PROJECT WHIRLWIND

(Device 24-x-3)

SUMMARY REPORT NO. 24

THIRD QUARTER, 1950

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SERVOMECHANISMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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Project D I C 6345

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FOREWORD

Project Whirlwind

Project Whirlwind at the Massachusetts Institute of Technology Servomechanisms Laboratory is sponsored by the Office of Naval Research under contract N5ori60. The objectives of the Project are the design and 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 among (1) test, maintenance, and checking methods in the computer; (2) design, construction, and test of terminal equipment; and (3) electrostatic storage.

The Whirlwind Computers

The Whirlwind computer will be 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), now being built, may be regarded as a prototype from which other computers will be evolved. It will be useful both 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 will permit the computation of many simulation problems. Calculations requiring greater number length will be handled by the use of multiple-length numbers. Rapid-access electrostatic storage will have a capacity of 32,000 binary digits, sufficient for large classes of actual problems and for preliminary investigations in most fields of interest. The goal of 20,000 multiplications per second 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.

I. QUARTERLY REVIEW (AND ABSTRACT)

As described in Summary Report 23, electrostatic storage was connected to the rest of the Whirlwind computer late in the second quarter, and initial operation was gratifyingly successful. Before long, however, it became evident that the storage was now subject to a number of difficulties that had not appeared when the tubes were tested independently of the computer system.

After careful consideration we decided that in order to increase reliability, we must make several changes in the storage-tube circuits that would alter the mode of operation of the tubes (see Section 2.1). Most of the third quarter was occupied in making these changes, so that general progress on the computer program was considerably delayed.

At the end of the quarter we were engaged in realigning the tubes according to the new procedure. (After the end of the period covered by this report, the lineup was completed, and the computer was operating reliably with electrostatic storage successfully integrated into the system.) In general, a maintenance period following each daily marginal checking period has kept the rest of the system operating reliably.

Continuation of the reliability test on the five-digit multiplier (WW prototype) has lead to two important conclusions: (1) Failures resulting from gradual deterioration of components can be practically eliminated by marginal checking; (2) poor electrical connections can go undetected for a long time, so that every possible precaution must be taken during the construction of a large-scale electronic system to ensure permanently good connections.

Further tabulation of figures for the life of vacuum tubes in the five-digit multiplier confirms the conclusions drawn in Summary Report 23. In the WWI computer, which operated 900 hours during the quarter, 37 tubes, most of them 7AD7's, failed. Many of the tubes have now been operating for over 4500 hours. Continued life tests corroborate the theory that impurities in the cathode sleeve are the cause of cathode-interface deterioration.

A system for storing binary information in small magnetic cores arranged in a three-dimensional array, with selection by simple line switching in the three dimensions, shows considerable promise for application to high-speed digital computers. Research on this system is described in Section 3.4.

During the quarter 21 storage tubes were produced, with a shrinkage of 43 percent. The high shrinkage was caused by an epidemic of surface troubles that had been overcome by the end of the quarter.

The equipment for punching paper tape described in Summary Report 23 was further refined, and it was used for 8 weeks during the quarter. The input tape reader was built; at the end of the quarter it had been tested with test storage but had not yet been used to read information into electrostatic storage. The output tape punch equipment was completed and subjected to initial tests, but had not yet been connected to the computer. During the last week of the quarter representatives of Eastman Kodak Co. suggested two changes to increase reliability of the film reader-recorders: a greater light intensity during recording and a new light source for scanning the reference marks. Steps are being taken to make these improvements.

Several useful practical problems were being prepared for solution by the computer as soon as electrostatic storage and the punched-paper-tape input and output system become available. Problems scheduled for early solution include a non-linear partial differential equation that arose in connection with the work on the three-dimensional magnetic-core storage system; a pair of simultaneous transcendental equations involved in a study of optical constants of thin metal deposits being carried out by the MIT Department of Chemistry; an eigen-valued system of differential equations encountered in work on atomic structure by the MIT Department of Physics; and a study of group behavior by the MIT Economics Department.

Registration of students in the MIT academic program in automatic computation signifies an active interest in this field.

2. SYSTEM ENGINEERING

2.1 DEVELOPMENT OF ELECTROSTATIC STORAGE SYSTEM

At the beginning of this quarter (July, 1950), one complete set of storage tubes had been installed in the computer and subjected to initial testing. Whirlwind I was operating with electrostatic storage. Short programs with orders in electrostatic storage were run successfully for periods of from a few minutes to an hour.

Experience with the operating system showed, however, that it was not sufficiently reliable. Furthermore, the behavior of the storage depended on the programs used and their frequencies, and it varied when different areas of the storage surfaces were used. There was evidently much that we did not understand about the operation of the storage as an integrated part of the computer.

Study indicated that several changes should be made in order to improve reliability. Some of these changes had previously been under consideration; some were new. The most important of them are listed below:

1) Selective writing. Spot interaction — the damaging of adjacent spots when a spot is read or written — is greater during writing than during reading. A sequence of writes of one polarity on a single spot — or adjacent to a single spot — causes excessive interaction unless a great deal of holding-gun time is inserted.

This interaction can be greatly reduced by a new system called selective writing. With selective writing, if a spot already possesses the desired polarity, the writing action is withheld. The entire word is first read out of storage and compared with the word that is to be written. Writing is carried out only in those digits that are to be changed. This selective write system was achieved by block diagram changes requiring little additional equipment.

2) Different write+ and write- gate amplitudes. The original circuits provided a single writing gate amplitude for both write+ and write- (1 and 0 respectively). The necessary difference between write+ and write- charges was provided in all the tubes at once by different write+ and write- gate lengths.

Variations in writing and erasing characteristics between tubes makes further control of the writing charge desirable. It can be provided by means of different gate amplitudes for write+ and write-, separately adjustable for each tube.

3) Improvement in the r-f system. Intermittent readout failures led to the decision (a) to improve r-f shielding in order to reduce pickup and feed-through in the r-f amplifiers and (b) to trim the r-f supply lines in order to equalize r-f drive voltages and reference voltages in all digits.

4) Improvement in test equipment. An improved TV display, r-f monitor system, and over-voltage protection for the storage-tube supplies were needed.

The design, construction, and installation of these changes required a large part of the quarter. At the same time a new storage-tube lineup procedure was developed to check all the characteristics of a computer digit column with tube installed, as well as the characteristics of the tube itself.

Now that the changes are complete, we are engaged in realigning the tubes according to the new procedure. This is taking some time, as all variations and unexplained results in each digit column are being investigated.

(After the end of the period covered by this report, the lineup was completed and the electrostatic storage successfully operated with the computer. A detailed account will be given in the forthcoming Summary Report 25.)

2.2 ROUTINE MAINTENANCE AND IMPROVEMENT

2.21 Daily Marginal Checking

Since a large portion of computer time has been devoted exclusively to the testing of electrostatic storage during the past quarter, relatively little time has been available for routine maintenance. Consequently, heavy reliance has been placed on daily marginal checking to disclose incipient troubles before they interfere with proper functioning of the system. In general the results of this procedure have been very satisfactory. However, several weaknesses have been noted: (1) margins which are poor because of improper timing in the system tend to be quite erratic; (2) in many cases margins vary widely with duty cycle. The most satisfactory way to minimize these difficulties is to schedule computer time in such a way that troubles may be located as soon as their symptoms are noticed, that is, by having a maintenance period immediately following the marginal checking. This procedure is being followed as far as practicable.

2.22 Improvements to the System

When electrostatic storage was integrated with the WWI system, a serious weakness appeared: when, because of a failure in electrostatic storage control, the pulse which terminates an ES read or write cycle (the ES end carry) failed to appear or appeared later than normally, the resultant loss of restorer pulses (see Summary Reports 3 and 16) would cause a number of flip-flops to stall. This

difficulty was serious, because it prevented cyclic operation of ES control in the event of trouble and consequently made it impossible to observe the functioning of ES control with an oscilloscope.

