PROJECT WHIRLWIND

(Device 24-x-3)

SUMMARY REPORT NO. 22

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SERVOMECHANISMS LABORATORY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Cambridge 39, Massachusetts

Project DIC 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 nearly all project resources are devoted to the design, construction, and testing of the computer.

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 at the end as an appendix.

I. QUARTERLY REVIEW (AND ABSTRACT)

The diagram on the next page shows the relationship of different parts of the Whirlwind I computer and the status of each. All of the computer is operating with the exception of electrostatic storage and terminal equipment.

During the first quarter of 1950 all 16 storage tubes and associated circuitry of the first bank of tubes were completed and installed in the computer. Two of the 16 digit columns have been under simultaneous test. We have been able to cycle test patterns in these two tubes without error for several hours. During April, May, and June the full bank of 16 tubes will be operated and tested. We hope that in this period the electrostatic storage system will become reliable enough so that it can be integrated with the rest of the computer in July.

The first Eastman film reader-recorder has been connected to the system and has recorded various number sequences generated by the computer using a program in test storage. One of these recordings contains 32,000 words which were recorded in 16 seconds. We still feel the need for more powerful methods for trouble location in the combination of input-output control, input-output register, and film recorder. During the next quarter we will make extensive tests of film reading as well as recording.

An outline of the test program for the next six months (April to September) is given in Section 2.14.

The proposed minimum terminal equipment is described in Section 5. Input equipment includes typewriter, tape punch, and film reader; output facilities consist of film recorder, typewriter, tape punch, and oscilloscope display. This system does not include magnetic-tape equipment. Magnetic-tape drives are on order, but substantial design work on their control must await operation of the above-described system.

We feel that, during the past quarter, satisfactory progress has been made in improving the operating margins and safety factors in those parts of the computer which have been in operation. A number of test programs have been worked out and additional checking circuits added to the computer, which decrease the time required to locate deteriorating components during routine marginal checking. A description of these expedients is given in Section 2.3.

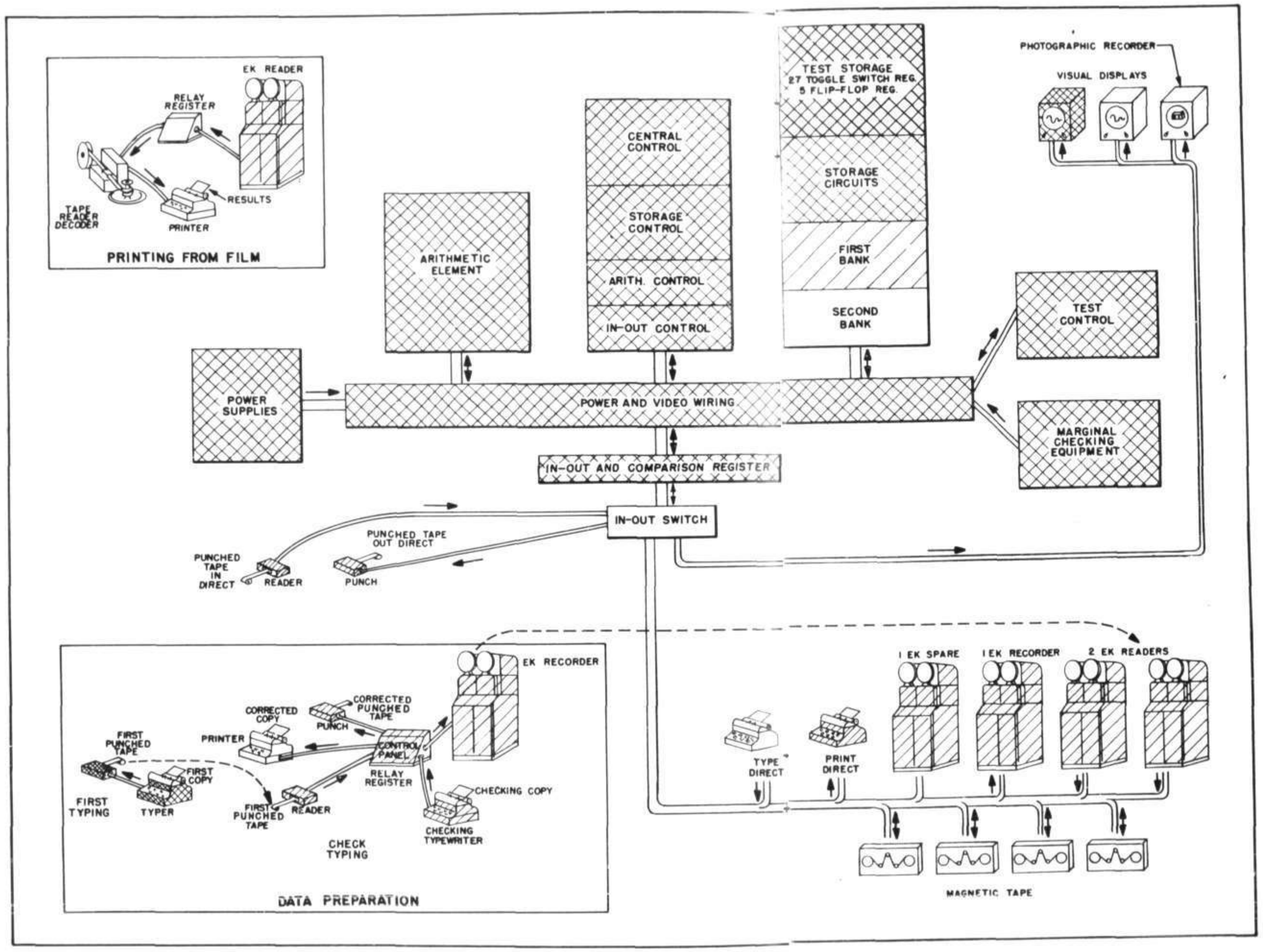
The five-digit multiplier made seven random errors during the period of January through March. There was one error-free run of 45 days. Vacuum tube data in the multiplier for the past year has been analyzed and is presented in Section 3.21. Of the two predominating tube types, 7AD7 and 7AK7, 65 percent remain in service after 10,000 hours. Our early experience with the Whirlwind system indicates the same trend, although the total operating time has been only 3,000 hours.

