electronic ring of seven tubes is driven by these pulses and each seventh pulse advances another electronic chain, whose pulses are applied to read out the memory units in groups of four, one for each line. As each memory unit is read out, its signals go to one of the four printing-line units where they are applied to a group of six trigger tubes or flip-flops, setting a corresponding trigger for each signal present. These are connected into a germanium crystal diode decoding ma-

trix in such manner that for each combination of signals, one and only one of the output lines corresponding to an alphabetic or numerical character is energized. Each output line is buffered by a cathode follower and is connected by crystal diodes into a 5-by-7 matrix of 35 gates or switches in the pattern of its character, as shown in Figure 8. When an output is energized, switches are open in this pattern. Five of the seven pulses which occur between reading of memory units are used to send a pulse into each column of seven switches in turn. A vibrator amplifier is connected to each row of five switches. Thus, as each column is pulsed, a signal is sent to an amplifier only if its switch in that column has been energized by the character signal. Each amplifier is connected to a vibrator, pulling it down when there is a signal, pulling it up when there is no signal. The paper tape is
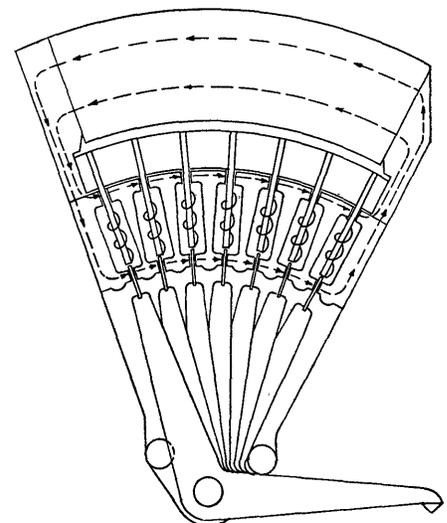
Figure 6. Vibrator diagram
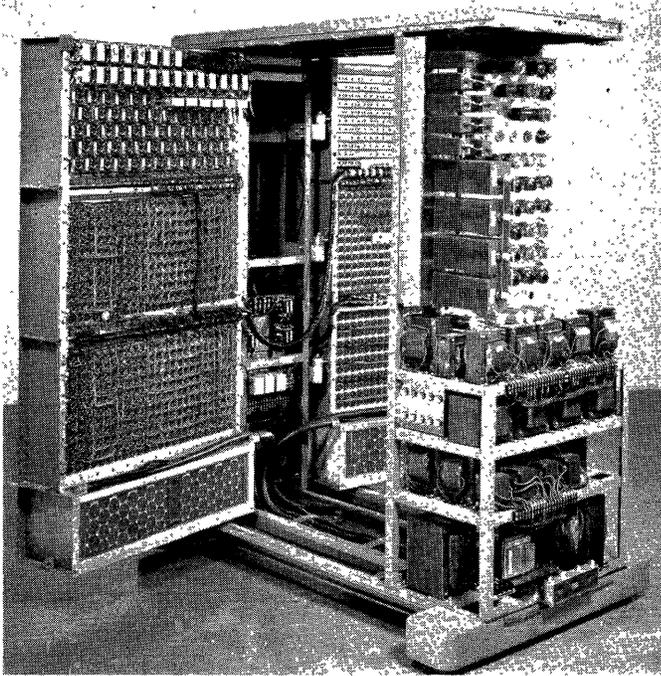
Figure 7. Electronic unit

Figure 8. Electronic matrix

moved one dot space as each column is pulsed, and the character is built up in 5 pulses. The fifth pulse resets the trigger tubes in preparation for the next character. All four line units operate simultaneously and each prints one line of the address.

At the decoding matrix, comparison is made to see if the total number of signals for a character is odd or even. If it is even, a signal must have been lost and an incorrect character could have been printed. The comparison circuit detects this and causes a black mark to be printed in place of the wrong character, at the same time lighting a warning light and shutting down the machine.

An additional feature is provided, consisting of three memory units into which can be read any three columns of the card. These are plugged into three letters of a city name or three numbers of a city code. As long as all cards have the same city name or code, nothing happens, but when the end of a city group is reached and the name or code changes, a signal is sent to the printer which prints a black mark at the end of the label. This enables labels from one city to be easily located.

It is frequently desirable to use a fixed card which has information common to a large group of cards, such as city and state names, dates, and so forth. A fixed-card station is provided which can be plugged in to print at any place in the address in the same manner as signals from the card feed. The card can carry

up to 24 characters, extending the capacity of address cards, while eliminating repetitious punching.

The main power supply for the printing is housed in the machine cabinet and furnishes 365 volts d-c at 6 amperes. Others mounted in the electronic cabinet furnish regulated supplies of 265 volts at 2 amperes, 150 volts at 1.8 amperes, 50 volts at 500 milliamperes, and −150 volts at 500 milliamperes. A separate floating supply for trigger circuits delivers +150 volts, −100, −175, −250 volts. Also, 6.3 volts a-c at 360 amperes is furnished to filaments, and 110 volts a-c to control relays. Power input is 30 amperes at 230 volts, 60 cycles, single phase. If a defective coil or other unit causes the main d-c supply to draw more than 6 amperes, the main circuit breaker will open, shutting down the machine. An overload of more than 30 amperes on the a-c line will also open the circuit breaker. Fuses are provided for other power supplies.

Operation

The main circuit breaker switch, the start button for the electronic unit, and the two indicator lights for the electronic unit are mounted on one end of the electronic unit cabinet. The main circuit breaker switch controls all the power for both the electronic unit and the printer. When this switch is on, power is connected to all control circuits but nothing is energized until the control buttons are
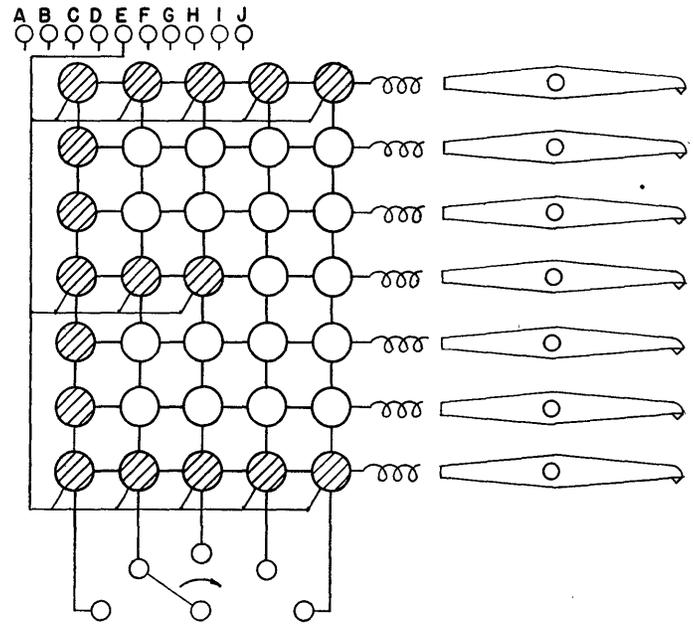
pushed.

The electronic unit is activated by pushing its start button. This turns on the filament power and lights one indicator light. After a few seconds' delay, the main power is turned on, lighting the other indicator light. The electronic unit and the printer are now ready to operate.

Operation of the printer is controlled by a start button which is duplicated on both sides of the printer. With cards in the hopper, pressing this button first starts the motor. As the motor comes up to speed, the card lifter drops, allowing the cards to feed. When a card is part way through the reading station, a signal is received from the electronic unit that engages the magnetic clutch, which starts the printer. The starting of the printer starts the read-out of the memory and printing begins.

A stop button is located on each side of the printer. When either stop button is pressed, the card lifter lifts the cards, preventing any more cards from feeding. When the last card in process has been printed, the clutch is de-energized, and the brake is applied, stopping the printer at the end of the label. After a few seconds, the motor will stop.

The printer will stop automatically, as if one of the stop buttons had been pressed, under any of the following conditions:

1. Hopper runs out of cards.
2. Receiving hopper is full of cards.
3. Paper, or carbon paper, breaks.
4. Cards jam.
5. Signal missing in memory.

6. Second card reads into memory when first has not been read out.

The Eastman Kodak Company has built a similar printer with the card feed and reading station reading four groups of holes in the card simultaneously, and printing the corresponding characters continuously as read. The signals from the card go directly to the flip-flops, then are decoded and energize the matrix in the same manner as in the foregoing description, but without the use of any memory. The entire 4-line address can be carried in a single card with the card punched for this purpose. The 4-line dick strip printer at this conference is so built, except that instead of reading holes in cards, we read holes in program disks by means of photoelectric tubes to obtain our signals. This is a demonstration set-up to be replaced later by a card feed.

Discussion

A. Hyman (Anderson Nichols Company): What advantages are there to the electronic printer as compared to the strip printer which is being used by *Life* and *Time* magazines?

Mr. Thompson: I hope nothing we have said has left the impression that our matrix, or multiple-stylus printer, supersedes the photoelectric printer that we developed and made for printing address labels. The machine, which scans addresses photoelectrically and prints them, has been very successful. We built 26 of them for *Time*, and the machines have printed the labels for all the mailed copies of *Time* and *Life* for the past 4 years. They operate a minimum of 5,000,000 labels a week, and run 16 hours a day, which gives them an equivalent life of 8 years. They are good machines and they have a definite field.

The multiple-stylus printer described covers a somewhat different field. Instead of printing from the photoelectric impulses, it prints from a signal that is received from the hole in the card. It is not necessary to print the address on the card; you simply punch the address in the card and print from that.

The multiple-stylus printer is a more expensive and much faster machine. The ratio of speed is about 6 to 1. The photoelectric machine, installed for *Time* and *Life* magazines and licensed to Addressograph, will print 120 labels per minute; our multiple-stylus printer will print six times that number.

Garment Tag Equipment

ORVILLE G. HESSLER

IN ANY operation where there is sufficient volume, and where transactions are recorded manually for purposes of controlling inventory and for providing management with reports, there is likely to be a clerical problem. This clerical problem manifests itself in several ways. First, the time taken to compile the information needed for controlling inventory becomes excessive, with the result that actual control is less effective as the volume of transactions increases. Secondly, management reports are delayed, so that situations in need of management action can become critical. Third, errors tend to occur more frequently with the increased volume of work, the increased pressure, and the greater number of new people.

As a way out of such bottlenecks, business, industry, and government agencies have turned to the punched card systems of International Business Machines Corporation and Remington Rand. Proper application of the punched card solves the problem by economies in time and personnel, and by being more accurate.

Large retailers run into this operating problem over and over again. The volume of units is extreme, and the need for proper control of inventory is vital. Reports to management are numerous. There are many fields within an organization in which a remedy may be needed and, of course, many factors must be considered before choosing an operation that is particularly troublesome from a clerical standpoint.

In looking for a solution to these problems, it was decided to apply mechanized inventory control to a line of merchandise that is bought at and distributed from a central location. One reason for this is to avoid having the required equipment duplicated in each retail store. Another reason is a fundamental of the punched card system: to start as far back in the operation as possible.

Inventory control by punched cards has not been readily adaptable to many lines of merchandise, and their use is especially difficult in the retail end of the business. Here, merchandise is on the display floor or on counters or racks. Since the punched card system starts to function at the time of a sale, it becomes obvious that the regular-sized card (about 3 by 7 inches) cannot be attached to many items, especially small ones, because of the relative importance thus assumed by the card. For some merchandise it would be a matter of attaching the item to the card, rather than the card to the item.

For a merchandising reason, then, it is not desirable to attach a standard punched card to an item. One alternative is to use one card for each group of identical items on display. But there is the obvious objection of not being able to serve several customers 'in parallel' if the customers each decide to pick up identical items and carry them to the salesperson. The punched card remains with the merchandise on display, and would have to be obtained by the clerk, who would also have to replace it. This procedure is not realistic, besides requiring that the card be 'read' at the time of the transaction.

Many kinds of merchandise are in need of better inventory control, so the problem is a broad one. On the other hand, it is wiser to make changes on a limited basis, prove them out, and then extend
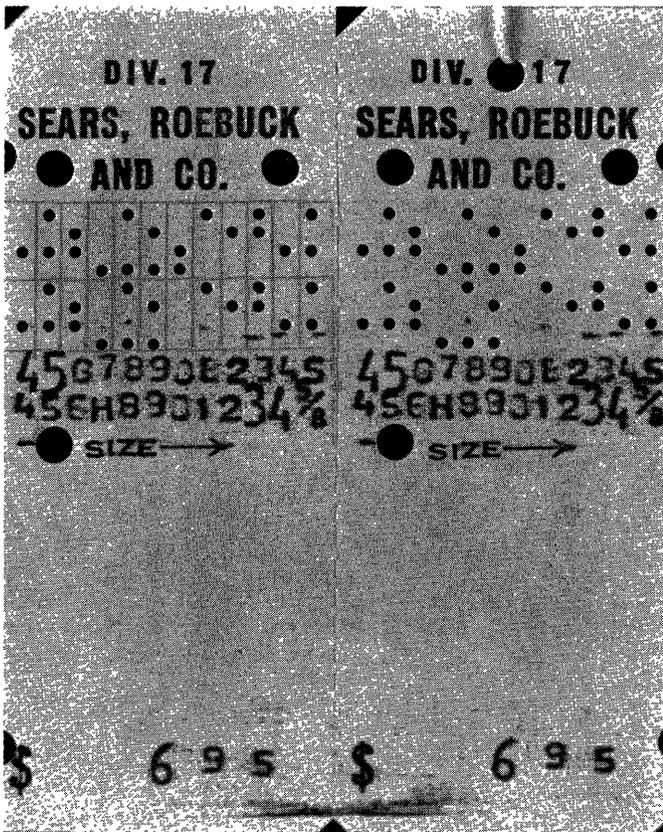
Figure 1. Two-piece garment tag, actual size 2¹/₄ by 2⁷/₈ inches

Figure 2. The garment tag marking machine

the revised system. Garments were in need of inventory control, and represented an operation more or less isolated from other lines of merchandise.

Because of the isolation of the garment merchandising activity, it was relatively simple to find a way to put the operation on a punched card system. The main objection was the size of the cards when serving as price tags. It seemed essential to develop a smaller tag if mechanization were to be realized. The requirements for a garment tag to fit into the desired system were many:

1. Small size.

2. Two-piece design, to be separated at the time of sale.

3. String for attachment to garment.

4. Provision for a maximum of 29 characters, printed and in code.

5. Provision for at least three price changes, printed and in code.

6. Material to withstand normal handling.

There being nothing like this available, it was decided to sponsor the development of appropriate equipment for marking and punching the tags, and for reading them and converting the information back onto standard-sized punched cards. The latter would undergo the necessary sorting and other operations to produce statistics for reports to manage-

ment. The work rate of the output equipment was to be similar to that of comparable standard punched card equipment.

