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-

H. F. Welsh and H. Lukoff are with the Eckert-Mauchly Division, Remington Rand Inc., Philadelphia, Pa.

* Reg. U. S. Pat. Off.

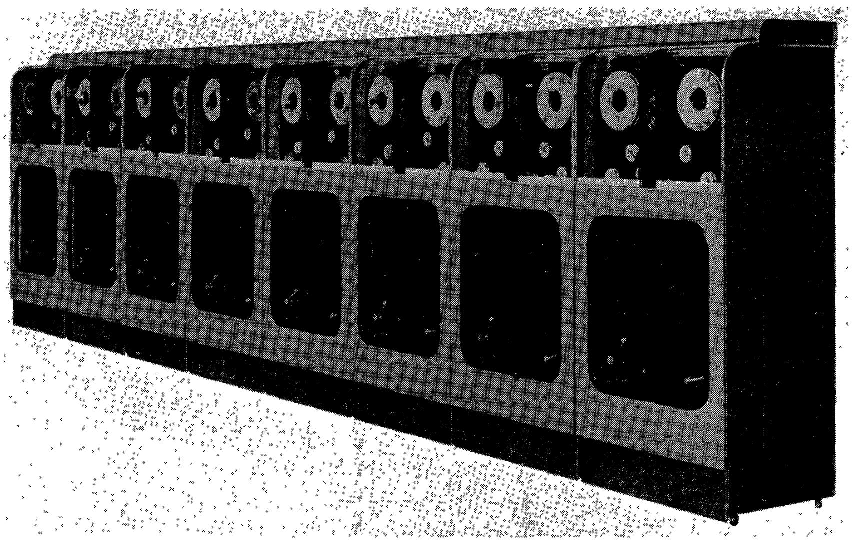


Figure 1. Bank of Uniservos

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 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-