This trouble has been eliminated by a new alarm circuit (designated the ESC alarm), which functions as follows: At the start of each ES cycle, a counter (the step counter is used at present) starts counting a fixed delay slightly longer than either the read or write cycle. If, because of a failure in ES control, the ES end carry does not appear within this time, the delay counter end carry terminates the ES cycle and restarts the restorer pulses. In addition, it lights an alarm light to indicate that a failure has occurred in ES control.

3. CIRCUITS AND COMPONENTS

3.1 FIVE-DIGIT MULTIPLIER

For the past 18 months the five-digit multiplier (a 350-tube prototype of the Whirlwind computer arithmetic element) has been undergoing an extended reliability test. The system is set up to perform periodic solutions of the product 31 × 31 and to check each solution. A single multiplication requires about 8 microseconds, and these multiplications are repeated about 15,000 times a second or over one billion times a day. Errors that occur are recorded on electromechanical counters, and the number of error counts obtained is used as a measure of system reliability. The test gives information on the life characteristics of electronic components and shows what are typical sources of error in a computing system. A period of about half an hour each working day spent in preventive maintenance evaluates the effectiveness of marginal checking and other trouble-location methods in finding and eliminating potential sources of error.

Multiplier performance for the period July through September 1950 is shown in the chart on page 9. During July and August the frequency of errors was comparable to the average obtained over the preceding year, but a sharp increase in error frequency occurred during the first two weeks in September. About the middle of September two cold-solder connections and one unsoldered connection were found and repaired; operation since that time has been without error.

Experience gained during the conduct of the multiplier reliability test indicates that two significant conclusions may be drawn regarding the problem of obtaining error-free operation of an electronic computer. First, failures of equipment resulting from gradual deterioration of tubes, crystal rectifiers, and other components can be practically eliminated by using marginal checking methods to locate weak circuits before they have caused operational failures. Second, lack of attention to the details of construction which ensure permanently good electrical connections throughout the system can result in potential sources of error which may go undetected for a long time. If such conditions exist, long trial runs with satisfactory operation do not establish the fact that the system is a reliable one.

Most of the errors obtained in the multiplier operation have been of a random and isolated nature and can not be attributed to marginal conditions brought about by deteriorated components. No satisfactory method for locating the sources of these random errors has been found, but performance records have shown in several cases that definite reductions in the frequency of errors have occurred after poor electrical connections have been repaired.

The components replaced as a result of marginal checking are listed on the performance chart. These total 15 crystal rectifiers and 29 tubes (see Section 3.21), as compared with 13 crystal rectifiers and 27 tubes during the preceding quarter. These replacements represent about 1.5 percent and 7 percent respectively of the total numbers of these units in the multiplier.

3.2 VACUUM-TUBE LIFE

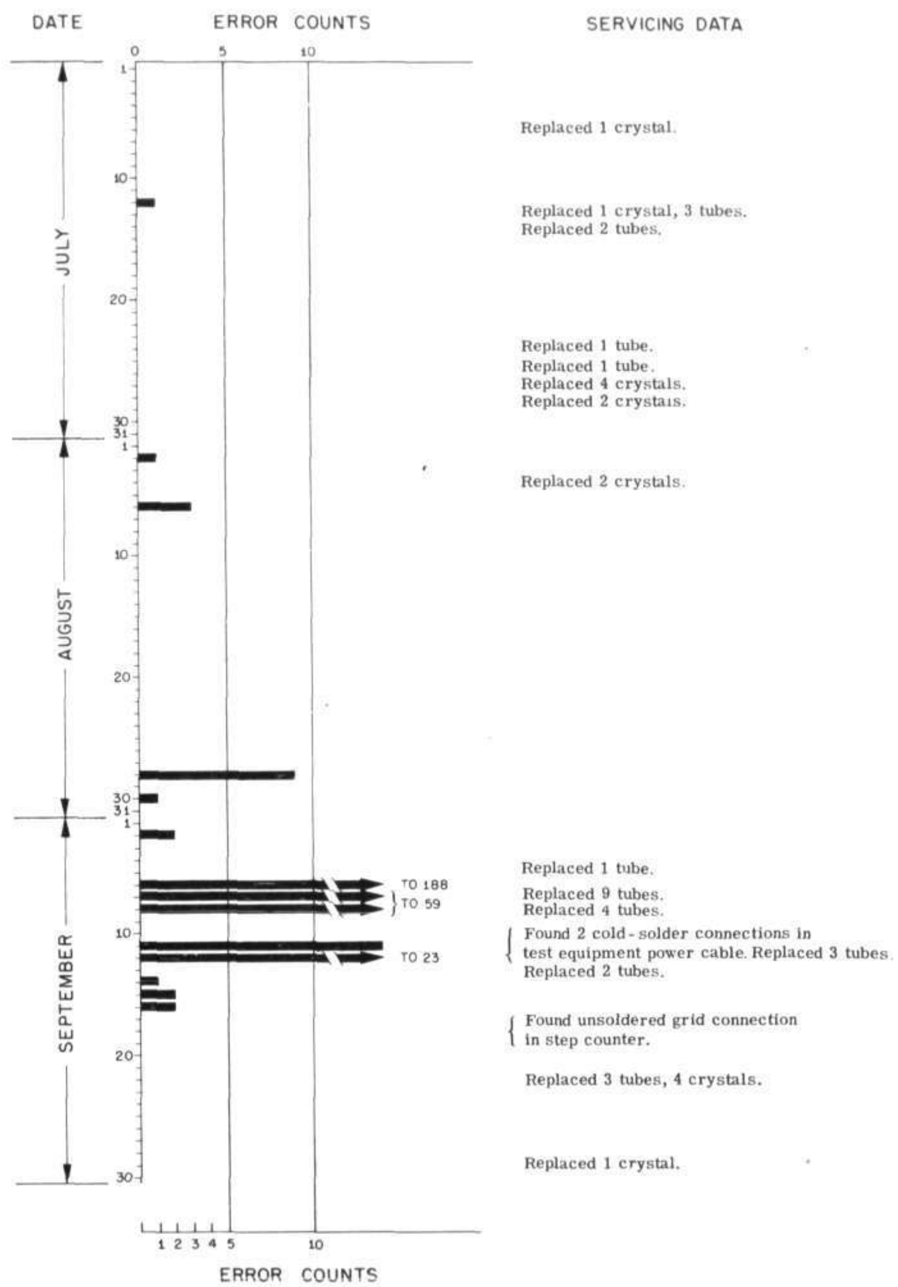
3.21 Five-Digit Multiplier

Significant information on vacuum-tube life has been obtained from records on tubes used in the five-digit multiplier. The multiplier contains about 350 tubes of which approximately half are types extensively used in the Whirlwind computer (40 percent 7AD7 and 10 percent 7AK7). About 18 percent of the tube complement is type 6AS6, while small numbers of other types comprise the remainder. At the present time the system has been in operation nearly 21,000 hours.

In the quarterly report for the period April through June 1950 (see Summary Report 23), some curves were given showing the life characteristics of types 7AK7, 7AD7, and 6AS6 tubes. These curves, extended to the 15,000-hour point, showed that after that length of time, 74 percent of the 7AK7 tubes, 57 percent of the 7AD7 tubes, and 30 percent of the 6AS6 tubes remained in service. During the past quarter, tube failures totaled 1 7AK7 tube, 17 7AD7 tubes, and 10 6AS6 tubes. Of these, 23 were retired because of changes in characteristics, while the remainder had intermittent internal shorts. The distribution of these failures is such that they would not significantly change the shapes of the survival curves previously published. Since information from both the original and the replacement tubes is included in the plots, the later sections of the graphs are based on smaller samples of tubes and consequently are less significant than the early sections. Therefore, the small amount of additional data obtained during the past quarter did not seem to justify a replot of these curves.

