Digital Computer Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

SUBJECT: USE OF THE MAGNETIC TAPE AND DELAYED OUTPUT EQUIPMENT

To: Scientific and Engineering Computation Group

From: H. Denman

Date: 3 July 1953

Abstract: The following memorandum concerns the present status of the magnetic tape units associated with the Whirlwind I computer, some changes which are to be made in their operation and use, and some further changes which have been suggested but not yet accepted. The discussion is mainly from the point of view of the programmer, but it also includes some details of the physical operation of the units and their control by the computer operators. The following does not represent either the final form of the equipment or final standards for its use, since changes in the equipment and its use will continue to be made. As changes are made the persons concerned will be notified as far in advance as possible, so that the necessary changeover can be made with the minimum of error or confusion.

NOTE: Much of the following data on the tape units has been obtained from the engineers in charge of these units (Edward Farnsworth and James Forgie), and from M-1623-1 (Programming for In-Out Units) and E-482 (Operation of Magnetic Tape Units). More detailed information on the operation of the tape units will be contained in a later memorandum by James Forgie.

I. General Features of the Magnetic Tape Units

Information can be stored on and read from magnetic tape in binary form, where the binary digits 0 and 1 are represented by two opposite directions of magnetization in a small region of the layer of magnetic material on the tape. Since WWI (Whirlwind I) programs, numerical data, Flexowriter characters, etc. may be expressed in binary form, they may be stored on the magnetic tape. This information may be used in several ways--it may be stored on the tape temporarily to be read back into primary (electrostatic) storage at a later time (auxiliary storage) or to activate directly an electric typewriter or punch (delayed output), or it may remain on the tape permanently to be used by many programmers. Other media can also store such information, but magnetic tape is used because it provides the computer with very large storage capacity per unit (an 800 foot reel of magnetic tape can store as much as 125,000 WWI words), this storage is non-volatile (the stored information can remain permanently on the tape with no effort necessary to maintain it), and the reading operation is non-destructive. Also, previous information can be easily erased and the tape used again, information can be fairly quickly transferred to and from the tape by the computer (after it has located the desired position on the tape), and when used as buffer storage for delayed output the tape can permit a considerable saving in computer time over direct output methods. The ability of the tape unit to run in either direction while reading, recording, or searching reduces the access time for information on the tape (the time required to locate and transfer desired information from auxiliary storage to primary storage).

At present there are five Raytheon magnetic tape units associated with the WWI computer; these units are referred to by the numbers 0, 1, 2, 3A and 3B. Figure 4 shows the five tape units, some of their controls, and the delayed output equipment. Three of these units (0, 1 and 2) are normally connected to the computer. One of the units 3A or 3B is normally connected to the computer, the other to the delayed output equipment (these connections are reversed by throwing the bar transfer switch above unit 2).

Although the present design of the tape equipment permits a maximum of six binary digits on a line across the 1/2 inch wide tape, these digits have been grouped in pairs in order to increase the reliability of reading and recording on the tape. One of these pairs of bits (or channels) is reserved for index pulses (a pulse in a channel is defined to be 1's in both bit positions of the channel), so that there are only two channels per line available to the programmer. An index pulse is used to indicate to the tape unit that information is stored in the other two channels of the line. The index pulse plays a role analogous to the seventh hole on paper tape and is necessary in this system to distinguish between no information on a line (erased tape) and a pair of 0's in that line. A 16 bit WWI word will therefore be represented on the tape by a group of 8 lines, each with an index pulse in its index channel. In order to separate the lines of information, spaces of erased tape (with 0's in all the channels) of length equal to that of the information lines are left between the lines of information.

Block marks, which are used to indicate the beginning of blocks of WWI words on the tape, consist of pulses in THE ODD ~~both information~~ channels, and 0's in the index channel.

Words are recorded on the tape only when it is moving at its normal speed of 30 inches per second and a pulse is recorded on the tape in 160 microseconds, so that a line of information or a block mark will occupy 0.0048 inches linearly along the tape. Thus the 8 lines and 8 spaces which make up one WWI word occupy 0.077 inches, and 2.56 milliseconds are required to record this word or for it to pass under the read-record head of the unit while reading. (Recording Flexowriter characters for delayed printing using the new si record orders produces automatically a lengthened initial space followed by 8 lines of information and seven normal spaces. See section II A 2.)

II. Control of the tape units

A. Automatic Control by the Computer

Only one piece of In-Out equipment can be controlled by the computer at a time; thus the computer can control at any instant only one of the four tape units connected to it (the selection of another tape unit or any other In-Out equipment will stop the tape unit which had been previously under the control of the computer). The computer can give the same set of instructions to any tape unit connected to it. These instructions include those of the form si ~~pqr~~ lxy (where the address section ~~pqr~~ lxy selects a particular tape unit and instructs it to operate in a certain mode and direction) and the group of in-out instructions rd, rc, and bi (which follow certain of the si instructions and complete the transfer of information between the arithmetic element and the tape). The modes of operation of the tape units (selected by the si instructions) are as follows:

1. Record forward and reverse*

The si record orders initiate a 14.5 millisecond delay count in the In-Out Delay Counter so that no other in-out instruction can be performed until this delay ends. The tape unit selected is instructed to run the tape in the desired direction** and the erase current is turned on. Because of the inertia of the tape and certain parts of the tape units, an average of 4 to 5 milliseconds is required before a tape unit which has been instructed to change the motion of the tape actually affects the speed or direction of the tape (this is called the mechanical reaction time of the unit). Thus if a tape unit is at rest when an si record instruction is given, the tape will be erased while still at rest and as it accelerates to normal speed. At the end of the 14.5 millisecond delay a block mark is recorded on the tape and the unit is then ready to record WWI words on the tape when so instructed by the computer. Until a record order or some other si instruction is given, the unit will continue to erase tape in the specified direction.

---

* The "forward" and "reverse" directions for the tape units are absolute as far as the programmer and computer operator are concerned. The system is wired so that when the tape is moving in the "forward" direction, tape is being wound up on the front reel of the unit (see Figure 2.)

** The last binary digit of the address of the si instruction indicates the direction of motion requested. If it is a 0, i.e., if the address ~~pqr~~ lxy is even, the forward direction has been selected; if the last digit is a 1, i.e., ~~pqr~~ lxy is odd, the reverse direction has been selected.

If the tape unit selected is already in motion, the si record instruction still immediately initiates the 14.5 millisecond delay count and starts erasing the tape as it passes under the read-record head. If the new si instruction calls for the same direction as the tape is moving, the programmer gets a longer interval of erased tape before the block mark (see Appendix B). If it calls for the opposite direction, the unit starts the delay count and erase current, but continues to move in the original direction for 4 to 5 milliseconds (reaction time), then decelerates to a stop and accelerates to normal speed in the new direction, retraces the portion of tape just erased, and records the block mark at approximately 0.1 inches in the new direction from the point on the tape which was under the head when the si instruction was given.

Each record order (rc) following an si order for recording sends the contents of the accumulator to the In-Out Register, from which the word is recorded (two digits at a time) on the tape, the left digit pair in the accumulator becoming the first line of the word on the tape, etc. A 2.56 millisecond total delay is counted in the In-Out Delay Counter during this operation. WWI instructions (other than in-out) may be performed during this recording. If another rc order occurs within the 2.56 millisecond period, the next word will be recorded on the tape after the first delay is completed. This will give the closest spacing of words on the magnetic tape (a space of 0.0048 inches between the last line of one word and the first line of the next word). If the next rc order does not follow within the 2.56 milliseconds, the unit will erase tape after the first word is completely recorded until another rc order or some si instruction taking the unit out of the record mode is given.

2. Record for delayed printing (forward and reverse)

These si record orders cause the tape unit selected to behave in the same manner as the si order described above. A 14.5 millisecond delay is counted in the In-Out Delay Counter, tape is erased, and a block mark is recorded at the end of the delay interval. The only difference occurs on following rc orders. In this case the initial space preceding the first line of the word is lengthened from 0.0048 to about 0.15 inches (corresponding to a 5.1 millisecond delay count); thereafter the recording of the word procedes as usual. The total delay count for the rc order following this si order will be about 7.5 milliseconds, which gives enough space for the magnetic tape to stop while the delayed output equipment is printing or punching the last Flexowriter character and then to accelerate to normal speed before reading the next character.

3. Read forward and reverse

The si read instructions initiate a delay count of 5.1 milliseconds in the In-Out Delay Counter to enable the reading circuits to become unsaturated if the unit had been previously in a record mode. The unit selected is instructed to move in the desired direction. If this unit has been at rest, the tape does not start to move for the 4 to 5 millisecond reaction time of the units. After the 5.1 millisecond delay has been counted, the unit starts examining the information on the tape as it passes under the head. After finding a block mark on the tape the unit sends succeeding groups of 8 lines (as indicated by index pulses) to the In-Out Register where they are assembled into WWI words by successive left shifts.* Once an si read instruction has been given to a unit and the first block mark after the delay detected, the unit ignores other block marks it finds on the tape while operating in this read mode.

In order to get words from the In-Out Register to the accumulator and to clear this register for the next word, a read (rd) order is required for each word to be read from the tape, or a block input order (bi) for a group of words. If the first line of a word arrives at the In-Out Register and finds the previous word still there (the register has not been cleared by a rd or bi order), a program alarm is given and the computer stops.

The programmer must give at least one rd or bi instruction after an si read instruction. If this is not done, the operation of the in-out equipment on the next si instruction becomes uncertain.