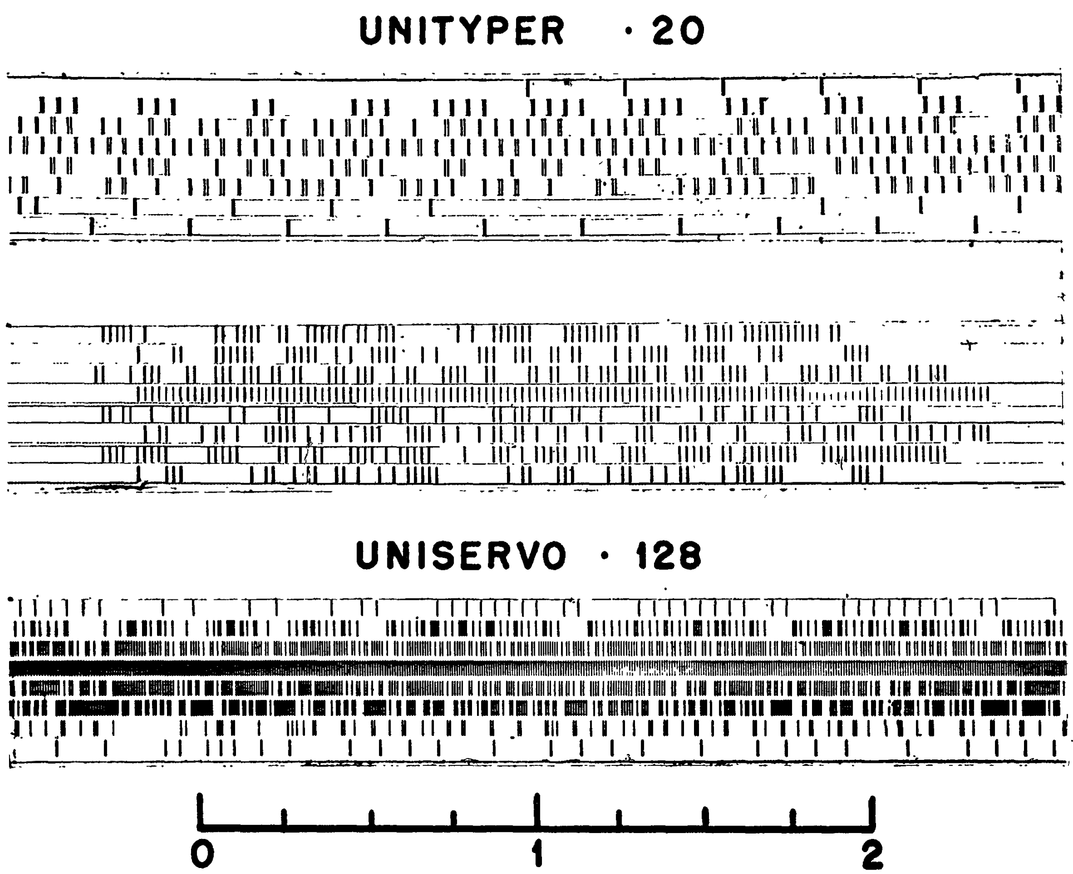


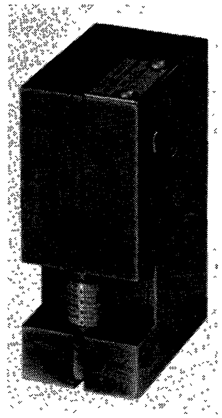
Figure 2. Magnetic tapes

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 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.



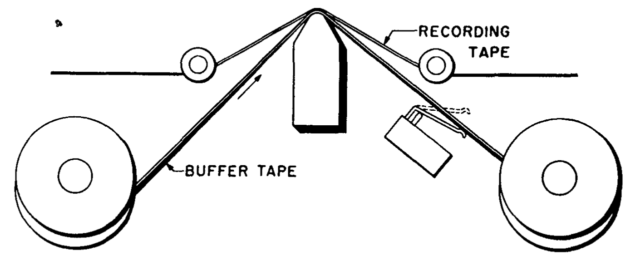


Figure 4 (left). Magnetic head close-up

Figure 5 (above). Tape spacer

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.

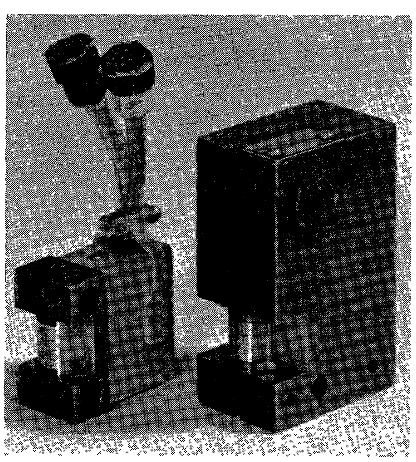


Figure 3. Magnetic heads

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.

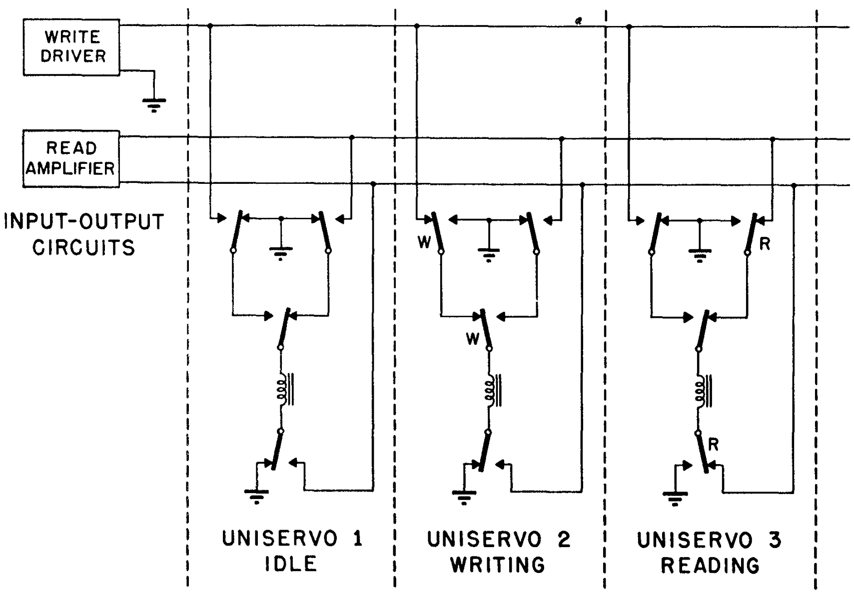


Figure 6. Grounding of relay leads

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 advantage 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 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