The multiplier experience indicates that both the 7AK7 and the 7AD7 tubes have good life characteristics in computer circuits, while, in comparison, the 6AS6 tubes are much less satisfactory. It should be noted, however, that a tube failure resulting from changes in characteristics is determined from failure of the circuit of which the tube is a part, so that the amount of tube deterioration that can be tolerated is a function of the circuit de-

FIVE-DIGIT MULTIPLIER PERFORMANCE



sign. In the multiplier, the circuits in which 6AS6 tubes are used do not have as wide operating margins as is the case for the other two tube types.

3.22 WWI Computer

The present vacuum-tube complement in the Whirlwind computer totals about 4000 tubes, the majority of which are types 7AD7 and 7AK7. A large portion of the tubes have been in service over 4500 hours. During the past quarter approximately 900 hours of operating time was accumulated, and a total of 37 tube failures occurred. A breakdown of the tube failures is given in the table on this page.

of the Raytheon Manufacturing Co. in his second quarterly report for 1950*, reveal that surface impurities are quite variable. This variation may account for the fact that tubes using normal (between active and passive in reducing action) nickel alloy in their cathodes sometimes show interface formation and sometimes do not. The wide variations in interface growth found in type 7AD7 tubes, therefore, may be due to surface impurities on the sleeves.

Recent tests on 5687 tubes (twin triodes) are quite interesting. Although earlier tubes showed serious interface formation, tubes produced during the last quarter of 1949 or later do not. A change in the cathode-sleeve material from active to passive alloy was made during the third quarter of 1949.

TUBE FAILURES IN WWI

July 1 - September 30, 1950

			Reason for Failure; Number Failed			
Type	Total in Service	Hours at Failure	Change in Characteristics	Mechanical	Burn-Out	Gassy
7AK7	1412	1000 - 2000 2000 - 3000		1 1		
7AD7	1622	100 - 500 1000 - 2000 3000 - 4000 4000 - 5000	 4 16 4	1 1 2 1		1
3E29	134	3000 - 4000 4000 - 5000	1	 1		
6SN7	366	2000 - 3000		1		
6AG7	80	500 - 1000	1			
2C51	29	500 - 1000			1	

The majority of these failures are among 7AD7 tubes, most of them being changes in characteristics. The 7AK7 tubes continue to show no appreciable deterioration, since none of these tubes have been retired for changes in characteristics for more than 6 months.

3.23 Life Tests

Further results on life tests of production 7AD7 tubes and experimental 6AG7 tubes have given more support to the theory that impurities in the cathode sleeve are the cause of cathode-interface deterioration. Tubes with passive nickel sleeves do not show deterioration, while those with active nickel sleeves do show interface formation.

Investigations of impurities on the surfaces of cathode sleeves, as reported by James Cardell

It has been observed that the section which operates normally-off during life tests shows cathode poisoning when tested for plate current at the end of 500 hours. It was suspected that this effect might be correlated with high envelope temperature; therefore the test was repeated with the tubes cooled by an air blast which reduced the bulb temperature from about 155 C to less than 130 C. On this repeated test, the poisoning was absent. (These tubes have been life tested with 90 volts on the anode of one section, no voltage on the anode of the other section, and zero bias on both grids.)

Life tests are being continued on types 7AD7, 5687, and 6AN5 tubes purchased from commercial productions. Also, some of the specially constructed 6AG7 tubes with different cathode-sleeve materials which have been used to study cathode-interface formation have been placed on a second life test in which operating conditions have been changed. In the second test those tubes formerly drawing plate current are now cut off, and those formerly cut off are now drawing plate current. All of the life tests now under way are for the purpose of studying types of deterioration that have been observed on this Project.

* Twelfth Interim Technical Report, 1 March 1950 to 1 June 1950, Contract N7onr-389, Task Order No. 1, Raytheon Manufacturing Company, Newton, Mass.

3.3 COMPONENT REPLACEMENT IN WWI

During the quarter 41 crystal rectifiers were replaced, as shown in the table on this page. The age at time of replacement continues to be random. The fact that the replacement rate during the last quarter is only two-thirds of the average for the previous year is not significant, since the tests which most readily detect inferior crystals were not carried out as frequently as before.

3.4 THREE-DIMENSIONAL INFORMATION STORAGE USING MAGNETIC CORES

3.41 Background

All digital storage devices currently used in electronic computers have serious shortcomings, and we should expect major improvements in the future. Such improvements will probably come through new combinations of storage elements and switching systems.

The storage of digital information is more a problem of selection and switching than it is a problem of simple storage. Many simple physical devices are available which can store information, but most do not lend themselves to a satisfactory simple high-speed selecting system. The acoustic delay line and the magnetic drum use time as one of their selecting dimensions; the consequence is a relatively low access speed. The various electrostatic storage tubes select information on the basis

FAILURES OF COMPONENTS IN WWI

July 1 - September 30, 1950

Component	Type	Total in Service	No. of Failures	Hours of Operation	Comments
Capacitor	0.001	2900	1	2170	Open
Crystal Rectifiers	D-357	7500	1 2 5	341 1000-2000 2000-3000	Reset crystal; excessive drift. Grid crystals; excessive drift. Reset crystals; excessive drift.
	D-358	3040			Clamping crystals; all failed because of excessive drift unless otherwise noted.
			2	0-500	1 low back resistance.
			5	500-1000	1 low back resistance.
			12	1000-2000	3 low back resistance.
			3	2000-3000	
			11	3000-4000	
Pulse Transformers	1:1	566	1	961	Open
	3:1	2542	1	3443	Open
Resistor (Variable)	10,000 ohms 2 watts	24	1	946	Shorted

of two space coordinates; time is not one of the selecting dimensions and the result is a high access speed. They are, however, bulky and expensive, and possess relatively short life spans.

In an ideal storage system it should be possible to arrange elementary storage cells in a compact three-dimensional array; storage elements inside the volume could be selected by suitably controlling three space coordinates along the edges of the array. A scheme of this type was first described by Jay W. Forrester in a Project memorandum, M-70, dated April 29, 1947, but the suggested medium — a glow discharge gas tube — was unsatisfactory. A suitable medium — small ferromagnetic cores with rectangular hysteresis loops — now shows good promise, and research on the problem is well under way.

3.42 Basic Operation of the Individual Core

Briefly, a small core made of a "hard" magnetic material may be magnetized in one direction or the other, and left that way. This bi-stability, like that of a two-position relay, may be used to express the two digits of the binary system, ZERO or ONE. A number may be stored, or written, by sending a current pulse through a magnetizing coil on the core. Reversing the polarity of this current reverses the core's magnetization.

The binary number in the core, represented by the core's flux direction, may be sensed, or read, by observing the voltage induced in a sensing coil when the magnetizing coil carries a current pulse of fixed arbitrary polarity and magnetizing amplitude. Relatively large signal voltages will be induced if the core flux direction is reversed by the read pulse, small ones if it is not. There are many possible variations on the basic scheme thus far described. Notable work has been done during the last few years by the Computation Laboratory of Harvard University (see Progress Reports 2 to 6 of that organization).

A core with a sufficiently rectangular hysteresis loop may be used in a scheme for utilizing line-switching along three space coordinates in the selection step of the storage process. Fig. 1(a) is a schematic representation of such a core. Windings A and B are magnetizing, or selecting, coils; S is a sensing coil. Assume that a hysteresis loop of the core is as shown in Fig. 1(b), and that, at the start, the operating point is at the lower stable position $-B_R$.

