PROJECT WHIRLWIND

SUMMARY REPORT NO. 27
THIRD QUARTER, 1951

Submitted to the

OFFICE OF NAVAL RESEARCH
Under Contract N5ori60
Project NR-048-097

and the

UNITED STATES AIR FORCE
Under Contract AF19(122)-458

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FOREWORD

Project Whirlwind

Project Whirlwind at the Massachusetts Institute of Technology Digital Computer Laboratory is sponsored by the Office of Naval Research under Contract N5ori60 and the United States Air Force under Contract AF19(122)-458. The objectives of the Project are the development of an electronic digital computer of large capacity and very high speed, and its application to problems in mathematics, science, engineering, simulation, and control. At the present time Project resources are about equally divided between (1) operation of the computer and improvement of its reliability; (2) applications of the computer to engineering and scientific problems; (3) storage research and development; and (4) design of additional terminal facilities

The Whirlwind Computers

The Whirlwind computer is of the high-speed electronic digital type, in which quantities are represented as discrete numbers, and complex problems are solved by the repeated use of fundamental arithmetic and logical (i.e., control or selection) operations. Computations are executed by fractional-microsecond pulses in electronic circuits, of which the principal ones are (1) the flip-flop, a circuit containing two vacuum tubes so connected that one tube or the other is conducting, but not both; (2) the gate or coincidence circuit; (3) the electrostatic storage tube, which uses an electron beam for storing digits as positive or negative charges on a storage surface.

Whirlwind I (WWI) may be regarded as a prototype from which other computers will be evolved. It is being used for a study of circuit techniques and for the study of digital computer applications and problems.

Whirlwind I uses numbers of 16 binary digits (equivalent to about 5 decimal digits). This length was selected to limit the machine to a practical size, but it permits the computation of many simulation problems. Calculations requiring greater number length are handled by the use of multiple-length numbers. Rapid-access electrostatic storage initially had a capacity of 4096 binary digits, sufficient for some actual problems and for preliminary investigations in most fields of interest. This capacity is being gradually increased toward the design figure of 32,768 digits. Present speed of the computer is 20,000 single-address operations per second, equivalent to about 6000 multiplications per second. This speed is higher than general scientific computation demands at the present state of the art, but is needed for control and simulation studies.

Reports

Quarterly reports are issued to maintain a supply of up-to-date information on the status of the Project. Detailed information on technical aspects of the Whirlwind program may be found in the R-, E-, and M-series reports and memorandums that are issued to cover the work as it progresses. Of these, the R-series are the most formal, the M-series the least. A list of the publications issued during the period covered by this Summary, together with instructions for obtaining copies of them, appears in the Appendix.

1. QUARTERLY REVIEW (AND ABSTRACT)

During the third quarter the computer has been available for applications studies an average of 30 hours per week despite shutdowns for several major modifications. Extensive circuit modifications were made in preparation for the installation of a second bank (Bank B) of storage tubes, and a number of changes were made to accomodate the new in-out system. Nevertheless, about 80 percent of the scheduled applications time yielded useful work.

The marginal-checking program has become so effective that most of the failures that now occur are intermittent or sudden mechanical failures that are difficult to predict by marginal-checking techniques. Special trouble-location programs are being written to facilitate the rapid location of such failures. The addition of a new amplifier circuit and the use of a more opaque paper tape have brought the photoelectric tape reader to a high degree of reliability.

The Applications Group has made significant progress in the development of techniques for preparing and performing computer programs. Interpretive subroutines are being prepared to facilitate the scaling of numbers so that the proper number of significant digits will be carried. Standard subroutines are being arranged in a clearly catalogued "library" to provide a quick and easy method for programming commonly needed operations such as evaluation of sines, cosines, tangents, exponentials, logarithms, and square roots, and the performance of routine procedures such as printing numbers, photographing curves that have been plotted on an oscilloscope screen, reading tapes, and interpolating in tables of functions.

A very flexible input conversion program has been developed to permit direct introduction of Flexowriter-coded punched tapes into the computer. A time-consuming intermediate operation, involving the punching of paper tape by the computer, will be much shortened when magnetic-tape equipment becomes available for buffer storage.

In addition to these general techniques of programming, the Applications Group has worked on the coding and solution of a number of actual problems listed in Section 6.2.

Predominant causes of vacuum-tube failures continue to be changes in characteristics (chiefly reduced plate current) and mechanical faults. The Digital Computer Laboratory is cooperating in research with the ASTM committee concerned with materials used in oxide-coated cathodes for vacuum tubes.

An experimental two-dimensional magnetic memory array using 256 small metallic cores is being constructed. It will have a minimum writing-reading cycle time of about 20 microseconds. Driving and sensing windings are single turn, and the first cores to be tried are 3/16-inch-diameter rings of Mo-Perm 216. A similar magnetic memory array using 256 ceramic cores is also being constructed. It is expected to have a cycle time under 5 microseconds. The cores are made of an improved version of Ferramic A.

A magnetic-core matrix switch that has been designed shows promise for a number of applications. It will be used to drive the 16 x 16 ceramic memory array. A model of the switch is illustrated in Section 3.43.

A dual of the two-dimensional magnetic-core storage is being designed using a matrix of ferroelectric condensers. If they can be made to work satisfactorily, ferroelectric circuits should provide very compact memory elements.

Operation of storage tubes has been made more reliable by a modification of the gun construction that eliminates r-f pickup on the deflection plates. The new 400-series prototype tubes have operated satisfactorily in test setups at a density of 1024 spots. Small changes in operating and maintenance procedures have corrected several conditions that contributed to random failures of 300-series tubes occurring after six months of operation.

Average age of storage tubes in the computer at the end of the quarter was 1300 hours (5 to 2400). Seven tubes have been in operation more than 1700 hours.

Research continues toward the development of higher-density storage and improved guns, and the elimination of dark-spot formation.

The magnetic-tape input and output mechanism shows further improvement. To permit the use of blemished tape, the six channels of the tape have been connected into three pairs, the two channels of each pair being operated in parallel. A hard-tube circuit for controlling the clutch in the magnetic-tape mechanism has been developed to replace the gas-tube circuits.

SYSTEM ENGINEERING

2.1 COMPUTER OPERATION

During the third quarter of 1951 the computer underwent several major modifications. Preparations were made for installation of a second bank (Bank B) of storage tubes. The resulting circuit modifications and changes were made in the individual digits and also in storage control. In addition, a number of the voltages for the Bank A storage tubes were changed. Besides the installation and changes made in storage, there have been a number of changes in the computer to accomodate the new in-out system. These changes consisted largely of installation of d-c wiring for the new in-out switch and in-out register, as well as provisions for modifying the comparison register for operation as an in-out delay counter. This d-c wiring installation was also accompanied by the normal hardware installation and addition of voltage-variation circuits, fuse panels, and other system connections.

In spite of these changes, the computer has been able to average approximately 30 hours per week of application time, 80 percent of this time being useful to the applications groups. Considering the major changes which were in progress, this seems to be quite satisfactory.

The scope of the marginal-checking system has been extended by the addition of a number of voltage-variation circuits to some of the new equipment and by the writing of a number of new marginal-checking programs. Marginal checking has become so effective that most failures are now intermittent or sudden mechanical failures in resistors, tubes, tube sockets, etc. These types of failures are difficult to predict by marginal-checking techniques. Therefore we are writing a number of special trouble-location programs to facilitate rapid location and elimination of these failures. As soon as the second bank of storage tubes has been completely installed and checked out, these trouble-location programs will be used more frequently, and it is expected that this will help to increase the percentage of usable applications time.

2.2 PHOTOELECTRIC TAPE READER

The photoelectric tape reader was installed and operated in the system during the second quarter. As described in Summary Report 26, it was not at first satisfactorily reliable. System tests indicated that the poor long-term reliability was caused by four major factors.

(1) Sensitivity of the amplifier to duty cycle caused errors on some tapes. This duty-cycle sensitivity was caused by a-c coupling. It was substantially reduced, although not eliminated, by a change in the coupling time constants.

(2) The gain of the amplifier was inadequate. This prevented both satisfactory clipping and reliable separation of signal and noise. Slight drifts in tube characteristics were enough to cause loss of clipping and thus spurious output signals.

(3) The paper tape used in the photoelectric tape reader was designed for a mechanical reader. No great effort had been made by the manufacturer to maintain uniform light density, and the paper was somewhat translucent. The variation in density of the paper was being sensed by the phototubes and was producing a noise background with an amplitude up to 20% of the maximum signal amplitude. It seemed probable that this noise could be tolerated if the amplifiers were redesigned to remove duty-cycle sensitivity and increase the gain.

(4) Difficulties in the tape-drive mechanism caused occasional creeping or unreliable starting of the tape. This mechanical trouble was corrected by machining the tape face plate in such a way as to drive the tape in a more positive manner.

To correct the first two troubles, it was decided to design a d-c coupled amplifier to replace the a-c coupled amplifier being used. The d-c coupling allowed more gain to be built into the same number of stages, and it also made the gain of the amplifier insensitive to duty cycle. The original circuit amplified the initial signals twice as much as it did the succeeding ones. This d-c coupled amplifier has been built, and advantages of the circuit mentioned above have been realized.