There were the usual trials and tribulations in developing the two machines, which we now call the tag marker and the tag reader. The tag underwent changes in size, coding, and layout, but eventually emerged as shown in Figure 1. Here can be seen the two fields for descriptive information and, at the bottom of the tag, the price. The coding used is 1-2-4-7. There are two fields of 12 characters each. Any given numeral or letter is indicated by the arrangement of holes in each vertical column. The top line of printing corresponds to the upper field, the lower line to the lower field.

The three large holes are located with the top and side edges of the tag as a reference with a tolerance of 0.015 inch. The fields of holes for information and price are located with reference to the three large holes, the tolerance being 0.002 inch.

Note the string used to attach the tag to the garment. This was bothersome during the development period, but the marker is now able to handle stringed tags without trouble.

The tag as shown measures 2¹/₄ by 2⁷/₈ inches. Each section contains the
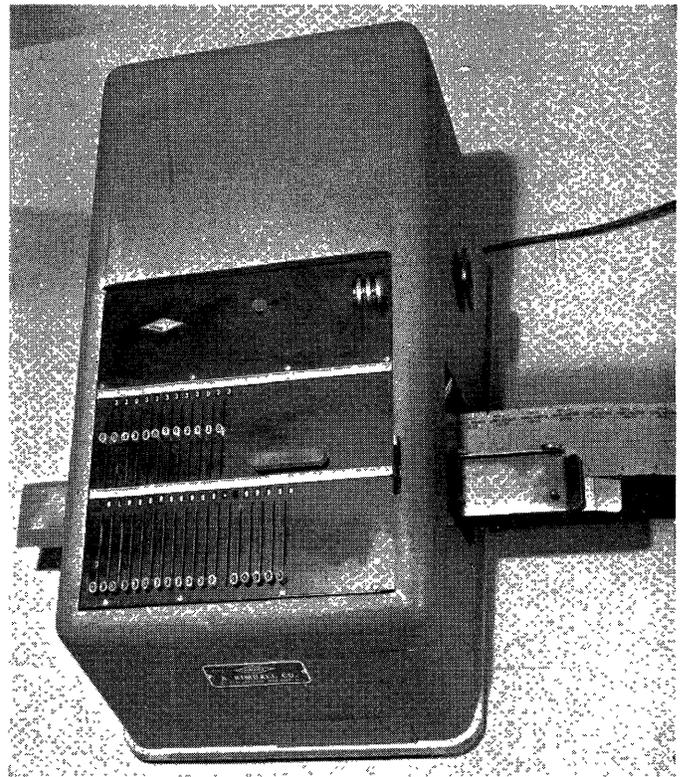
same information as would a standard punched card, yet it is less than one-sixth the size.

The machine that makes these tags is shown in Figure 2. The feed is from right to left. The dials at the upper right of the panel are set to the number of tags wanted. Descriptive information and price are selected by the slide levers. Figure 3, the interior view, shows the rack-and-pinion arrangement actuated by the levers on the panel. As the type wheels are set, the motion is transferred laterally to the bars opposite, which are set up according to the coding to select the proper hole punches.

There are several stages of operation before the tag emerges both punched and printed:

1. Punching both fields of description plus three reference holes.

2. Advancing and punching price field.

3. Printing price.

4. Printing description.

In certain cases it is desirable to use letters rather than numbers, so certain of the print wheels have letters in place of numbers. This can be handled simply by assigning letters to the code instead of numerals for whichever print wheels or columns are involved.

The holes that make up the fields of coding are 0.040 inch in diameter. If all the possible holes were punched in the
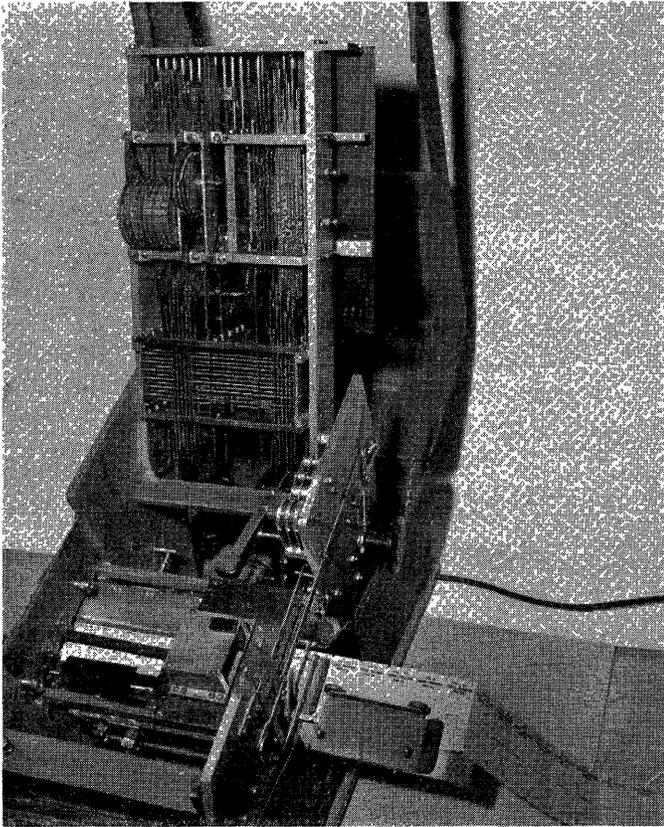
Figure 3. The garment tag marking machine, interior view

Figure 5. The garment tag reader, interior view

two description fields, there would be 96 of them, in an area of less then 1/2 square inch.

The tag marker is designed to make 2-, 3-, or 4-piece tags, and will stop when the preset quantity is reached. It will also stop automatically if blank tags are no longer being fed into it. Pilot models will mark over 250,000 2-piece tags before the punches and die plates have to be serviced. Improvements are expected to double or triple this figure.

After the tags are punched and printed, they are attached to dresses, housecoats, or other garments. When a shipment is made to a retail store, the garments can go directly to the floor for sale. To simplify this activity, more short cuts are possible. The color of the tag is useful in identifying the department, the price range, or the style.

Because it is not uncommon to reduce prices for special promotional events, there must be provision for making changes in the tag while it is on the garment. A hand operated marker has been developed which will punch and print the new price, and cut off the old price information. The tolerance of two mils with reference to the three large holes is maintained.

When the sale is made, the left-hand portion of the tag is detached. Up to this time the garment tag has no significant advantage over the usual tag. However, its potential advantage is great, because it contains all the information needed to produce statistics. Assuming that human error has not entered the picture, it is possible to take inventory while sitting at a desk, just sorting and counting cards, instead of taking a physical count on the sales floor. But even that can be improved upon, by using the tag reader. This can be done within a large department store, although the operation most familiar to the writer takes place at a central depot which purchases the garments in volume and serves as a source of supply to a chain of retail stores.

Figure 4 shows the tag reader, which is pictured again in Figure 5 but with the cover panels removed. In the left-hand section are the power supplies, on the two lower shelves. Included are 70-volt, 125-volt, and 500-volt supplies, a half-wave 2,000-volt supply, and two low-
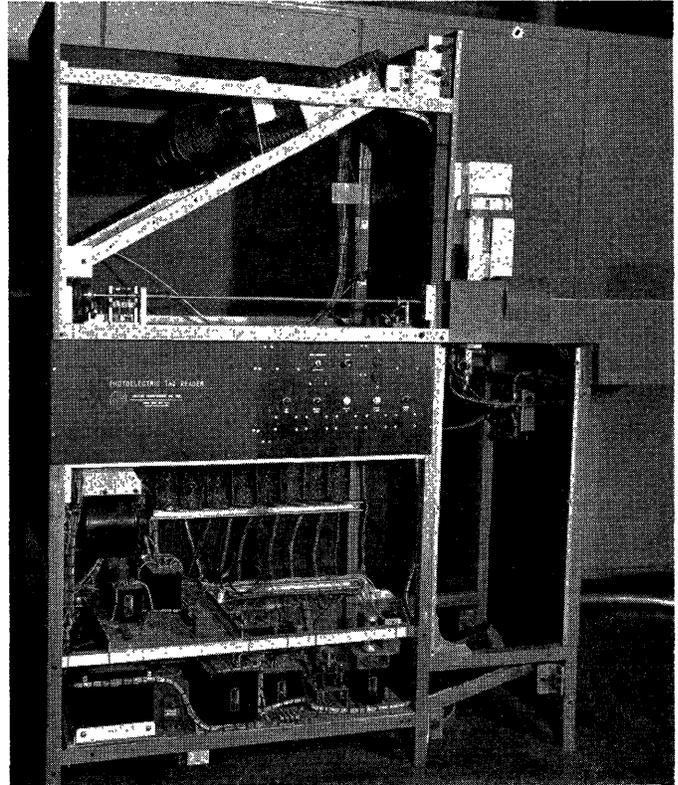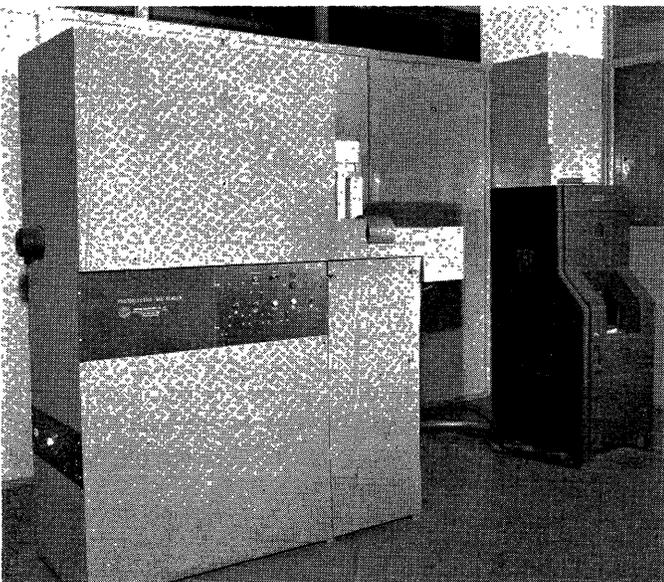
Figure 4. The garment tag reader with associated punched card equipment

Hessler—Garment Tag Equipment

voltage bias supplies. The 70-volt supply is used for the phototubes and is both regulated and adjustable. All power supplies are fused, and time delays are used in the primary circuits to delay application of high voltage until the filaments of all tubes are up to operating temperature. On the far side, visible below the control panel, are mounted relays and strips of electronic circuits. Above the control panel is a blower, and to the right, a slanted mosaic of phototubes, which receive light from the mirror at the lower right. The feed system for the garment tags is at the upper right. A multiconductor cable connects the reader to a reproducing punch which punches standard-sized cards for subsequent processing in business machines.

The tags are loaded into a vertical hopper, and are picked off the bottom of the stack one at a time. The feed mechanism slides the tag horizontally into position for reading, which is done photoelectrically.

Above the reading position is a lens system and a gas-type photoflash tube. The function here is to enlarge the image of the holes. Since the 'throw' is appreciable, the light path is folded by using the mirror, which reflects the images of the holes onto the mosaic of phototubes. Timing of the flash tube is controlled by photoelectric sensing of the proper position of the tag.

When the flash occurs, light passes through the lens system and through the holes in the garment tag. Wherever there is a small hole, the corresponding phototube fires a thyratron which has a relay in its plate circuit. This is a parallel operation, all holes being read at the same time, rather than by scanning. The relay, which has multiple double-throw contacts, is de-energized when the thyratron extinguishes, and is ready for the next tag. The rate is 100 tags per minute.

When the last tag has been read, the reproducing punch is automatically stopped. This is handled by an extra set of contacts on each of the four relays in the circuits which sense holes for a single digit. These contacts are in parallel with each other. Not more than two relays are energized at the same time while reading, but when no tag is in the reading position, all phototubes are activated, resulting in all four relays opening the circuit to the punch. Consequently, there is an automatic stopping of the reader feed mechanism and of the reproducing punch.

In describing the tag marker it was mentioned that a 1-2-4-7 code was used. The reason for this choice should be explained. The usual binary coding of 1-2-4-8 requires a combination of as many as three of those digits to equal all decimal digits zero to 9. With the coding 1-2-4-7 any digit from zero to 9 can be represented by combination of not more than two of the code numbers. The adding of two numbers by use of relays is somewhat more readily accomplished and less expensive than the adding of three numbers, and the marker has to punch no more than two holes per digit.

Including the provision of circuits for reading three possible price changes, the price circuits include 96 sets of phototubes, thyratrons, and relays, and the description fields 96 more, a total of 192 sets. Additional tubes and relays are used in control and indicating circuits. Neon indicators are located appropriately to show visually that the sensing circuits are operating properly, and to show which of the various sections of the reader are ready to start operations.

Discussion

A. Shostak (Office of Naval Research): It is perfectly clear that this kind of an inventory system could be applied to the distribution of Government Issue equipment on ships and in other Navy applications. In particular, I should like to know about the difficulty with the strings. Also, I am curious to learn how to keep the vertical hopper feed from jamming when a bunch of tickets are in it at one time.

Mr. Hessler: The strings at one time caused trouble by dragging along the mechanism, but it is possible to use strips of folded tags without having the strings catch in any part of the mechanism. There are slide guides which permit it to pass through without hooking over anything.

We have had troubles with the feed mechanism. The return of the tags from the stores involves education on the part of the stores to keep the tags in fairly good shape. The edges of the tags are not involved in the reading, since the picking off is from the bottom of the stack directly from the edge of a well-protected hole. There is also a vacuum system involved.

L. W. Brehm (International Business Machines Corporation): Since the holes for code sensing are quite small in diameter, do you experience any difficulty as to garment fuzz, dirt, or grease getting in the holes and mutilating the sensing feature?

Mr. Hessler: The difficulty was not in fuzz from garments, dirt, grease, or anything like that, but in fuzz from die and punch wear. The tags now being used give us, about 0.05 per cent error, the last figure on a 10,000 random run.