The application of a magnetizing force of amplitude $H_M/2$ moves the operating point to x, resulting in a very small change in flux density B; return to H = 0, which occurs at the end of the $H_M/2$ pulse, moves the operating point to $-B_N$, a point not far removed from $-B_R$.

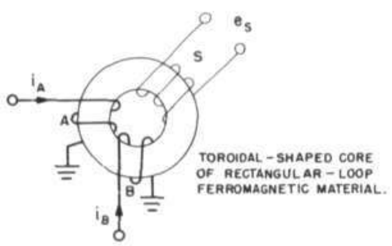


Fig. 1(a). A Two-Current-Coincidence Memory Unit

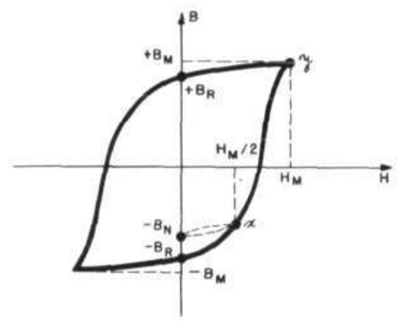


Fig. 1(b). Paths of Operation of a Magnetic Memory Unit

The result for the application and removal of the full H_M is quite different; the operating point moves to y, and then to $+B_R$. The core reverses its magnetization upon application of H_M; in the process there is a large change of flux density B, with a correspondingly large pulse induced in the signal coil.

If the currents i_A and i_B are made equal and of such an amplitude that they correspond to values of magnetizing force equal to $H_M/2$ each, then the magnetization of the core can be changed from $-B_R$ to $+B_R$ only by the addition, or coincidence, of i_A and i_B. The development of a relatively large signal pulse would therefore depend on such coincidence. Similarly, the flux in the core may be changed from $+B_R$ to $-B_R$ by the coincidence of $-i_A$ and $-i_B$.

3.43 Two- and Three-Dimensional Storage

If now for example, nine of these cores are arranged in a two-dimensional array as in Fig. 2, and currents of magnitude $I_M/2$ are caused to flow in selected lines y_2 and x_3 as shown, core F is the only core in the array which has the full magnetizing force H_M impressed. Cores D, E, C, and I have $H_M/2$ pulses (called "non-selecting" pulses) impressed; the rest have no impressed magnetizing force. The only core, therefore, whose magneti-

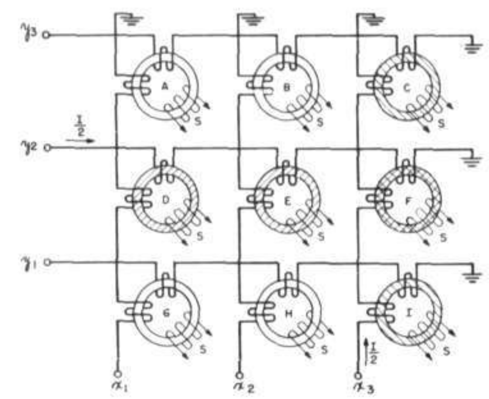


Fig. 2. A Two-Dimensional Array of Cores

zation can be significantly affected is the one at the junction of the selected lines. The output signal may be taken, after suitable mixing, from the coils marked S which are all connected in common.

The extension to three dimensions may be accomplished by stacking two-dimensional arrays, like the one of Fig. 2, in back of each other, with respective x and y lines connected in common. In this arrangement the selection of lines x_ℓ and y_m energizes a vertical plane and a horizontal plane in the array as shown in Fig. 3.

This results in the selection of a line $x_\ell\, y_m$ along which all cores have full magnetizing force impressed. The rest of the cores in the x_ℓ and y_m planes have only half-magnetizing (non-selecting) force impressed; cores out of those planes have none.

All that is necessary now is to have a third set of magnetizing (selecting) windings on the cores, connected together in each plane, and so wound as to result in a magnetizing force for each core equal to $-H_M/2$ for an applied current of $-I_M/2$. The application of $-H_M/2$ to each z plane except, say, z_n will result in magnetizing forces of only $H_M/2$ (non-selecting pulses) left on each core in the line $x_\ell y_m$, except for the core at the junction of this line and the z_n plane, core $x_\ell\, y_m\, z_n$, which is the selected core.

For the Whirlwind I computer, the z plane might well represent the 16 digits of the number on the number bus, while two 32-position switches control the x and y coordinates for selecting the desired register (or word) from the 1024-register storage array.

3.44 Experimental Results

Experimental work so far has concentrated on two aspects of individual-core operation, core response times, and signal and information-retention criteria.

The core response time indicates the length of time it takes for the flux distribution within a core to reach steady state (or rather, within one percent of steady state) after a change in applied magnetizing force has occurred. It was found that the response times of small toroidal cores with rectangular hysteresis loops vary from tenths of a

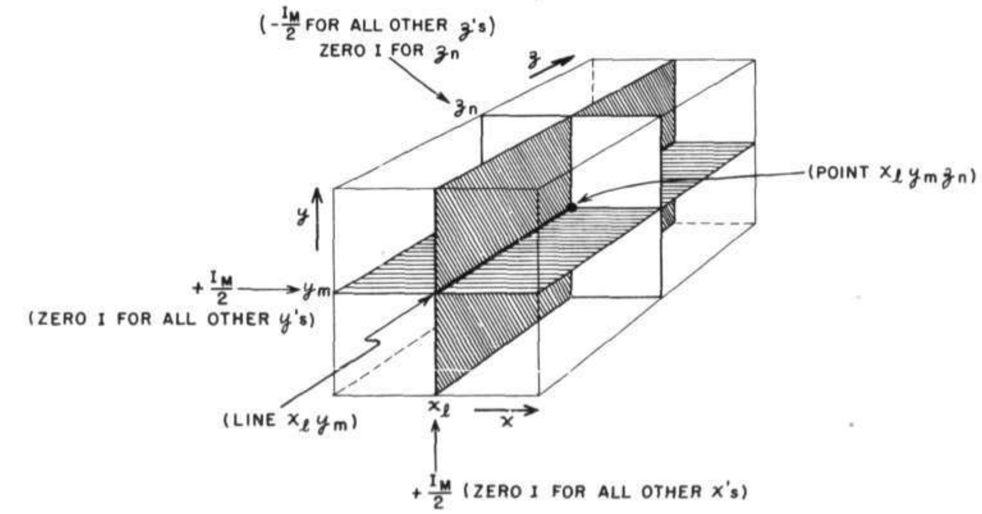


Fig. 3. A Three-Dimensional Selection Scheme

second down to less than a microsecond, largely governed by eddy-current shielding effects. Metallic (tape-wound) cores have response times ranging from tenths of a second down to tens of microseconds; cores of the magnetic ferrites range from tens to tenths of a microsecond. (Some time has been spent in analysis of the eddy-current shielding problem; the non-linear aspect of it will be studied on WWI; see Section 6.11 of this report).

Signal and information-retention ratios were defined to be criteria of a core's performance as a coincident-current memory cell. The two most meaningful of these are as follows:

a) The disturbed-signal ratio, S_D, is the ratio of the output from a core holding a ONE to the output from the core holding a ZERO, both outputs in response to full "read" (H_M) pulses which have been preceded by a large number of non-selecting read ($H_M/2$) pulses.

b) The non-selecting signal ratio, S_{ns}, is the ratio of two outputs from a core holding a ONE. The numerator of the ratio contains the value of the output in response to a full read (H_M) pulse which has been preceded by a large number of non-selecting read ($H_M/2$) pulses; the denominator contains the value of the output in response to the first one of the non-selecting read ($H_M/2$) pulses.

Both of these signal ratios should be very much greater than 1 for satisfactory operation.