Storage-tube production from January through March was characterized by extremely low shrinkage. Twenty-nine standard or special tubes were built; 27 passed initial tests; one of the rejected tubes was successfully reprocessed. A full bank of 16 tubes has passed dynamic acceptance tests for use in the Whirlwind I computer. Additional tubes await this final test. A table in Section 4 shows the operating ranges of 13 of these tubes.

Two tubes have been made with both high-velocity and holding guns in one neck. This simplified construction will probably be used in new model tubes. Both tubes had about the same performance as equivalent two-neck tubes.

Several tubes have been built with different type guns and with various sizes of beryllium mosaic. Tests are not sufficiently complete to permit full evaluation of these changes.

Standard automatic sub-routines as aids to a programmer are discussed in Section 6.1. They are compared in utility to (1) built-in operations and (2) the writing of whole sequences of orders each time they are needed. Programs which have already been carried out on the computer using the limited capacity of 32 registers of test storage are described in Section 6.2.



STATUS OF WHIRLWIND I COMPUTER

LEGEND

Complete and operating

Being completed

Not begun

Areas on the diagram are roughly related to the amounts of equipment involved in different components but do not show the research effort in developing the various parts of the machine. The terminal equipment shown pictorially represents about 25% of the total amount of equipment in the machine.

2. SYSTEM ENGINEERING

2.1 DEVELOPMENT OF WWI

2.11 Reader-Recorder Operated With System

Testing of the first Eastman-Kodak reader-recorder reached a point during the past quarter which permitted operation of the unit as a recorder under control of the computer. The tie-in was successful, and several recordings were made under these conditions. The information to be recorded was controlled by coded programs set up in test storage. These included (1) a series of blocks, each having a predetermined number of words, (2) a predetermined number of blocks each having a predetermined number of words, and (3) one block containing all the binary numbers from $-1 + 2^{-15}$ to zero. The last of these recordings contains over 32,000 words, occupies about 27 feet of film, and requires about 16 seconds to make. Representative samples of the developed film are reproduced on this page.