If the tape unit selected by the si read order has already been selected by the previous si instruction so that it is already in motion, then the behavior of the unit depends on the combination of the two si instructions. The 5.1 millisecond delay is counted in any case. If the unit has been running in the direction now requested, the unit simply waits the 5** millisecond delay, starts looking for a block mark, and after finding one starts sending lines to the In-Out Register to be assembled into words. If the unit has been running in the opposite direction, the tape continues to move in the original direction during the reaction time, then decelerates continuously until it is up to normal speed in the other direction. At the end of the 5 millisecond delay count, however, it again starts searching for a block mark, and after finding one, starts reading.

Since the delay of 5 milliseconds before starting to look for a block mark is used after all si read instructions regardless of the speed and direction of the tape, the programmer must insure that the head of the tape unit selected is in an erased section of tape if the si read instruction is given while the tape is at rest or required to change direction of motion. If this is not done, the tape unit starts to look for a block mark when at rest or moving very slowly, and this causes the

* If the unit is running in different directions during the recording and reading of a word on the tape, the word must be rearranged either before the rc order or after the rd order to obtain it in the desired form.

** Hereafter, in reference to the 5.1 millisecond delay we will simply write 5.

reading operation to be marginal--a line of information on the tape might be misinterpreted as a block mark, causing the tape unit to read the succeeding lines into the In-Out Register. If the si read instruction is always given so that the head is in an erased section of tape until the tape reaches normal speed in the desired direction, then although the unit will be searching for a block mark while moving slowly, there will be no information on the tape which can be misread as a block mark.

The computer can perform internal (non in-out) instructions while the delay is being counted and the unit is searching for a block mark. Unless the programmer knows exactly how much blank tape exists between the point at which he gave the si read order and the first word after the block mark, he cannot program for more than 7.7 milliseconds of computation between the si and the next rd or bi instructions. If the words are recorded on the tape at maximum density, the programmer may perform 2.56 milliseconds of internal orders between successive rd orders; if the recording was made at lower density, more time will be available between successive rd orders. As long as the word in the In-Out Register is read before the first line of the next word arrives, no program alarm will occur.

If a block input (bi) instruction follows an si read instruction, and if the accumulator contains ±n when this instruction is given, the tape unit will send the next n words on the tape to the In-Out Register and the computer will automatically transfer them into electrostatic storage, storing them in a block starting at the address of the bi instruction. No other WWI orders of any kind can be performed until this operation is completed, and the length of time required depends on the spacing of the words on the tape. If these words are all in one block and recorded at maximum density then the transfer will require 2.56 n milliseconds from the time the first word starts into the In-Out Register. Later block marks passing under the head during this operation are ignored. If the contents of the accumulator are ±0 when the bi order is given, one word will be read from the tape into the In-Out Register (as a result of the previous si read instruction), but the bi instruction will not transfer it into electrostatic storage. If the programmer wishes to transfer this word into the accumulator, then he should give an rd or a non-zero bi order. This order must follow the zero bi order within 300 microseconds in order to prevent a program alarm. If the programmer is not interested in this word, then he may clear the IOR and thus prevent a program alarm by giving any other si instruction within the 300 microseconds. Each bi order should be preceded by an si read instruction; it may also be preceded by one or more rd orders. If a non-zero block input order is followed by a rd instruction, this rd order will bring a ±0 into the accumulator, and further rd orders will behave in normal fashion. Care must be taken to follow the last rd or bi order after an si read instruction with some instruction de-selecting the tape unit, in order to avoid a program alarm due to further information arriving in the In-Out Register when it contains a word.

4. Re-record forward and reverse

A tape unit given an si instruction to re-record in either direction switches to the read mode and moves in the desired direction. After it detects a block mark the unit switches to the record mode. Since the unit starts in the read mode, a 5 millisecond delay is initiated in the In-Out Delay Counter, and after this delay is counted the unit searches along the tape until it locates a block mark. When one is located, the unit switches to the record mode, and therefore starts erasing tape unless an si instruction occurs in time to prevent this. This order is used either to record over a block of information (in which case this order will be followed by rc orders) or to skip blocks in either the forward or reverse directions prior to reading or re-recording.

This instruction should not be given while the tape is at rest in a section containing information or where it will cause the tape to reverse direction of motion while in a region containing information. This is because the unit starts in the read mode when given this instruction, and therefore the same situation prevails as described in section II A 3.

5. Stop orders

a. General

Any si order de-selects all other pieces of In-Out equipment except the one to which it refers. When free-running units such as the magnetic tape units or the photoelectric tape reader are de-selected, they are instructed to stop (these units ignore any information they pass over while coasting to rest). Thus si orders, such as si 0 and si 1, which do not refer to any particular piece of in-out equipment, de-select any piece of in-out equipment in use, but also may stop the computer. If it is desired to de-select a piece of in-out equipment and to continue computer operation, then the programmer should use an si 408 (decimal) or 630 (octal). When de-selected, a tape unit continues during its reaction time to travel at normal speed in the direction in which it has been moving, and then decelerates to a stop in an additional 0.5 to 1.0 milliseconds.

b. Stop in cleared area

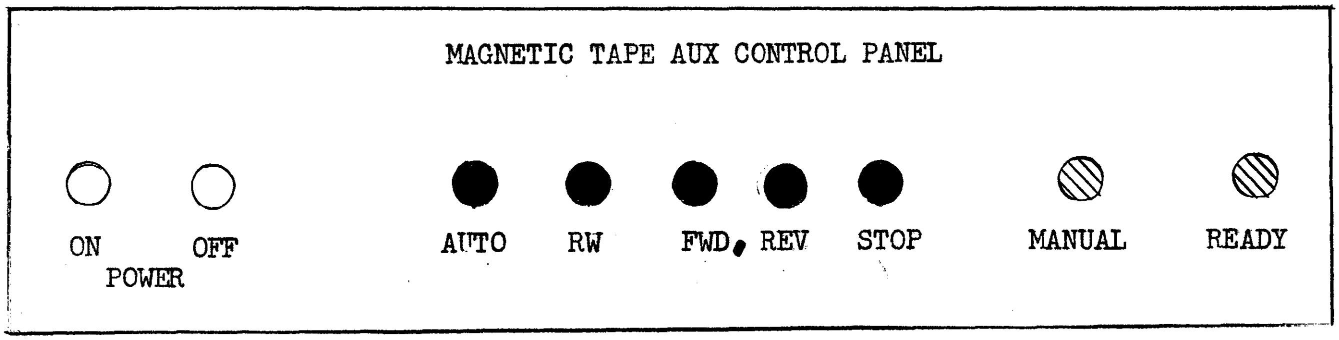
This si instruction stops the selected tape unit in a cleared (erased) section of tape. The direction specified in the address of this si instruction (see Appendix C) should correspond to the direction of motion of the tape when the order is given. Physically, the tape unit switches to the record mode if it is not already in this mode, and a 14.4 millisecond delay count is initiated. At the end of this delay the unit switches to the record mode in the opposite direction, and another 14.3 millisecond delay is counted while the tape reverses direction. At the end of this delay, the unit is de-selected. (At this time the tape has been cleared about 0.58 inches beyond the point where this instruction was given, and the tape finally stops, if permitted, about 0.18 inches beyond the point where the instruction was given.) No block marks are recorded on the tape during this operation. The total delay count is therefore about 28.7 milliseconds (there is no delay count associated with the de-selection of the unit). The computer clock is stopped during this delay, so that no computer operations can be performed for this 28.7 millisecond period. At the end of this period, the unit is de-selected, and it then coasts to a stop moving in the direction opposite to the original. If an si instruction in this new direction occurs before the unit has come to rest, the unit may accelerate to normal speed without actually coming to rest; if the new si instruction is in the original direction, the tape unit must coast to a stop before accelerating to normal speed in the original direction.

This instruction should not be used at interior points in a recording even if given in an interblock space, because the tape is erased so far ahead of the point at which the order is given (see above) that it will erase part of the beginning of the next block (unless the interblock spacing is made longer in some way, as by counting a delay when the unit is erasing tape in the record mode).

B. Manual Control of the Tape Units

A certain amount of manual control of the tape units by the computer operators is occasionally either necessary or desirable. For this reason certain manual controls are provided for each of the tape units and the delayed output equipment. These manual controls are used to turn on power for the units, to position the tapes with respect to the read-record heads, to put the units under the control of the computer, to erase tape, to connect certain units to the delayed output equipment, etc.

All of the Raytheon tape units have the following controls on the front of the units (see Figure 3): two toggle switches marked STANDBY and POWER, a light labeled POWER ON, and a five-position rotary switch (marked A S F S R), as well as a set of four neon lights which indicate the action of the clutches and brakes of the unit. All units have, in addition, a separate control panel (labeled MAGNETIC TAPE AUX CONTROL PANEL) which is used instead of the controls on the unit itself. One of these panels is shown in Figure 1.



Pushbutton
Latching Pushbutton
Neon Light

Figure 1: Magnetic Tape Auxiliary Control Panel

Manual control of units with the auxiliary control panel is accomplished as follows: on the tape unit, the STANDBY and POWER switches must be ON (up) and the five position rotary switch in the A (Automatic) position. These switches are to be left permanently in these positions and all manual control of the units done by means of the auxiliary control panels.* On the auxiliary control panel, the STOP pushbutton must be on (pushed in) in order to start the unit. When the POWER ON button is pressed, the tape unit is turned on (if the STOP button is pushed in) and after a timed delay of about 45 seconds for the servomechanism to warm up, full power is applied to it. At this time the unit is ready to operate under manual or automatic control, and the READY light goes on. Then if the pushbutton AUTO (Automatic) is pressed in, the unit is connected to the computer and may be operated by the program. If the operator wishes to position the tape under the head by running the tape in either the forward or reverse direction he simply presses the FWD(Forward) or REV (Reverse) pushbutton respectively, and then presses the STOP button when the tape is in the desired position. When the operator wishes to rewind (i.e., move the tape in the reverse direction) the tape to one of the limit switches** on the tape, he pushes the RW (Rewind) button and the tape unit automatically rewinds the tape until the closest limit switch is reached, and stops the tape at that point.