S. L. Pollack (National Bureau of Standards): How does bending of the tag affect the subsequent reading of the tags?

Mr. Hessler: The tag could be bent and folded in such a way that it would not pass through the feed mechanism, but most of the cards are small enough so that when they are transmitted through the mails or by other means to the reader location, there is little, if any, bending, and it is usual for the operator of the reader to flex the cards in this fashion and set them so that they will not be bent in any particularly troublesome way. If they are bent, the load on the feed mechanism, and the vacuum attachment for pulling the card through, straightens them out. The picker will operate successfully even on tags which have been deformed.

R. E. Briesemeister (Consolidated Edison Company of New York, Inc.): Would you describe the portable punch in more detail?

Mr. Hessler: I can to a limited extent, yes. It is much like the punch that is used by a notary public, except that it has about twice as much print on it. It has a wheel which has pins set for marking the price on it. There is also a print wheel. As the print punch is closed, perforations are made, the printing is done, and the old section of the tag is cut off.

The Input-Output System of the Ferranti Universal Digital Computer

D. J. P. BYRD   B. G. WELBY

WHEN Ferranti Limited started to build an engineered computer, it was decided to use tape for input-output but to develop improved methods of processing. Efforts were first concentrated on the input system as it was felt that this was the more amenable of the two and more likely to show considerable improvement. The new reader, together with a modified punch and teleprinter, was installed with the present computer at Manchester University, and has operated successfully for 18 months.

Attention was now turned to a faster tape punch, and at the same time work was commenced on an alternative system of input-output involving a high-speed parallel printer and punched card machinery.

The computer now under construction will incorporate the advantages of tape for a fast input system with those of a high-speed printer for output.

The Tape Reader

The Ferranti high-speed tape reader has been designed for use in the input systems of digital computers and other similar electronic equipment. The reader will accommodate either 5- or 7-unit teleprinter tape and the tape is read by means of a photoelectric system. A tape feed mechanism has been developed that is capable of driving the tape at a speed of 200 characters per second and that can stop the tape within 0.03 inch of the point at which braking commences.

Because the reader is designed for use in an electronic system, the associated control circuits are extremely simple, and this enables a high degree of reliability to be obtained. See Figure 1.

THE OPTICAL PROJECTION SYSTEM

A single prefocused lamp having a straight coiled filament, rated at 12 volts 36 watts, provides the source of light for reading the tape. The lamp is mounted so that the length of the filament, 0.2 inch long, is parallel to the length of the tape and is approximately 1 inch above it. Immediately below the tape is a masking plate. This plate contains eight holes each 0.07 inch in diameter; seven of these holes are arranged to coincide with the possible holes of a character and the eighth hole coincides with the small sprocket hole in the tape.

The light from the lamp passes through the holes in the tape and masking plate on to eight phototubes mounted 0.9 inch apart on an arc 9 inches below the lamp. This system is based on the 'pinhole projection' principle; each hole in the tape produces a magnified image of the cylindrical filament. Because the diameter of the filament is less than the space between the holes in the tape, the individual images are projected without any overlap of light on to adjacent photo tubes.

The phototubes, Mullard-type *90A V*, have a photosensitive cathode of approximately 4 square centimeters coated on to the inside of the glass envelope; this tube is a hard vacuum type which has a sensitivity of 45 microamperes per lumen.

THE PHOTOELECTRIC CELL AMPLIFIERS

Mounted on the same chassis as the phototubes are the voltage amplifiers. Each phototube has a load resistance of 10 megohms, and the voltage developed across this load is applied directly to the grid of one-half of a type *12AT7* double triode, the cathode of which is connected to a −150-volt supply. The anode of the triode is connected to a +150-volt supply through a 220,000-ohm anode load, and the particular digit output voltage is taken directly from the anode.

The initial bias applied to the control grid is chosen so that for blank tape the output potential is more than 25 volts negative with respect to ground, and when a hole is present in the tape the output potential is positive.

THE TAPE FEED MECHANISM

Instead of the movement of the tape being controlled by the rotation of a sprocket wheel a new tape feed mechanism has been developed that is more suited to the higher tape speed required by electronic computing machines. A friction drive between the tape and the feed mechanism is used; this is desirable so as to reduce to a minimum the deterioration of the tape. The friction drive is also advantageous, in that if the tape is twisted or otherwise prevented from passing through the reader in the correct manner it will slip in the mechanism without being torn. Tests have shown that a tape can be passed 10,000 times through the reader without appreciable wear. Splicing of the tape is not critical, and the two sets of perforations need not coincide as would be necessary if a sprocket drive were used. If the joint is made so that the sprocket holes overlap each other and therefore light is unable to pass through that portion of the tape, then, due to the method of control used, this portion of tape will pass nonstop through the reader without being read.

The tape feed mechanism consists of a differential gear together with two electromagnetically operated brakes. The differential input shaft is continuously rotated by an induction motor; one of the differential output shafts carries a brake drum, while the other output shaft carries both a brake drum and the tape-driving drum. If either one of the output shafts is held stationary, the other output shaft will rotate with a velocity of twice the input shaft velocity. The two independent electromagnetic brakes are controlled by the opposite phases of a 2-state triggered circuit, or staticisor, the condition of which will decide whether the tape-driving drum will be made to rotate or be held stationary.

All those parts of the feed mechanism that are subjected to the intermittent motion are constructed so that they have the minimum rotational inertia consistent with ease of manufacture. Figure 2 shows the construction adopted. The driving and braking drums take the form of hollow cylinders supported on outer races of the bearings, and the inside races are fitted on to a stationary shaft, this shaft providing a common support for both drum assemblies and the differential input gear wheel.

THE ELECTROMAGNETIC BRAKES

The brakes are constructed as shown in Figure 3. Each brake assembly consists of two individual units mounted on opposite sides of the brake drum. This twin arrangement allows the two braking forces to counterbalance each
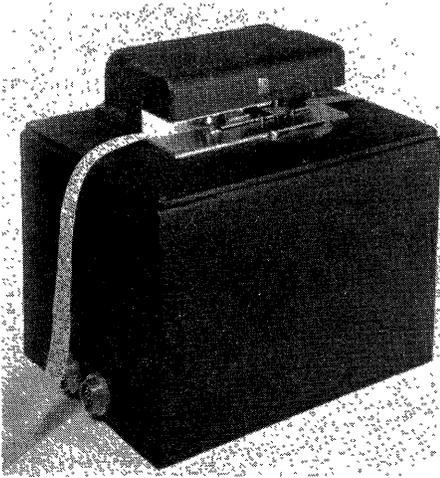
Figure 1 (left). The high-speed tape reader Mark II
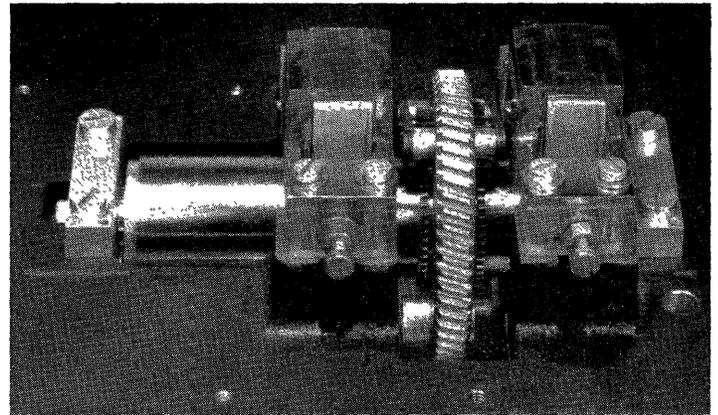
Figure 2 (right). The tape feed mechanism

other and therefore produce no bending loads in the main shaft. Slight variations in concentricity of the brake drum surface will produce a variable magnetic air gap which in turn affects the braking force. With the twin electromagnet an increase of the air gap at one magnet is compensated by a reduction of the air gap at the other magnet. The total braking force therefore does not depend on the rotational position of the drum.

The brake shoes are made from a resin-bonded fabric. This material was chosen because of its hard-wearing properties and the ease with which a suitable light shoe can be manufactured. A light spring retains the armature in close proximity to the laminated core of the electromagnet and the brake shoe is therefore always in contact with the brake drum. The braking torque due to the spring is negligible. When the electromagnet is energized, the greater part of the force produced is utilized in compressing the brake shoe against the drum instead of having to expend energy in moving the armature; in addition, owing to the negligible movement required of the armature, the air gap between the armature and the electromagnet core can be adjusted to a minimum, thereby ensuring a high gap of flux.

Each coil has an inductance of 2 henrys and a resistance of 80 ohms. A current of 60 microamperes is required through the winding to provide the correct braking force; it is essential that the build-up of this current shall be as rapid as possible. To attain this condition, a large voltage must be applied across the coil initially and this voltage should then be allowed to decay until the correct value of working current is reached. By operating the electromagnet from a 300-volt supply in conjunction with the circuit of Figure 4, a current rise time of 0.5 milliseconds is obtained.

Location of the Tape

Because a friction tape drive is used, it is necessary to provide a means of monitoring the position of the tape relative to the holes in the masking plate, so that an indication is given when the required character is in the correct position for reading, and also to determine the instant at which the brakes should be applied if it is required to stop the tape. Accurate location of the tape is obtained by allowing the tape sprocket holes to control the amount of illumination received by an additional phototube. This tube is referred to as the location phototube.

The amplitude of the phototube output voltage, together with the direction of voltage change, defines the position of the character relative to the holes in the masking plate. By applying this voltage to a squaring circuit, a negative transition is produced the instant the tape enters the reading position, and this output wave form is used to initiate the change over of the electromagnetic brakes to stop the tape. This negative voltage persists as long as the tape remains within the limits of the reading position, but as soon as the tape passes beyond this limit a quick return to the zero voltage level is produced. A negative output voltage

Figure 3. Arrangement of the electromagnetic brakes

therefore indicates that the character can be read.

During the zero voltage period, that is, while the tape is moving from one character to the next, an internal gate causes all of the 7-digit output voltages to fall to their negative level, thus preventing any information, other than seven zeros, from being read when a character is not correctly located.

The squaring circuit is designed with a predetermined difference in input switching levels. This is desirable so that any random voltage variation superimposed on the phototube output voltage cannot cause multitransition of the squared output voltage. Both the location squaring circuit and the digit gates are mounted on the same chassis as the phototubes.

The Input Control System

Figure 3 shows a block diagram of a control system that can be used with this tape reader.

In the input system of the Ferranti universal digital computer, Mark I, the five digits of a 5-unit teleprinter character are serialized by means of 5-time marking pulses and the digits are then gated with an input wave form. This input wave form is generated by the presence of a special input code specified by the program in use, and by a wave form defining the appropriate time period for the transfer of information into the store. The input code is set up just before the end of a computer cycle, the commencement of the next cycle depending on the presence of a release signal. Normally this signal is always present but if the tape is not in the correct position for reading when the input code is set, then it is inhibited and the computer remains quiescent.

When the tape is correctly located, the inhibit is removed and the store input wave form is generated. After passing through the input gate the five bits of information are stored in the selected line
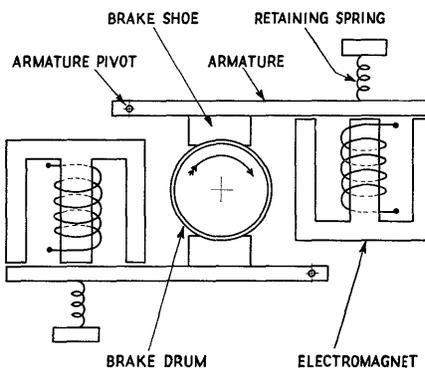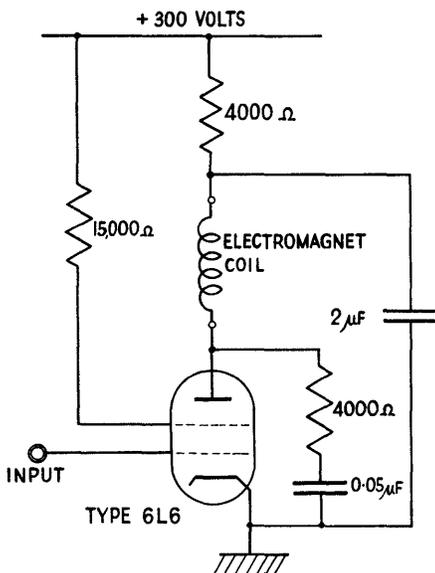
Figure 4. Circuit used for operating the brakes

of the cathode-ray tube store. A 20-digit number is assembled by taking four characters and shifting the significance of each character by an appropriate amount. *

The input wave form, mentioned previously, is inverted and differentiated before being applied to the right-hand input of the staticisor, wire A, Figure 5. Therefore, on completion of reading, this wire is activated and causes the triggered circuit to be set so that the 'tape drive' electromagnet is energized. At the same time wire E returns to the nonactive condition so as to prevent the computer from reading any further input information.

When the tape has moved forward so that the next character enters the reading position, the location output wave form is actuated resetting the triggered circuit, which energizes the 'tape stop' electromagnet and generates the reading signal. If the computer is ready to accept the
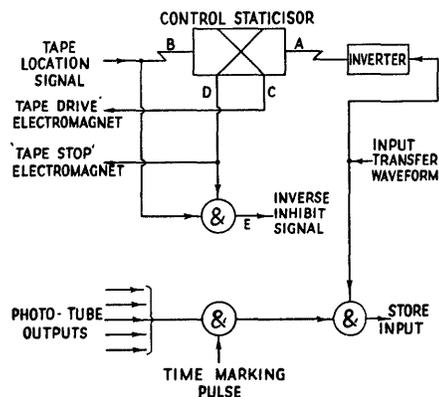
Figure 5. Logical diagram of the input organization

new character, the input wave form will be produced and the tape will immediately continue to move forward. If, on the other hand, the computer does not require a new input, the tape stop electromagnet will remain energized and the movement of the tape will be arrested while the character is still located over the reading station. The tape can remain in this position indefinitely; as soon as the information is required, it can be read and the tape will then move forward.

In the event of the tape overshooting the limits of the reading station before the character is read, as a result of faulty adjustment of the tape reader, then the loss of signal on wire B will inhibit the reading signal and prevent erroneous reading.

DEPENDABILITY

The mechanical construction of the tape reader is relatively simple. Only two adjustments are necessary; first, adjustment of the air gap between the electromagnet cores and their armatures, and second, adjustment of the position of the projection lamp. Because the wear of the moving parts is almost negligible, very little mechanical maintenance is required other than occasional lubrication.

To prolong the life of the lamp, the applied voltage is reduced to 10 volts in place of the 12 volts for which the lamp is rated, and the heat developed is dissipated by a stream of air blown through the lamp housing. The use of a prefocused lamp reduces the necessity of realigning the lamp position every time a lamp is replaced, although an occasional lamp may need a readjustment.