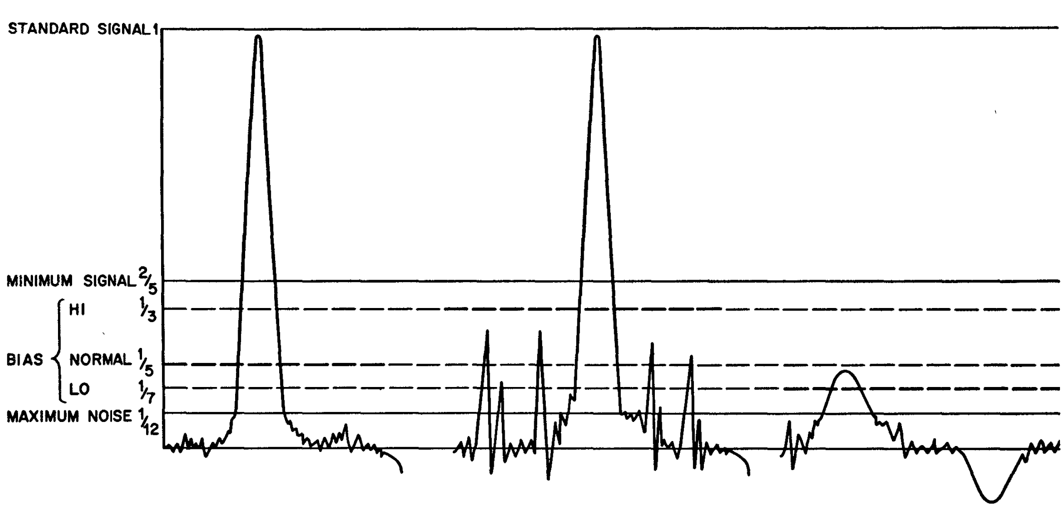


Figure 7. Input bias levels

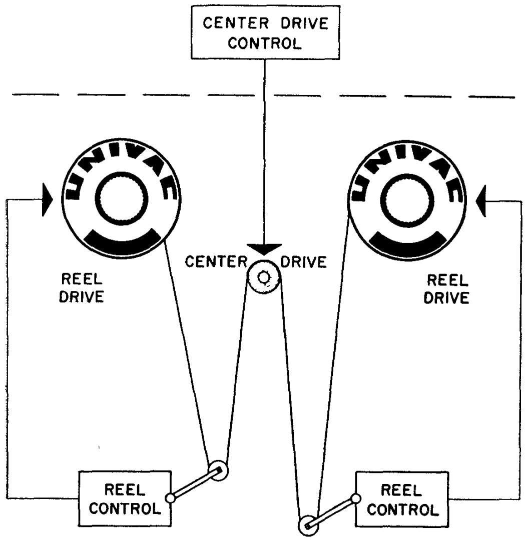


Figure 8 (left). Tape transport control

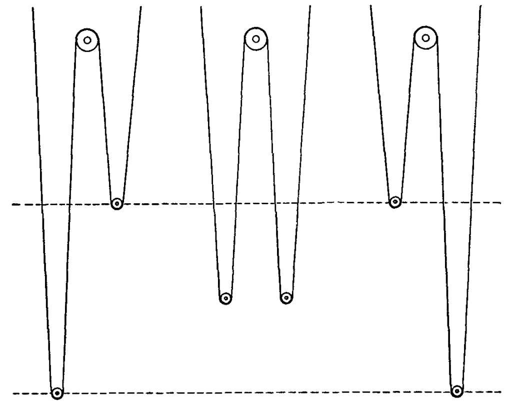


Figure 10 (right). Balance points

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.