---

* Since each tape unit normally is controlled manually by means of the auxiliary control panel, it should not be necessary for the operator to lift or remove from the unit the transparent plastic dust cover which protects each unit.

** A limit switch is a group (usually two) of metallic strips attached across the tape. When one of these strips touches a pair of wipers located several inches along the tape in advance of the read-record head, the unit stops. These limits act only when the unit is under manual control(in the Rewind mode), not when under the control of the computer.

The last four mentioned pushbuttons (RW, FWD, REV, STOP)put the unit under manual control and therefore the MANUAL light is lit whenever any one of these buttons is in and the power is on.

If there are two sets of limit switches at the beginning of a tape with some permanently recorded data on the tape between them and if the operator wishes to position the tape at the first limit switch though the tape is past the second limit switch, he may press the Rewind button and wait for the tape to stop at the second limit switch, switch to Reverse until the limit switch completely passes the head, and then press the Rewind button again. The tape will now stop at the first limit switch, and after the Automatic button is pushed the unit will be ready to start under computer control at the beginning of the permanently recorded data.

If the operator wishes to turn off any unit he simply presses the POWER OFF pushbutton.

At the beginning of a computer period, each tape unit is normally positioned at the beginning of its tape. Unit 0, however, has the Comprehensive System conversion program permanently recorded between limit switches on the first 150 feet of its tape, and Units 3A and 3B similarly have data permanently recorded for checking these units and the delayed output equipment. If this material is to be used, the computer operator can run these tapes back to the first limit switch by the method outlined above. The programmer can assume that these units will be positioned at or past the second limit switch, and since these limits are ignored by the unit when it is under computer control (in Automatic), he should never program to run the tape back past the point where he starts recording on the tape.

Units 1 and 4 do not have permanently recorded data on their tapes. Therefore, these tapes have only 1 limit switch each, located near the beginning of the tape. The heads of these units are normally positioned at these limit switches when a program referring to these units is started. Since none of the tape units are protected from the tape running off either reel when under computer control, the programmer using the magnetic tape units should not program run-back of any unit past the point where he starts his recording. Such a run-back may either destroy some part of one of the permanently recorded sections or run the beginning of the tape off the reel. If a program is being run which uses a tape unit with a permanent recording stored on it which is separated from the remainder of the tape by a limit switch, the computer operator must insure when the program is started that this tape is positioned so that the head is at the limit switch forward of this permanent recording. The only guarantee against destroying permanently recorded information on a tape unit would be to disconnect the recording circuits for that unit, which would prevent the programmer from using the remainder of the tape on this unit. The limit switches can offer protection to this permanent data only if both the operators and programmers obey these instructions.

Erasure of the tape units

Units 0, 1, and 2 can be erased only by programs in the computer. If it is desired to erase a portion of the tape on any of these units, the programmer can simply give an si record order for the proper direction and then count a delay in the program until the desired amount of tape has been erased (see Appendix B). A block mark will be recorded after the first 14.5 milliseconds, so that it may be necessary to add 14.5 milliseconds to the programmed delay to get a certain length cleared area after this block mark. As long as the programmer remains in this area, there will be no information except what he records there. Normally this is not a necessary procedure, since tape is erased as a recording is made, and even the tape passed over while stopping can be erased by using the si stop in cleared area orders. However, if a programmer wishes to be able to position the tape manually to the beginning of his recording on the tape (as he would do if he wanted to start the program over again because of an alarm during the performance of the program or to make use of an undisturbed recording for another run of his program, etc.), it is advisable to erase the tape around the limit switch and then start recording in this erased portion of tape. Then the slight differences in tape position which may occur in stopping the tape by the limit switch when rewinding will not allow any old information in the vicinity of the switch to be read into the computer when the program is started again with the tape at the limit switch at the beginning of the recording.

If the computer operator wishes to erase a section of the tape on units which do not have external erase current, he should first position the tape so that either end of the section he wishes to erase is under the head. The following program is then put in Flip-Flop storage

Register	Instruction
2.	si record for desired unit and direction (see Appendix C)
3.	sp 3

This program is started by putting 2 in the PC Reset switches, and pressing the START OVER pushbutton for the computer. The program will select the tape unit and start it in the indicated direction with the erase current on. It lays down a block mark after 14.5 milliseconds and then continues to erase tape until the computer is stopped by the operator, which will de-select the unit and allow it to coast to rest in the read mode. The tape can then be used or positioned manually before use. If the operator wishes to lay down a series of block marks with erased tape between, he can

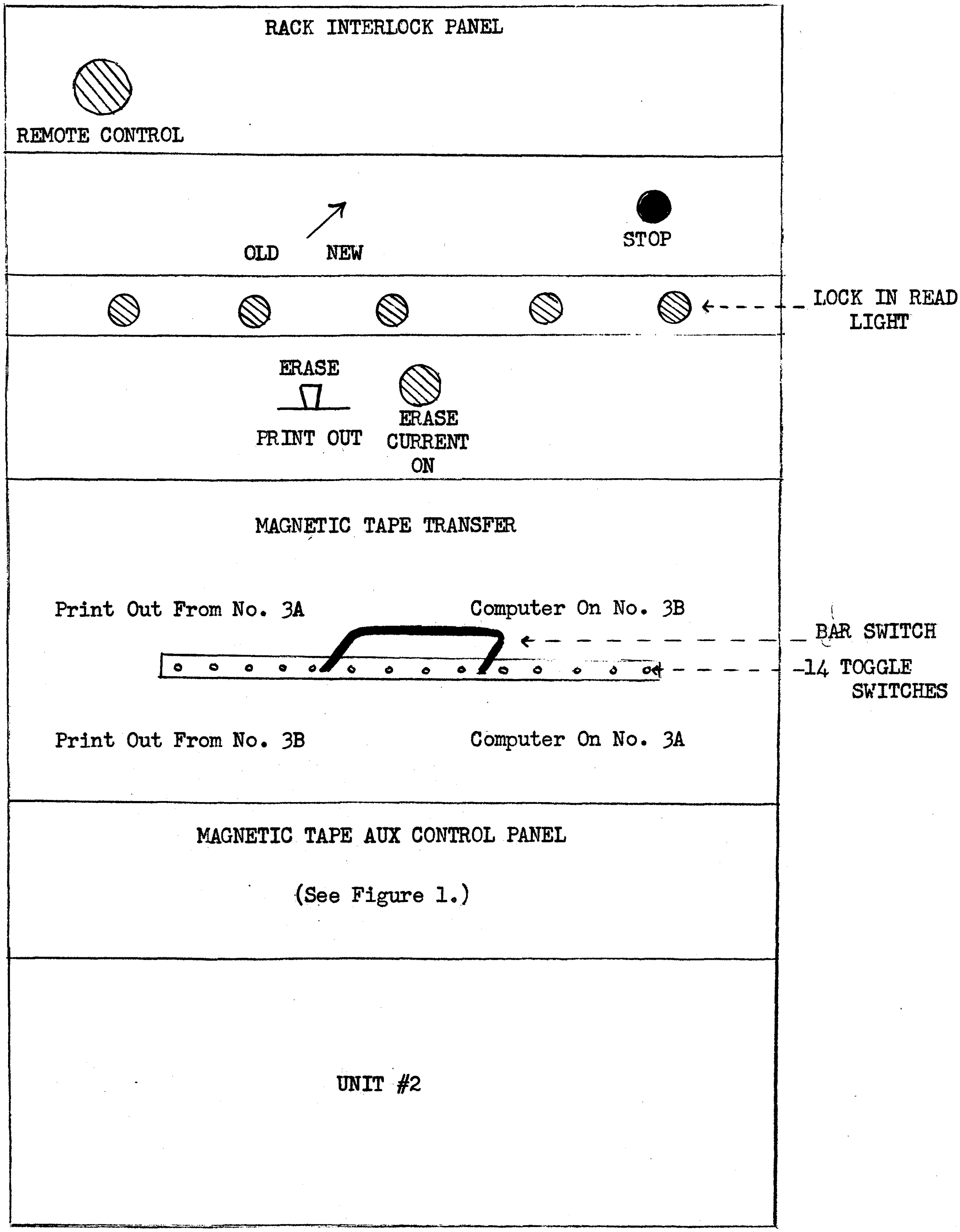


Figure 2: <u>Magnetic Tape Unit #2 and Manual Controls and Indicator Lights--Center Rack</u>.

use the above program and put sp 2 in Flip Flop 3.

Special provision has been made for manual erasure of units 3A and 3B by the computer operators without using computer time. To erase a particular section of one of these tapes, first put the bar transfer switch on the MAGNETIC TAPE TRANSFER panel in position so that the unit to be erased is connected to the print-out equipment (See Figures 2 and 4). The tape should then be positioned manually to either end of the section to be erased and the ERASE--PRINT OUT toggle switch above the MAGNETIC TAPE TRANSFER panel put in the ERASE position. (The ERASE CURRENT ON red light goes on.) Then start the unit in the correct direction by the manual controls and the tape will be erased as it passes under the head as long as this current is on. Note that only the tape unit connected to the delayed print equipment is erased and the erasure occurs while the unit is under manual control. The ERASE-- PRINT OUT switch should be returned to the PRINT OUT position after erasing.