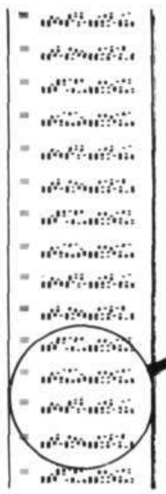


Fig. 1

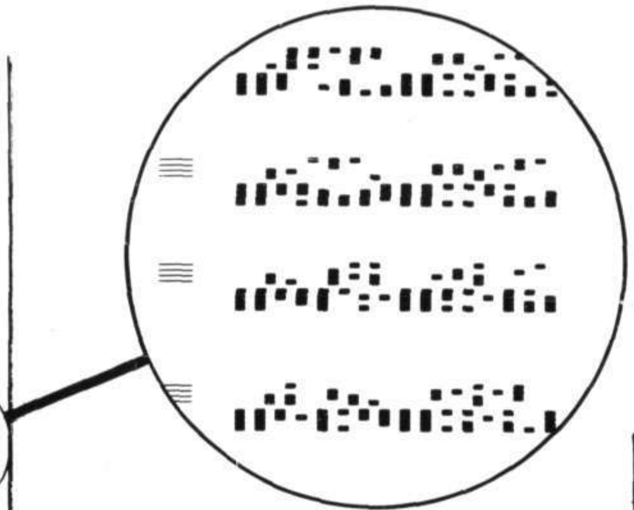


Fig. 2

Figure 1 is an actual-size recording of 4-word blocks, a section of which is shown enlarged in Figure 2. Each word has 16 binary digits which are represented by the presence or absence of dark spots on the film. The dark spots in a row across the film opposite one of the reference marker lines designate 1's digits in a word. Complements of each word are also recorded on the film; they appear as spots in the fifth row below each word row. Alternate columns on the film are assigned to word and complement spots so that if more than 5 words are recorded in a block the spots representing one word become interlaced with spots representing the complement of a previous word. Figure 3 shows blocks of about 100 words with normal interlacing. This is a recording of computed values of the function sin x.

Fig. 3

Experience obtained from this tie-in indicates that more powerful methods of locating sources of error are needed. Since, with the present system, push-button operation one step at a time cannot be obtained, it is often difficult to decide at which step in the sequence an error occurs. A procedure found most effective in testing the Whirlwind arithmetic element is to set up a cyclic operation which can be stopped at an arbitrary point in each cycle so that, effectively, step-by-step operation is produced although dynamic conditions are maintained. The adaptation of a similar testing procedure to the reader-recorders is complicated considerably by the fact that these units are not synchronous with the computer. Progress is being made in devising a suitable test control to perform the needed type of checking.

2.12 Testing of WWI

The computing portion of the Whirlwind system — the arithmetic element and central control — has been in operation with 32 registers of test storage for about 8 months. This portion of the system contains 3500 vacuum tubes and 9500 crystals; comparable numbers of resistors, coils, and condensers; and the associated hardware. Such an electronic system is subject to failure when any of these components (most often a tube or a crystal) deteriorates to a point where the associated circuit does not perform adequately.

In the Whirlwind project any system failure is regarded as more than a maintenance call for a new component. A study of why the failure occurred leads in two directions. First, the circuit in which the component is used may be too sensitive to weak components; circuit changes can often be found that will allow wider variations in the characteristics of these components. Second, the component itself may be faulty. Sometimes appropriate tests will eliminate such components before they are installed in the system. If these steps fail, a marginal checking program or technique can often be used to uncover imminent failures before they cause any computing errors.

Both of these directions have been followed in testing the central portion of Whirlwind. Noticeable improvement in operating tolerances has been achieved by installing clipping circuits in the amplifiers which send control pulses to the arithmetic element. A similar improvement has been realized by a change in the circuitry of the bus driver panels which communicate with the central bus system. Some other improvements are listed below:

1. A slicing circuit in the control matrix driver to increase tube tolerance.
2. Improved decoupling circuits in the matrix drivers.
3. Improved timing in test-storage switch read-out system.
4. Improved timing in program register read-in.
5. Adjusted amplitudes on check bus for optimum performance.

2.13 Progress in the Electrostatic Storage System

The electrostatic storage tube installation in Whirlwind is the first attempt to use such a memory system as an integral part of a complete computer. It must be possible to read in and out of 16 of these storage tubes simultaneously to achieve extremely short access time for the 16 digits of the words used in Whirlwind.

To operate 16 of these tubes simultaneously with the same power supplies, control voltages, and pulses, it is necessary to supply low-impedance transmission facilities to all of the units in parallel. The circuitry which carries out the necessary sequences is known as storage control. This portion of the system contains 850 vacuum tubes and requires 8 separate carefully regulated power supplies not used elsewhere in the Whirlwind system.