The problem is bracketed by two very promising cores. One is a metallic core (Allegheny Ludlum's MTS 4382) whose optimum signal ratios approach infinity in magnitude for a 20-microsecond response time. The other is a ferritic core (Ferramic 34A F109 b.o.) whose optimum signal ratios are around 10 for a ½-microsecond response time.

3.45 Conclusion

Further development work should be aimed in two directions: toward improving materials to reduce eddy-currents and increase hysteresis-loop rectangularity, and toward uncovering and solving the problems associated with operating large numbers of these cores in a high-speed memory system. Investigations of this nature are being undertaken.

Two pertinent reports on the subject are available. R-187 was issued on May 16, 1950; it describes the scheme in some detail and includes a few of the very early test results. A master's thesis was issued as R-192 on September 8, 1950; it covers the detailed research work performed on individual cores to date.

CHARACTERISTICS OF RESEARCH TUBES

July 1 — September 30, 1950

Research Tube Number	Description
RT 143	100-mesh tiltable target assembly to study holding-beam incidence angle.
RT 154	100-mesh, 0.002-in. mosaic on 0.0015-in. mica, short throw; stability studies.
RT 155	Plain mica, short throw; HG restoring current tests for plain mica.
RT 157	All Be surface, 200-series throw.
RT 159	100-mesh, 0.001-in. mosaic, 0.004-in. mica, 9-in. throw, 0.010-in. target-collector spacing with 7 spacers, separate A_2 and G_2. All known parameters selected for optimum storage density.
RT 160	Like RT 159, but no spacers; negative leakage high in one area.
RT 165	100-series ST, mosaic evaporated in Demountable System No. 4.
RT 167	100-series ST, mosaic aligned with deflection plates; 100-mesh × 0.001-in. collector spaced 0.006 inch from mosaic on 0.005-in. mica.
RT 170	100-series ST, mosaic evaporated in Demountable System No. 4.
RT 171	100-series ST, mosaic evaporated in Demountable System No. 4.

4. ELECTROSTATIC STORAGE

4.1 TUBE PROGRAM

Effort of the storage-tube group during the third quarter has been concentrated on tube testing and lineup for the operation of the first bank of tubes in the computer. Because of vacations and the moving of the tube construction shops, relatively few tubes were made. Work on higher-density tubes has been deferred until information from computer experience is available.

4.11 Tube Production

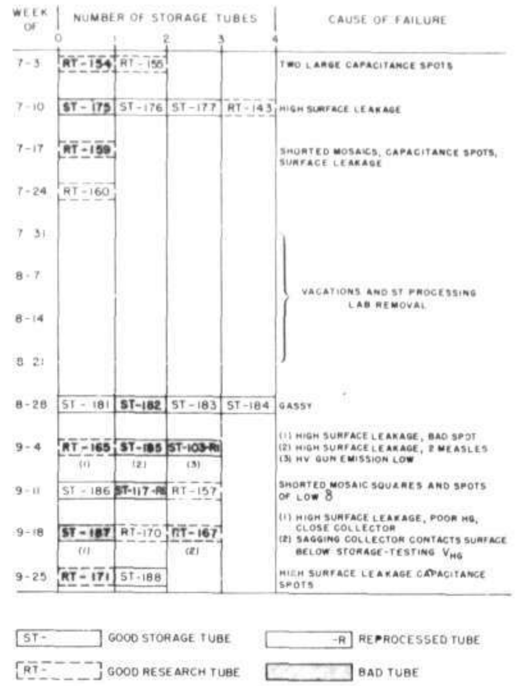
The total production for this quarter was 21 storage tubes, of which 11 were standard 100-series tubes and 10 were research tubes of various types. Shrinkage was 43 percent, due largely to an epidemic of surface troubles. The tube shop was moved from the second floor to the basement during this quarter and several weeks were required before the production was moving smoothly again.

Four standard storage tubes were rejected for high surface leakage and one for being gassy. Two tubes were reprocessed, neither successfully. One reprocessed tube had too low high-velocity beam current, the other had a damaged surface. The surface leakage difficulties had been overcome by the end of the quarter. Five research tubes showed surface troubles that more or less reduced their usefulness.

The accompanying chart shows the tube production record for the third quarter of 1950. The table on page 14 gives a brief description of the research tubes listed on the production record. One research tube, RT-170, is a standard tube in every respect except for method of processing, and is available for computer use.

4.12 WW Acceptance Tests

Analysis of tube operation in the computer has led to an entirely different set of WW acceptance tests. There are now two separate tests, one static, the other dynamic. The static test, now called pretest, consists of measurements of holding-gun coverage and cutoff, V_{HG} stability range, high-velocity-gun transfer characteristics, gas pressure, and a thorough TV study of the storage surface. A tube that passes pretest is usually satisfactory for computer use. The second or dynamic test is made in the reliability tester after the tube has been installed in a mount box and given video and r-f alignment. The dynamic test is used to determine high-velocity-gun bias, signal-plate and gun-driver gates, and r-f characteristics for the particular tube.



Storage Tube Production Record

At present these revised tests are being made in electrostatic-storage row to all storage tubes in the computer. As soon as the entire row is completely tested, new and replacement tubes will be given acceptance tests in the storage-tube laboratory.

4.2 STORAGE-TUBE DEVELOPMENT

4.21 Construction of Simplified Tubes

Several research tubes were built during the quarter using storage mosaics evaporated in the demountable systems. One of these passed all tests and has been installed in the computer. Two others exhibited bad surface leakage and are unusable. The question of this technique is by no means settled, however, since several standard tubes made at this time also showed high leakage.

4.22 Storage Density Research

The studies of electron guns, storage surfaces, and tube geometry are proceeding at a low level while we await the results of computer operating tests.

5. INPUT - OUTPUT

5.1 PUNCHED PAPER TAPE

5.11 Preparation of Punched Paper Tape

The operation of the tape-preparation equipment was described in Section 5.1 of Summary Report 23. Since the publication of that report, tests on this equipment have been completed, operators have been trained, and it has been in use for about eight weeks. Certain refinements in the equipment have been made, particularly in error indication. Arc suppression on the relays in the control panel and in the Flexowriter equipment itself were thoroughly investigated, and certain changes were made to insure longer life for all the relay contacts.

As mentioned in Summary Report 23, during the preparation of a checked tape it is very easy for the operator to overshoot the point at which he has made a typing error, and type extra characters on the manuscript after the error has been detected. Although these extra characters are not punched, their presence on the typed copy is confusing to the operator, who must determine just where the error occurred in order to correct it. To reduce this confusion, an error counter has been added to the equipment. This counter does two things. First, when the first extra character is typed after a typing error has been made, an alarm gong sounds to warn the operator to stop. Second, a stepping-switch counter counts each extra character put on the typescript after the error was made, indicating the number by a light (the gong sounds each time, too). When he finally stops, the operator back-spaces the number indicated, plus one, which puts him back at the point where the error occurred. He then presses the retype button and hits the correct typewriter key. The comparison with the original tape is made in the relay registers as usual, the character and its complement are punched, the error counter is cleared, and the operator is ready to proceed. This system has proved to be very helpful in keeping the operator in phase with the equipment.

The gong also sounds if the typist types more rapidly than the equipment can accept information. If no extra characters have been hit after the gong sounds, it is merely necessary to retype the character that was last hit. Since the previous cycle has not been completed when the next key is struck, the relay register has not been set up, and no buttons need to be pressed. If, however, any extra characters have been struck after the "too-fast" alarm is given, the system recognizes them and counts just as when an overt error has been made. The operator therefore proceeds to back-space exactly as before, presses the retype button, and types the proper character.

The equipment has not yet had intensive use, as it will have when the computer is running. Its operation to date has been satisfactory, and no changes are planned on it at the present time.