Units 3A and 3B are both equipped with limit switches on the tape, and a rewind pushbutton has been put on the junction box on the delayed output equipment table. To rewind one of these units to a limit switch, the Automatic pushbutton should be pressed in and the transfer switch moved to such a position that the unit to be rewound is connected to the delayed output equipment. The tape may be rewound by means of the pushbutton on the junction box and may be erased simultaneously if the erase current is turned on while the unit is being rewound.

Some of the tape reels have been marked so that the operator can judge approximately how much tape still remains on either reel. The operator can then tell from the programmer's estimate of how much tape he will use on that unit whether the program can be run immediately or the tape will have to be run back, and in the latter case, he can tell more accurately when he has run it back sufficiently.

When the REMOTE CONTROL light on the RACK INTERLOCK PANEL is lit, the tape units are all under remote control from the computer room, and cannot be operated by the computer or the computer operators using the above-mentioned controls until this light is off. When the Lock In Read light is on, the record circuits for the units are inoperable, and the tape can only be read. (See Figure 2.)

III. Use of the Magnetic Tape Units by Programmers

A. Auxiliary Storage

The programs and numerical data required to solve certain problems on the Whirlwind computer occupy more registers that the 2016 available in primary (electrostatic) storage. In these cases the programmer must decide how to store the additional information (instructions or data) required. Among the auxiliary storage media available to the programmer are paper tape, magnetic tape, and the magnetic drum.

However, the fundamental method of getting information into electrostatic storage (ES) is through the photoelectric tape reader. Thus if a programmer wishes to store auxiliary information on the magnetic drum or tape, he must first have it punched on paper tape and read through the photoelectric tape reader into ES; he then transfers it to the tape or drum. (If the extra information is generated in ES by the program, then only the original data and program have to be read in by the photoelectric tape reader.) Thus, if we have certain information which will not fit in ES but which is to be used only once and in a certain definite sequence by a program in the computer then the simplest and fastest method would be to have this data punched on paper tape in the proper sequence and read into the computer through the photoelectric tape reader as it is needed. If it is to be used more than once, but in this same sequence, then it might be punched on paper tape and this tape made into a loop (if it is not too long), so that it can be run through the photoelectric tape reader as many times as needed. However, the reading speed of the photoelectric tape reader is about 47 words per second, which is much slower than the magnetic tape and drum. (Also, the photoelectric tape reader can not be reversed and information can not be easily and quickly recorded on paper tape and read back without the intervention of the operator.) Thus if information which can not be stored in ES is going to be needed a number of times or requires random access to it by the computer, or if information is generated in ES which must be stored for future reference, time considerations lead us to consider either the magnetic tape or drum for auxiliary storage.

The random access time for reading or recording a block of material from the magnetic drum to ES or vice versa is the sum of 8.3 milliseconds for finding the starting point of this block on the drum (assuming that it is all stored in one drum group and that it is not necessary to change the drum group reference) plus 64 microseconds per word for completing transfer of the block of information between the drum and ES. If it may be necessary to change the drum group reference, then the random time to find the start of the block on the drum is 19.3 milliseconds and again 64 microseconds per word are required to complete the transfer. However, although there are 24,576 registers of storage on the drum (12 groups of 2048 registers each), the recording circuits of about seven of these groups (0,6,7,8,9,10,11) may be disconnected so that they will not be available to the programmer for recording.

The arbitrary access time for a block of information on one of the magnetic tape units depends on how much of the reel of tape is used. If T is the time required for the tape to travel at normal speed from one end of a recording of information to the other, and if we disregard the interblock spacings and assume that no time is required to accelerate or decelerate the tape, then the random access time (starting at an arbitrary point in the recording and going to another arbitrary point in the recording) is T/3, plus a minimum of 2.56 milliseconds per word to complete the transfer of information between tape and ES. Thus, for a 25,000 word maximum density recording on one tape unit, T is about 64 seconds, and the average time to obtain the beginning of the desired block about 21 seconds. Therefore, if the full drum capacity of 25,000 words were available to the programmer, the average time required to find the beginning of a block of words on the drum would be about $1/1000^{th}$ that for the same amount of data on one magnetic tape unit, and the speed of transfer of information from auxiliary storage to ES is about 40 times faster for the drum than for the tape.

When information is to be read linearly into ES from magnetic tape (i.e., the information is read into ES in the same fixed sequence a number of times), then the access time when the head is between blocks is very short--on the order of 15 milliseconds to start the tape unit and run over the interblock cleared space to the block mark and then 2.56 milliseconds reading time per word if recorded at maximum density. (The drum access time in this linear case is the same as given above.) However, at the end of the recording the tape unit normally must be reversed and run back to the beginning of the recording to start over again, and since this must usually be done under computer control (in some cases it might be possible to ask the operator to do this while the program in the computer is doing something else, but this is not advisable), this runback time is wasted computer time (this is not necessary for the drum; at worst, for a recording on one group, it will take 16.7 milliseconds to pick up the start of the recording again, or 28.7 milliseconds if it is necessary to change groups). For such linear cases, it does not matter materially whether this information is put on only one tape unit (if not too long) or spread over several, since essentially the same time will be required for reading in the information and running back over it (in fact, the latter case will require slightly more computer time because it will be necessary to calculate in the program which unit should be referred to next). If, however, random access to the information is required, then it is very advantageous to spread it over as many units as possible, since it takes only a few WWI orders in the program in ES to find out which unit contains the next desired information (which requires time on the order of a millisecond) so that the random time to get to the beginning of the block would be reduced to about T/3n, where n is the number of units on which the recording is stored, assuming that it is evenly distributed over the n units.

Since there are four tape units under the control of the computer, it is possible for the programmer to use all four for auxiliary storage. However, units 3A and 3B are reserved primarily for delayed output use, and it is expected that unit 2 will also be used this way in the future. Therefore, it is preferred that programmers do not use these units for auxiliary storage. If it seems desirable to the programmer and his associated staff member to use units 2 and 3 for auxiliary storage, it is possible to do so, but this may cause some delay in having the program performed, since it may interfere with the use of these units for delayed output. Unit 0, with the permanent recording of the CS conversion program occupying about the first 150 feet, can store a maximum of about 100,000 WWI words, while unit 1 can store up to about 125,000 words (and also unit 2). Units 3A and 3B, if used as auxiliary storage, can hold about 155,000 words maximum.

An additional degree of freedom which the magnetic tape provides the programmer is the ability to vary the spacing between words on the tape when recording, so that on reading there will be an interval between the necessary rd orders which will provide enough time for certain calculations. Even at minimum spacing, there is time for about 30 to 50 WWI operations between successive rd orders. In this way it is possible to save part or almost all of the running time of the tape while reading, though it may take some additional time for recording. To get the desired spacing while recording, the programmer normally will have to count the necessary delay, unless he wants the minimum spacing or the longer spacing of about 7.5 milliseconds for delayed print recordings (see Appendix C), both of which are given automatically. A typical delay counter which the programmer may insert between his rc orders is as follows:

```
a.        ca y
a + 1.    ad 1
a + 2.    cp a+1
```

If we have the number -n in y, this program will go through the ad 1, cp a+1 cycle n+1 times. Each cycle takes 60 microseconds (the ad 1 order requires only 30 microseconds because its address is in test storage). Since this counting is done in parallel with the In-Out Delay Count, the complete desired delay between rc orders must be programmed. For example, if a space corresponding to about 3 milliseconds is desired between words (from the end of one to the start of the next) on the tape, then the count above would have to take 5.56 milliseconds, and therefore, n would be 92 decimal. If other internal instructions have to be performed before recording each word, then this counted delay can be reduced.

Programming for Auxiliary Storage

The usual method of recording information on the magnetic tape is as blocks of WWI words. In this way the wasted (from the programmer's point of view) tape and time taken by the si record and stop orders can be averaged over a number of words. To record a block of words on the tape, the following orders may be used:

1. si pqr--starts the selected tape unit in the indicated direction, given by

the address pqr. A 14.5 millisecond delay count is initiated and the erase current is turned on. At the end of the delay a block mark is recorded, and the unit is ready to record WWI words on the tape. WWI instructions, other than in-out, may be performed during the delay interval.

2. rc--records on the tape the contents of the accumulator, during a 2.56 millisecond delay count (or a 7.4 millisecond total delay count if the si orders for delayed print are used). This order can not proceed until the delay count for the previous si record order or rc has been completed. As many rc orders as desired may be given before the next si instruction. Any number of WWI internal orders may occur between the rc orders, but to get the maximum density of stored information on the tape the rc orders must follow within 2.56 milliseconds of each other.

3. si--stops the selected tape unit in the direction specified by the si record order above. This is used after the block of words has been recorded, and will stop the tape unit without leaving any old data on the tape between the last word of the block and the point where the tape stops. If the tape has been previously cleared so that erased tape exists in this region, then the programmer can use the general in-out equipment stop order si 408 (decimal) (which is si 630 octal). The proper addresses for the si instructions are listed in Appendix C.

If other blocks of data are to be recorded it may not be necessary to stop the tape unit. In order to get an interblock cleared space and a block mark before the next block of data is recorded, the programmer can give another si record order in the same direction. However, if some other in-out unit is referred to between the end of recording one block and the beginning of the next, it is necessary to stop the tape unit in cleared tape first, since reference to the other in-out equipment will de-select the tape unit and if it were not stopped in a cleared area would permit old data to remain on the tape.

The system does not permit recording on the magnetic tape by means of the block output (bo) order.