The reader is marginal-checked by varying the amplifier grid bias while a test tape is being cycled through the reader. Information on the tape is compared with the same information stored in the computer. The lower extreme of this bias excursion is reached when the noise voltage is sensed as information pulses; the upper extreme occurs when the bias is so great that the signal does not receive sufficient amplification to allow its information to pass into the computer. At either of these extremes the computer indicates an error by giving an alarm. The bias is adjusted for normal operation to a value about half way between these two extremes. As described here, the marginal checking

was used only to adjust the amplifiers, but actually the magnitude of the allowable grid-bias excursion can be used as an indication of the condition of the amplifiers. Any deterioration in components will be shown up by a decrease in this allowable swing.

The photoelectric tape reader using this new amplifier circuit and a more opaque gray tape instead of the yellow tape used previously has operated now for six weeks with a very high degree of reliability. One poor feature which did show up during this period was the short life expectancy of the exciter lamp being used. This difficulty was corrected by using a low-voltage lamp with a much heavier filament structure. The result of all these modifications has been a unit which can be easily adjusted and then left unattended for several weeks without the need for readjustment.

3.1 FIVE-DIGIT MULTIPLIER

At the end of the second quarter of 1951 the reliability test on the five-digit multiplier was terminated. Results of this investigation have been reported periodically in summary reports issued during the past two years. The principal reasons for concluding the test were: (1) The achievement of a high degree of reliability in the operation of electronic computing circuits has been demonstrated. (2) Sufficient experience has been obtained in operation of the Whirlwind computer to indicate that the performance of the computer is comparable with that of the multiplier, so that further studies of maintenance techniques on the multiplier system are of little value.

Currently the multiplier is being used for instruction of new personnel in computer system logic and trouble shooting. In the future the multiplier will be used for testing new computer circuits and components.

3.2 VACUUM-TUBE LIFE

3.21 Five-Digit Multiplier

Curves showing the life characteristics of types 7AD7, 7AK7, and 6AS6 vacuum tubes when used in the multiplier were published in Summary Reports 22, 23, and 25. Fig. 3-1 presents similar curves plotted out to 26,000 hours. The plots include information from both the original and the replacement tubes in one graph. The test data are similar to those which would be available from many different lots started on test at different calendar dates. The method of analysis combines the data at corresponding ages for the different lots, and

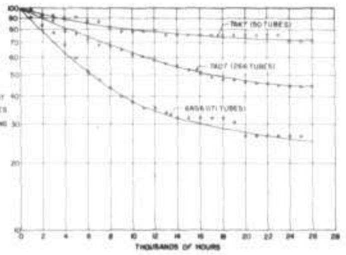


Fig. 3-1. Tube-life Experience in Multiplier

the results are plotted as a curve of survival percentages versus length of service. The early section of the curve is based on a larger sample of tubes than the later sections, which do not include data from so many replacement tubes. On the graph, the figures in parenthesis give the total number of tubes on which experience has been obtained.

Although the curves of Fig. 3-1 are extended more than 25% over those previously published (see Summary Report 25), very little change in their shape is evident. The logarithmic scale for the ordinates of the graph was chosen so that the slopes of the curves would show the relative rates of failure. For all tubes the rate decreases for increasing length of service, as indicated by the flattening out of the curves. It is probably not valid to conclude that this is typical of tube behavior, since the samples involved are small.

3.22 WWI Computer

The failures of vacuum tubes that have occurred in WWI during the past quarter are tabulated in Fig. 3-2. This tabulation shows no significant changes in the failure patterns over those which have been published for previous quarters. The predominant causes of failure continue to be (1) changes in characteristics (primarily reduction of plate current) and (2) mechanical faults (mostly tap shorts).

Calculations have been made of the average failure rates for the five types of tubes most used in the computer circuits. These types constitute about 90 percent of the tube complement of the computer. The calculations do not include data on replacement tubes, since the records have not yet been transcribed onto punched cards for easier analysis. These failure rates, listed in Fig. 3-3, are averaged over a period of about 7000 hours and include failures from all causes. Types 7AD7 and 3E29 showed the largest failure rates. The type 3E29 tubes exhibit serious cathode interface deterioration.

3.23 Life Tests

Life tests made during the last quarter have been directed toward the resolution of an anomaly, the formation of cathode-interface resistance in SR-1407 tubes constructed with passive cathode base material (less than 0.01 percent silicon). According to previous studies, this formation would not be expected in tubes with such cathodes. Furthermore, previous experience has shown that in tubes

Type	Total in Service	Hours at Failure	Reason for Failure; Number failed			
			Change in Characteristics	Mechanical	Burn-out	Gassy
7AD7	1800	0-1000 1000-2000 2000-3000 4000-5000 5000-6000 6000-7000 7000-8000	2 3 3 2 8 14 4	 1 6 2 8 11 5		
7AK7	1500	41 7000-8000		1 3		
6SN7	400	2000-3000 4000-5000 6000-7000 7000-8000	2 1 	 3		1
6Y6G	300	4889		1		
6AS7G	80	2757 7352	2 3			
6L6G	80	842 2146	 1	1 		
2C51	20	3918			1	
6AH6	7	4534	1			
5U4G	24	3000-4000 4000-5000 5000-6000	 2 2	1		1
6X5GT	22	7638 7709 3396	1 1 1			
3E29	160	4000-5000 5000-6000 6000-7000 7000-8000 8000-9000	2 1 1 2	 1 		
715B	20	25 5000-6000	 2	 1	1 2	 1
EL3C	2	3988	1			
6V6	50	2786	2			
ELC16J	12	4000-5000 3688	2 1			
OD3/VR150	28	2000-3000 4534 8206	2 1 	 1		
6SL7	11	8206	1			
5651	24	4534 8206	1 1			
5Y3GT	5	5110		1		

Fig. 3-2. Tube Failures in WWI
July 1 - September 30, 1951

Tube Type	Failures per 1000 tubes per 1000 hours
6Y6G	14
3E29	35
7AK7	4
7AD7	35
6SN7GT	10

Fig. 3-3 Failure Rates of Vacuum Tubes in WWI

subject to interface deterioration, the interface resistance forms slowly during the first few hundred hours and more rapidly as the tubes grow older. In samples from a production run of SR-1407 tubes, sufficient interface formed during a 500-hour accelerated test to indicate that the tubes were unsatisfactory. However, in a life test of these tubes under normal operating conditions it was found that their rate of formation of interface decreases as they age; and at 2500 hours it appears that the amount of interface deterioration will not be important in tubes operated under the normal conditions of computer circuits. It is evident that further study of this behavior is necessary and that the concept of accelerated life testing to determine susceptibility to the formation of interface resistance must be reviewed.

The Digital Computer Laboratory is now cooperating with the ASTM committee concerned with materials used in oxide-coated cathodes for vacuum tubes. The ASTM designation for this committee is B4, sub-section VIII-A. The Laboratory equipment for the determination of the impedance associated with the cathode interface has been used in cooperative testing of one lot of tubes (type 25L6GT) which were also tested in the laboratories of the General Electric Company and at the Evans Signal Laboratory. Standard ASTM diodes have also been analyzed for interface impedance as an assistance to the Raytheon Manufacturing Company research program.

The Digital Computer Laboratory is interested in the ASTM cathode program for two reasons. First, the Laboratory is vitally interested in the cathode improvements which can be made in standard receiving-type tubes; second, any improved cathode materials may well prove useful in the construction of storage tubes. Although the ASTM program is not primarily concerned with these improvements in materials, the testing techniques being developed through this program are essential before improved materials can be produced.

3.3 COMPONENT REPLACEMENTS IN WWI

Fig. 3-4 lists the replacements of components other than tubes during the third quarter of 1951.

3.4 FERROMAGNETIC AND FERROELECTRIC CORES

Summary Reports 24, 25, and 26 contained discussions of (1) a scheme for storing digital information in a three-dimensional array of magnetic cores, (2) the results of research work on the individual cores, (3) experimental operation of a 4-core array, and (4) an extension of the original scheme which results in improved speeds and signal ratios.

The following paragraphs discuss activity during the last quarter, including (1) progress in the design and construction of two 256-core memory arrays and (2) the conception of a magnetic-core matrix switch which may be the answer to the selecting/driving problem of the ceramic array and which has many other possible applications. Also discussed is the state of research on ferroelectric-slab storage and some work done on Harvard-type magnetic-core stepping registers.