5.12 Input Tape Reader

Section 5.2 of Summary Report 23 described the operation of the input tape reader in general terms. During the past quarter this equipment was built, and was tested with the computer sufficiently to indicate that it will satisfactorily read information into electrostatic storage. At the end of September it had not yet been used for this purpose, and had been tested only with test storage.

It was mentioned in Summary Report 23 that information read from paper tape to the computer will enter the system via a flip-flop storage register. This is accomplished as follows (see Fig. 1): a Flexowriter tape reader reads the tape in the normal fashion; its sensing or feeler pins operate a relay register each relay of which has two double-throw contacts, one in series with each of the reset lines to one digit of flip-flop storage register No. 3. With the regular reset switches for the register in the zero position, when holes in one line of the tape cause corresponding relays in the relay register to operate, one pulsing of the video reset line of flip-flop register No. 3 will transfer the contents of the relays to the flip-flops.

The present equipment consists of a Flexowriter reader and a separate relay panel. In the free-running mode, it may be started manually, the reader cycling continuously, the computer operating and accepting information asynchronously from the reader. Or, in the normal mode, it may be under the control of the computer, which orders a line of holes to be read, waits for the reader to cycle, and restarts on receiving a completion pulse from the reader. This pulse also resets flip-flop No. 3, transferring the relay information to the computer.

Tests of this equipment have been made by comparing information punched on tape with the same information in toggle-switch storage. In one run with the reader in the normal condition, and order qr used to actuate the reader, the same group of 20 numbers was read in and checked about 400 times without an error. This took about an hour.

As may be seen from this example, the reading of information into WWI from paper tape is quite slow with the interim equipment. With a checked tape prepared in sexadecimally-coded binary form (4 significant binary digits per line of holes), it will take about five minutes to fill 256 registers of electrostatic storage. When the computer prepares its own tape in the so-called "6-5-5" fashion (see Summary Report 23, Section 6.15), only about 3 minutes will be needed. Section 6.14 and 6.15 of

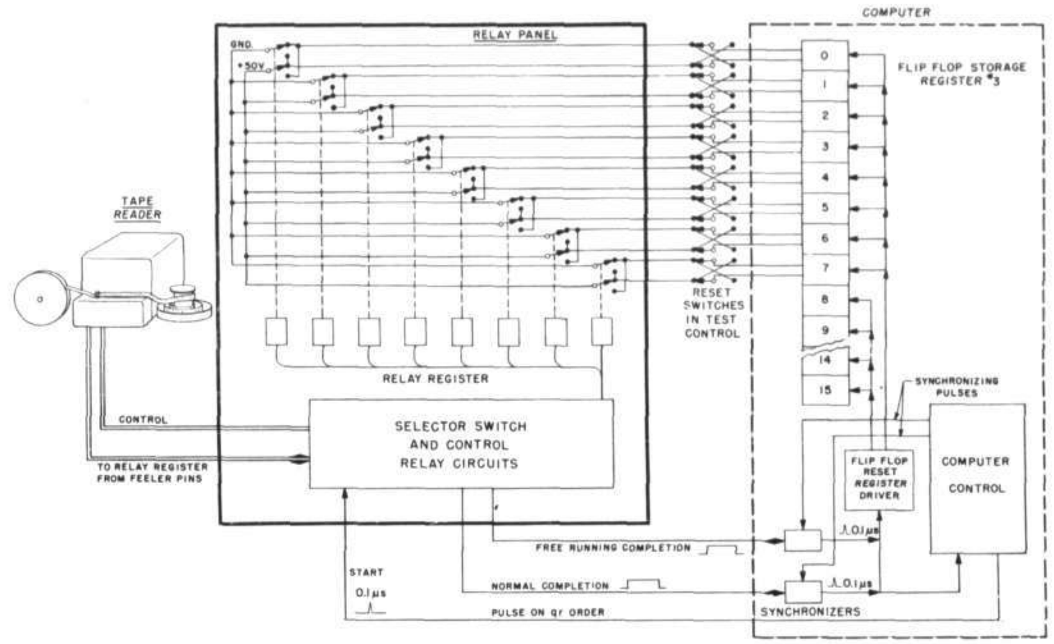


Fig. 1. Pictorial Diagram - Input Tape Reader

Summary Report 23 also contain a discussion of other ways information can be placed on paper tape.

An Engineering Note, E-380, describes the relay circuits used in the interim tape reader more completely, and gives details of its operation.

5.13 Output Tape Punch and Printer

During the last week of September the output relay panel and control box were completed in the assembly shop, and bench testing of the complete output system was begun. Results were encouraging, as no serious faults were found in the design, and the various modes of operation performed satisfactorily. A number of minor troubles were encountered which must be corrected before reliable operation can be expected. Work is progressing on this cleanup phase, and the output system will be ready for test with the computer about mid-October.

In Summary Report 23 a preliminary block diagram of the output system was shown in Fig. 4 of Section 5. The physical arrangement is shown below in Fig. 2. This equipment may accept information from two sources: the computer, or previously prepared paper tape. The source is selected by a toggle switch on the control box.

When the computer is the source, the equipment accepts information from the indicator lights of flip-flop storage register No. 2, digits 8 to 15 (in any combination), which sets up a thyratron relay register. At a computer command (given by the shift-and-print order qp), the reader clutch is energized, and the reader cams cycle once, setting up the basic timing for the output system. When the cycle is over, a completion signal is sent to the synchronizer which sends a start-clock pulse to the computer, restarting it. A new print command is given, and new information in digits 8 to 15 is transferred to the relay register. What the relay register does with the information it gets each cycle depends on the setting of the mode selection switches. The following five combinations may be set up:

1) Print every character.	Automatic typewriter prepares typed copy. Machine functions such as tabulate, carriage return, etc., can be supplied by the computer.
2) Print every other character.	Only intelligible information is printed. To be used only if computer reads out both words and their complements.
3) Punch every character.	Perforated tape prepared. Words and complements are always punched, if read out of computer.

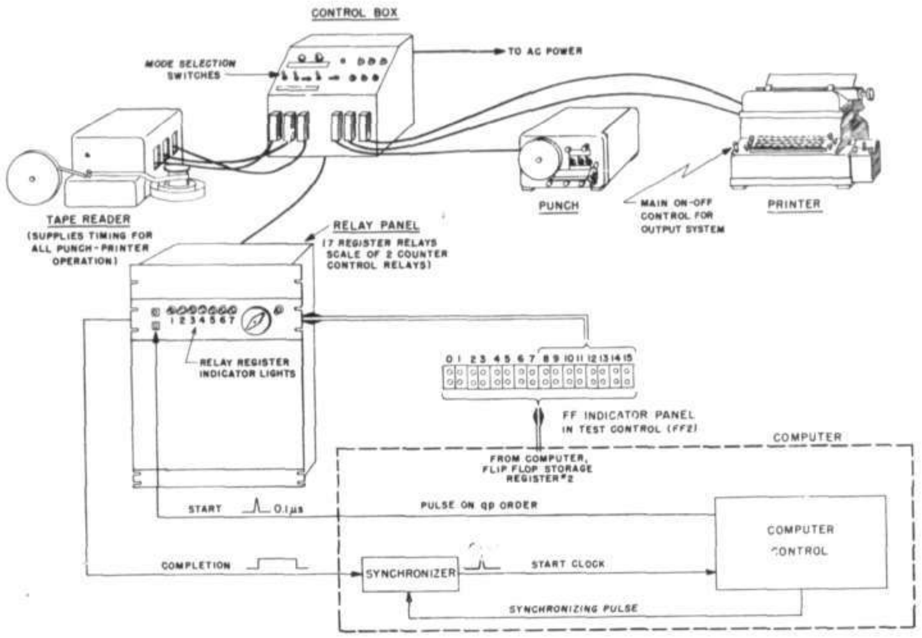


Fig. 2. Pictorial Diagram - Output Punch and Printer

4) Print and punch every character.