The phototubes are operated well within the manufacturers' ratings.

Output

A block diagram of the tape output organization is shown in Figure 6. A 20-digit number is divided into four characters each of five digits; the individual characters are fed to the output staticisor where the five digits are stored until they are either perforated on teleprinter tape or printed on a roll of paper by means of a teleprinter. Either one or both of these output mechanisms can be in use; the form of output required is selected by a switch under the control of the operator.

When the program specifies an output instruction, a code is set up, the presence of which will inhibit the progress of the computer if the output mechanisms are not ready to accept the new output charac-
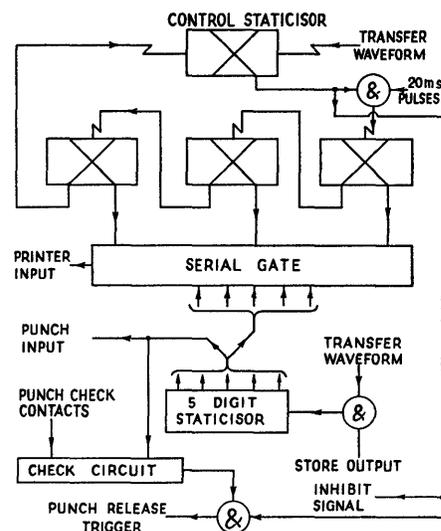
Figure 6. Logical diagram of the tape output organization

ter. As soon as the mechanisms have completed their previous operation, a signal is generated which will remove the inhibit and allow the computer to proceed, a store transfer wave form is then generated and this resets the 5-digit output staticisor and allows the new character to be set. The store transfer wave form also sets the output control staticisor and thereby initiates the operation of the selected output mechanism. Completion of the output operation resets the control circuit in readiness for the next character.

THE TELEPRINTER

The teleprinter requires a serial input current, and this current is provided by the output from a multiple gate controlled from a 3-stage binary counter. During periods when the printer is not operating, the counter chain remains in the zero state. When an output instruction is given, the output control staticisor opens a gate to allow a train of pulses to trigger the counter chain. The first count produces a current to release the clutch on the printer, the next five counts sample the outputs from the 5-digit store, and the last two counts are inactive so as to allow the mechanism time to set up the type in readiness for printing. When the counter reaches the initial state of zero, the output control staticisor is reset and this closes the trigger gate.

THE TAPE PUNCH

Various tape punches have been developed. The earliest mechanisms were standard punches modified to the extent of fitting individual electromagnets to operate the digit selection mechanism. The present tape punch has been specially

STATICISOR

OUTPUT

FIXED CONTACT   FIXED CONTACT
MOVING CONTACT
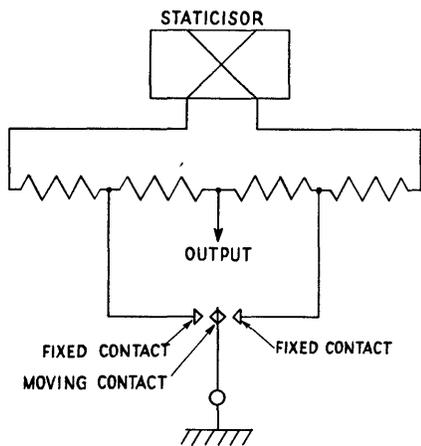
Figure 7. The check circuit

designed for use on computers and other similar electronic equipments. Four main factors have influenced the design: the need for utmost reliability, a high speed of output, simplicity of associated electronic circuits, and the need for a minimum amount of routine maintenance.

The tape used in this punch can be either five or seven units wide. Two tapes can be perforated simultaneously at a rate of 50 characters per second. To simplify the mechanical design, the mechanism has been divided into two parts: one part consists of the main shaft together with the punch anvil and eccentric, while the second part is associated with the storage and transfer of the character and the tape feed. This subdivision has been made so that the heavy parts associated with the anvil can be allowed to function continuously while the intermittent motion is confined to the relatively light transfer unit. Punching of the tape takes place only when the transfer unit operates.

Each digit output controls the energization of a separate electromagnet, and the position of the armatures determines the holes to be perforated. Because of the importance of the correct functioning of these magnets, a set of contacts is incorporated to determine that the armatures are set correctly in relation to the output of the store. Only when each armature is displaying the correct mechanical setting is the clutch allowed to operate.

When the clutch is released, it engages with a single tooth mounted on the main shaft. A single tooth is provided so that angular synchronization is obtained between the main shaft, which carries the anvil, and the code transfer mechanism, which is driven through the clutch. The clutch will complete one revolution before it can be disengaged. Rotation of the

clutch causes the code transfer arm to move towards the digit electromagnets and thereby transfer the displayed information to a set of mechanical storage arms. Continued movement of the transfer arm brings the selected storage arms into engagement with corresponding interposer bars.

The selected interposers are then pushed between the reciprocating anvil and the punch rods, the forward movement of the anvil is transmitted through the selected interposers, and the tape is punched. As soon as the punch anvil has completed its maximum forward movement, the interposers are withdrawn to their nonpunching position. The last 60 degrees of rotation drives a Maltese cross connected to the tape feed sprocket wheel.

A tape punch of the type described allows the optimum allocation of operating time for each individual part of the mechanism consistent with a high overall speed. Because the code setting is transferred from the electromagnets to the mechanical storage arms at an early stage of the punch cycle, the electromagnets are available for resetting to a new code in time to release the clutch before disengagement shall occur at the end of the punch cycle. Therefore the tape can be perforated continuously without halting the mechanism.

THE CHECK CIRCUIT

A circuit has been developed to indicate any discrepancies between the mechanical setting of an electromagnet or other controlled mechanism and the electrical potentials defining the condition required. An example of the application of this check is the positional monitoring of the digit selection armatures on the tape punch relative to the controlling voltages on the output of the staticisor store.

The circuit used for this check is shown in Figure 7. Four resistors are connected in series across the antiphase outputs of the staticisor; the output from a staticisor is either −50 volts or ground depending on its condition. Therefore, for any given digit, one end of the resistor chain will be negative and the other end at ground potential. Two contacts mounted on

SECTORS

	•	O	I	2	3	4	5	6
7	A	B	C	D	E	F	G	H
8	J	K	L	M	N	P	Q	R
9	S	T	U	V	W	X	Y	Z

ZONES

Figure 8. The coding chart of the Bull printer

either side of the armature are joined to the intermediate tappings on the resistor chain, and the armature carries a contact connected to ground. When the armature is correctly positioned, the associated contact together with the appropriate resistor junction are then grounded. This makes the potential at the center tap of the network zero. If the armature fails to move to the correct position, a negative voltage is produced at the center tap.

The derived output voltage is fed to the control grid of a pentode used for energizing the clutch electromagnet. The suppressor grid is switched by a controlling wave form. Only when the electromagnets are correctly set and the control wave form is at ground potential can the clutch be energized.

The High-Speed Printer

As tape equipment was developed, it became obvious that there was a need for a faster type of printer, for although the tape had been used successfully on a variety of programs including representative commercial problems, the limitation in output printing speed of the teleprinter was a serious drawback if this type of computer was ever to be used outside a university. The punched-card system was chosen rather than an input-output medium peculiar to computers, such as film or magnetic tape, as it was thought that many large firms already had considerable capital and experience invested in punched cards, and would therefore favor a system using their existing equipment. Also, when a printer is used, the information is immediately visible with no further processing.

When a high-speed output system was considered for the Ferranti computers,

SCANNING STORE AND SETTING MAGNETS		OPERATION OF MAGNETS	COUNTER SETS TO 8	SCANNING FOR 7s	
6 m.s.	3 m.s.	14 m.s.	4 m.s.	6 m.s.	3 m.s.
POINT 8				POINT 7	

Figure 9. Timing diagram for one point period

Figure 10. Logical diagram of the high-speed output system

WFS FROM COMP.
ARE UNDERLINED

it was decided not to shoulder the additional burden of making a new mechanical print unit, but to use one of the existing printers designed for use with a punched card system. The decision was also made to use a wheel or bar-type printer rather than one using a field of wires, both because the type quality of the former was better and because the wire-type printer was available only in the United States.

At the time the system was being considered, one of the fastest machines being produced was the printer made by the Compagnie des Machines Bull, of Paris. This machine was capable of a very high standard of print, at a speed of 150 lines per minute, each line containing up to 92 characters. This speed was felt to be approaching the highest reliable speed attainable by the conventional type of printer and, because of this and other attractive features, this machine was chosen as the basis of our unit.

THE PRINTER MECHANISM

Each printing cycle of the machine is divided into 15 'points.' The normal speed of the machine is 150 cycles per minute giving about 27 milliseconds per point. The points are numbered 9, 8, 7, 6, 5, 4, 3, 2, 1, 0, 11, 12, 13, 14, and 15, in that order, and the machine cycle starts just before the 9 point. The last printing operation occurs just before point 15.

The print wheels are divided into nine sectors, each sector having four zones. Each zone contains a character, one of the four characters in a segment being numerical and the other three alphabetic.

The coding is shown in Figure 8. Thus, on a print wheel, there are 36 character positions which contain the numbers from 0 to 9, the alphabet, except O and I which are common with 0 and 1, a decimal point, and a mechanical zero. Special wheels with different character configurations can be produced if required.

Each print wheel has an electromagnet associated with it, and selection of both sector and zone is controlled by the same magnet. It is energized during points 9, 8, or 7, to select the zone, and during a subsequent point to determine the sector. Thus, to print a 3 the magnet would be energized once only, during the 3 point; but to print L it would be energized first during the 8 point and again during the 1 point.

The fact that the same magnet is used for both selections, thereby simplifying the electronic switching, was one of the factors determining the choice of this printer for the output system.

The zone and sector selection is done by two arms which engage in teeth on two ratchet wheels. During points 9, 8, and 7, only the zone arm can move, so the differentiation between zone and sector information is automatic. When the ratchet wheels are stopped, this transfers the drive to the print wheels, which rise and at the same time move outward, pressing the ribbon against the paper. Thus the characters are printed with a sharp rolling action.

The only two consecutive points which would produce a character if both were energized are 7 and 6, which produce H. To prevent this being printed accidentally

due to overlong energization of the magnet on point 7, a return bar is provided. This bar starts to move about 10 milliseconds before the 6 point begins and forcibly returns the magnets to the unenergized position. The bar returns to its original position at the beginning of point 6.

THE BASIC SYSTEM

As with the other output devices described, the main point in the specification is that the computer should have to pause for the shortest possible time in order to output its information. Since the printer uses its information at different times throughout its cycle, this criterion involves some form of secondary storage, either output staticisors or a separate fast-access store. On the grounds of economy, staticisors were ruled out and a design was formulated around a Williams tube store of the same type as those used in the computer itself. It was decided that this should be a normal store when no output was taking place, but should be divorced entirely from the computer during an output cycle.

The information in the store is arranged to suit the Bull coding: that is, it consists of a pair of 4- or 5-digit groups, each group representing one point position. During an output, the information in the store is converted into fairly long pulses with the right timing in the output cycle, and these pulses are routed to the correct magnet, the position of a character in the line of print being determined by the number of its line in the cathode-ray tube store.

A separate control unit controls the switching of the output, or 0 store, effects the mechanical-electrical timing conver-

sion, and provides the check or fail-warning facilities.

The output system may thus be split into three parts: the store, the decoder and distributor, and the control unit.

TIMING

Before discussing the printer in detail, the timing sequence must be understood. The points occur serially and during each one the store must be scanned. Where groups corresponding to the particular point occur the correct interposer magnets must be energized.

The magnet coils are such that they require the voltage applied to them to be maintained for at least 14 milliseconds to ensure correct latching, so, as the points are 27 milliseconds long, 13 milliseconds remain for the scanning operation. However, as previously stated, there is a bar which forcibly resets the magnets between points 7 and 6 starting 10 milliseconds before the 6 point, and thus all magnets must have operated 10 milliseconds before the end of a point. This leaves only 3 milliseconds free at the beginning of a point.

The normal time needed to scan a cathode-ray tube store of 64 20-digit lines is about 16 milliseconds (240 microseconds per line), but as only ten digits per line are used for output, the 0 store can be scanned at twice the normal speed during an output operation, all 64 lines being read in just under 8 milliseconds. This enables the whole store to be read within the time available. Taking these considerations into account, the timing for the system is as follows:

The start of a scan period for a point occurs 6 milliseconds before the end of the previous point, and continues for 9 milliseconds, during which period all necessary magnets will have been energized. A period of 14 milliseconds is allowed to ensure that the mechanical latches have operated, leaving 4 microseconds before the next scan period to allow for resetting of counters, and so forth. The timing is shown diagrammatically in Figure 9. If a magnet is energized during the first 6 milliseconds which are in the previous point, it will still select the right character because of the mechanical timing and the inertia of the control linkage.

Reading occurs at every point from 9 to 11, and a flip-flop is set for this period, which is the period of nonavailability of the 0 store to the main machine, that is, approximately 300 milliseconds.

The timing pulses from the printer are obtained from a magnetic cam, which emits three pulses per point at 3, 17,

and 21 milliseconds after the start. This cam consists of a permanent magnet fixed in the periphery of a tufnol wheel and rotating past three pickup heads consisting of small mumetal U laminations with a coil wound on one arm. The wheel accomplishes one revolution per point.

MACHINE ORGANIZATION

The Store Unit

The secondary storage for the output unit is provided by a Williams-type fast-access cathode-ray tube store, and it is the capabilities of this type of storage that make the extreme flexibility of the output system possible.

When no ouput is taking place, the store can be considered as a part of the ordinary fast-access storage of the computer. It is entirely under the control of the computer, and access may be had to any individual line by means of the line address staticisors.

If it is desired to output any information, it is placed in the correct position in the 0 store, and this can be done in several ways. In general the 0 store will be filled by the transfer of a half-track from the large capacity magnetic storage using the normal magnetic transfer instruction, but the store may also be filled line by line as the information is computed, and this may be done direct from other units in the machine, such as the accumulator.

When the contents of one print line have been assembled in the store the in-

struction 'print' is given to the output control circuits, and gates controlling the input to the 0 store are closed.