Component	Type	Total in Service	No. of Failures	Hours of Operation	Comments
Capacitor	0.5 mfd 600 V Bath-Tub	50	1	5066	Loose terminal and oil leakage
	560 mmfd Mica	1	1	3297	Burned out by short in 715B tube
	0.001 mfd Mica	3300	1	3297	Burned out by short in 715B tube
	2 x 20 mfd Plug-in	40	1	540	Blew out
Choke	25 μh RF	300	1	5960	Short in 715B tube
Delay Line	0.3 μsec 1100 ohms	1	1	6444	Open
Pulse Transformer	5:1	300	1	6982	Open primary
			1	7073	Open winding
	1:1	600	1	4555	Open primary
Toggle Switch	SPST	500	1	6982	Intermittent open
Resistor	Carbon 2200 ohms 1 watt	200	1	7673	Change in characteristics
	Carbon 220 ohms 1 watt	9300	1	6332	Overheated
			1	5496	Overheated
	Carbon 1.5 meg 1/2 watt	10	1	5367	Intermittent open
	Wire-Wound 5000 ohms 8 watt	700	1	7163	Open
			1	7398	Open
			1	5477	Open
	Wire-Wound 6300 ohms 8 watt	25	1	7878	Open
			1	0	Intermittent open
	Wire-Wound 1600 ohms 8 watt	750	1	0	Open
	Wire-Wound 2000 ohms 8 watt	750	1	7801	Open
			1	5064	Open
	Precision 50 K ohms 1 watt	100	1	3266	Open
Crystal Rectifiers	D-357	7500	2	2000-3000	1 low R_b 1 oscillation
			1	4000-5000	low R_b
			3	5000-6000	2 low R_b 1 high forward resistance
			1	6000-7000	low R_b
			5	7000-8000	4 low R_b 1 oscillation
	D-358	3100	1	1000-2000	low R_b
			4	4000-5000	low R_b
			4	5000-6000	low R_b
			3	6000-7000	low R_b
			2	7000-8000	low R_b

Fig. 3-4. Failures of Components in WWI July 1 - September 30, 1951

3.41 16 x 16 Metallic Array

A 256-core planar array using small metallic cores is being constructed. It is designed to be operated with selecting-current ratios of either 3:1 or 2:1 and will have a minimum cycle time (the time necessary to read and write) of about 20 microseconds.

Driving and sensing windings are single turn (one pass of each conductor through each core), and driving currents are approximately 1/4 ampere. At the low duty factors planned for this array, these driving currents can be delivered by type 5687 vacuum tubes. A total of 70 of these tubes are needed; most of them would be common drivers for the additional digit planes of a large computer memory. The array, the selecting and driving system, and the necessary test equipment is being installed in three 19-inch racks.

The first cores to be tried are made up of 3/16-inch-diameter rings of Mo-Perm 216, the low-energy material discussed in the last Summary Report. For this application, 400 cores are being pulse-tested.

Operating modes will resemble those used with the 4-core array. The ability of a core to hold information in the face of disturbing activity in the array will be tested. Pick-up noise and crosstalk are expected to be major problems and will be given careful attention.

Assembly of the memory and the associated testing system is not expected to be complete until late in November, and the testing system may be in proper operation early in December.

3.42 16 x 16 Ceramic Array

A 256-core planar array using small ceramic cores is being assembled. It is designed to be driven by two magnetic-core matrix switches (described in Section 3.43), and to have a cycle time under 5 microseconds.

Like the metallic array, this one has single-turn driving and sensing windings. Driving currents are delivered directly by the above-mentioned switches. Four 3E29's and sixteen 6AS7's make up the tube complement necessary to operate the switches from the "address" flip-flops and the logical test setup; most of these might be common drivers for the additional digit planes of a large computer memory. All of the equipment fits into three 19-inch racks.

The memory-core rings are made of a slightly improved version of Ferramic A; they measure under 1/4 inch in outside diameter. The assembled 256-core memory fits on a square less than 7 inches on a side.

Operating modes will be somewhat different from those of the metallic array, largely because of the inherent differences between vacuum-tube driving and magnetic-core-switch driving.

Partial results are expected in December.

3.43 Magnetic-Core Matrix Switch

The unique feature of the multi-dimensional magnetic memory is the straightforward method by which the memory units are selected. There remains, however, a switching problem involving the selection of one line along each co-ordinate axis and driving it first in one direction and then in the other. Using present techniques this can be done with a crystal-matrix switch followed by hard-tube drivers. This scheme is expensive and rather awkward for large arrays, so other switching arrangements have been considered.

A magnetic matrix switch has been designed which seems very promising. It is to be tried in the experimental ceramic memory. To drive a single-turn ceramic array from hard tubes would be very expensive because of the large number of heavy tubes needed to supply the heavy driving currents. A complete multi-dimensional memory which uses the magnetic matrix switch might, however, need only two large driver tubes.

The magnetic matrix switch contains one saturable transformer for each position of the switch. The primaries of all the transformers are driven in series from a common source, but all except the selected transformer are saturated by at least one of the control windings. These control windings are connected in a typical binary scheme to the flip-flops, as shown in Fig. 3-5, so that any one of the transformers can be left unsaturated.

A model of the switch (Fig. 3-6) has been constructed to demonstrate its operation. It is an eight-position switch driven from a 5,000-cycle sinewave source with a d-c source supplying the control windings through three single-pole double-throw toggle switches. The output position is selected by the toggle switches and is indicated by a lighted lamp bulb. This model, using Deltamax core material, has a selected to non-selected voltage ratio of 50:1.

It is expected that there will be many other uses for this switch in applications requiring the switching of power circuits as well as in information-carrying circuits.

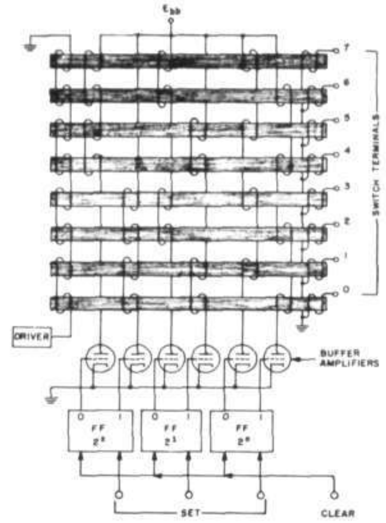


Fig. 3-5. 8-Position Magnetic Switch

3.44 Ferroelectric Storage

Ferroelectric condensers are available which have hysteresis loops in the D-E plane with shapes similar to the hysteresis loops of the ferromagnetic materials in the B-H plane, as mentioned in Summary Report 26. Information can be stored in ferroelectric condensers in a way analogous to that used to store information in magnetic cores. Voltage sources are substituted for current sources as drivers, and current detectors are substituted for voltage detectors for reading the stored information. In general, ferroelectric condensers can be used in circuits which are the dual of the circuits for their ferromagnetic counterparts.

A dual of the two-dimensional magnetic-core storage is being designed using a matrix of ferroelectric condensers. A voltage of plus V/2 applied to one row and a voltage of minus V/2 applied to one column subjects the condenser at the intersection of the row and column to a reading voltage, V, which is set so as to be slightly greater than the knee of the hysteresis loop. If, when this voltage is

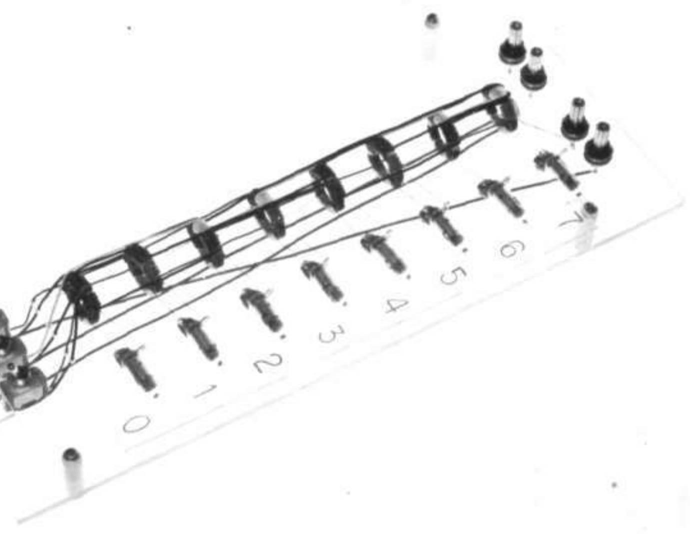


Fig. 3-6. Model of 8-Position Magnetic Switch

applied, a large current flows into the selected row (and out of the selected column), one knows that the condenser has switched from the bottom of its hysteresis loop to the top, or vice-versa. If the condenser does not switch, the current will be nearly zero. Changing the polarity of both of the externally applied voltages allows the inverse function (write) to be accomplished. The logic of reading and writing is identical to that of the two-dimensional magnetic-core memory. By applying minus V/6 to the unused rows and plus V/6 to the unused columns (or vice versa while writing) all condensers except the selected condenser are disturbed by a voltage of V/3. The equivalent 3:1 selection scheme for the magnetic matrix has been discussed in Summary Report 26.

Ferroelectric circuits have at least two potential advantages over ferromagnetic circuits: First, because a magnetic field is a divergenceless field, a complete closed path is required for each magnetic circuit, whereas an electric field can terminate on a charge-carrying material; this fact relieves the electric circuit of the topological difficulties involved in obtaining flux-linkages, and permits improvements in packaging. Second, the energy storage per unit volume in ferroelectrics is higher by about two magnitudes than in the ferromagnetic materials currently in use. These facts make possible extremely compact storage.