5) Print every other character and punch every character.

When the equipment accepts information from paper tape, it may prepare duplicate tapes or print the contents of either checked or unchecked tapes. This function is useful in making a corrected typescript of the tape about to be read into the computer, and for visual checking of the contents of any tape. The same five modes of operation are available with tape input as with computer input.

The interconnections between the various pieces of equipment also are indicated in Fig. 2. A Flexowriter reader, punch, and printer are connected by cables to a central control box where the mode selection is made. A single cable connects this box to the remotely located relay panel on which are mounted the relay register, scale-of-two counter, and other control circuits. The flip-flop storage indicator-light register is also tied to this panel. This use of the indicator lights as a source of information does not disable the panel, which continues to operate in normal fashion.

5.2 EASTMAN READER-RECORDERS

The past quarter was spent in improving the reading operation of the film units. The principal objectives were to obtain satisfactory signals from both the digit phototubes and the reference-marker phototubes during the reading operation. The reading phototube circuits were redesigned so that the output is now taken from the ninth dynode of the phototube instead of from the anode. This type of output provides positive pulses of about nine-tenths the amplitude of the negative pulses obtained at the anode. The positive pulses can be used to drive a normally-off amplifier in which the bias can be adjusted so as not to pass the small noise pulses. A cathode follower on the phototube output reduces the effect of capacitances in the circuit, and this results in much sharper pulses throughout the circuits.

Many attempts were made to improve the performance of the reference-marker reading circuit by changes in the electronic circuits, but none of these changes gave satisfactory operation.

In the course of the work, it was found that the performance of the film units was very sensitive to curvature of the sweep of the cathode-ray tube. This sensitivity necessitated replacement of the tube that we had been using, and led to a study of the optical system. Some time was spent in familiarizing ourselves with adjustments of the optics, and in adjusting them to give maximum output during the reading operation.

As was mentioned in Summary Report 23, new masks of larger spot size were considered. A set of masks having spots half again as wide as the old ones were ordered from Eastman Kodak Co., along with new timing rings that would place the recordings twice as far apart on the film. Since the new masks used the same size reference marker, it was hoped that the larger spot size would permit a greater latitude in the timing of the sweep with respect to the position of the reference marker during reading, but the new masks did not appear to improve the operation.

During the last week of September, representatives of Eastman Kodak Co. visited the Project to study the troubles that we were having with the units. They decided that the signal-to-noise ratio out of the digit-reading phototubes could be increased by increasing the light intensity during recording. We had not done this because the halo and light scattering in the cathode-ray tube resulted in a slight exposure, or fogging, of the clear spots on the film. They found, however, that an increased exposure did increase the signal-to-noise ratio, and that increasing the amplitude of the cathode-ray tube unblanking gate more than compensated for the loss in signal caused by fogging.

The Eastman representatives also decided that the solution to the reference-marker troubles was to use a new light source for scanning the reference marks. Tests made while they were here indicated that this would increase the output, and also the signal-to-noise ratio, of the reference-marker phototube by a factor of five. In the original design, the light scanning the film hit the lucite light-conducting rod at an oblique angle, which resulted in considerable light loss in multiple reflections. The new source is to be so positioned as to direct the light normal to the surface of the rod. A satisfactory design for the new light source has not been attained yet, but Eastman Kodak Co. will do some work on the problem, and will visit us again for more tests when they have completed a design. In the meantime steps will be taken here to utilize the advantages of more signal out of the phototube circuits.

6. MATHEMATICS, CODING, AND APPLICATIONS

6.1 GENERAL APPLICATIONS FOR THE COMPUTER

As soon as the initial complement of 256 electrostatic storage registers and the interim punched-paper-tape input and output equipment become available, the Whirlwind computer will be able to undertake useful work on practical problems. The problems which are already being prepared for early performance on the computer are of an extremely varied nature. They range from the solution of a non-linear partial differential equation to the solution of a pair of simultaneous transcendental equations; from the solution of an eigenvalued system of differential equations to a study of group behavior by a Monte-Carlo procedure.

6.11 Non-Linear Partial Differential Equation

The partial differential equation

$$\frac{\partial^2 H}{\partial x^2} - \sigma \frac{\partial B}{\partial t} = 0$$

$$B = f(H)$$

with boundary conditions $H(x_0,t) = H(-x_0,t) = H_0$, $H(x,0) = 0$ arose in connection with the work on high-speed storage of binary information in magnetic cores (see Section 3.4 of this report). The magnetic flux density B is related to the magnetic field strength H by an empirical function (a B-H curve) which for iron is by no means linear. The physical situation involves a core formed from a thin ribbon of Deltamax iron wrapped with several windings. When current is suddenly passed through one or two of the windings, a voltage proportional to the rate of change of flux is induced in the third winding. To find the rate of change of flux, one assumes an idealized form for the problem: an infinite sheet of Deltamax iron of thickness $2x_0$ to which a constant field H_0 is suddenly applied parallel to the two surfaces of the sheet. The equation above, with the boundary conditions indicated, then describes the situation. By solving the equation for $B(x,t)$ and then finding $\varphi(t) = \int_{-x_0}^{x_0} B(x,t)dx$, one can find the total flux and then the desired rate of change of flux.

This problem is interesting for two reasons. First, the successful solution of it might aid in developing better cores for the magnetic storage. Second, the solution of the problem for some conditions is already known from actual measurements of the induced current, so that a fairly good check can be made on the validity of the physical assumptions and choice of the numerical solution. Consequently, considerable effort has been devoted to the investigation of the problem, and this effort has led to a definite coded program requiring about 200 registers of storage. This program will be tried out as soon as the computer becomes available. The numerical method to be used in the first attempt is essentially that described by Crank and Nicolson for a related heat-flow equation (Proc. Camb. Phil. Soc.; 43, 50-67, 1947).

6.12 Transcendental Equations

In connection with an investigation of the optical constants of thin metal deposits, Dr. Arthur Loeb, of the MIT Department of Chemistry, has undertaken the programming of an extensive calculation involving the solution of equations in which the unknowns appear in transcendental functions of complex numbers. In this case it seems likely, although it is not certain, that the problem can be handled with the initial storage capacity and interim terminal equipment to be available soon.

6.13 Eigenvalue Problem

The eigenvalue problem referred to is one which arises in work on atomic structure by the MIT Physics Department, leading to a determination of the potential distribution within and near an atom. As usual, the assumption of spherical symmetry, with a small correction term, is made. Investigation on this problem has just begun.

6.14 Group Behavior Study

Members of the Economics Department of MIT have proposed a problem involving a Monte-Carlo game. They have access to considerable data about the behavior of small groups of people when faced with an idealized problem, and they wish to determine how nearly the members of the group behave in a purely random manner when acting in a group. To do this they intend to let the computer play a game in which it takes in turn the part of each member of the group faced with the given idealized problem and makes a random move for each member in turn. By comparing the results of the purely random game played by the computer with the supposedly non-random result of a real group in the same situation, the economists feel that they can learn something about the behavior of groups.

6.2 PROGRAMS FOR USING INTERIM TERMINAL EQUIPMENT

All the essential coded programs for controlling the interim punched-paper-tape input and output equipment have been prepared and to some extent tried out on the computer. Other experimental modifications and refinements are still being worked on. Such work will not of course be completed until the equipment has been in use long enough to permit the accumulation of considerable experience. At the same time, however, primary attention is still being directed towards techniques to be used in the final system, one phase of which was described in Sections 6.11, 6.12, and 6.13 of the previous Summary Report (SR-23).