After this instruction, until the store has been printed out correctly it is isolated from the computer, and the information in it cannot be altered. Each line is read and regenerated simultaneously, the lines being scanned sequentially at twice the normal speed under the control of counters in the output control unit, there being no necessity for separate regeneration and reading periods, as there is no need to specify individual lines. If the computer attempts to use the 0 store during this period, it is prevented from continuing its routine, and keeps attempting to obey the same instruction until the 0 store is free. This caters for any mistake in the output system, for if one occurs the store is kept isolated as though a print were taking place, thus preserving the information until it can be printed correctly.

Control Unit

Under this heading are grouped the start, fail, and check circuits, and the two counters associated with the system.

The instruction to print operates a flip-flop, $PF1$, which energizes the clutch magnet on the printer, and is reset after the last useful reading point, as shown in Figure 10.

This flip-flop also sets $OAWF$ which provides the wave form to isolate the 0 store. $OAWF$ is equivalent to $PF1$ but
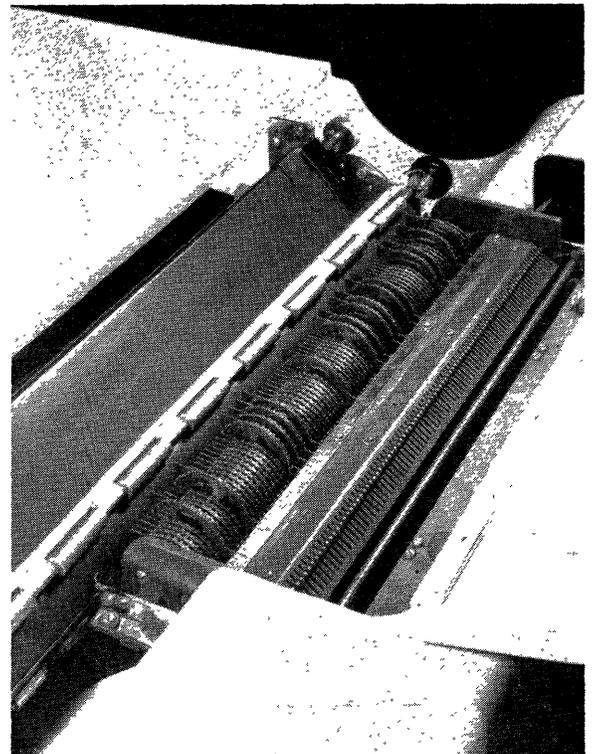

Figure 11. View of the print wheels showing some raised after printing

is synchronized with the computer.

The double-speed scan is controlled by *PF2* which provides the bright-up pulse for the line time base and, also, during output, triggers the line address counter which controls the *Y* time base. This counter is *LC1* to *LC6* and is normally triggered by the same signal that controls the computer regeneration counter to ensure that all lines are regenerated within the correct period.

The other counter in the control unit is the point counter *PC1* to *PC4*. This is triggered by the pulse from the magnetic cam which occurs 10 milliseconds before a point but, since it must only count 15 to fit in with the point cycle, an additional trigger is inserted during point 14. This counter is checked for synchronism at three points in the cycle by contacts on the printer which give signals at points 4, 11, and 15. If the counter is out of synchronism at these points, the flip-flop *SF1* is set, which sounds an alarm and keeps the 0 store isolated. The operator can then come over to the machine, erase the faulty line, and cause the same storeful to be reprinted after having reset the counter. Alternatively he can bring some other output device into operation.

One of the other main flip-flops in control is *PF6*. This causes the computer to idle if either the 0 store or another print cycle is called for while a print is already in progress.

Decoder and Distributor Unit

This unit compares the machine point position with the output from the 0 store and routes the information to its correct position in the print line.

The machine point position signal is decoded from the point counter by means of a set of gates and decoder trees. The coding for this depends on the coding of the computer with which the printer is associated. The printer in use with the Manchester University computer uses the 2-out-of-5 code, to give some measure of check on the cathode-ray tube store,

since the accidental gain or loss of a digit will produce nonsense.

The output from the store consists of two 5-digit groups in the 2-out-of-5 code, each group representing a point position. For numerical printing, one of the groups will contain nonsense, but for alphabet both will be used. The correct Bull coding is contained in a directory store in the computer, and the information to be placed in the 0 store may be obtained by reference to this directory.

The two signals are now examined for equivalence over five digits. This is done by examining each pair of digits separately for nonequivalence. If nonequivalence occurs, a flip-flop is set, and the state of this is examined after each group of five digits. If it has not been set, then the two groups must have been identical, and a further flip-flop is operated. This last may be set half way through, or at the end of a 10-digit line, so the information is shuffled on to the beginning of the next store line and sets a flip-flop for the duration of this line. This shuffle entails setting the distributer one line back.

The equivalence signal is now passed through the distributor network, which is controlled by decoder trees from the line address counter, and is used to trigger a flip-flop, which operates the power valve energizing the correct interposer coil. All these flip-flops are reset after each point.

MECHANICAL CONSTRUCTION

The first model has been made in three units; the print console, a circuitry pillar, and the power supply. The print console, besides housing the printer itself, contains the power supply controls, the reset and reprint buttons and the chassis for the distributor and power valves. The printer, its motor, and the gear train, are mounted on a separate cradle in the console, which is rubber-mounted on the main frame. The chassis in the console

are also antivibration mounted.

The pillar contains all the other circuitry associated with the printer, including the store. In subsequent models this will be included within the computer, and the power supplies will be common.

The circuitry, except for the power valves and the store, has been constructed on flat chassis 2 feet by 1 foot, with provision for 24 valve bases of the miniature 7-pin or 9-pin types down the center. The components are mounted flat on tag strips down the sides of the chassis. The power valves are on the same size of chassis, but are mounted in four rows of nine down the sides with their few associated components in the center. These chassis provide maximum accessibility to both components and valve bases, and are exceptionally easy to service. At the moment, interconnections between chassis are provided by Breeze terminal blocks for signal leads and Breeze plugs for power.

There has been an attempt to standardize the valve type in this equipment, and the majority of valves used are *12AT7*. The power valves are Mullard *EF 55*, and a few other types have been used in the circuitry connected with the store.

SUMMARY OF MAIN CHARACTERISTICS

Maximum speed...150 lines per minute
Characters per line.64 spaced anywhere in 92
Type spacing......4 millimeters
Type height.......2.5 millimeters
Line spacing...... 2 millimeters
Carbon copies.....original plus two copies
Provision for single, double, or treble spacing, or the use of preprinted forms.
Computer time for output, 33 milliseconds

FUTURE PROJECTS

Work is being carried on in conjunction with Powers-Samas Accounting Machines Limited of England, on a system of input-output, using punched cards. It is expected that reading and punching of cards will be possible at speeds of the same order as those of the present printer, or at greater speeds.

A Numerically Controlled Milling Machine

J. C. McDONOUGH   A. W. SUSSKIND

A MILLING machine which is controlled by numerical instructions is now in operation at the Servomechanisms Laboratory of the Massachusetts Institute of Technology. Figure 1 shows the entire system. The machine tool is located at the right of the picture and the control equipment is housed in the L-shaped structure at the left. The controls, which employ approximately 270 vacuum tubes, 170 telephone-type relays, and 300 germanium diodes, have been arranged on vertical panels for maximum accessibility of all parts.

Operation

In the operation of any milling machine, the complete path of the tool over the work must be controlled. In the machine shown, the path of the tool is controlled by instructions from punched paper tape. New instructions are provided whenever the direction of the path changes. Each instruction will cause the tool to move from one specified point on the work to the next along a straight line, and also will prescribe the time interval which is to be consumed in executing that straight line. The straight lines are generated by a suitable combination of the three orthogonal motions of the machine tool (the table, the head, and the cross-slide), which form a Cartesian coordinate system. One may then state the input-output relationship of the system as follows:

Input. Numerical specification of the x, y, and z components of the motion which the tool is to execute and the time interval required for that motion.

Output. Straight-line motion of the tool from where previous instructions have placed it to the newly specified point.

The flow of information through the system is shown in Figure 2. The machine instructions are read from punched paper tape under supervision of the control circuits and routed via stepping switches to the appropriate storage relays. Storage is shown as divided into three assemblies, one collecting the instructions for the table of the milling machine, one the instructions for the head, and one the instructions for the cross-slide. Each assembly can store two commands, called the A and B numbers. As the A number controls the machine, the B number is being read in from the tape so that when the A number has been executed, the B number is fully assembled in storage and ready for use. Upon switching control to the B number, the next instruction is read in from the tape and stored in the relays which had been cleared upon completion of the original A command. By thus alternating between the two registers, continuous control of the machine is achieved.

The next step in the flow of information consists of generating a set of three pulse trains, one for the control of the milling-machine table motion, one for the control of the head motion, and one for the control of the cross-slide motion. Each pulse train consists of as many pulses as are specified in the instructions and each is distributed over the same interval of time, also specified by the instructions. These three pulse trains are generated by the pulse generator and distributor shown in the center of Figure 2.

Finally, the three pulse trains are translated into three machine motions. This operation involves two steps. Step 1 is carried out by the decoding servomechanisms which translate the pulse trains into shaft rotations. Step 2 is carried out by the power servomechanisms located remotely at the machine tool proper, and consists of transmitting the shaft rotations and translating them into linear motions of the machine ways.

The units of greatest interest are the pulse distributor and the decoding servomechanisms. The remainder of the system is sufficiently conventional to require no further discussion.

Pulse Distributor

Consider first the single flip-flop shown in Figure 3. The flip-flop is so connected that it changes its state with every input pulse. If the flip-flop is initially assumed to be in the 0 state, then all the odd input pulses cause the flip-flop to switch from 0 to 1, and all the even pulses cause it to switch back from 1 to 0. By connecting a differentiating circuit to each of the tube plates, one output will give a positive pulse for the 0 to 1 transition, and the other output will give a positive pulse for the 1 to 0 transition. The pulse generated by a 0 to 1 change is called a non-
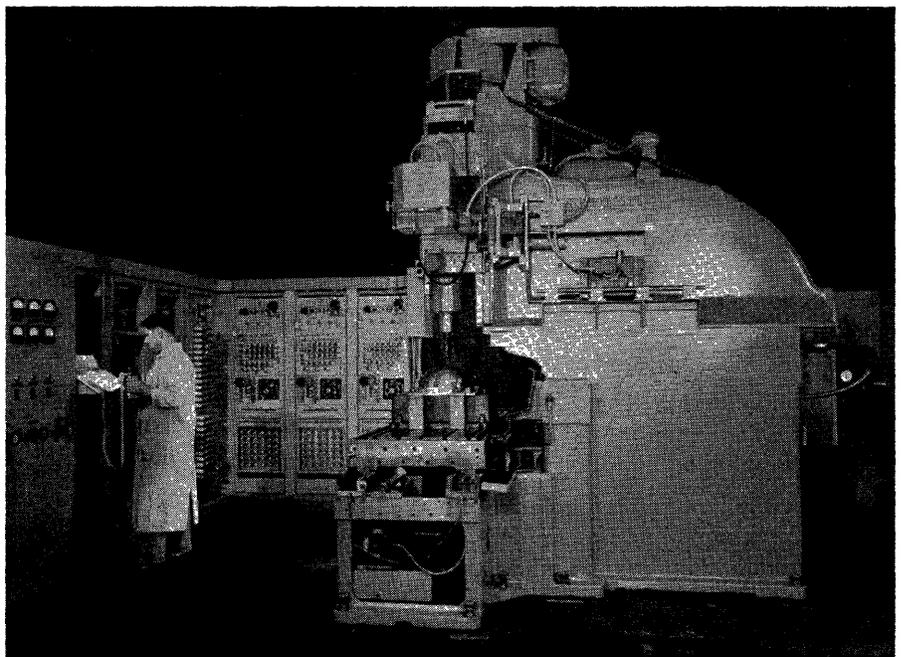
Figure 1. Numerically controlled milling machine

PULSE DATA

PULSE
GENERATOR

A   B

DATA DISTRIBUTORS

TABLE   HEAD   CROSS
                              SLIDE

PULSE
TRAIN

DECODING SERVOMECHANISMS

NUMERICAL DATA

TAPE READER   CONTROL CIRCUITS

HEAD

SYNCHRO DATA TO
POWER SERVOMECHANISMS

CROSS
SLIDE

TABLE

NUMERICAL DATA
FROM RELAY STORAGE

ALARM CIRCUITS

PULSE
DISTRIBUTOR

TABLE   HEAD   CROSS
                              SLIDE

RELAY REGISTERS

A   B   A   B   A   B

NUMERICAL DATA
TO RELAY STORAGE
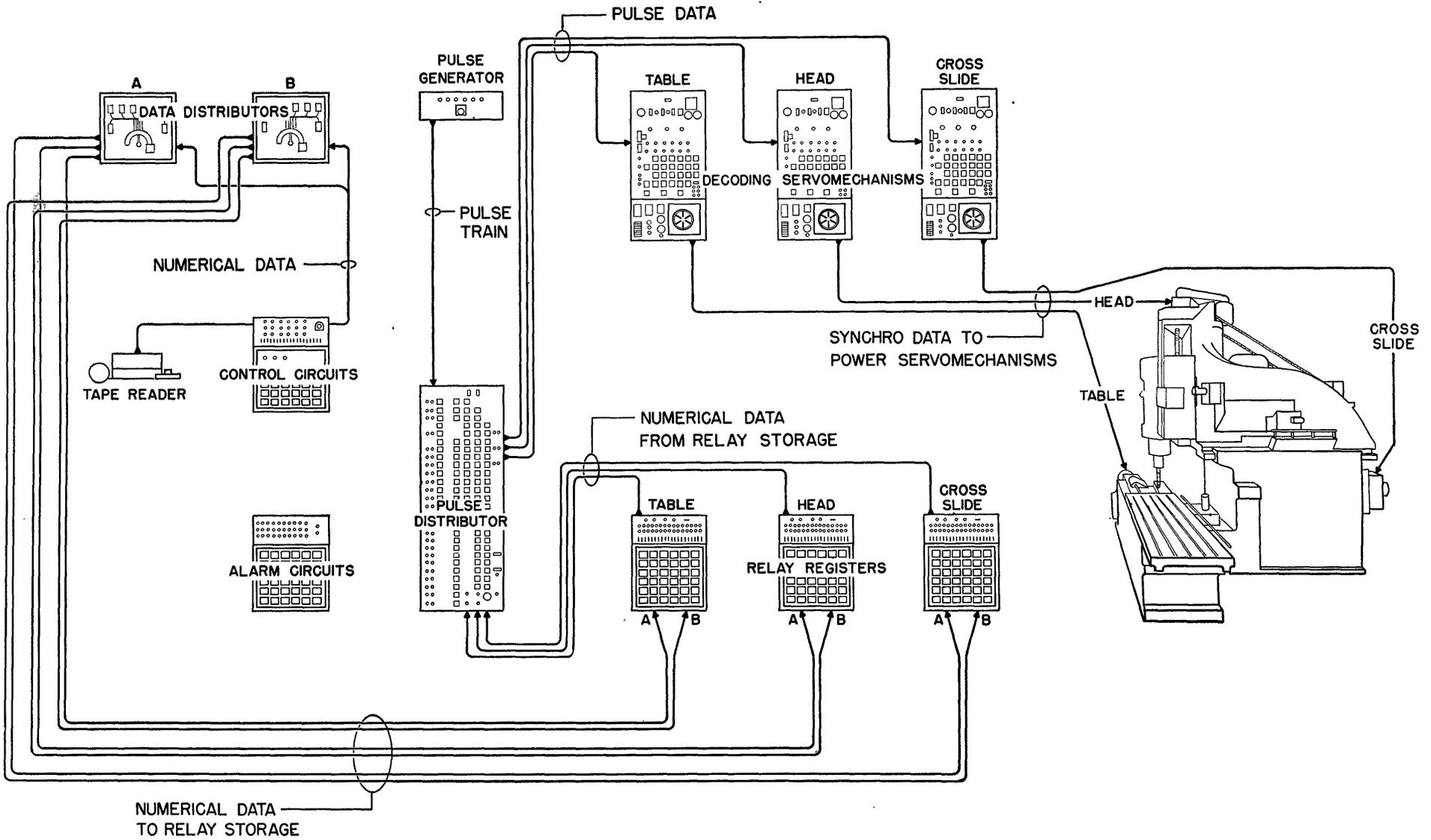
Figure 2.   Flow of information

carry pulse. Hence, a noncarry pulse is generated for every odd input pulse, and a carry pulse is generated for every even input pulse.