3.45 Magnetic Stepping Registers

One of the inputs to WWI may be information pulses which arrive serially at relatively low rates. The information is to be stored and then delivered to the computer, at its request, in parallel groups of sixteen pulses. The series-to-parallel conversion plus the requirements for buffer storage led to a consideration of the magnetic-core stepping register for the job. A study of the commercially available stepping registers was made to determine their reliability and maximum operating speeds. The reliability was found to be poor and the operating speeds limited by the Deltamax core material. In the light of recent developments in magnetic ferrites, a four-core stepping register was made using ferrite cores and D-359 germanium diodes in the inter-core coupling circuits. This first model operated at 109,000 information transfers per second, about three times the maximum operating speed of the commercial units. No attempt has been made to optimize the circuit parameters so as to go to higher speeds.

3.5 DEFLECTION AMPLIFIER FOR 16-INCH DISPLAY SCOPES

In an article on the new 16-inch display scopes in Summary Report 26 (Sec. 5.5), it was stated that special direct-coupled amplifiers had been developed for the tubes. The available tubes, which were designed for radar or television, are magnetically deflected. In both radar and television applications the display is continuous and repeating, as far as the deflecting coils are concerned. This simplifies the problem of attaining large deflecting currents, since transformers may be used. For the Whirlwind display, the position of the beam is entirely random, so that a direct-coupled amplifier is necessary.

The deflection yoke, which was made by Air Force Cambridge Research Laboratory, contains as many turns of as fine wire as it conveniently can. Even with this relatively large number of turns, so much current was required that it was necessary to use type 715 tubes for the push-pull output stage. A 715 is rated at 60 watts plate dissipation, and can just handle the load.

Where such large currents are involved, it is necessary to use feedback to get adequate linearity, as shown in Fig. 3-7. A voltage is developed across a resistor in the cathode of each output tube proportional to the current drawn by the tube through its deflection coil. However, the net deflecting field in the oscillograph tube is proportional to the difference of these currents. In order to obtain a signal proportional to the difference of the tube currents, one cathode voltage is fed to a phase inverter, and the resulting inverted signal added to the other cathode voltage, giving a single voltage that is proportional to the difference in deflection currents. This is the feedback signal which is subtracted from the input to get an error signal. The error signal is fed to a phase inverter, amplified, and fed to the output tubes, completing the loop.

One advantage of this procedure is that the individual output tubes may operate at low currents when the beam is not deflected; when the beam deflection is large, one tube will conduct heavily and the other will be cut off. Thus the tube dissipation for an undeflected beam will be much less than that for full deflection, a favorable condition for the output tubes. A second advantage is that the quantity being stabilized by feedback is the quantity that deflects the beam, which is the difference in the currents of the output tubes.

The amplifier is capable of deflecting the beam from one edge of the tube to the other within 20 microseconds. The oscillograph tube has 12 kilovolts accelerating voltage, and only 5 microseconds intensification time is required to burn a spot on the P-7 screen that will last for 15 seconds.

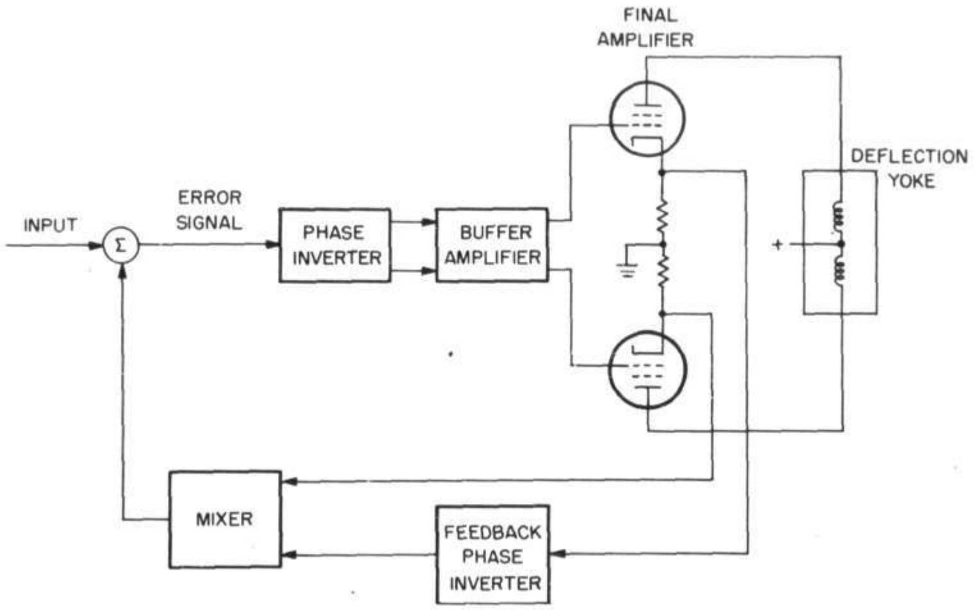


Fig. 3-7. Deflection Amplifier for 16-inch display scope

4. ELECTROSTATIC STORAGE

4.1 TUBE PROGRAM

Margins of reliable computer operation for storage tubes were increased substantially during this period by the elimination of r-f pickup on the deflection plates. A slight modification of the gun construction helped in reducing this pickup and has improved the high-voltage performance of the guns.

Further tests on the new 400-series prototype tubes have shown that they operate satisfactorily in test setups at 1024 spots and that the non-uniform ion current, which was responsible for the formation of dark spots in the 300-series tubes, can be effectively suppressed. Experience with the 32 x 32 tubes operating in the computer will soon be gained, as the second bank of storage now being installed uses tubes of this type.

4.11 Tube Experience in WWI

After six months of operation in the computer with excellent reliability, several of the 300-series tubes began giving serious trouble during the early part of this quarter. These tubes failed to read out a positive array even when a television-type scan showed a normal array of spots. The type of failure was different from that exhibited by the 100-series tubes (see Summary Report 25) in that errors occurred at a completely random rate and at widely separated points. During the subsequent investigation to determine the cause of this trouble, several conditions were uncovered which, in the aggregate, would certainly have caused marginal operation. In addition, a basic fault in the tube design was found which has now been corrected.

The first group of conditions comprised: a reduced r-f phase-reference amplitude caused by weak tubes and a bad component in the r-f pulser; a severe unbalance between the two halves of the deflection output amplifiers because of deteriorated tubes; the presence of a small amount of 60-cycle ripple on the deflection lines introduced by heater-cathode leakage in the current-switch diodes of the deflection decoder; and a small pickup on the deflection lines of the sweep voltages used for a television-type read-out of the storage-tube surfaces caused by a common power-supply decoupling impedance. Most of these troubles indicate the need for a more rigorous maintenance schedule. To remedy the last one, the TV sweep generator is now made inoperative during normal computer operation.

The other fault discovered was the presence of as much as 5 volts of 10 megacycles on the deflection lines during the time of the r-f readout pulse. Whenever this r-f pickup on both plates of a coordinate pair is not equal in both amplitude and phase, the beam is shifted away from its normal position. (The normal position is determined by the output of the deflection amplifier; consequently it is the position of a spot written on the surface when the r-f pulse is not present.) Among the possible causes of an unbalance, the most prominent is the difference in capacitance to the control grid (the source of r-f pickup) of the two deflection plates nearest the target in a storage tube. The lead from one of these plates gets to the base along the outside of the gun structure. The lead from the other plate is brought to the base through a ceramic stem, around which the control-grid cylinder is clamped for a distance of approximately 1/4 inch. Although the capacitance introduced by the latter lead construction is only a few micromicrofarads and the deflection line to the tubes is terminated in its characteristic impedance of only 178 ohms, the r-f unbalance with many tubes connected to the deflection transmission line was great enough to cause serious trouble. A test in which the beam was shifted while it was reading an array of positive spots provided evidence of this unbalance. It was observed that the reading beam could be shifted about three times farther in one direction than in the other, since a readout signal is produced only on the positive swing of the 10-mc r-f voltage at the control grid. A similar test had been carried out when storage tubes were first put into the computer, but unfortunately only a few tubes were then installed and connected to the deflection transmission line.

Two steps have been taken to eliminate the r-f pickup on the deflection plates. First, the gun construction has been changed so as to bring all deflection-plate leads to the base along the outside of the gun structure. Second, series LC circuits, tuned to 10 mc, have been installed from each deflection plate to ground. These circuits give an attenuation of about 50 to 1 of any residual r-f voltage on the deflection plates. Tests using a 32 x 32 array of spots (which are smaller than the spots used for a 16 x 16 array) indicate that these solutions are satisfactory, because the r-f voltage on each plate is low enough for proper operation and it is kept from feeding out onto the transmission line. The construction change has also improved the high-voltage characteristics of the guns, since in the tubes lost because of an arc-over in the high-velocity guns this arcing generally took place between the control-grid cylinder and the deflection-plate lead running through the ceramic stem. Starting with ST366-1, all storage and research tubes have been made with the new gun construction.