7. ACADEMIC PROGRAM IN AUTOMATIC COMPUTATION AND NUMERICAL ANALYSIS

An expanded graduate-school academic program in Automatic Computation and Numerical Analysis being offered in 1950-51 by the MIT Electrical Engineering Department was described in the Second Quarter Summary Report, SR-23. Registration of students for the fall term indicates an active interest in these subjects, as shown in the table below. Numbers refer to the MIT catalogue, where descriptions of the subjects may be found, as well as in SR-23.

Subject and Number	Students Registered
Numerical Analysis, 6.531	23
Seminar in Numerical Analysis, 6.533	5
Introduction to Digital-Computer Coding and Logic, 6.535	20
Control Systems Employing Two-Valued Elements, 6.567	27

8. APPENDIX

8.1 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, Servomechanisms Laboratory, 211 Massachusetts Avenue, Cambridge 39, Massachusetts.

The following reports and memorandums were among those issued during the third quarter of 1950.

No.	Title	No. of Pages	Date	Author
SR-23	Summary Report No. 23 Second Quarter, 1950	31		
R-179	Vacuum Tube Life Experience (Abstract and Appendix in E-360)	32	6-29-50	H. B. Frost
E-345	The Transition Region between Negative and Positive Regions on Storage Tube Surfaces	18	6-15-50	H. E. Rowe
E-356	Equipment and Techniques for Inserting Information Into WWI	9	7-12-50	C. W. Adams
E-357	Test Program Number VII, Alarm Circuits Check	6	7-28-50	J. M. Salzer
E-358	The Technique for Evaporation of a Beryllium Tube	8	8-2-50	T. F. Clough
E-361	Additions to the Whirlwind I Order Code (October 1949 to August 1950)	3	8-10-50	C. W. Adams
E-363	Washing Procedures — Series W	27	8-15-50	J. Palermo T. R. Parkins
E-367	Construction of a Beryllium-Evaporation Target Assembly	3	8-17-50	J. Palermo
E-368	The Distribution of Capacitance on the Beryllium Mosaic Surface	13	8-22-50	A. R. Tanguay
E-379	A Coincident-Current Magnetic Memory Unit (Abstract of R-192, A Master's Thesis)	2	9-11-50	W. N. Papian
E-380	Operation of Interim Tape Reader Equipment	8	9-12-50	C. W. Watt
M-1055	Meeting of the Mathematical Computing Advisory Panel, June 8, 1950	5	6-15-50	C. W. Adams
M-1060	Whirlwind I Marginal Checking — Summary and Recommendations	2	6-30-50	R. A. Nelson
M-1070	Correlation Between Signal Plate to Collector Capacitance and Mica Thickness and Collector-to-Mica Spacing	2	7-24-50	M. Florencourt H. Platt
M-1072	Measurements of Deflection Plate Spacing and Deflection Factors of 5 U Guns	4	7-26-50	R. Shaw H. Platt
M-1083	Interim Display Equipment and Temporary Operation qf: F - Scope Display	1	8-7-50	C. W. Adams
M-1084	Temporary Operation qp: Punch/Shift Right	1	8-10-50	C. W. Adams

TABLES

A table has been prepared which permits rapid conversion both ways between decimal-based and octal-based numbers, the whole decimal range from 1 to 6000 in steps of 1 being included on only one 11 × 17-inch sheet. The economy of space is achieved by splitting each number into two easily-obtained parts. The table is entered through both parts, and a two-part result is obtained which is easily combined to form the desired converted number. An Ozalid copy of this table (SB-36045) is available on request. A similar table for conversion between decimal and sexadecimal is in preparation.

8.2 PROFESSIONAL SOCIETY PAPERS

Two members of the Project staff have recently delivered papers to IRE groups:

Jay W. Forrester spoke on "Digital Computers as Information Processing Systems" before the Boston Section of the IRE on September 28.

A paper by S. H. Dodd and P. Youtz on "The MIT Electrostatic Storage Tube" was presented by P. Youtz to the West Coast Convention of the IRE at Long Beach, California, on September 15.

8.3 VISITORS

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

Capt. G. C. Miller, Navy representative to the Air Navigation Development Board.

Mr. Floyd G. Steele, Mr. D. E. Eckdahl, and Mr. J. E. Reed of the Computer Research Corporation and Mr. E. B. Staples of the Air Force Cambridge Research Laboratory.

Mr. G. P. Bieging of the U.S.A.F.

Mr. J. A. Kessler and Mr. O. V. Fortier, of the MIT Acoustics Laboratory, who were interested in analysis of experimental data by digital computers.

A group of officers of the Research Unit of the Naval Reserve.

Mr. John K. Jackson of the Marquardt Aircraft Company.

Mr. G. B. Devey of the Undersea Warfare Branch of ONR, who discussed the application of marginal checking to electronic systems other than digital computers.

Mr. L. J. Cutrona of the Aeronautical Research Center of the University of Michigan.

Mr. L. R. Philpott of the Air Navigation Development Board.

Prof. Alex Bavelas and Dr. Oliver H. Straus of MIT, who were interested in applications of digital computers to group intercommunication studies.

Mr. R. D. Parker of the National Security Resources Board.

Mr. Warren Dickinson, Assistant to Chief Engineer, Douglas Aircraft Company, Santa Monica, California.

Mr. J. Dedeka of the Boston University Optical Research Laboratory, to discuss the future use of the computer in lens design.

Mr. M. Rubinoff of the University of Pennsylvania.

Mr. A. S. Householder and Mr. C. L. Perry of the Oak Ridge National Laboratory

Dr. Arthur L. Loeb of MIT who was interested in using WWI to calculate the optical constants of thin metal deposits from experimental data.

A group from the Radar Panel of the Committee on Electronics of the Research and Development Board.

Mr. H. E. Sennett of the Industrial Mobilization Section of Air Materiel Command, and Mr. John Parsons, Mr. R. H. Marsh, Mr. R. Allen Price, Mr. F. L. Stulen, and Mr. R. B. Parker, of the Parsons Corporation.

Mr. C. D. Richard of the Superior Tube Company, and Mr. T. H. Briggs of Burroughs Adding Machine Company, who discussed cathode interface problems.

Lt. Cdr. S. J. Riordan and Mr. Arnold Shostak of the Armament Branch of ONR.

Mr. D. Olivetti, Mr. G. Beccio, Mr. G. Pero, Mr. J. L. Peyretti, and Mr. E. Prelle, of the Olivetti Corporation of America.

The week of the International Congress of Mathematicians, 1950, at Harvard in September brought many visitors to this Laboratory, among whom were the following:

Mr. L. Fox of the National Physics Laboratory, England.
Mr. Arthur Grad of ONR, and Mr. S. C. Lowell of ONR London.
Mr. J. H. Curtiss, National Bureau of Standards.
Mr. H. Schutzberger of the Test Data Division of the Sandia Corporation.
Mr. Edmund C. Berkeley, Secretary of Association for Computing Machinery.
Mr. J. W. Odle, Head, Mathematical Division of the Research Department of the Naval Ordnance Test Station, Inyokern, California.
Dr. H. D. Huskey of the National Bureau of Standards.
Mr. Fritz John of New York University.
Mr. George B. Dantzig, Hq., U.S.A.F.
Dr. M. V. Wilkes of the University of Cambridge, England.
Dr. E. G. Hill, Sir Charles Wright, and Mr. R. A. Fairthorne of the British Joint Services Mission.
Mr. J. C. P. Miller, Dr. Franz L. Alt, Mr. Robert R. Reynolds, and Mr. J. W. Wrench, Jr., of the National Bureau of Standards.
Prof. M. H. Newman of Manchester University, England.