If the programmer wishes to skip in either direction over blocks of recorded information on the tape, prior to reading or re-recording certain blocks, he may use the si re-record orders. These orders should be given only when the tape unit selected is in an erased area of tape, since the unit starts in the read mode on this order (see Section II A 4.). After the 5 millisecond delay the unit starts searching for a block mark in the indicated direction, and should pick up the first block mark in this direction. (The programmer should remember that block marks are normally recorded only at the beginnings of blocks of words by the si record orders.) After this first block mark is detected, the unit would normally switch into the record mode, but if another si re-record instruction occurs by this time, the unit will switch into the read mode again and go on to the next block mark after the delay, disregarding the block of information passed over between the two block marks. Thus, to skip on the tape in the same direction as the recording was made, where only one block mark has been recorded per block of information, one simply gives m+1 si re-record orders separated by not more than 5.1 milliseconds (in a cyclical program if desired); after the last such order the unit will have just read the block mark at the beginning of the $(m+1)^{st}$ block and will switch to the record mode, ready to re-record this block of information if given the necessary rc orders. If the programmer starts in the clear space at the end of a block and skips blocks in the direction opposite to that in which the recording was made, then each si re-record order actually causes us to skip a block. Therefore, m such orders cause the unit to skip back m blocks. After the completion of the m^{th} si re-record order the unit has just read the block mark of the m^{th} block back, going in the opposite direction to the recording; it now turns on the erase current while moving over the already erased interblock space in front of this block. If the programmer wishes to re-record the block of information just passed over, he should give an si re-record order in the original direction. The tape unit will then turn around in the interblock space (it will start looking for a block mark while at rest or moving slowly, but this will not cause trouble, since the unit is in an erased section of tape), pick up the block mark just passed, and then switch into the record mode, ready to re-record the block. In this case a total of m+1 si re-record orders have been given in order to re-record the m^{th} block back on the tape.

A difficulty with re-recording blocks of information is in terminating the re-recording. If one re-records a different number of words in a block, then the interblock spacing will be shortened if the new block is longer, or information must be erased if the new block is shorter. Also, if, after a re-recording, the programmer uses the si stop in erased section order in the interior of a sequence of blocks already recorded, he will erase part of the beginning of the next block under normal spacings (see Section II A 5.). An alternative is to de-select the unit, so that it will simply coast to a stop in the interblock space, ignoring any information it passes over. If the re-recording does not fall exactly on the old information, there may be some old information left at the end of the block. For this reason it is advisable to leave the unit in the record mode for a period after the last word of the block has been re-recorded, a period sufficient to erase any old information which might remain. If the re-recorded block is the same length as the block it replaces, then the programmer can count a delay after the last rc order sufficient to erase 1 to 2 milliseconds of tape past the last word (the total time for the counted delay must include the time required for the last rc, so that a counter of the form given in Section III A would require an n of about 70 decimal). Then the programmer can safely de-select the unit, and it will coast to a stop in the cleared area without leaving data on the tape.

If the programmer wishes to stop the unit in the cleared space in front of a block after skipping blocks in the direction opposite to the recording and uses the si stop in cleared area order, a long space will be erased in front of this block. If this is not the first block of the recording, the unit will erase a portion of the end of the preceding block. De-selection of the unit would be satisfactory if it occurs soon enough so that the head stops at least 0.01 inches from other information on the tape.

If the programmer wishes to skip in either direction prior to reading a particular block, the si re-record orders may still be used. For skipping in the direction opposite to that in which the recording was made, the procedure above can still be used, if an si read in the original direction is used instead of the last re-record order; the unit will turn around in the space in front of the m^{th} block mark, and start to read this block. If skipping in the same direction as the recording, the programmer should program m si re-record orders to skip the first m-1 blocks, then give an si read order in this same direction to pick up the first word in the $(m+1)^{st}$ block. This last must be done because the si re-record orders switch the unit into the record mode after detection of a block mark and therefore do not permit reading this block.

The si read orders can also be used to skip blocks, since they too cause a delay of 5 milliseconds and must find a block mark before any other in-out instructions can be performed. To skip m blocks in the direction of the recording and to read the $m+1^{st}$ block, from a start in an erased interblock space, one need only give a succession of m+1 si read orders with each of the first m followed by a dummy rd or bi order (see Section II A 3); after the $(m+1)^{st}$ si read instruction the unit will pick up the block mark preceding the desired block and will start transferring its words into the In-Out Register. If skipping in the direction opposite to that in which the blocks were recorded, starting in an interblock space, the unit should be given m si read instructions in the opposite direction to the recording, each followed by a dummy rd or bi order, which brings the unit to the start of the desired block. The unit is then given an si read instruction in the direction of the recording, so that the unit will turn around in the interblock space before the desired block, pick up this block mark again, and start reading this block.

In order to read blocks of information from the tape in the same direction in which they were recorded, starting with the unit in the cleared area in front of the block of information which is to be read, the following orders may be used:

1. si read in the direction of the recording. After the 5 millisecond read delay, during which the unit starts to move if it were at rest or moves over 0.15 inches of blank tape if it were already in motion in this direction, the unit picks up the next block mark, which should be the one in front of the desired block of information. After it detects this block mark, the next word is read from the tape and sent to the In-Out Register where it is assembled into a word. To prevent a program alarm, this word must be read or cleared from the In-Out Register before the first line of the next word arrives there (see Section II A 3). Since the first rd order will not be performed by the computer for at least 7.7 milliseconds after the si read instruction, the programmer can use this time for non-in-out instructions.

2. rd--reads the word which has been assembled in the In-Out Register into the accumulator and then clears the In-Out Register. The unit is still in the read mode, however, and continues to search for information, indicated by index pulses, and to send it to the In-Out Register. If the recording was made at maximum density, then until the end of the block is reached, words will continue to fill the In-Out Register and must be read out with the rd orders each 2.56 milliseconds. If larger spacing was used, then the rd orders can be correspondingly further apart.

3. When all of the words in the block have been read, and it is desired to continue reading, then the programmer can continue to give rd orders, the first of which will take a longer period to complete, since it will require traveling over the interblock distance and the next block mark before it will find the next word. The programmer could also repeat the si read order above.

4. If the last desired word has been read, and the programmer wishes to stop the unit, he should, if he has just finished a block of information, simply de-select the unit in the read mode with an si 408(decimal) order. If the tape is more than one word from the end of the block,it is not advisable simply to stop the unit in this way, since it may come to rest in part of the recorded information, which may cause difficulty on later si read instructions (see Section II A 3). In this case, the programmer could continue to give rd orders, without transferring the words into ES, until he gets to the end of a block where it is safe to stop.

The programmer may replace a series of rd instructions with a bi instruction, if he first puts into the accumulator the number of words he would like to read and indicates by the address of the bi instruction where in ES he would like to start to store this block of words. Either a rd or bi instruction must follow each si read order. If it seems advisable, the programmer may mix a series of rd and bi instructions after an si read, but if he does, he should note the peculiarities of such operation as given in Section III A 3.

To summarize, the use of the magnetic tape for auxiliary storage provides the programmer with very large storage capacity at the expense of access time. In general, due to the operating features of the tape units, the programmer should store his information on the tape in blocks of WWI words. These words occupy a minimum of 2.56 milliseconds of tape running time each. The blocks of words may be read or re-recorded many times on the tape, and by means of several different programming procedures. The use of block input orders makes programming the reading of blocks of words very simple, but does not permit any of the time required for the transfer of the information to ES to be used for the performance of internal orders.

The programmer should carefully note the position of the read-record head (with respect to his own recorded information or to areas which have not been erased and therefore may contain old data) during the performance of the program. This is especially important when it is necessary or desirable to stop the tape unit in the interior of a recording or to de-select the unit anywhere. To prevent program alarms while reading from magnetic tape, care must be taken to prevent information from arriving at the In-Out Register before the old information has been cleared.

B. Delayed Output

The output media available to the programmer include the direct output typewriter and punch, the oscilloscope, and the delayed output typewriter and punch. Because of the low operating speed of the direct output typewriter and punch (137 milliseconds to type an alphabetical or numerical character and longer for machine functions such as shift, carriage return, etc., and 93 milliseconds to punch one line of paper tape), their use for output is discouraged except under such special circumstances as when the programmer has only a small amount of output or when he needs to see his results immediately (and there are not too many of them). Because of the parallel operation of the computer and these direct output devices, it is sometimes possible, if the total calculation time of the program is equal to or greater than the time required to print the results directly, to mix the printing or punching operations with the calculations in such a way as to reduce substantially the time the computer must wait to finish a previous direct output instruction before going ahead with another.
As a simple example, if the results of a program can be put in one-to-one correspondence with the Flexowriter characters or the 128 possible combinations of holes punched in one line on the paper tape, and if the time to calculate such a result is equal to or greater than 137 or 93 milliseconds respectively, then these calculations can be

carried on while the corresponding characters are being printed or punched, so that no computer time is lost to output.

Printing of alpha-numerical characters on the scope can be accomplished at speeds 15 to 20 times faster than the direct printer, despite the fact that each such character must be constructed from a number of points. By use of the camera mounted on the scope, pictures of such an output display can be taken. These photographs usually are not available until some time after the program has been performed. For details on the use of the scope and camera, see M-2188, PROGRAMMING FOR AND OPERATION OF OSCILLOSCOPE AND CAMERA. At present, the scope and the delayed printer have approximately equal speeds when used to print alpha-numeric characters, but when the oscilloscope character and vector generators now under construction and testing are ready, it should be much faster to use the scope.