At the end of this quarter, the average age of fifteen 300-series tubes in the computer (the sixteenth being a research tube on computer test) is 1300 hours, ranging between 5 and 2400 hours. Seven tubes have been in service longer than 1700 hours. The most frequent cause for replacement has been severe dark-spot formation due to ion bombardment.

As mentioned in Summary Report 26, one of the 400-series prototype tubes, RT210-3, was placed in the computer. Using a higher overall acceleration voltage from separate power supplies, and with a reduced throw compared to the 300-series, this research tube operated at a density of approximately 25 x 25 when the rest of the tubes had a normal 16 x 16 array. The tube gave satisfactory operation for roughly 1000 hours. Then a dark spot made it impossible to satisfy both positive and negative writing requirements with adequate safety margins. This tube had an auxiliary collector which was set 250 volts positive with respect to the holding-gun cathode. For a further discussion of RT210-3 and the formation of dark-spot areas having low secondary emission, see Section 4.21.

4.12 Tube Production

The total tube production for this quarter was 34 new and 3 reprocessed tubes. They included additional 300-series replacements for the computer; research tubes for studies of higher density, surfaces, and guns; and 400-series prototype tubes for 32 x 32 tests and subsequent installation in the computer. Of the fourteen 300-series tubes made, two were rejected for the reasons listed on Fig. 4-1. Two others were classed as marginal because of weak high-velocity guns. With the construction of these tubes it was felt that adequate 300-series spares were available, and since August 24, 1951, no more tubes of this series have been made.

Nine 400-series prototype tubes were completed of which seven are satisfactory for use in the computer. One tube was lost because of poor emission of the high-velocity gun. The second, RT232, exhibited severe leakage over the entire surface. Testing and observation of the surface after the tube was dissected indicated that a particularly thin coating of beryllium had migrated during processing. Particles of beryllium completely covered the mica moat area and shorted together all of the individual squares. A value of only 10 ohms resistance was observed between the two sides of the storage surface.

Fig. 4-1. Storage Tube Production Record

Five other research tubes were needed in the course of development work for the 400-series tubes. One of these tubes has collector meshes of four different sizes. Another has two different meshes for both collector and auxiliary collector, with the dividing diameters crossed at 90° to one another. Two tubes were used to test new designs of a target assembly to hold the auxiliary collector. The fifth was made without the square mica spacer so that restoring currents could be measured as a function of auxiliary-collector voltage.

Research tube RT214 was made with a Philips type "L" cathode, which is described further in Section 4.22. RT226-1 was assembled in a standard 5-inch cathode-ray tube envelope for testing the technique of supporting the gun structure from a 10-pin stem without a deflection plate lead running through the ceramic tube on which the gun elements are mounted. It was used for r-f feedthrough tests and is now available as a deflection monitor.

The four other research tubes were used for studies concerning the lower stability point. One had a plain Vycor surface, and another used a glass surface sintered directly onto a metal backing plate. The third was a standard 300-series tube without the collector screen, while the fourth had 13 Faraday cages in place of the normal storage assembly. The front surface of the aperture plate for these cages was coated with beryllium oxide.

4.2 STORAGE-TUBE DEVELOPMENT

4.21 Tests on 400-Series Prototype Tubes

Before research tube RT210-3 was installed in the computer to operate at a higher density, tests had indicated that an auxiliary collector screen gave a definite improvement in controlling spot interaction. This interaction is most severe when negative writing is carried out adjacent to positive spots. This condition is ideal for the low-velocity secondary electrons to go to the neighboring spots instead of falling back onto the spot under bombardment to charge it in a negative direction. Since the reduction in this type of interaction was observed when the auxiliary collector was raised 50 volts or more above the collector voltage, it was felt that the effect of the auxiliary collector was to increase the angle at which secondary electrons left the bombarded spot and to prevent the return to the surface of any secondaries which penetrated the collector screen. This indicated that the potential of the auxiliary collector should be set as high as possible.

With more than 350 volts between this electrode and the holding-gun cathode, however, the field between the auxiliary collector and the retaining screws for the collector screen caused such a severe distortion of the holding beam that it no longer covered the storage surface in the vicinity of these screws. Accordingly, the auxiliary collector was set to 250 volts. Being more positive than all other electrodes except the holding-gun anodes, the auxiliary collector would set up a barrier for positive ions so that dark-spot formation would be substantially reduced.

This solution was not satisfactory, however, for after only several hundred hours of use, a dark spot started to form on RT210-3 and progressed steadily until the tube had to be rejected. With this knowledge, a series of tests was undertaken on other 400-series tubes using a procedure (described in Section 4.13 of Summary Report 26) in which the ion current is allowed to charge a negative surface above first-crossover voltage. This charging takes place during the application of a negative gate to the signal plate. The length of the gate is variable between roughly 0.01 and 30 seconds. As shown in Summary Report 26, the ion-current density is greatest near the center of the tube, so that the size of the positive spot produced during the test is directly related to the length of gate used. Neglecting electron emission caused by the impinging positive ions, one may calculate the ion-current density at the radius of the positive spot produced in a given time when the surface capacitance and first-crossover voltage are known.

The data shown in Fig. 4-2 were obtained by this procedure. Here the positive ion-current density is plotted as a function of the radius from the peak density, which normally lies near the center of the tube. Figure 4-2 shows the cumulative effect upon the ion current of changing the more important parameters. The top curve represents 300-series operating conditions, the bottom curve 400-series operating conditions. For the four curves in between, the variables other than those marked are set to the last value indicated above the particular curve. Thus, for the curve marked $V_{A1} = V'_{A2} = 350$ volts, V'_B (the holding-gun bias) is -10 volts, V_{A3} is 110 volts, and both collector and auxiliary collector are at 100 volts (V_{HG} and V_{AC} respectively).

The logarithmic scale for the ion-current density should be noted, as well as the marked change between $V_{AC} = 250$ and $V_{AC} = 400$ volts. It was found that most of this change took place between $V_{AC} = 320$ and 375 volts, indicating that many ions were being created back in the holding-gun structure at a space potential very near that of the holding-gun anodes. These curves indicate that the dark-spot formation would be eliminated if the auxiliary collector were operated more positive than the holding-gun anodes. However, a reduction of the anode potentials lowers the holding-beam current available for stabilization while raising the auxiliary collector leads to serious distortion in the holding-beam coverage. This situation was remedied by designing the target assembly so that the retaining screws for the two collector screens were in back of the surface and would not seriously affect the low-velocity electrons comprising the holding beam. In addition, the holding-gun anodes were reduced from 500 to 350 volts. Tests have shown that the restoring currents on 400-series tubes are reduced by a factor of two from that in 300-series tubes, but this loss is outweighed by the virtual elimination of positive-ion bombardment. The first tube with the reversed screws on the target assembly has now been operated at 1024 storage spots for more than

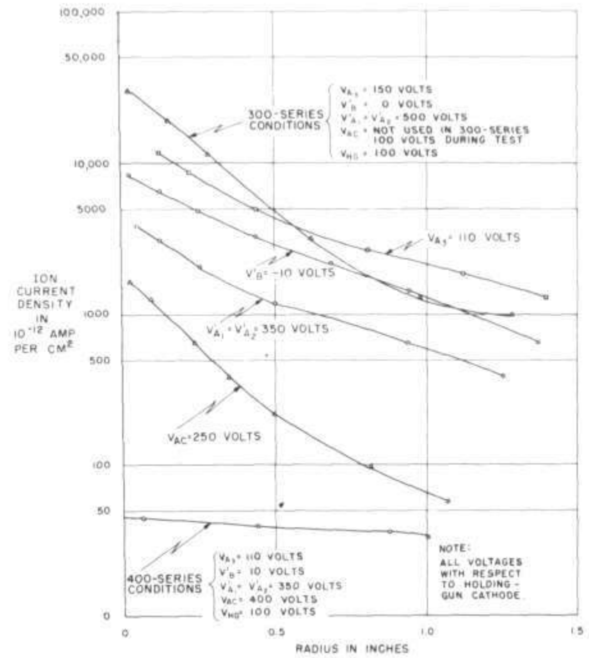


Fig. 4-2. Positive ion-current density distributions

1300 hours without the slightest trace of dark spot. An additional power supply has been added in the computer to provide 400 volts for the auxiliary collectors, and 400-series tubes are being installed in the second bank under the new operating conditions.

The effect of mesh sizes of the collector and auxiliary-collector screens upon the operation of storage tubes was investigated during this quarter. While the action of these screens is not easily treated analytically, one feels intuitively that a relatively coarse mesh would allow more current from both beams to strike the surface, but would be less efficient in controlling redistribution of secondary electrons than a finer mesh. For a complete explanation of storage stability, the screen spacings, the mosaic-square size, and the spot-to-spot separation should be taken into account, but values for these variables have been rather well fixed from other considerations. With the operation at higher density required of 400-series tubes, it seemed worth while to study the effect of the screen mesh sizes experimentally.