Consider now a set of three flip-flops interconnected as shown in Figure 3, that is, the carry pulses from each flip-flop are connected to the input of the next flip-flop and the noncarry pulses appear on the vertical lines still not designated. If the remarks made in connection with the top flip-flop are now kept in mind, it is readily verified that when eight pulses appear at the input to the 3-stage counter, four (1,3,5,7) appear at the noncarry output of the first stage, two (2,6) appear at the noncarry output of the second stage, and one (4) appears at the noncarry output of the third stage. The addition indicated in Figure 3 shows that of the eight input pulses to the counter, seven are recovered on the noncarry lines. It can also be observed from Figure 3 that the noncarry pulses from the various stages never coincide in time. It will be shown later that this is a most valuable feature.

If the end-carry pulse is used to stop the input to a counter having S stages and the counter is originally preset to 0 it receives exactly 2^S pulses at the input. Of these, 2^{S-M} pulses are recovered at any one stage on its noncarry line, where M indicates the serial number of the stage. Since the noncarry pulses from the various stages never coincide in time, it is possible to mix, that is, add, the outputs in any combination to obtain the desired number of output pulses. The largest number of pulses that may be so obtained from 2^S input pulses is $2^S - 1$. For example, the 3-stage counter of Figure 3 supplies five pulses if the outputs of flip-flops 1 and 3 are mixed.

The pulse distributor used in the director of the numerically controlled milling machine utilizes the type of interconnection just discussed. Consider first only the main part of the distributor, shown in Figure 4. Here, a 10-stage counter similar to the previous 3-stage example is drawn. The 10-stage counter has a capac-

ity of 2^{10} or 1,024 input pulses. The input of the counter is shown connected to a 512-pulse-per-second source, so that the counter will give an end carry every 2 seconds. During every 2-second interval, the noncarry outputs can supply a maximum of 1,023 pulses, of which 512 appear at the output of the 10th flip-flop, 256 appear at the output of the 9th flip-flop and so forth. These pulses are generated regardless of the particular instructions to the machine. We will call them potential command pulses.
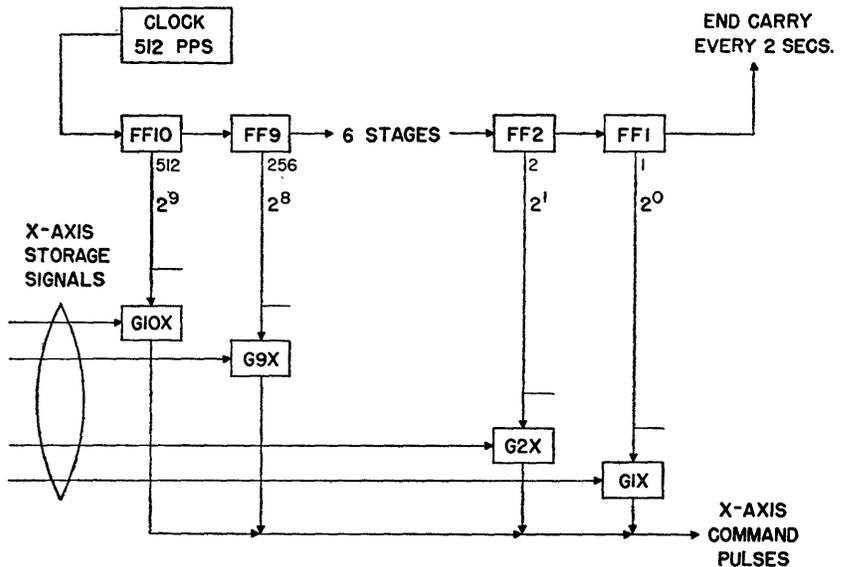
Actual command pulses for a decoding servomechanism are derived from the potential command pulses by gating the outputs of the flip-flops. For example, if the desired pulse train is to contain 515 pulses, gate $G10$, $G2$, and $G1$ pass pulses from their respective flip-flops, while $G3$ to $G9$ are cut off. The gating signals for the gate tubes are the commands which are held in storage. The resulting deviation from a uniform pulse repetition rate is subsequently smoothed in the decoding servomechanism.

For the sake of simplicity, Figure 4

shows only the X-axis gate tubes. The Y- and Z-axis gate tubes have one input connected where the horizontal bars are shown and the other input controlled by the Y and Z storage registers in a manner identical to that discussed for the X axis.

The pulse distributor used in the system differs from the one shown in Figure 4 by the addition of seven flip-flops (numbers 11 through 17) which are connected ahead of flip-flop 10. Clock pulses are gated to any one of the eight flip-flops numbered 10 to 17. If the clock pulses are applied to flip-flop 11, for example, an 11-stage counter results which gives an end carry every four seconds and decreases the pulse repetition rate at each of the flip-flops 1 to 10 by a factor of 2. By thus selecting the number of counter stages used, the following two results are achieved:

1. The average pulse repetition rate of a given desired command pulse train can be varied by factors of 2, hence the time required to execute a given command can be made to be 2, 4, 8, 16, 32, 64, 128, or 256 seconds.

Figure 4. Basic pulse distributor

Figure 3 (below). Flip-flop connections

Figure 5 (right). Decoding servomechanism
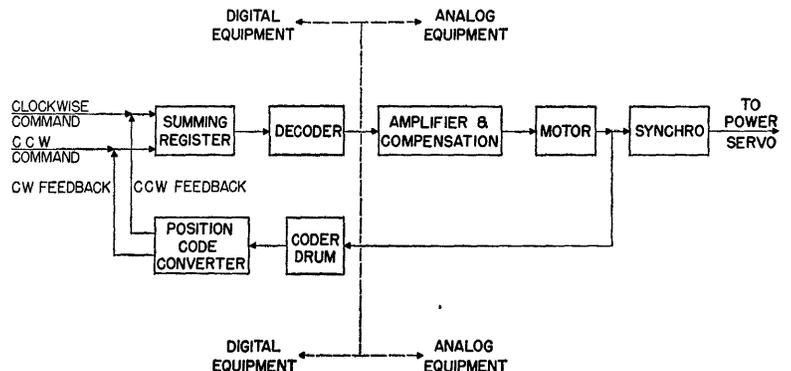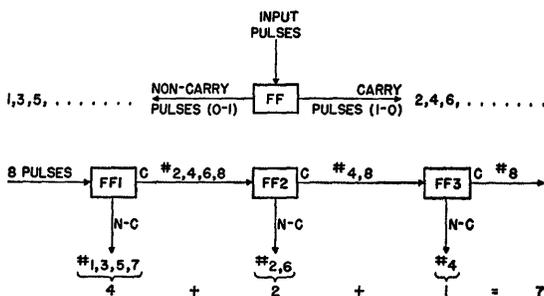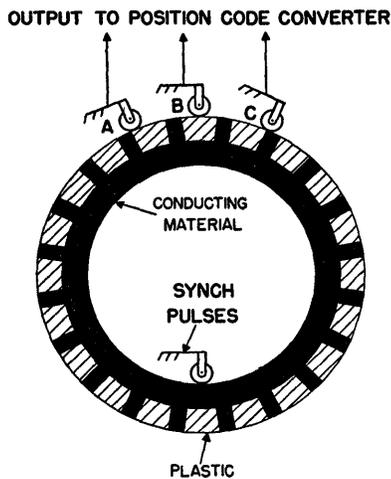
Figure 6. Coder drum

2. Depending upon the number of counter stages used, the command numbers may have a length of from 10 to 17 digits.

Decoding Servomechanism

The operation of the decoding servomechanism, shown in block diagram form in Figure 5, can be seen by considering an example. Let us assume that there is a train of input pulses on the clockwise-command line. As each pulse arrives, it is added to the contents of the summing register, a reversible binary counter. The new contents of the summing register cause a change in the output voltage of the decoder. The output of the decoder is amplified and drives the motor.. A coder drum, to be described, turns with the motor shaft and sends out a pulse for every degree of rotation. These pulses are interpreted by the position-code converter which, since the motor is turning clockwise, sends out the pulses on the clockwise feedback line. Pulses on the clockwise feedback line reduce the count in the summing register. When there are as many feedback pulses as there are command pulses, the count in the summing register is zero, the decoder voltage is zero, and the motor stops.

The dynamic elements of this servomechanism were designed to provide minimum bandwidth consistent with reasonable transient-response specifications. The purpose of this approach was to provide maximum smoothing of the slightly irregular output from the pulse distributor.

A simplified drawing of the coder drum is given in Figure 6. Since the summing register handles both command pulses and feedback pulses but cannot add and subtract simultaneously, it is readily recognized that command pulses and feedback pulses must never coincide in time. For that reason, all pulses originating from the coder drum must be derived from a train of pulses generated externally and known never to coincide with possible command pulses. A source of such pulses, called synchronizing pulses, is connected to the input of the coder drum and applied to a commutatorlike ring by the roller shown on the inside of the drum. Hence, the synchronizing pulses are available at any of the teeth, which are separated by an insulating plastic. For the configuration shown in Figure 6, the synchronizing pulses appear continuously at output roller C. If the drum now turns clockwise, the next roller to make contact is A, and further motion results in roller B making contact with the commutator. For counterclockwise rotation starting with the configuration shown in Figure 6, the next roller to make contact with the commutator is B followed later by A. Hence, for this rotation the sequence is CBA. Thus C followed by A implies clockwise rotation, C followed by B implies counterclockwise rotation, and C followed by C implies no rotation. Similar statements can be made about any other sequence of events.

Having now examined the operation of the coder, the rule for interpreting its output can be stated as follows: Identify the sequence in which the output pulses from the three rollers occur and decide if it represents clockwise, counterclockwise, or zero motion. The interpretation of the outputs of the coder is carried out by the box called position-code converter in Figure 5. While the interconnections are complex, only three flip-flops and six gate tubes are used in the unit.

Programming

The steps in the preparation of the instructions for the Massachusetts Institute of Technology machine include determination of the desired tool path over the work, reduction of that path to incremental straight-line segments, numerical specification of the end points of the segments, translation of the specification into a form which can be punched on

paper tape, and, finally, perforation of the tape.

In more detail, the programming procedure is as follows. On the basis of the drawings and specifications of the part to be machined, the desired cutting paths and feed speeds to be used in machining the work are determined. Since this determination involves the conventional decisions as to cutter type, sequence of machining operations, setup of work on the machine, and so forth, it requires a sound knowledge of machining practices.

The locus of the tool center which will produce the desired cutting paths is next determined by making proper allowance for the geometry of the tool. This locus is then divided into a series of straight-line segments. The segments should be as long as possible without differing from the desired tool center locus by more than the machining tolerance. Each straight-line segment requires a separate instruction. Hence, the longer the segments, the smaller the number of instructions. As the segments need not be parallel to the machine ways, their dimensions must be resolved into components parallel to each of the three orthogonal motions of the machine. The time to be consumed in executing each straight-line segment at the desired feed rate is then specified. The foregoing steps vary in difficulty of computation with the particular part to be made. They can be reduced to routine computations for many useful types of work.

Finally, the three components and the time interval for each segment are coded and punched on paper tape.

The computational and coding steps can frequently be performed by machines. The use of digital computers in programming becomes particularly advantageous in those cases where the work surface can be conveniently described in terms of equations. Several parts have been machined on the numerically controlled milling machine which were programmed by Whirlwind I, the digital computer developed at Massachusetts Institute of Technology. Whirlwind I is capable of supplying at its output tapes which can be used directly to machine parts. International Business Machines (IBM) equipment also has been employed in programming. Equipment modifications are planned which will permit the use of IBM-prepared instructions without further processing.

Discussion

A. Liebersohn (Government Division, Philco Corporation): What is the possibility of receiving better tolerances than 0.001 inch?

Mr. Susskind: In a process of this nature, the only thing that limits the accuracy of the machine parts is the basic tolerances in the machine tool proper. Any slop in the gibs of the machine, any misalignment of the ways, any tool wear will show up in the finished work. We are not considering this system as being applicable only to a milling machine, but we feel it has a great many applications entirely unrelated even to machine tools. If you give me a Swiss jig borer and we agree to put it in an air-conditioned room, the chances are we might get work better than 0.001 inch. We have always been able to make the control information more accurate than the machine tool.

Mr. Liebersohn: What is the possibility of controlling power servos directly from digital data?

Mr. Susskind: Briefly, we feel that it is not economical to tie up a large-scale computer, like our Whirlwind, with a little machine tool in another building. This would be inefficient. We have tried to strike a reasonable compromise between the computing ability within the machine tool and that which is external to it. The present machine is equipped only to carry out linear interpolation. We left the machine control very stupid, giving it new instructions whenever it changes direction. The division into a decoding servo and a power servo was dictated by development considerations. It is entirely possible to have a single closed loop rather than two closed loops in cascade.