When using the magnetic tape delayed output system, special WWI words are recorded on a magnetic tape unit (now only on unit 3A or 3B) while this unit is connected to the computer. When this tape unit is connected to the delayed output equipment, these words are read from the tape by the delayed output equipment independently of the computer operation (except for the power supply), and these special words are used to select the proper output character and the mode of the delayed output (typewriter or punch, and seventh hole punched or not); then the selected output device types or punches the desired character. Since the operation of printing an alpha-numerical character or punching a line of paper tape takes on the order of 100 milliseconds and only 1.28 milliseconds are required for the 8 necessary binary digits (4 lines) of information in the special word on the tape to pass under the read-record head of the tape unit at normal speed, some method of reducing the effective speed of the tape is required in order not to use a very long length of tape per output character. In addition, typewriter machine functions take long (up to about 1 second) and varying amounts of time, so that it can not be predicted in advance exactly how much time will be required to print a certain character on the typewriter. For these reasons, it was decided to stop the magnetic tape while the delayed output typewriter or punch is operating. In this way it is only necessary to leave enough erased space on the tape between any two special words recorded there for the tape to coast to a halt after the first word is read and to accelerate to normal speed again (after the character is printed) before the next one appears on the tape.

The physical arrangement on the magnetic tape of the word corresponding to one output character is as follows: the first three lines of the word on the tape (corresponding to the left six digits of what appears in the accumulator when the rc order is given, i.e., AC0 to AC5 inclusive) give the binary code for the Flexowriter character to be printed or the binary combination to be punched in the first six channels of the line on the paper tape. The fourth line of this word on the magnetic tape selects the seventh hole (for the paper tape) and the output mode (typewriter or punch). If a 1 occurs in the second channel of this line on magnetic tape (corresponding to the eighth digit in the accumulator, i.e., AC7), the punch is selected; if a 0, the typewriter is selected. If the typewriter is selected, and the PUNCH ON switch on the typewriter is off (up), the typewriter will print only, but if this switch is on (down), the typewriter will print and punch simultaneously. (This is advantageous when more than one copy of the results is desired - the punched paper tape corresponding to the printed results can be used on any other Flexowriter to obtain more copies of these results. Also, if known errors occur in the print out, these can be corrected on the tape by duplicating it to the point where an error occurred, punching in the correct character, then continuing the duplication.) If the punch is selected either by a 1 in AC7 or by means of the PUNCH ON switch, a 1 in AC6 will cause the 7^{th} hole of the line on the paper tape to be punched. Any combination of typewritten and punched characters can be recorded on the magnetic tape for mixed output.

Since only 4 lines of the word on magnetic tape are required to give the complete output information for one character, the delayed output equipment has been set up to read only the first 4 lines of each WWI word on the magnetic tape (block marks are ignored during the reading operation for delayed output). As soon as these first 4 lines of the word are read, the tape unit is instructed to stop, and the last 4 lines of the word are ignored and the tape passes over these lines as it coasts to a stop. The tape remains at rest until a completion pulse comes from the typewriter or punch indicating that this character has been typed or punched. When this completion pulse is received by the tape unit it starts forward to read the first 4 lines of the next word and repeat this cycle of operations.

Under normal operation of the tape for delayed output, words are recorded in the forward direction and later read back into the delayed output equipment in the same direction. However, it is possible to read the tape in the reverse direction for delayed output; this is done by means of the REVERSE PRINT switch which is presently located in the equipment room, but which will soon be put in the computer control room. When this is used the tape starts reading in reverse, and in order to print the correct characters, the programmer must record in reverse, or scramble the words so that the proper digits are in the last 4 lines of the special words if recording in the forward direction. The use of this mode makes it unnecessary to run the tape back after a recording is made on the tape and before it can be printed.

The amount of tape which passes under the head of a unit while it decelerates to rest and then accelerates to normal speed is about 0.16 inches, and equals the amount which passes under the head of the unit in about 5.3 milliseconds when the tape is running at normal speed. Also, 1.28 milliseconds are required for the 4 lines of a word containing the output information corresponding to one Flexowriter character to pass under the head, so that a minimum of about 6.6 milliseconds of tape at normal speed is required per output character. However, this is based on good adjustment and operation of the clutches and brakes on the units. In order to give operating margins, about 7.5 milliseconds of tape at normal speed should be used per output character. This is the spacing given by the rc orders following an si record for delayed print order.

Thus, to program for delayed output, the programmer simply gives an si record for delayed print order (this applies only to units 3A and 3B at the present time). He then gives an rc order each time the special word corresponding to a desired output character is obtained in the accumulator. This process is as economical of computer time as can be obtained, since calculations to obtain these special words can be done while the previous rc order is being carried out by the In-Out equipment. If the calculations to obtain an output character take more than 7.5 milliseconds, then magnetic tape will be wasted if it is left running. However, stopping the tape unit (in cleared area) requires 28.7 milliseconds of computer time, and since, when the next character is to be recorded, another si record for delayed print order will be necessary, such a procedure will use up about 15 milliseconds of tape. Therefore, it is not desirable to start and stop the unit frequently. The usual procedure (for single length WWI words), is to store up a group of results, convert and record the corresponding Flexowriter characters at one time, then stop the unit and go on with the calculations. In using the subroutine now available for (24,6) double register numbers, the tape unit is stopped after each such number is printed (see Section V B).

When a recording is finished, the magnetic tape must be stopped. In addition, the tape must be stopped when it is being read back for delayed printing. If this is not done, the unit will search ahead after the last character is printed, looking for the next special word on the tape. If the tape has been erased, it will continue running until the end comes off the reel. If there is old data on the tape, it will be printed, and if the operator does not know how much material should be printed by the program it may not be easy to determine when the unit should be stopped manually. However, if when he is finished the programmer records a word on the tape which contains the Flexowriter stop character (110001) and which selects the typewriter, the typewriter, when it receives this character, will not send a completion pulse back to the tape unit. Therefore the unit will not start again until the operator manually starts the delayed print equipment.

It is also desirable that each programmer who uses the magnetic tape for delayed output on the typewriter end his recording with the character for a carriage return before the stop character. Then the typewriter will be left with its carriage at the left for the next printing. In addition, if the programmer shifts the typewriter to upper case for the last part of the printing, he should always put in a shift to lower case before ending the recording. This is because the typewriter locks in these cases, and if the computer operator does not notice that the machine has been left in upper case after a delayed print-out, the next program, which may assume the machine is in lower case, will start printing in upper case. The programmer may, if he wishes, always record a lower case character at the start of his recording if he wishes to type in lower case.

The Flexowriter unit used with the delayed output equipment has a long carriage, with a usable length of about 160 spaces. The size of the type is 10 characters to the inch. The tab settings have been set arbitrarily at 10 spaces apart.

IV. Manual Control of the Delayed Output Equipment

At the start of a computer period, units 3A and 3B are normally positioned with their heads at the second limit switches on these tapes. The area between the first and second switches contains test recordings for checking the operation of these tape units and the delayed output equipment. If the operator wishes to check either of these units, he rewinds it to the first limit switch, puts the transfer switch in the position where the unit to be tested is connected to the delayed output equipment, and starts the unit reading forward (with the Automatic pushbutton on, the START READ switch on the typewriter is pressed). The permanent recordings operate the typewriter and punch to give certain standard results when they are operating properly. These should print out without significant error, except in the capstan test, where the spacing between words on the tape is successively reduced. When significant failure occurs here, the operator looks at the print to see if a certain number corresponding to the spacing on the tape is below a certain limit when the failure occurred. If the number is below this limit, the test is satisfactory; if it is not the engineers should be informed. If both units do not give the proper results, the trouble probably lies with the delayed output equipment rather than the tape units. If only one unit is malfunctioning, then the operator can still use the other.

There is a maximum of 1200 feet of magnetic tape on these two units, but a certain amount must be left on both ends so that the ends will not come off the reels. In addition the permanent test data occupies a small region at the beginning of each tape. Thus there is a maximum of about 1150 feet on each unit available for the programmers, but if there is breakage of the tape near the ends, the reel may not be replaced until the length available to the programmer drops below 1000 feet. This minimum of 1000 feet is enough to record about 53,000 output characters at maximum density (one each 7.5 milliseconds), and requires a minimum of about 6.7 minutes to record it. The typing of such a recording would require at least 85 minutes. (The delayed output typewriter can type 10 characters [not machine functions] per second if the corresponding words on the magnetic tape are 7.5 milliseconds apart.)

After a recording (which starts at the limit switch) for delayed output is put on unit 3A or 3B, depending on the position of the transfer switch when the recording is made, the operator normally throws this switch and proceeds with the next program. While this program is being run, the unit which has the recording is run back to the limit switch by means of the pushbutton on the junction box. The <u>START READ</u> switch on the typewriter is then pushed, and the tape is read by the delayed output equipment and the results are printed or punched. Should an error occur or the typewriter fail to stop at the end of the recording, the computer operator can stop the tape unit and Flexowriter by pressing the <u>STOP READ</u> switch on the typewriter.

If two programs in succession record on magnetic tape for delayed output and the first recording takes so long to print or punch that it is not completed when the second program has finished recording its results on the other tape unit, then this second set of results can not be printed out immediately. If another program which uses the delayed output equipment is now performed, it is necessary to record this data on the second unit, following the second recording. If a very long recording was made on the first unit, it is possible that the whole reel of tape of the second unit will be filled with results before the first results are completely printed. In this case it would be necessary to replace the reel on the second unit. Also it is possible to record so much data for printing out that it can not be finished in the computer period. If the computer power is shut off in the next period, this information can not be printed out until a period in which the computer power is on. Other utility programs also use the magnetic tape units for delayed printing or punching, such as post mortem tapes and the conversion programs which store data for the punching of 556 tapes. These uses of the magnetic tape and the low speed of printing or typing results can lead to serious problems for the computer operators and in the scheduling of programs to be run.

To avoid such problems, the Scientific and Engineering Applications (S&EC) Group has adopted the practice of postponing the performance of certain programs for which such difficulties might arise. Therefore, it is important that programmers carefully fill in the "Max. No. Ft. Forward" (i.e., the number of feet of magnetic tape required for his program) column in the magnetic tape section of the S&EC Performance Request form (DL-324-8). If this practice does not obviate these difficulties it may be necessary to penalize programmers who have very large amounts of output by charging a portion of their delayed output time against their allotted computer time.