Two research tubes were made having the geometry of 400-series tubes but with varying collector and auxiliary-collector meshes. Subsequent spot-interaction tests indicated a definite advantage for a 70-mesh collector rather than the 100-mesh previously used. A slight improvement was also obtained with a 70-mesh auxiliary collector instead of the 40-mesh which was first selected. The 70-mesh screen is now being used for the collector on all 400-series tubes, but 40-mesh auxiliary collectors are still being used until procurement difficulties are alleviated.

4.22 Research

Another research tube with a Philips "L" cathode was made during this period. The cathode was successfully activated, but during aging a grid-cathode short developed which precluded additional tests and life runs. In the next quarter the grid-cathode spacing will be increased and the grid aperture increased as necessary to obtain a usable cutoff characteristic.

Research work for a master's thesis is

being devoted to an investigation of the current-density distribution in the fringe region of the high-velocity beam. Further data gives evidence that this distribution is not as dependent upon beam throw as was at first suspected. Two factors which have not yet been explored are the emitting area of the cathode and the velocity distribution with which electrons leave the cathode. For studying these aspects, a Philips "L" cathode will be placed in a storage tube as soon as feasible, and a research tube with a shield over part of the cathode area is under consideration.

Studies to develop a conductive coating of tin oxide have been actively resumed, and research tubes utilizing this coating in place of aquadag may be made during the next quarter. A resistance of approximately 100 ohms has been observed across the films which have been produced. The problems remaining are the coating of the large envelope sections used in making a storage tube, the change in technique in working the glass because of heat conduction through the tin oxide layer, and the maintenance of conduction between the two envelope sections after the body seal between them has been made.

The first tube with a sintered-glass surface has been processed and tested. The results were not encouraging, and further work has been suspended. The technique developed was satisfactory, but the secondary-emission properties of the glass make it unattractive as a storage-tube dielectric. Also, the dielectric constant is not appreciably different from that of mica, so that there is nothing to be gained in the way of reduced writing-charge requirements.

The shortcomings of the sintered-glass surface have pointed up the need for exploratory tests on another mode of storage-tube operation, that of using only one mosaic square per storage spot. This procedure offers the greatest promise of reducing the writing times from the present values of 32 microseconds to something less than 10 microseconds, but the accompanying difficulties in deflecting to the single squares are considerable. To understand how the reduction in access time can be achieved, one must consider the capacitive coupling between individual mosaic squares. For the surface to have satisfactory dynamic stability in the presence of a large unbalance between positive and negative restoring currents, the capacitance from a mosaic square to the signal plate must be roughly twice that to the four neighboring squares. Since the size of the mosaic squares must be set on the basis of the total number of spots and the number of squares required per spot, an upper limit is placed on the thickness of the mica target. For 400-series tubes this limit is in the order of 0.005 inch, and the peak current-density available from the high-velocity gun in conjunction with the required voltage swing of 100 volts and the capacitance of the 0.005-inch mica indicates that 32-microsecond writing gates should be used to insure adequate operating margins.

Now if only one square is allowed for each storage spot, the mica thickness for the same stability could be increased to possibly 0.025 inch or 0.030 inch, and a corresponding reduction in length of the writing gate would be possible because of the lower capacitance. The problem associated with deflection tracking onto single mosaic squares and the improvement in operation which might be realized are being evaluated as a master's thesis topic.

5. INPUT-OUTPUT

5.1 MAGNETIC TAPE

A temporary setup including one magnetic-tape mechanism has been installed in the computer according to the plans discussed in Summary Report 26. The system has not been fully tested yet, but all problems encountered so far have been solved.

The attack on the problem of eliminating errors due to blemishes and dust on the tape has changed in the past quarter. The use of an air blast to blow dust off the tape (together with the use of radioactive material to discharge static electricity and loosen the dust) has been abandoned because the air blast would not remove the dust. The best method found for removing dust is to wipe the tape. At present Kleenex paper tissues are being used for this purpose. However, the wiping does not completely eliminate all dust problems, and for this reason it was felt that marking the bad spots on the tape would not give a permanently valid indication of the condition of the tape.

It has been found that the tape blemishes cause errors in the form of missing pulses. There is some background noise on the tape that could cause extra pulses, but this noise is of a relatively small amplitude and does not appear on the output of the reading amplifiers. It has also been noticed that the blemishes, on the tapes we have used, never cause pulses to be dropped out of more than two adjacent channels in any one line of recording.

In order to permit the use of blemished tape in the present system, the six channels of the tape unit have been connected into three pairs, with one channel of a pair being separated from the other channel by two interposing channels. The two channels of each pair are operated in parallel, and in this manner if a pulse is lost on one channel due to a blemish it will be picked up on the other. This scheme reduces the effective number of channels to three, but it permits the use of the whole tape, and does not require any extra equipment.

Work is also being done on other aspects of the tape problem. A hard-tube circuit for controlling the clutch has been developed to replace the gas-tube circuits in the tape mechanism and permit operation from the WWI input-output switch. Developmental work is also progressing on the design of better reading amplifiers and on equipment that will permit the transfer of information from magnetic tape to a typewriter independent of the computer.

5.2 MAGNETIC DRUM

An order has been placed with Engineering Research Associates of St. Paul, Minnesota, for two magnetic-drum storage systems. These systems will extend the usefulness of the Whirlwind computer by enlarging its terminal facilities. A brief description of the intended use of these drums (one for auxiliary storage within the computer and one for temporary storage of randomly arriving input data) is given in Summary Report 26.

In the past quarter studies were started on methods for integrating these drums into the Whirlwind system. The controls for this additional storage could be designed in several ways. The principal goals are: (1) Minimum cost of equipment to be constructed, (2) efficient use of computer time in transferring information between the drums and the computer, (3) a set of control orders which are simple to use from the programmer's viewpoint, and (4) maximum flexibility in modes in which the drums may be operated. Since some of these goals are in conflict, the choice of the "best design" must be a compromise. Block diagrams of several proposed controls are being worked out in sufficient detail to evaluate their relative merits. During this planning period close liaison is being maintained with Engineering Research Associates to ensure that any control designs chosen will be compatible with the drum systems under contruction.

6. MATHEMATICS, CODING, AND APPLICATIONS

6.1 PREPARATION OF COMPUTER PROGRAMS

As stated in Summary Reports 25 and 26, a primary objective of the Applications Group -- the group working on scientific and engineering applications of the Whirlwind computer -- has been the development of simple means for preparing and performing computer programs. The need for efficient methods is particularly evident in small problems, in which excessive time spent in coding or preparing tape, as well as in using the computer, can result in relatively enormous increases in the cost of performing the computations. The desired end -- to perform small computations quite inexpensively -- is especially important at the Digital Computer Laboratory, where one avowed purpose is to show the feasibility of using large, fast, general-purpose computers to solve many relatively small-scale scientific and engineering problems each requiring perhaps only a few minutes of machine time. Furthermore, it is not the intention of the Laboratory to provide the necessary staff for programming all of the problems which are to be solved on the Whirlwind computer, but rather to provide only a staff capable of assisting the originators of problems in preparing programs of their own for performance on the machine. Hence the system evolved must not only be economical and efficient but must also be easy to teach and to learn.

The preparation and execution of coded programs involves several steps, each of them susceptible of a certain amount of simplification.

One way of enumerating the several steps is as follows:

1. Formulating the problem in mathematical terms.
2. Devising a suitable step-by-step numerical procedure for solving the problem.
3. Scaling numbers so that enough significant digits are carried.
4. Coding the procedure into a coded program.
5. Preparing the program and data for the computer:
   a. By converting the operation code symbols, addresses, and numbers to their proper binary form.
   b. By putting the information on punched tape or other input medium.
6. Operating the computer.
7. Obtaining data to permit location of mistakes if they occur.
8. Locating mistakes in coding.
9. Checking results.

Steps 1, 2, 3, 4, 7, 8, and 9 constitute the programming of the problem, of which items 4, 7, and 8 and to some extent 3 and 9 make up the specialized phase called coding. Steps 5 and 6 are routine manual procedures.

6.11 Preliminary Steps

Steps 1 and 2 can be facilitated only by making available the experience and results of previous work of others, either in the form of texts or of advice from one of a staff of programmers experienced in a wide variety of problems.

Most of the tedium and mistakes likely to be encountered at step 3 can be removed by somehow making the computer automatically prevent the loss of precision caused by numbers growing too large or too small in short, fixed-point storage registers. Interpretive subroutines for the performance of extra-precision and floating-point arithmetic are being developed to accomplish this purpose, as briefly described in Summary Reports 20 and 26.

6.12 Standard Procedures

Simplifying the procedure of coding a problem for the Whirlwind computer (step 4 in the overall procedure) is accomplished largely through the development of easily usable standard subroutines for the performance of various commonly needed operations which are not built into the control element of the computer. These operations include the evaluation of sines, cosines, tangents, exponentials, logarithms, square roots, etc., and the performance of the routine operational procedures of printing numbers, photographing curves or numbers that are plotted on an oscilloscope, reading data tapes, interpolating in tables of values of arbitrary functions, matrix manipulations, complex number calculations, and the like.