Work in the first quarter of 1950 has centered around the installation, testing, and improvement of this storage control to a point where it will perform about as reliably as the rest of the computer. Circuit requirements in this portion of the machine differ from those in the arithmetic and control sections of Whirlwind. This is particularly true of such circuits as the deflection decoder, which directs the reading and writing beam of each storage tube to any of its 256 storage areas. Here requirements on power-supply regulation, crystal stability, and linearity of amplifiers all become more stringent than in the typical on-off circuitry of a digital system. Problems of power-supply ripple, noise, and amplifier balance have been overcome successfully.

To coordinate the storage work with other Whirlwind activity and centralize the control, all storage-row test equipment, including the storage-tube television scanner, has been collected in the Whirlwind control room in a revised testing system. This new system allows the viewing of any of the 16 storage surfaces on the television display for surface potential study, or on a scope for the observation of read-out signals while cycling tests are underway.

Two of the 16 storage tubes in the storage row have been operated in many test sequences which simulate final tube operation as closely as possible. The use of two storage tubes and some associated checking circuits in the program register has permitted marginal checking on many of the channels in this system.

The progress to date in this activity has been steady. Two tubes have run without error on a pattern cycling test for several hours. The storage control is now reliable enough to justify addition of the 16-tube complement, and test of the storage row as a complete unit preceding its integration with the computer.

2.14 Program for Next Six Months

During the next six months we expect to test the various parts of the computer and integrate them in the system in the sequence given below. Subdivisions indicate that two activities will be carried on simultaneously.

1. (a) Temporary but functionally complete tie-in of film reader-recorder with computer and test storage. To be removed after about a month of testing.
   (b) Complete testing of electrostatic storage system before tie-in with computer.
2. (a) Tie-in of electrostatic storage system with the computer and the test storage, but without the film reader-recorder.
   (b) Testing of film reader-recorder and punched-paper-tape equipment independent of the computer.
3. Tie-in of both electrostatic storage system and film reader-recorder with computer.
4. Operation of complete computer with the interim terminal facilities described in Section 5.

2.2 INSTALLATION OF WWI

During the first quarter the installation of the equipment and wiring for the computer proper was completed. Electrostatic storage, including its special power supplies and power-supply control, was installed. Much temporary equipment was consolidated and made permanent, and marginal checking was made available to the whole computer. The only substantial construction and installation work remaining to be done is on terminal equipment described in Section 5.

2.3 CHECKING

2.31 Coded Programs Used in Testing

For obtaining special detailed data on certain parts of the computer, the test sequences developed as part of a master's thesis have turned out to be very helpful (A Method of Test Checking an Electronic Digital Computer, Project Whirlwind Report R-177). Using the sections into which the computer has been physically divided by the assignment of the various voltage-variation lines (cf. E-326 for details of these assignments), the author of the thesis worked out sequences of orders which would, on paper at least, check every circuit in the section for any sort of malfunction. For convenience in using them, he then combined as many of these sequences as he could squeeze into the 32 registers which comprise the present storage of WWI, and called the result a test sequence. Such sequences have been worked out in complete detail for checking the step counter and the flip-flops of arithmetic control and in less detail for other parts of the computer. Long-term data are now being gathered to permit a comparison of these specially-developed sequences with the more general test programs in terms of how well they each reveal trouble in the particular sections in question. The real value of the sectional approach cannot be well assessed until more of these data have been collected.

Since the computer has been undergoing almost constant testing during the past few months, a number of programs for checking and especially for trouble location have been written informally on the spur of the moment. The Whirlwind code being quite easy to learn and use, it is often easier to make up a new program than to hunt for an old one. Consequently, most of these impromptu programs have never been written down. In any event, none of them is worth reproducing here. For general test purposes, such as in the routine marginal-checking period each morning, Test Programs I and II (cf. Summary Report 20, page 35) have proved quite satisfactory.

2.32 New Checking Circuits

2.321 Control-Switch Checking

In the course of testing the computer, a number of possible failures not adequately checked by the present built-in checking have been either encountered or anticipated.

For example, the correct operation of the control switch is necessarily presumed in most test programs, since no predictable results can be obtained if the control switch (which interprets the orders in the program) should fail. The transfer of the five-digit operation section of each order from storage to the control switch has heretofore been checked in the usual transfer-check fashion by reading back out of the control-switch flip-flops to the check register and making an identity check. In order to check the operation of the switch itself, the read-out is now being performed through gate tubes associated with the control matrix. Thus the control switch must actually set up and select the correct one of the 32 different operation lines in order for the read-out to be correct. An incorrect read-out shows up as a transfer-check alarm.