Mr. Liebersohn: What is the time response of the power servo in terms of the resonant frequency?

Mr. Susskind: It is, roughly, 3 cycles.

Summary and Forecast

S. N. ALEXANDER

I WOULD like to call attention to the significance of the theme chosen for this year: the characteristics of the input-output systems and the equipment that has been incorporated into several typical electronic digital computing systems. Pertinent auxiliary equipments needed to supplement the input and output functions in approaching a fully automatic data-processing system have been covered in the conference. The choice of this theme and the enthusiastic response given this choice are indicative of the tempo at which digital data-processing equipment is being extended from a specialized tool solely for the scientist into equipment that is going to be extremely useful to the managers of commercial, industrial, and governmental activities. A few remarks regarding the forces that have been at work accelerating this trend may be of interest.

A similar conference held in Philadelphia in December 1951 created the assurance that arithmetic, control, and fast storage functions had been achieved by more than one approach. Furthermore, it appeared that these basic units had exhibited initial reliability that was fully as unexpected as it was gratifying. Because there had been many discouraging delays in the progress of the first computer projects, it was natural that the completion of machines which performed reliably should engender great elation. In fact, in this elation, a certain development tended to be overlooked—the attainment, much sooner than expected, of a level of effectiveness for the internal machine functions that was outstripping the ability to get the information into and out of the machines. There was a backlog of significant computations that need little communication with the outside world and this tended to obscure the situation. This initial elation was short-lived in the face of the mental audacity of the men who began posing problems for the machines that required input-output performance not yet available. Beyond these scientific needs there was an accumulating pressure from potential users of these devices who planned to use them more as generalized information processors than as digital calculating machines.

Perhaps this might be considered to be a distinction without a real difference. I believe not, because the generalized information processor application naturally places emphasis on the input-output characteristics so that the system can function effectively on tasks for which numerical manipulations have a secondary role. A pioneering example in this area has been set by the Bureau of the Census in their recent tabulation of a portion of the 17th Decennial Census with electronic equipment. Incidentally, this role of pioneer in data-processing techniques is not a new role since Census was the first organization to make major use of the punched card techniques developed by Hollerith and Powers at the turn of the century. Census' experience with their initial electronic installation has served to emphasize the weight that needs to be allotted to the characteristics of the input-output features in estimating the effectiveness of digital equipment for data processing.

With this background, it seemed entirely appropriate for this conference to be devoted to the characteristics of the input and output equipment that is now available for use with both computing and data-processing systems. The program for the first part of the conference was selected mainly to provide an orientation for comparing the features of the input-output facilities now available on complete machines. Following this, the specific installations selected for presentation represented several ways to approach the organization of the input-output equipment. In addition, these presentations contained information on equipment that has been completed and, in most instances, equipment for which operational experience is available. There is a host of ingenious ideas which relate to improved performance of such equipment and which deserve attention. However, the limitations of time at this conference required that they either be included in the survey papers or left unmentioned. The fact that certain systems and equipments were given space on the program does not necessarily imply superiority of their approach over that of others known to be in development, but rather a commendation for the energy and zeal of their creators in making them available at this early date. The evident importance of this class of equipment is certainly a provocative

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challenge to rapid further improvement which should justify another conference on the same subject in the near future.

A part of the program for the final sessions was devoted to items that look toward additional areas of applications for information-processing machinery; in particular, the survey papers on analogue-to-digital converters and the numerically controlled milling machine. These both relate to the early beginnings of the use of digital-data processors as a key element in a control system by which the information processor exerts a direct influence over the actual handling or processing of material things. Let us defer detail consideration of this new area for the moment and speculate briefly on some trends in the application of information-processing machines to the automatic handling of the ever-increasing burden of paper work that has accompanied the expanding activities of commerce, industry, and government.

At the present time, there is keen interest in the possibilities of transferring much automatic handling of the routine paper work that is becoming such a burden to all organized endeavor of modern man. There are good reasons to expect that other successful applications will soon follow in the wake of the pioneering example of the Bureau of the Census. As a measure of the importance that some people attach to this field, these anticipated improvements have been frequently referred to as a second industrial revolution that is to occur in the office. This is an obvious direct parallel to the first industrial revolution which occurred in the factory. Here mechanization and standardization of ways of handling and processing material things were developed that led to vastly increased output with great reductions in unit costs. If there is to be an industrial revolution in the office, it apparently is going to take the form of the application of mass-production and assembly-line techniques to the handling and processing of data and information through the use of electronic processors with appropriate auxiliaries. Such outright predictions of a revolution in techniques do not give adequate credit to the less dramatic improvements that are already being achieved through the use of conventional office machinery and punched-card equipment. However, these improved mechanical techniques do not have the potential for keeping pace with the growth of the problem. It has been reported that the ratio of new clerical workers needed to new factory workers needed has increased threefold in the last 25 years, until today clerical workers actually outnumber agricultural workers in this country. On the other hand, the new electronic techniques do appear to have the potential for achieving a fully automatic approach to the handling of the paper work such as that associated with record keeping, billing, accounting, inventory control, and production scheduling.

Many developments have been discussed during the conference that appear applicable to these tasks, but they are but steps along the way toward an adequate scheme for coping with the steadily increasing magnitude of the problem. Certainly, there exists today the need for extremely larger reservoirs for data storage that can be interrogated both by people and by the electronic processors. Development teams are actively looking into possible ways of achieving such functions, as well as others closely related. It does not seem unreasonable to anticipate supplanting a large number of file cabinets, together with their paper documents, which now must be removed during use and subsequently replaced, by completely automatic files. Such files could employ some form of automatic playback device that uses magnetic recording techniques. It would then no longer be necessary to remove and replace the 'source' record in order to process the information, since telegraphic communication techniques could be employed between the files and the users, whether they are people or electronic processors. Either could 'dial the file' for the desired information in much the same way in which we now dial into the telephone system to get information about the time or the weather. These files can not only be interrogated at a distance, they can also be 'written into' from a distance. Some of the advantages that might accrue from this approach to the automatic file problem are:

1. Less space will be required for filing documents.

2. Reference to the file can be made automatic, since no one need go to a filing cabinet and physically pull papers.

3. Reference to the file does not remove the original data from its storage place, even while the information is being used or the file is being brought up to date.

4. Because the files can be remote from the users (and contact made via telegraphic communication), records can be housed in underground vaults that are safe against bombing or fire raids.

5. If a metallic magnetic medium is used, the resulting records are probably more durable than paper or microfilm, and will be more resistant to damage by both water and fire.

6. For security reasons, to protect confidential military or corporate information, the files can be arranged so that they will not yield information to anyone until a key code word has been supplied. The code word (equivalent to a key to a lock on a filing cabinet) could readily be changed every day, if necessary. Finally, if extreme security is required, such information can be stored in a scrambled form, and the information processor would unscramble or decode the information only for people authorized to interrogate the files.

Doubtless other devices will be required to round out this proposal to fit it for various areas of applications. A few of these that quickly come to mind are inexpensive print-out devices akin to a stock ticker, fast printers for the billing functions, simple cash register–magnetic recorder units to enter data into the system at the point of the original transaction. The trend is definitely in this general direction, but the eventual form it will take is difficult to predict. The scheme just proposed by which these additional electronic data-handling functions can be attained is based on technology that is essentially established. However, there is still the question: Is this likely to be an economic means to these ends? It is hard to see how this kind of question can be properly answered without a trial installation.

Let us now turn from possible extensions of these techniques in the paper-handling field and examine the subject matter of this conference from a somewhat different point of view. The processing of paper work is essentially a matter of organizing the results of past activity. The source records, such as sales slips, vouchers, and production data, are the symbolic representation of this past activity. There is no fundamental reason why the digital-data processor should deal only with records of past activity, provided that the data processor is fast enough and that means are available to provide direct contact with the real world about it. The converters from analogue to digital represent means whereby such contact can be established.

A simple example of a situation in which this is meaningful arises in connection with measurements taken in wind tunnels. The quantities measured in the wind tunnel are not necessarily the ones by which the design engineer can most easily estimate performance. If data converters can insert the measured quantities directly into a data processor, the desired interpretation can be made available to the scientist conducting the test rapidly enough for him to adjust the parameters for the next test in the sequence. Indeed, if he is not engaged in

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an original class of experiments, the scientist could have feedback converters arrange actually to alter the controlled parameters so that the installation could move on to the next test quite automatically. While this might appear a bit visionary at present, it seems a technically feasible proposal. Here again, the fundamental question is whether this is an effective and economic means to these ends.

The concept of having the data processor in continual direct contact with the outside world suggests other more ambitious applications. We can speculate on providing far more powerful aids to the controller in the tower of an airport traffic center. These aids are needed because the data regarding the activity around the airport, as well as for the approaching air routes, do not arrive in the traffic center in a form and a sequence that are suited for immediate interpretation and use. Flexible data processing and presentation can do much toward making more effective use of the controller's experience and judgment. Note that the processing system is intended primarily as a means for giving the controller more opportunity to concentrate on those functions involving judgment and decision. However, it might eventually be feasible to adapt extremely routine situations to standard operating practice in a way that would permit machine analysis of the situation. The recommended course of action would be presented to the controller for him either to release or override. In this way the controller could quickly cope not only with the situation in which the machine is malfunctioning, but also with the situations for which he deemed that standard operating practice is inapplicable. With this point of view, it seems reasonable to look forward to seeing this class of application of digital processors in experimental trials in the near future.

Another interesting area of application is the one in which the machines are to provide prediction calculations. Indeed, the possible use of these machines for estimating the weather from such prediction calculations has already received considerable publicity in the popular press. Granting that it may be possible in principle, it is extremely easy to underestimate the magnitude of this task. For example, the estimation of long-term trends in the weather is an ambitious undertaking for even the most competent of existing machines. Far more powerful equipment will be needed before we can hope to predict the general character of tomorrow's weather from calculations made on today's observations. However, the significance of even partial success with this task is so great that all the efforts are more than justified.

Prediction calculations of another type have been explored during the past several years by a group in the Office of the Air Comptroller, United States Air Force, and are well worth comment. In this program the plans of the Air Staff are to be interpreted into the manpower, money, training, housing, material scheduling, transportation, and all the other requirements necessary to execute the plan. The detailed accounting and estimating for this task are being formulated as mathematical procedures in order to systematize the massive calculations that are involved. The use of the new electronic data processor has done much to make this orderly approach to the problem one that has an acceptable time scale. As soon as better analytical and processing techniques are available, this type of prediction calculation should become of interest to many other activities, both in and out of government.

An embryonic example is a co-operative study among the economics departments of several universities, the Bureau of the Budget, the Bureau of Mines, the Bureau of Labor Statistics, and the Bureau of the Census. The purpose here is to assemble the pertinent data about the United States economy and attempt to use the interindustry calculation technique for estimation of the impact of the defense effort on the over-all economy. While it is natural to suspect that these first efforts are subject to oversimplifications, there seem to be reasonable possibilities for eventually obtaining techniques that will provide useful estimates of these economic interactions. No doubt more powerful machines will be required, but it seems safe to predict that the eventual limitation will reside in the need for better data and techniques.

So much for the forecast of things that might come into being. If a significant portion of the advances that are being contemplated is attained, something akin to a second industrial revolution may really be achieved. These expanded electronic information processors may then come to be regarded as one of the significant inventions of our time. They may enable science, industry, and government to tackle large-scale complex problems which heretofore could not be handled very effectively in the time allowed. (Notice the last, "in the time allowed.") They may eventually reduce the necessity for centralization and attendant overcrowding by permitting the dispersal of people and equipment without sacrificing some of the advantages of centralized control. Thus they may ease the burdens of large enterprises, both industrial and governmental, by permitting the integration of many diverse activities into a smoothly functioning unit while retaining the flexibility of smaller organizations.

In closing, I wish to express my appreciation of this opportunity to interpret for you some trends that appear to be reasonable expectations for the future. However, I have the usual hesitation about the risk that goes with making estimates about the future. Indeed, if words possessed any nourishment whatsoever, would not many of us in this field grow sleek and fat from eating the words that we have spoken in forecasting the future!

General Discussion

Raymond H. Lazinski: My thesis is that engineers and logicians of the computing machinery and information-handling equipment fields have not availed themselves of the abundance of pertinent information gathered by members of the field of biological sciences. Biophysicists, biochemists, and neurophysiologists have investigated the components and circuitry of the most highly developed information-handling equipment as we know it, the mammalian nervous system. These components have been described in great detail in numerous publications in the field of neurophysiological histology.

The comparisons drawn between the brain and automatic computing machinery by A. M. Uttley,[1] W. Grey Walter,[2] and E. C. Berkeley,[3] are an endeavor to show the similarity of two types of mechanisms which have in common the fact that their outputs result from the manipulation of information either stored or obtained directly from input equipment.

A more quantitative approach is necessary if the members of the computing machinery field are to take full advantage of the knowledge gained by biological researchers. In order to understand and extrapolate on the workings of a nervous system, a working knowledge of its basic unit, the neuron, is essential. Only after the reader has acquired a knowledge of the characteristics of the individual neuron can he appreciate the integrative nature of a neural network.[4] As this is not intended to be a text on neurophysiology for the engineer or a repetition of information so ably presented in many texts, a minimum of physiological terminology will be used. Instead, this brief paper will be a description, in simple terms, of the neuron and its interactions with other neurons.