The second half of step 5 is simplified, and made more efficient, by assigning the preparation of punched tape to one or two specially-trained typists. Similarly, trained technicians normally operate the Whirlwind computer (step 6) during the solution of all general problems, as described in Summary Report 25. A full discussion of step 5a, which is to be performed by the computer, is deferred until Section 6.16.

6.13 Location of Mistakes

The process of gathering data to aid in the location of mistakes (step 7) was originally performed by special tape-punch recording facilities built into the computer. But, as mentioned in Summary Report 25, magnetic-tape storage and enlarged electrostatic storage capacity will soon permit programmed methods to be used instead. Among the special programmed routines or subroutines are included programs which print the contents of selected storage registers after a program has somehow gone amiss. These printed results greatly facilitate the work of the programmer in detecting his mistakes. A second form of error-diagnosis procedure, based upon a method suggested by Wilkes at Cambridge University, employs an interpretive subroutine to direct the performance of the whole program (even though that program could be run directly in the machine without any interpretation). This procedure permits, the interruption of the course of the program at any instant, under the control of the computer, to print certain specified information: for example, a list of operations performed during the program, a list of numerical results that have been obtained in the accumulator, or a list of addresses to which control has been transferred by transfer-of-control instructions.

6.14 Cataloguing of Subroutines

One of the most important questions to be considered in organizing a library of subroutines is whether the subroutines are so catalogued that a programmer can readily select the particular one which performs the task he has in mind. As in selecting a book, a programmer should be able to select from a catalogue the group of subroutines which perform the general function he has in mind, and then from a more detailed description of those subroutines, the particular subroutines which he wishes. In order to reduce the number of subroutines which must be provided, it is necessary that parameters such as the number of digits to be used, the precision of the calculation, or the address of the register to which the result is to be transferred should be readily variable by the individual users of each given subroutine. Such parameters, which are to be specified at the time the subroutine is incorporated into a program and not ordinarily changed during the course of the program, are called preset parameters.

6.15 Orientation of Subroutines in Storage

The problem of incorporating preset parameters into each subroutine as it is used is in addition to the problem (already discussed in Summary Report 20) of orienting each subroutine to its assigned position in storage. The orientation problem arises because each subroutine must be written as if it were stored beginning at some particular storage location, say zero, whereas in fact it will be used starting at some arbitrary position in storage. Therefore the address sections of some of the instructions involved must be changed to orient them relative to the new location in storage.

Detailed procedures have recently been worked out for handling the incorporation of preset parameters into subroutines and the orientation of the subroutines to their assigned storage location during the process of converting coded programs and data into the binary form needed by the machine. As mentioned in Summary Report 25, the introduction of information into Whirlwind I is by means of Flexowriter equipment which prepares punched paper tape similar to Teletype. The task of the coder has been simplified in two ways: first, by assigning to the computer itself the laborious job of converting from coded alphabetical and decimal numerical form to binary form, and second, by providing clerical help to prepare all tapes to be used in the computer.

6.16 Conversion Program

With present limited electrostatic storage and with magnetic-tape storage not yet available, it appears that any program capable of converting two Flexowriter-coded alphabetical characters into one five-binary-digit number to make up the operation section of a Whirlwind instruction necessarily will utilize a large part of the storage capacity of the machine and thereby prevent the storing of the program which is being converted. Consequently, the procedure outlines in Summary Report 25 is still being used. A separate computer operation is performed: the program is converted to binary form and then punched in a special intermediate (5-5-6) form on paper tape which can later be read in by the short input program permanently stored in test storage. It is anticipated that use of erasable and rereadable magnetic tape soon to be available will permit direct read-in, conversion, and performance of a given program using intermediate storage on magnetic tape without the time-consuming manual operations and mechanical punch actions involved in the present process.

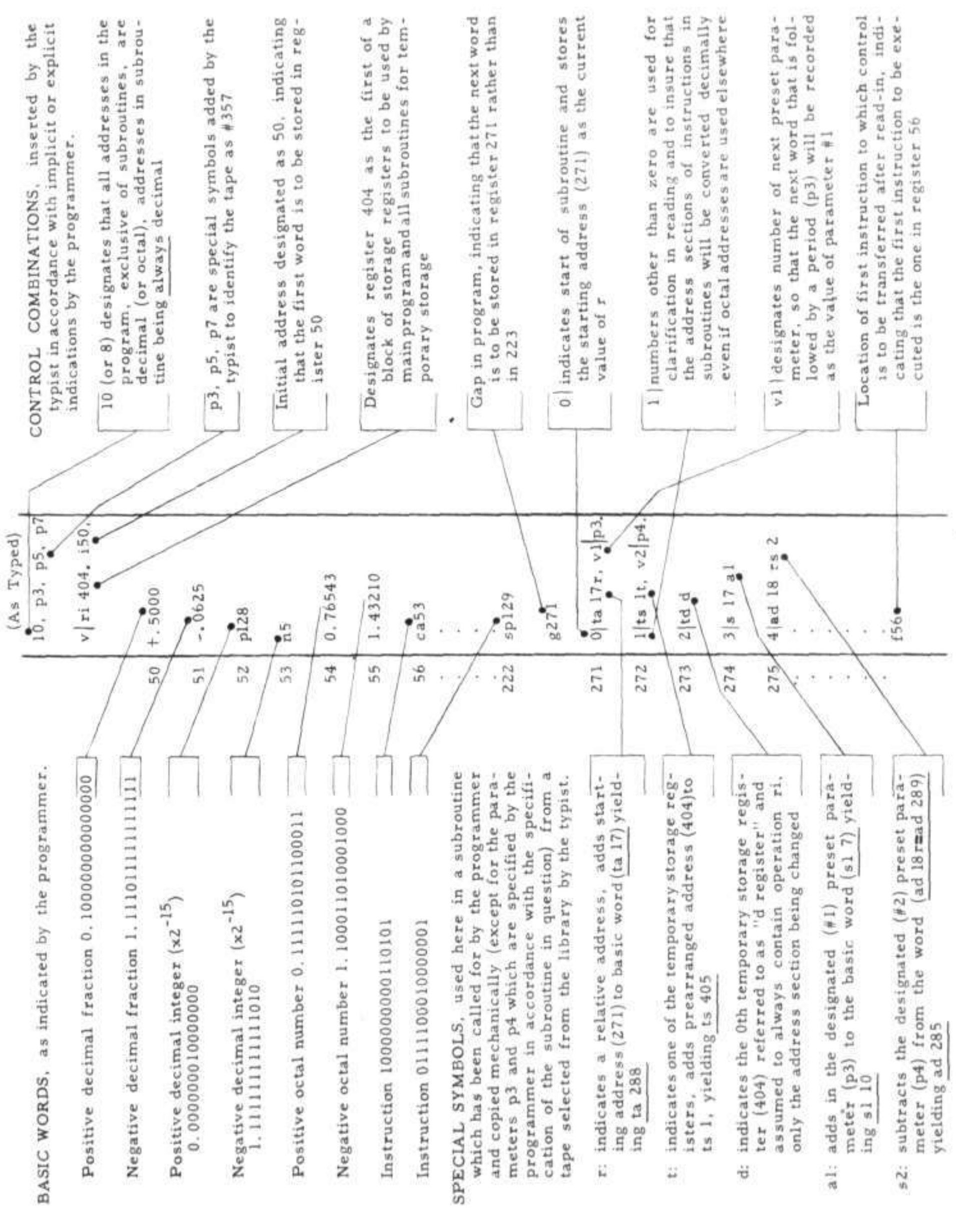
Since a conversion program cannot at present be short enough to fit unobtrusively into one corner of storage, it may as well be as long and as elaborate as is desirable. The following desiderata were established:

1. Instructions will be written in the form most convenient for the programmer using the standard two-letter abbreviation for each Whirlwind operation, and decimal (or octal, if desired) address sections.
2. Numerical data will be written in decimal or octal form directly as integers or fractions without recourse to the equivalent instruction form.
3. Convenient provisions for incorporating preset parameters and for orienting subroutines should be made.
4. The typewritten copy produced by the typist should be a legible and comprehensible copy of the original program.

The process of selecting a desired subroutine from the library (as described in Summary Report 22) will, it is hoped, be put to use in some modified form as soon as sufficient magnetic-tape storage is available. At that time, at least some of the most frequently needed library subroutines can be permanently recorded on tape directly accessible to the computer. At present, the process of selecting the desired subroutines is performed by hand by the typist during the preparation of the original punched tape.

The combinations of symbols which can be correctly interpreted by the present conversion program, which is to say the vocabulary of the conversion program, are illustrated in the specimen program in the center of page 25. For convenience, the descriptions have been divided into three groups: The first deals with fundamental words, either instructions or numbers. The second deals with special symbols used for orienting subroutines and incorporating preset parameters. The third deals with the control combinations which instruct the conversion program to interrupt the normal consecutive assignment of words to registers in order to perform certain functions needed at the start and end of the program and when subroutines or gaps are inserted.