In order to check against the possible selection of some extraneous line in addition to the correct one of the 32, a special circuit has also been added to detect multiple selection. This circuit connects all 32 of the lines through crystals and resistors to a common resistor so that if two or more lines are simultaneously selected, the extra current drawn through the common resistor produces a change in voltage which can be detected. With these two additions, the control switch is much more thoroughly checked than heretofore.

2.322 Inactivity Alarm

A considerable number of possible malfunctions can result in a "hung" condition in which the computer is neither running nor in the strict sense stopped, but simply inactive. For example, during multiplications, divisions, or shifts, the main control element of the computer stops temporarily to let the arithmetic control element perform the arithmetic operation. If certain failures occur within arithmetic control, no pulse will be sent back to main control to start it up again. No alarm results. The computer simply waits. Similarly, when the computer and a reader-recorder are working together, it is possible for a malfunction or an error in programming to cause a situation in which each unit waits for the other to send a pulse, and they both stand still.

The inactive condition can be easily detected from the neon indicator lights, all of which assume some definite condition rather than flickering or showing dimly on both sides at once as they do when the computer is operating properly. But such a condition might not be noticed for some time if no careful observer were present. Consequently, a new alarm has been added to detect the situation automatically and ring the alarm bell. The circuit consists simply of a flip-flop which is repeatedly hit on the zero side by transfer check pulses from the central control element. A monitor pulse, occurring every few milliseconds, is sent to the one side of the flip-flop and to a gate tube connected to the one side. Thus, if no transfer check pulse at all occurs between any two monitor pulses, the first monitor pulse opens the gate on the one side and the second monitor pulse passes through it to give an alarm. Since the absence of a transfer check pulse indicates either that the computer is hung up or that a critical failure has occurred, the resultant alarm indication is very useful.

2.323 Continuous Alarm Indication

The regular alarm circuits in the computer all feed through gas tubes to operate a relay. A single alarm pulse fires the associated gas tube and stops the computer. For manual marginal checking, it is desirable to be able to make several passes with the variation potentiometer in order to determine the point of failure, while in other cases it is desirable to keep restarting the computer every few milliseconds and to know whether alarm pulses are occurring regularly or only intermittently. But once the indicator gas tube has fired and the relay has come in, the indicator circuit must be manually cleared before a repetition of the error can be detected. Therefore, a "continuous alarm" circuit, consisting of an integrator to integrate the alarm pulses, has been installed. In this circuit a neon light glows whenever alarm pulses are occurring continuously, and stops glowing when the alarm pulses stop.

3. CIRCUITS AND COMPONENTS

3.1 FIVE-DIGIT MULTIPLIER

For the past year, the five-digit multiplier, which is a prototype of the Whirlwind arithmetic element, has been operating on an extended life test for the purpose of studying system reliability. The test consists of periodic solutions of the product 31 × 31 at a rate of about 15,000 times a second. Circuits are provided which check each solution, and if an error is found it is registered on electro-mechanical counters. The aim of the work is to determine what are typical sources of error in a computing system and to discover the most effective methods of finding and eliminating potential source of error. The measure of the effectiveness of the work is the freedom from incorrect solutions.

The results of the multiplier reliability tests for the period April through December, 1949, have been published in previous quarterly reports (see Summary Reports 19, 20, and 21). A summary of the operation for the period January through March 1950 is shown in the accompanying chart. The total of seven error counts registered represents a slight improvement over the performance for the two preceding quarters. Of greater interest is the fact that the system operated from January 19 to March 5, a period of 45 days, without making an error. Previously errorless runs of about three weeks were the longest that had been obtained.

No satisfactory explanation could be found for any of the errors in the past quarter. The same has been true of isolated failures which have occurred previously. Attempts have been made to discover some pattern in the times of day at which these errors occur or some correlation with marginal-checking data or with events taking place in the environment, but so far these attempts have been unsuccessful.

Maintenance work done on the multiplier has consisted of routine marginal checking performed for about one-half hour each working day and such servicing as has been necessary to correct any low margins that have been found. Components replaced during the quarter totaled 19 tubes and 28 crystals, or about 5 percent and 3.5 percent, respectively, of the total complement of these items.

3.2 VACUUM-TUBE LIFE

Studies of computer circuit reliability both in the five-digit multiplier and in the Whirlwind computer are closely allied with studies of vacuum-tube life. Valuable information on tube performance is being obtained from both of these systems. Controlled life tests also have provided useful data on the rate of deterioration of different types and production lots of tubes.