V. Subroutines Available to the Programmer for Use With the Magnetic Tape

A. Auxiliary Storage

Some subroutines have been written for recording on and reading from the magnetic tape when used as auxiliary storage. They provide the programmer with facilities for recording an arbitrary number of blocks of arbitrary word length (within the capacity of the unit) on units 0 and 1, for skipping forward or backward any number of blocks within the recording, and for reading or re-recording any of these blocks. Certain of these routines provide a check on the reading operation and if an error is detected repeats the reading operation until it checks properly. More details on these routines can be obtained in a report entitled Magnetic Tape Subroutines, dated January 2, 1953; this report is available in the Tape Room of the Digital Computer Laboratory.

It is intended that the Comprehensive System of Service Routines (CS) will later include subroutines such as these which will be given automatically to the programmer when he writes a certain special word in his program.

B. Delayed printer

The only subroutine presently available for printing out results on the magnetic tape for delayed printing is one for printing the contents of the multiple register accumulator (in CS programs) as a (24,6) generalized decimal number. The programmer can vary the number of significant digits he wishes to print and can also obtain such machine functions as space, carriage return, and tab by entering the routine at different points. After the number is recorded on the magnetic tape, the character for a space is added, and then the tape unit is stopped. It also is stopped after recording machine functions. This subroutine is entered in the interpretive mode. It takes about 1/4 second to record a number on the tape by means of this routine (including the space, but not additional machine functions), and therefore about 0.6 feet of magnetic tape is required per number. This subroutine is also described in the report mentioned above under VI A.

It is also intended to include subroutines of this type in these given automatically by the CS program when the programmer includes certain output instructions in his program. In addition this subroutine is to be rewritten in order to increase its speed of operation and thus to use less tape per number. Provision for rounding-off the numbers may be included.

VI. Further Changes and Suggestions

A. Changes

1. The present bar transfer switch is to be replaced by a single toggle switch which will perform the same function the bar transfer switch now performs. This switch is to be mounted on the junction box on the Flexowriter output equipment table. Thus the computer operators will be able to interchange units 3A and 3B from this position, and will have complete control of these two units without going to them.

2. At present the Rewind buttons on the auxiliary control panels for units 3A and 3B do not operate--rewinding is done by means of the pushbutton on the junction box on the Flexowriter table. It is planned that both these pushbuttons will also rewind the unit in the future. If the computer operator is at the unit, it can be rewound with the pushbutton on the control panel--in this case the unit is under manual control and ignores whether this unit is connected to the computer. When the unit is rewound with the button on the junction box, the Automatic pushbutton on the auxiliary control panel must be pushed in and the unit must be in print-out.

3. A short-carriage Flexowriter unit is to be connected to unit 2, so that it also may be used for delayed output. A transfer switch will be installed for this unit also--in one position unit 2 will be connected to the computer, in the other to the delayed output equipment. This switch and a Rewind pushbutton will be located on a junction box by this typewriter.

B. Suggestions

1. It may be possible to put another limit switch near the end of the tape, so that if the unit goes past this point on the tape some type of signal will be given to the computer operator (whether the unit is under manual or computer control) and he will know that the unit has almost run out of tape. If possible this unit will be stopped and the information put on another unit (in the case of output information this would be done for units 3 by throwing the bar switch). This is to avoid the tape running off the reel. Otherwise the program will have to be stopped by the operator if he thinks it will run off the end of the tape; since this will spoil the program anyway, he may as well spoil it by stopping the program before the tape has run off. This indication will probably also occur when the tape is being rewound or run in reverse, since it will be activated by the limit switches.

2. It has also been suggested that an alarm or signal be given if the computer selects one of the magnetic tape units and instructs it to operate when its power is not on.

3. An interlude utility tape may be provided for the operators to read into the machine after a program using the delayed printer. This utility tape will record on the magnetic tape some carriage returns and a stop character, and then perhaps information (such as the date) which will be typed as a heading for the next set of results from the typewriter.

Lists of Photographs

A-55528

A-55529

Signed: H. Denman

H. Denman

Approved: J. D. Porter

J.D.Porter

HD:JDP:mm

Drawings attached
A-55528
A-55529

APPENDIX

Appendix A. In-Out Delay counts for various orders

1. si instructions

si read--5.1 milliseconds
si re-record--5.1 milliseconds
si record--14.5 milliseconds
si record for delayed print--14.5 milliseconds
si stop in cleared area--28.7 milliseconds

No other in-out instructions can follow the above orders before the ends of these delay counts. In the cases of the si read and re-record orders, no other in-out instructions can be performed until these delays have been counted and the unit has detected a block mark afterwards. Internal WWI orders can be performed during all of these delays except the last, where no other orders can be performed until this delay is finished

2. rd - none (information comes into the In-Out Register from the tape at intervals depending on the spacing of the words on the tape--at least 2.56 milliseconds per word, but no delay is counted in the In-Out Delay Counter (IODC). If the In-Out Register is not full when this order is given, the computer waits until a word is assembled).

bi - none (as for the rd, no delay is counted, but the time required to complete the order and to permit another instruction is given by the total time required to read the n words from the tape into storage; at maximum density, 2.56 n milliseconds.)

rc - 2.56 milliseconds if it follows an si record order

7.5 milliseconds if it follows an si record for delayed print order

Appendix B. Amount of tape used for magnetic tape instructions

If the tape is running at normal speed of 30 inches per second when a certain delay of d milliseconds is counted in IODC, then to determine the length of tape in inches which has passed under the head during this period, which we call L, we simply use

$$L = .030\, d$$

Thus, if we rc one word (after normal si record order), d = 2.56, and L = 0.077". If the rc follows the new si record order, d = 7.4 and L = .222". But if the tape is at rest or is required to change direction of motion by the si instruction, then the length of tape passing under the head is not given by the above equation. The delay count is the same, but the tape is accelerating during the period and therefore a smaller length of tape passes under the head. No exact formula can be given for this since the acceleration depends on the action of certain mechanical clutches and brakes and their actions vary with time. The following estimates were based on the assumptions that the average reaction time of the units is 4.5 milliseconds, the average acceleration time is 0.75 milliseconds, and the acceleration is constant.

Whenever an si instruction is given to a tape unit, about 4 to 5 milliseconds elapse before the tape motion can be affected (this is the reaction time required for the clutches or brakes on the unit to act on the spindle which drives the tape).

This is followed by a period of high acceleration or deceleration of the tape to its normal velocity of 30 inches per second in the desired direction. Thus if the tape is at rest and is ordered to si read or re-record in either direction, the tape will have just started to move at the end of the 5 millisecond delay count. Therefore it will have moved a negligible distance past the head when it begins to look for a block mark. If the tape is at rest and is ordered to record in either direction by the appropriate si order, the tape will not move during the reaction time (about 4.5 milliseconds), will accelerate to normal speed in about 0.5 to 1.0 milliseconds, and therefore will be moving at normal speed for about 9.5 milliseconds of the counted delay of 14.5 milliseconds. At the end of the delay count the head will be about 0.29 inches from the point on the tape at which the si record order was given.

If the tape is moving when an si order referring to it is given and if this instruction directs the tape unit to move in the same direction, then the equation above can be used. We find that at the end of the delay count, for an si read or re-record order, the tape has moved about 0.15 inches from the point at which the order was given, for an si record order about 0.44 inches. If directed to si stop in a cleared area in the same direction, a section of tape about 0.58 inches long will be cleared, and the tape unit, after a delay count of 28.7 milliseconds, will be de-selected at about .32 inches from the point at which the order was given, and if permitted to coast to stop will finally stop about 0.17 inches from this point.

If the tape is moving in one direction and the si instruction directs it to change direction, the delay counts remain the same, but the tape will continue to travel in the original direction while the clutch-brake mechanism starts to decelerate the tape until its velocity in the original direction is reduced to 0. The tape then accelerates to normal velocity in the desired direction, which requires another 0.5 to 1.0 milliseconds. If the new si is for reading or re-recording, the tape will travel at normal speed in the original direction during most of the timed delay, so that the position of the tape at the end of the delay will be about 0.15 inches from the starting point in the original direction of motion. If the si instruction is for recording, the tape will travel in the original direction about 0.15 inches (erasing the tape), and then will reverse direction and the block marker at the end of the delay will be recorded about 0.12 inches in the desired direction from the starting place. If the si instruction is to stop in cleared area in the opposite direction, the tape unit again erases about 0.15 inches in the original direction, retraces this region, and erases about 0.27 inches of tape in the new direction, reverses direction again and is de-selected at just about the point where the order was initiated, but travelling in the original direction. If the unit is permitted to stop, it will coast about 0.15 inches in the original direction before stopping.

A word recorded on the tape using the regular si record orders occupies about 0.077 inches of tape. If the recording for auxiliary storage is made at maximum density, there is no distance between the words (other than the 0.0048" interline space already included in this figure). When recording using the si record for delayed print order, each word occupies about 0.225 inches, 2/3 of which is the long space given automatically before each word so that the unit can stop between words on the tape while the output equipment is operating. For auxiliary storage it may be desirable to increase the spacing given above; for delayed printing the spacing given above is minimum. If calculations to obtain the next output character after recording one on the tape require more than 7.5 milliseconds, and the unit is left running in the si record mode, a longer space will be obtained between these words on the tape, its length depending on the time required for the calculations.