The features intended primarily for use in connection with subroutines are of great flexibility and have many uses in connection with the writing of the main program itself. In particular, it is possible with the vocabulary as given to perform the function of assembling the main program, groups of constants, sets of temporary storage registers, and all of the desired subroutines without actually assigning addresses by hand to any of these blocks of the program but the first. Communication between one block and another without knowledge of the actual location to be assigned to the blocks in storage is accomplished by using the special symbols intended for incorporating preset parameters in lieu of definitely assigned storage addresses. Many of the facilities of the conversion program were suggested originally by the work of Wilkes, Wheeler, and others at Cambridge University. The modifications of their procedures have consisted largely in the provisions for converting numbers as such, the introduction of a little greater flexibility, and the attempt to choose characters and forms which are mnemonically simple and typographically clean.



SYMBOLS INTERPRETED BY THE WHIRLWIND CONVERSION PROGRAM

6.2 WORK OF THE APPLICATIONS GROUP

The following is a list of problems that have been or are being worked on at the Digital Computer Laboratory. The first section contains actual problems, mostly of external origin; the second section lists projects originated within the Laboratory largely intended to simplify the process of coding by the means described in Section 6.1.

6.21 Problems

Name	Prob. No.	Originator	Started	Completed
Industrial Problems	6, 7	Alan Manne, Harvard Economics School	2-1-51	9-1-51
Magnetic Flux Density Study	8	Internal	7-7-50	
Oil Reservoir Depletion Study	9	M.I.T. Project (DIC 6751)	10-1-50	
Roundoff-Error Studies	16	Internal	10-6-50	
DuMont UHF TV-Channel Allocation Problem	19	T. T. Goldsmith, Jr., Allen B. DuMont Lab., Inc.	4-26-51	
Intact Stability Study (SM Thesis - R-156)	20	Internal	4-12-51	
Optical Constants of Thin Metal Films	21	Prof. L. Harris, M.I.T. Chemistry Dept.	5-24-51	
Computation of Autocorrelation Coefficients	27	Aaron Fleisher, M.I.T. Meteorology Dept.	6-20-51	6-22-51
Ambipolar Diffusion	28	Prof. W. P. Allis, M.I.T. Physics Dept.	6-25-51	
Digitally-Controlled Milling Machine Program	30	John Runyon, M.I.T. Servo Lab.	7-17-51	
Volkenstein Adsorption Isotherm	33	H.H. Rachford Humble Oil. Co.	8-20-51	

6.22 Procedures, Subroutines, and Training

Name	Problem No.	Started	Completed
Floating-Point and Extra-Precision Interpretive Subroutines (Programmed Arithmetic, PA)	4	2-1-51	
Iterated Solution for Potential Functions of Nuclei	5	10-15-50	6-1-51 (suspended)

Name	Problem No.	Started	Completed
Interim Input and Output Conversion	10	12-1-50	1-7-51
Point-by-Point Scope Plotting of Alpha-Numerical Characters (Output Camera, OC 1)	11	3-30-51	
Combination of Demonstration Programs	12	4-2-51	5-7-51
Point-by-Point Scope Plotting of Calibrated Axes (Output Camera, OC 2)	13	3-23-51	
Photographs for Use on a Poster	14	4-10-51	5-23-51
Demonstration Program: Polynomials, Roots, and Axes on Scope	15	10-6-50	5-1-51
Print-Out of Contents of Storage (Post-Mortem Error Diagnosis, PM)	23	7-11-51	
Matrices, Determinants, and Systems of Linear Equations	24	5-28-51	
Directional Broadcast Antenna Design (Demonstration)	25	6-1-51	
Subroutine Orientation Procedures	26	6-15-51	
Study of Proposed Magnetic-Tape Systems for Use in Input and Output	35	10-2-51	
Investigation of Methods of Approximating Functions	36	9-20-51	

7. APPENDIX

7.1 REPORTS AND PUBLICATIONS

Project Whirlwind technical reports and memorandums are routinely distributed to only a restricted group who are known to have a particular interest in the Project. Other people who need information on specific phases of the work may obtain copies of individual reports by making requests to John C. Proctor, Digital Computer Laboratory, 211 Massachusetts Avenue, Cambridge 39, Massachusetts.

The following reports and memorandums were among those issued during the third quarter of 1951.

No.	Title	No. of Pages	Date	Author
SR-26	Summary Report Number 26, Second Quarter 1951	32		
R-198	A Study of the Holding Beam in the MIT Electrostatic Storage Tube (M.S. Thesis)	73	9-10-51	J.O. Ely
E-410	The Complementary Circuit Method for Determination of Interface Resistance	6	7-23-51	H.B. Frost
E-411	Additional ES Test Program	12	7-24-51	G. Cooper
E-413	Selection Systems for Magnetic Core Storage	13	8-7-51	R.R. Everett
E-419	The Development of an R-F Readout System for Electrostatic Storage Tubes. Pt. II: The Initial WWI System	24	9-4-51	W.J. Nolan
E-420	Some Observations Upon a Method of Determination of Oxide-Coated Cathode Operating Temperatures	6	8-27-51	H.B. Frost
E-421	Transistor Bibliography	8	8-28-51	N.T. Jones
E-425	A Discussion of Soft Solders and Soldering	14	9-13-51	M.C. Manderson
E-426	An Investigation of Soldering Problems	7	9-14-51	M.C. Manderson C.W. Watt
E-427	Initial Standard Tests (Pretest) for WWI Storage Tubes	3	9-26-51	C.L. Corderman
M-1059	Detailed Coding of the Initial Program	21	5-11-50	C.W. Adams
M-1235	Operation of In-Out Control	26	8-30-51	B.E. Morriss
C-107	Applications Group Meeting - A Comparison of WWI and EDSAC Input Conversion Programs	5	7-20-51	P.A. Fox
C-108	Applications Group Meeting - Preset and Program Parameters in Subroutines	4	7-25-51	P.A. Fox
C-109	Applications Group Meeting - General Subroutines Usage	4	7-26-51	P.A. Fox

No.	Title	No. of Pages	Date	Author
C-110	Applications Group Meeting - Orientation of Subroutines, Con't.	4	7-27-51	P.A. Fox
C-111	Applications Group Meeting - Proposed Subroutine Techniques	3	7-31-51	H. Saxenian
C-112	Applications Group Meeting - Subroutine Notation	2	8-1-51	H. Saxenian
C-113	Applications Group Meeting - Designation of Numbers in WWI: Preset Parameters	3	8-2-51	H. Saxenian
C-115	Applications Group Meeting - Subroutine Library, Reference Library	2	8-7-51	H. Saxenian
C-118	Applications Group Meeting - Proposed Orders for WWI Code	3	8-17-51	H. Saxenian

7.2 PROFESSIONAL SOCIETY PAPERS

At the IRE Convention held in San Francisco August 22-25, William K. Linvill presented a paper entitled "Sampled Data Control Systems Studied Through Comparison of Sampling with Amplitude Modulation."

7.3 VISITORS

During the past quarter the Laboratory has had among its visitors the following:

Dr. C.V.L. Smith and Mr. N.M. Blachman of the Office of Naval Research.

Mr. W.K. Halstead of RCA.

Mr. H. Wagener of the Evans Signal Laboratory, who discussed the problems associated with the measurement of interface resistance in vacuum tubes.

Dr. R.I. Hulsizer of the University of Illinois.

Dr. H.H. Rachford of the Humble Oil Company.

Mr. D.J. Wheeler, Senior Mathematician of EDSAC at Cambridge, England, who discussed programming techniques.

Captain J.S. Harper of the U.S. Navy.

Mr. M. Holter and Mr. Dean H. Wilson of the University of Michigan.

Mr. John Chisholm and Mr. P.C. Rapp of Bell Aircraft Company, who are interested in computers for control purposes.

Mr. E.A. Eckhardt of Gulf Research and Development Company.

Dr. Charles F. Pulvari of George Washington University, who discussed the possibilities of ferroelectric materials as storage elements.

Mr. T.B. Lane, Jr., Mr. S.S. Snyder, Mr. Q.M. Cardwell, and Mr. H.C. Snyder, of the Department of Defense.

Mr. A.V. Block and Mr. P. Prentky of Raytheon, who were interested in checking techniques.

Dr. G.W. Brown of Rand Corporation.

Dr. D. Shreve of the Carter Oil Company, who discussed the use of the computer to solve oil reservoir depletion problems.

Mr. H.T. Engstrom and Mr. W.C. Norris of Engineering Research Associates, Inc.

Mr. S.F. Knights and Mr. L.C. Godden, of the Royal Canadian Navy.

Mr. K.R. Tuttle and Mr. B. Wellman, Northrop Aircraft Company.

Mr. D.G. Wilson, Mr. G.F. Prehmus, and Mr. D.E. Lane, of General Electric.

Mr. J.B. Russell and Mr. R.J. Schwary, of Columbia University.

Mr. N.P. Stevens of the Magnolia Petroleum Company, who was interested in using the computer to solve oil production problems.