The neuron, which is a single cell, is composed of three major parts: the soma, the dendrites, and the axone. The soma is the cell body of the neuron. The dendrites, which serve to transmit impulses to the soma, are small hair-like processes which emerge from the cell body and branch out in all directions. The axone serves to carry the impulse from the soma to a junction of dendrites and axones of other neurons. The axone may range in size from $1/30,000$ to $1/30$ inch in diameter and it may be several feet in length. The hair-like branches of the axonal ending are arranged in intermeshing proximity with the dendrites of other neurons

(as illustrated by Kuntz[5]). This junction between the axonal endings and dendrites is called a synapse. The impulse which travels along the neuron is described by Adrian[6] as an all-or-none type of impulse. The polarization potentials maintained between the inside and the outside of the axone (owing to the interchange of potassium and sodium ions through the axonal membrane by means of a biological 'sodium pump,' as shown by Hodgkin and Huxley)[7] deteriorate when sufficient stimulus is applied to the dendrites of the neuron. This depolarization will travel from the soma along the axone towards a synapse. The velocity of this electrochemical impulse ranges from one meter per second in thin axones to 160 meters per second in thick axones. Gasser and Erlanger[8] show that the velocity is proportional to the square root of the axonal diameter. Immediately after a neuron has been stimulated and caused to 'fire,' it enters an absolutely refractory phase, that is, a second impulse can not be initiated, regardless of the intensity of the stimulus. A relatively refractory phase immediately follows the absolute refractory one, that is, a period during which a large stimulus is needed to initiate an impulse. This phase exists until the neuron is repolarized. It is now apparent that stimuli from more than one neuron at a synapse may be necessary to cause another neuron to initiate an impulse. To be effective the incoming impulses need not arrive at a synapse simultaneously, but they must arrive within the period of latent addition.[9] Not all impulses from adjacent neurons are facilitating; they may in fact be inhibitory.[10] It is now clear that the firing of a neuron depends upon its polarization (a function of metabolism); its refractoriness; the relation of its dendrites to the axones of other neurons[11]; the relative time of arrival of stimulating impulses; axonal transmission delays; synaptic delays, and so forth. For more detailed information on the operation of the components of neural networks, the interested reader may consult an article entitled "The Nerve Impulse" by B. Katz.[12] If not satiated, he can then consult a chapter on neurophysiological histology in almost any modern anatomy or physiology text.

It was shown by Lorente de N6[13] that a chain of neurons forming a closed loop can be made to trigger each other indefinitely around a closed circuit. Due to the pres-

ence of the inhibitory and facilitory[14] neutrons at many of the synapses within the closed loop, the path and velocity of the impulses can be altered. Because of the temporal and spatial summation at a synapse, solitary as well as cyclical impulses can be readily routed. Saunder and Young[15] imply that this is the basis for learning. MacKay and McCulloch[16] suggested that the nervous system uses a pulse interval modulation system to transmit its information. The characteristics of neurons and synapses have been used by McCulloch and Pitts to develop a 'logical calculus'[17] of neural nets. Shimbel and Rapoport[18] consider a probabilistic approach to neural networks in differentiation to what they call McCulloch's and Pitts' deterministic approach. Landahl and Runge[19] have applied a matrix algebra to neural networks. The extension of the McCulloch and Pitts logical calculus manifests itself in an explanation of the operation of some sensory organs. They have used these concepts to explain the operation of auditory and visual sensation, and recognition of form.[20] Culbertson[21] has described the optic nerve conduction and form recognition in these terms. This type of information input mechanism is certainly of greater value than a photoelectric word reader, such as the 5-by-7 matrix reader, which reads only print of a certain type with a specific orientation and size.

Channelized education has been responsible for the seeming diversity of the neurophysiological and information-handling fields. It is for this reason that the aforementioned principles have not been used to advantage in the field of information handling. Unfortunately the lack of personnel trained in both fields has served as an obstacle to the interchange of pertinent information. It is the belief of the writer that implementing of the study of neural networks, with a view toward their information-handling abilities, will result in an advantageous change of emphasis in the automatic computing machinery field. Obviously the system under discussion is ripe for investigation for, after all, it does work.

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G. N. Patterson (Burroughs Adding Machine Company): There was one thing that I noticed in connection with the matrix printers which I thought might be worth a comment. Although the numerical value has not been emphasized here, there is a great amount of redundancy from the information point of view in the matrix printing process.

Most of the printers which are designed to do alphameric work seem to use about 7 by 5. In other words, about 35 bits of information can be handled in the matrix, whereas in an alphameric character there are less than six bits, but let us just say six, to use a convenient number. This would mean approximately 85-per-cent redundancy in the output.

It might be interesting to note that the Braille system uses a 2 by 3 matrix, which is exactly the six bits. Perhaps we should employ more blind people and design our output system to print Braille. We would have a much more efficient over-all system.

The same amount of redundancy was also present in the matrix printer designed to print only decimal digits. As I remember, that was a 3 by 5 matrix—in other words, 15 bits, whereas there are less than four bits in the decimal digit, again giving a redundancy figure of about 75 or 80 per cent.

The only device I saw which tended in this direction—although I do not think it was very successful—was passed over in silence. This was the Holden attempt to use certain shaped areas other than just plain dots. I do not think this is necessarily a solution to the problem of eliminating some of the redundancy. Perhaps co-operative research of the psychologists on determining the optimum size of the matrix might be of some interest. It is probable that deterioration in the quality of printing can be tolerated. I thought that the Post Office would complain when Time and Life magazines went over to Fax dick strips, but apparently there has been no complaint. Consequently, there is some room for degradation in the type face without its becoming unacceptable for this semisoft copy.

S. N. Alexander (National Bureau of Standards): I would like to take issue a little bit with the idea that efficiency in the code is necessary to get efficiency in the over-all system. I think we live in a world so full of redundancy that it is hard to imagine our ever training it out of ourselves. The fact that a 5 by 7 matrix is acceptable, as you pointed out, I think is quite encouraging. There have been several comments made to the effect that if this is acceptable as text for business documents, it would be a very convenient method for reading the material back into the system, because scanning this dot array will give unique identification of the characters, and you can go from printed characters directly into the machine.

This is certainly not a new idea. It crops up everywhere, and it is about time somebody actually carried it out. I am sure that, with that characteristic added, the acceptance of this sort of print face would make better headway with business firms and would point up the importance of the efficiency of the notation rather than its appearance.

R. L. Snyder (Snyder Laboratories): Dr. Brainerd has said that he would like someone to state what the ideal input-output system might be for a computer.

If you start with the input system, I think the ideal input would be something that would read a page of printed matter with sufficient Gestalt to keep track of slight errors in the printing. It should be able to read at speeds comparable with the speeds at which tapes, both perforated and magnetic, can be read. It should be something that is cheap enough that the average person can hope to use in his business. Short of this, it seems to me that you must have something which is legible on the input, if nothing more than perforated tape.

For the output, I think one should have a printer fast enough to print out the contents of the memory and find the trouble in a few minutes. Even so, when computers have been developed to the point where errors are not too likely to occur, high-speed printing is still desirable, so that more work can be pushed through a computer. Undoubtedly the real value of the computer will be in direct proportion to the amount of use that can be gotten from it, and no more computers will be built than will be used.

For intermediate storage, it seems to me that something like the present rotating drums are quite good. If the capacity can be made large enough, it seems unnecessary to have tremendously fast access times required in the internal memory. I believe methods will be found to program computers with memory capacities of the order of 1,000 words, so that they can efficiently use a much lower speed large-capacity memory. I do not believe it will be economical to build 10^6 word memories with access times in the order of a microsecond or so. I think it will be much cheaper to use a 1,000-word high-speed memory with very, very large external memories, and probably a number of machines using the same external memory.

J. C. McPherson (International Business Machines): Speaking as an engineer, I should like to ask: Is this the time when we should consider standardization of the input medium, at least the input medium which looks most attractive, for which we have no standardization at present, namely, magnetic tapes? In the past it would have been quite helpful. Many people have taken advantage of early standardization, first of the Teletype tapes which have a standard positioning of hole and distance between holes and sprocket feed, and also the punched card; and of both International Business Machines (IBM) and Remington Rand which have established a degree of standardization which make interchangeability of reference between all sorts of organizations practical.

In this new medium of magnetic recording, it is quite clear that we would benefit by having a common pattern such as appears on the Teletype tape which, by and large, machine designers would follow. This would permit some degree of interchangeability of tapes between various units, and their ultimate transportation from one organization to another. Would anybody care to comment on whether this is the time for making an advance in this direction and on what would be the best method?

F. J. Maginniss (General Electric Company): It seemed to me that Mr. Snyder, in talking about the ideal input-output system, laid down some specifications, for example, for a printer. I would go a step further; I wonder whether it is time the computer industry, which is in its infancy, started thinking about standardization of more than just mediums that can be passed around from one outfit to another, but rather standardization of component parts in computers themselves. In at least one industry this has turned out to be very economical, both from the point of view of the manufacturer and from the point of view of his customer.

Dr. Alexander: Since I happen to be on the staff of the National Bureau of Standards, I ought to be an outstanding exponent of standardization, but I should like to take strong issue on this. In a field that exists by virtue of a memorandum of 1942, less than a decade has passed from the original conception of these devices in memorandum form to today. I think we are rushing the art a bit. Imagine what would have happened to the automobile industry if they had standardized 10 years after their inception.

I feel very strongly that this would pro-

duce a mental strait jacket hardly worth the efficiency that might result. I feel particularly strongly about it because technically there is no great burden associated with these translations. This is one thing I think these machines do with their little left finger. If you want the machine to do it, with a reasonable amount of ingenuity, I think translators to and from the various mediums can be had. I know in our own operation in Washington, D. C., we go from IBM cards to punched paper tape, from punched paper tape to magnetic wire, from magnetic wire we get it onto magnetic tape, and it is not very painful.

There are many problems that plague us much more than that, so I would recommend on this particular one holding up a bit. In fact, I would like to expand this point and say that I am afraid there is a Russian-like secrecy growing up in this business because everyone thinks he has the sole key to salvation.

I feel it is much too early to close the laboratory door. Mr. Kettering is very right in this, that you shut out much more than you close in if you close the laboratory door in these stages. I appreciate the difficulties of patent positions, and all that, but the customer does not buy your patent position; he buys good, working equipment, and in this case I put on my hat as a purchaser of equipment for the Government. We at least do not care who owns the patents, and I doubt if very many of the commercial users really care. If you pay a license fee, so what? Add it to the price. If the equipment is good, we will love it.

Member: I just wondered whether it would interest the meeting to know of a discussion held in London a little while ago on this very subject of standardization in computing work. The general feeling of the meeting I attended was that it would be very unwise to standardize, because, as Mr. Brainerd has said, it undoubtedly would result in much more being lost than would be gained, but one thing that did come out—and I intend to support it—was the need for standardizing terms. I feel the tendency has grown up in this field for rather slangy nomenclature, and perhaps some of the organizations could do a little bit in this direction. I believe that internationally it would help.

R. H. Lazinski (Moore School, University of Pennsylvania): I should like to know the policy of the Association for Computing Machinery (ACM) on the discussion of the true computer and the optimum analogue-to-digital converters. I personally am very interested in the biophysical connection with computers. I feel that this analogue computer, combination of digital and analogue computer which we all carry around, has a great deal of information to give to the field, and I have heard only one paper describing the type of work in this field, which was given at the Pittsburgh meeting by Dr. McCullough. I just wondered how ACM feels about this, and do they welcome papers from people in the biological field

which would deal with information input and output in the animal, and with its application, possibly, and the generation of idea in the field of automatic computers.

Chairman Brainerd: Is this directed to ACM, or to this conference?

Mr. Lazinski: I should like a general opinion on this. I suppose I should write to ACM, but I should like to know how people in general feel about this, because I, dealing very lightly in the field, feel that it can, by crossing the field of the biological sciences, give a great deal of information to the field of computing machines.

Dr. J. G. Brainerd: We probably feel input-output is not exclusively within the engineering field. This was brought strongly to my attention by the fact that one of my Congressman friends working on an input-output study told me not long ago that he had heard that the engineers had taken up the words 'input' and 'output.' The psychologists use the terms, but psychologists I know recognize that they have been using them for a relatively short time There is a very interesting question as to whether the input-output studies which involved input-output mechanisms would not gain something by considering the parallels in our own field.

S. B. Williams (President, ACM): I should like to have a letter written on this subject to ACM, because ACM is about ready to expand along various lines. One thing we are doing is to set up a nomenclature committee, which is about as far toward standardization as I would like to see us go at this time. I do think we should all have a common language, and a common nomenclature. I agree with Dr. Alexander, that we should not attempt to standardize any of our hardware at this time.

N. H. Taylor (Massachusetts Institute of Technology Digital Computer Laboratory): I should like to say a word about the general plans of the AIEE-IRE-ACM Committee regarding topics that have been discussed today. Most of you, I am sure, attended the Philadelphia meeting a year ago. We thought that this field first needed a review of the computers that existed in the field and some document that one could turn to, to get an idea of what a computer does, which computers do what, and some basis upon which one could compare computers. I think the best evidence of that document's reception is that over 1,600 copies have been sold of last year's discussion. It was quite difficult for us to decide that this topic, input-output, should be the subject for discussion this year. I believe we have brought ourselves up to date. We have already covered what computers are available; we painted that with a broad brush. We are now painting input-output with a rather broad brush. There are a lot of things we have not done, and I think that we on the committee are very conscious of this. One was just mentioned in the biological field.

A lot of people have come to me during the conference and asked why do we not do

this or why do we not have a paper on that? We are trying to develop a policy, and I would like to pass it on to you for your comment.

We believe that this Joint Conference, which we hope will become an annual affair, should bend its energies toward the engineering end of the computing field. The engineering end is only a portion of the effort, however. The AIEE and IRE are the strong group here in the sense that this is a meeting for engineers. There is no other meeting exclusively for computer engineers. We are doing this so that the ACM in the prime work of their organization can stress the application of computers, the programming problems, and how such problems can be put on machines: just how one goes about deciding when a problem should or should not go on a machine.

Apparently we are getting to a point where we need to communicate with other than engineers and other than mathematicians, because very few of us are actually using the machines ourselves. I wondered whether a next year's conference held by these organizations should try to cover the topic.

Another thought along these lines is that it has been 3 years since we had our conference in Atlantic City, N. J. We have not had a talk about computer components since that time in any degree of detail. Somewhere within the next 12 months I think we need to review what is available to the computer designer in the component field. Computer components certainly have improved since the Atlantic City conference, and we have several new components which have not even been mentioned and which perhaps are of more interest and in some ways more important to what we are going to do in the future than anything else.

These are the subjects we worry about in our joint committee, and we welcome your comments during the year. We would like very much to hear from you as to what you would like to have discussed.

Mr. Sephaban (Monroe Calculating Machine Company): I am wondering about the kind of components to be used in the future. The question that often comes to my mind is, have we investigated all the possibilities of more reliable components? Often the trouble we have is not the result of how we go about making input-output devices, but in the components we use. There was very little information on the components in this conference.

Another question in my mind concerns the use of transistors. They are being given a lot of attention at Bell Laboratories. I have asked their engineers about the magnetic cores. Have these cores been investigated enough? (They seem to be more reliable than tubes or transistors.) Or has the invention of the transistor created so much excitement that we have forgotten about other things? The answer I usually receive from the engineers is, "We often wonder about that, too."