Appendix C. Reference list of si addresses for the magnetic tape units

si Instruction	0	1	2	3A or 3B**
Re-record forward	100(o) 64(d)	110(o) 72(d)	120(o) 80(d)	130(o) 88(d)
Re-record reverse	101(o) 65(d)	111(o) 73(d)	121(o) 81(d)	131(o) 89(d)
Read forward	102(o) 66(d)	112(o) 74(d)	122(o) 82(d)	132(o) 90(d)
Read reverse	103(o) 67(d)	113(o) 75(d)	123(o) 83(d)	133(o) 91(d)
Stop in cleared area forward	104(o) 68(d)	114(o) 76(d)	124(o) 84(d)	134(o) 92(d)
Stop in cleared area reverse	105(o) 69(d)	115(o) 77(d)	125(o) 85(d)	135(o) 93(d)
Record forward	106(o) 70(d)	116(o) 78(d)	126(o) 86(d)	136(o) 94(d)
Record reverse	107(o) 71(d)	117(o) 79(d)	127(o) 87(d)	137(o) 95(d)
Record for delayed print forward*	146(o) 102(d)	156(o) 110(d)	166(o) 118(d)	176(o) 126(d)
Record for delayed print reverse*	147(o) 103(d)	157(o) 111(d)	167(o) 119(d)	177(o) 127(d)

(o) = octal
(d) = decimal

* When these si record instructions are used, there is the usual 14.5 millisecond delay counted in the In-Out Delay Counter while tape is being erased, and a block mark is laid down at the end of this period. Succeeding rc instructions generate a 7.5 millisecond total count in the In-Out Delay Counter. This order is chiefly designed to be used with Units 3A and 3B, because this delay automatically provides the minimum delay necessary for use with the delayed printer and punch.

** These si addresses refer to whichever unit is connected to the computer through the transfer switch.

A-5552

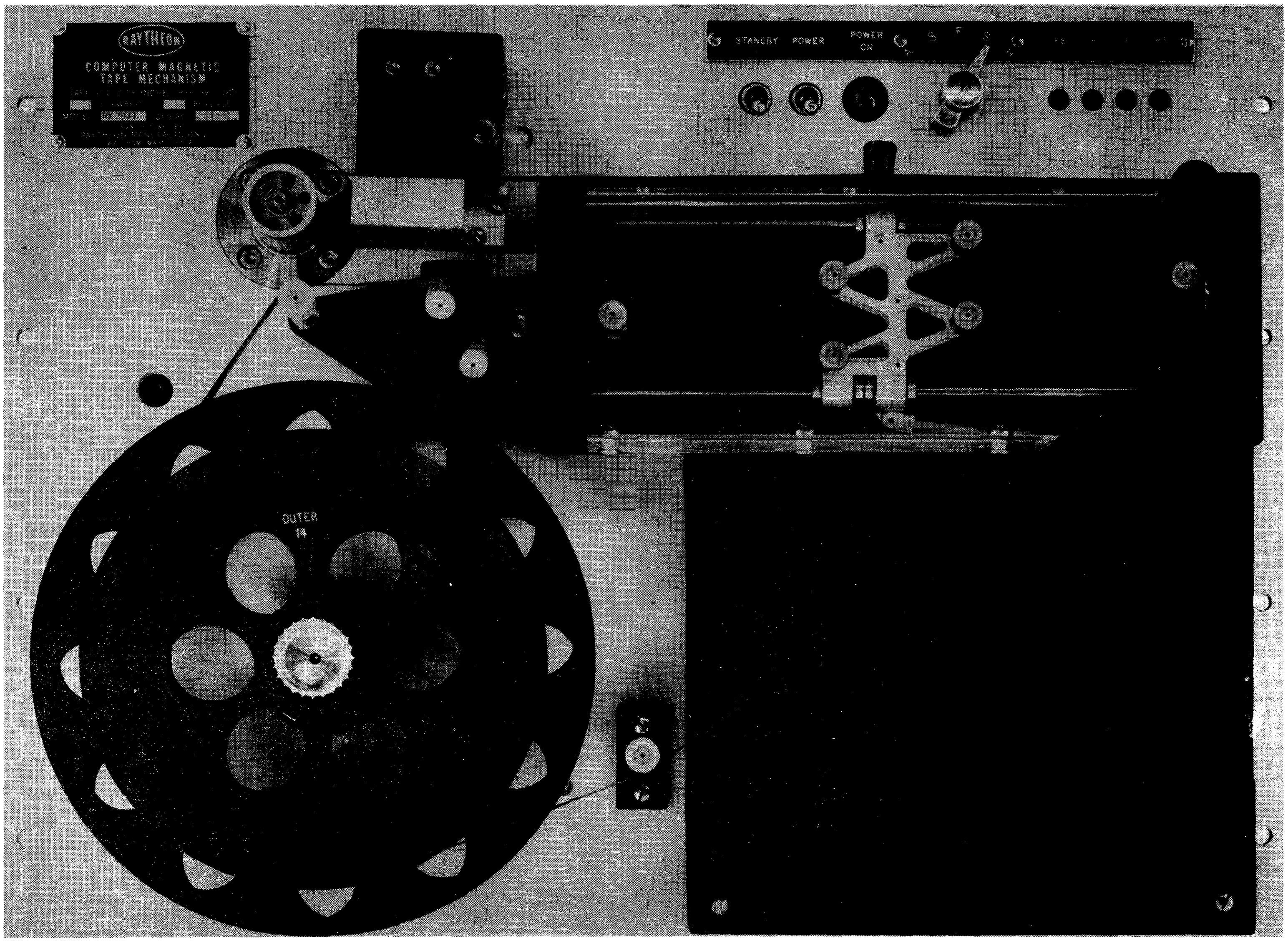


FIG. 3
RAYTHEON MAGNETIC TAPE UNIT

F-1307

A-5552

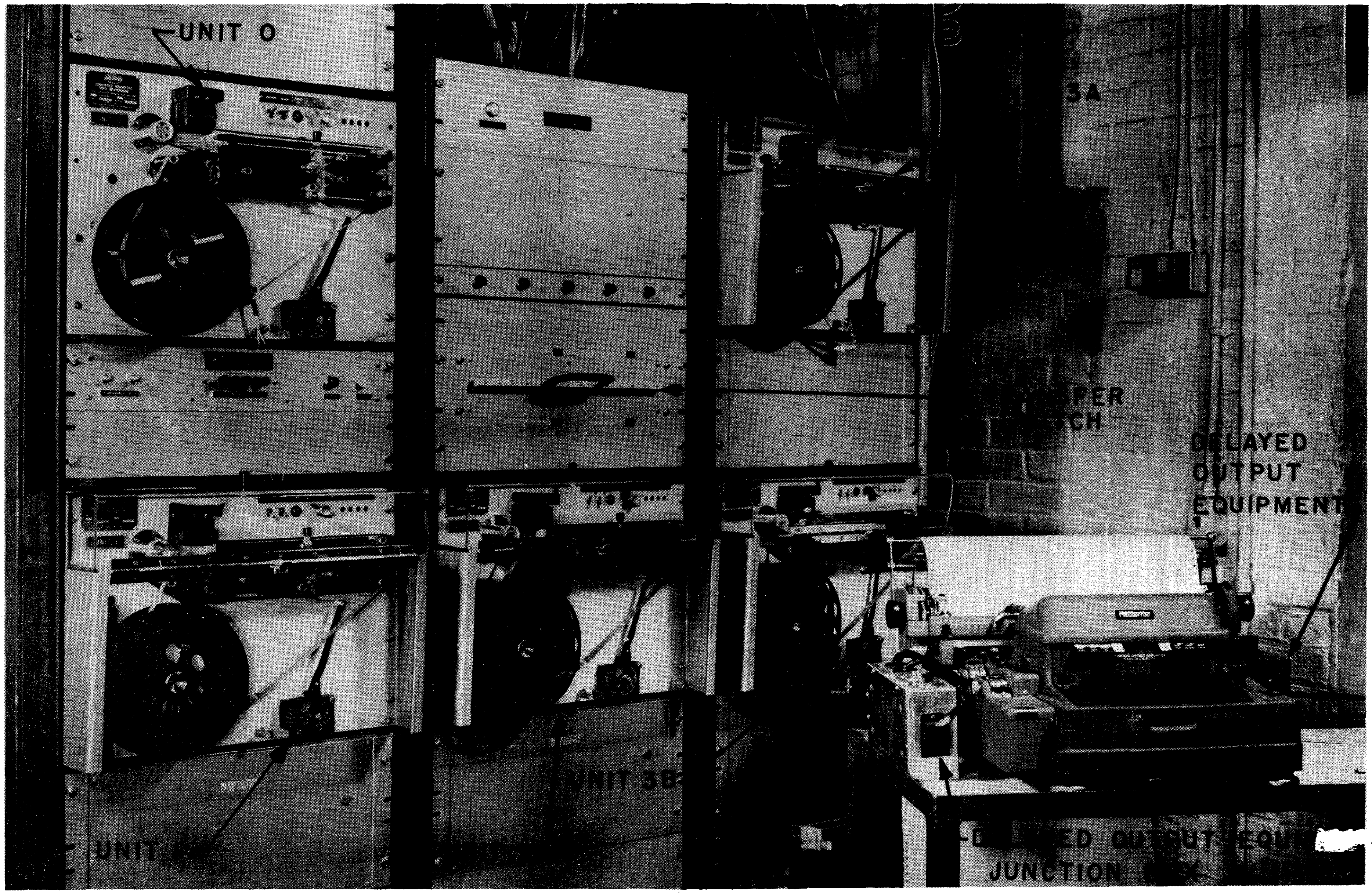


FIG. 4

MAGNETIC TAPE UNITS AND DELAYED OUTPUT EQUIPMENT