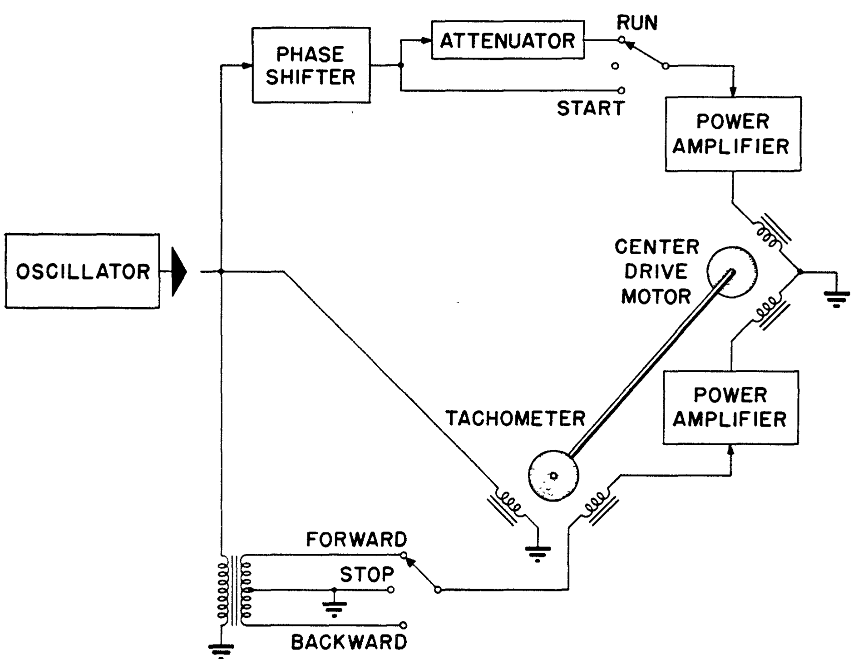


Figure 9. Tachometer-controlled center drive

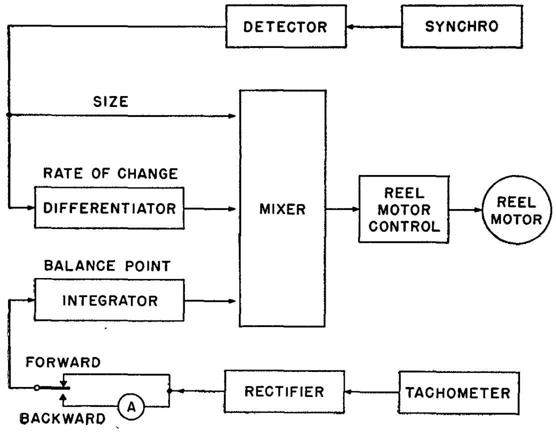


Figure 11 (above). Reel control

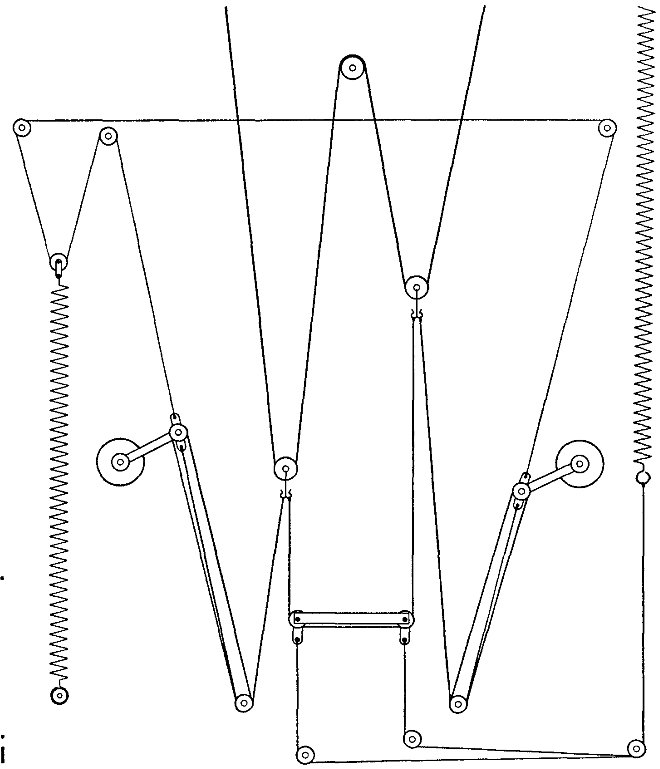


Figure 12 (right). Uniservo front panel

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.

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 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,

L. D. Wilson and E. Roggenstein are with the Eckert-Mauchly Division, Remington Rand Inc., Philadelphia, Pa.