3.21 Five-Digit Multiplier

The five-digit multiplier has been in operation long enough to produce some significant information on the life characteristics of the tubes used. Three types of tubes predominate in the multiplier, the 7AD7, the 6AS6, and the 7AK7. Of these, the 7AD7 and 7AK7 types are used extensively in the Whirlwind computer.

Data might be presented for the survival curve of only the original complement of tubes. However, to do so would exclude from the results valuable information which is available from the replacement tubes which have seen service.

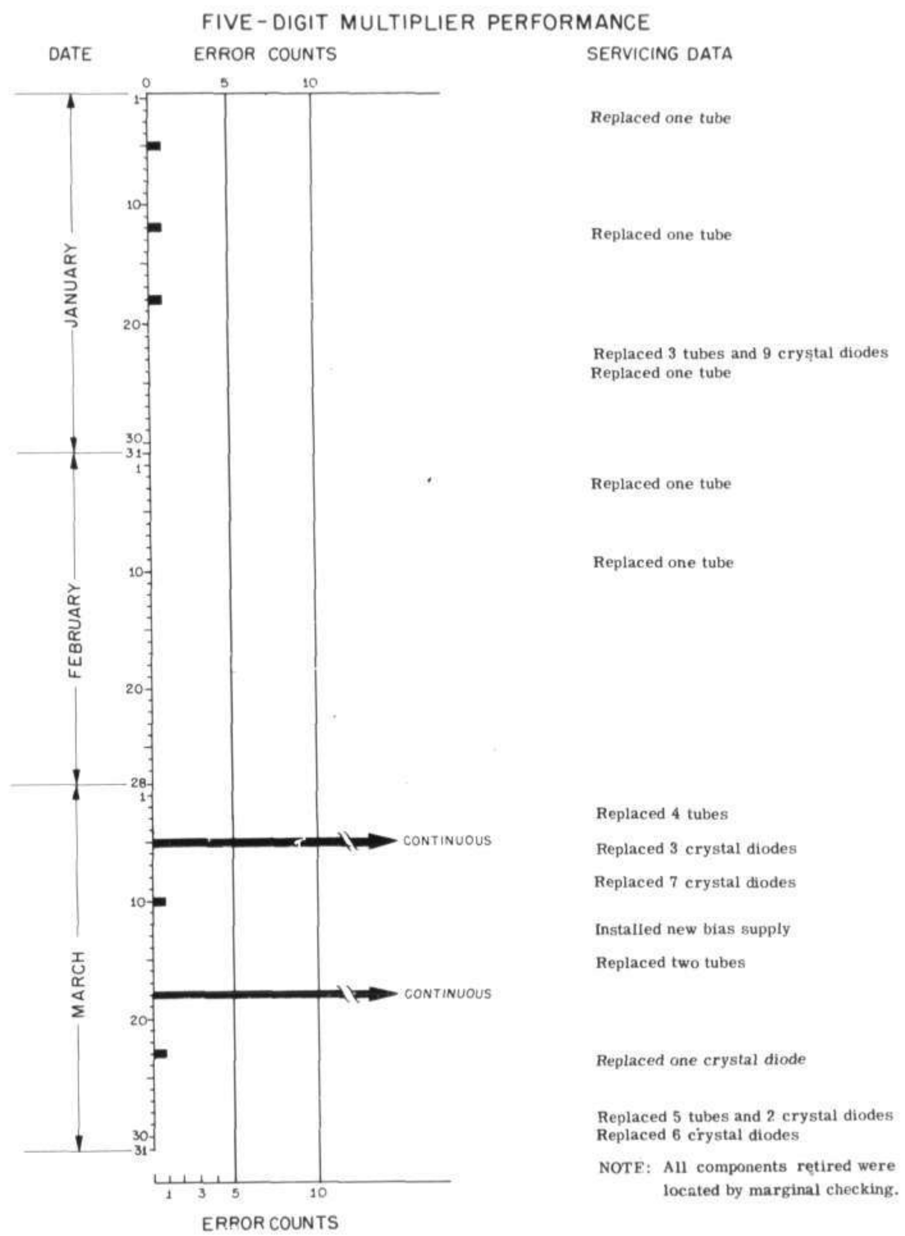
In order to include information from both the original and the replacement tubes in one graph, care must be taken in the choice of a method of data analysis. The test data are similar to those which would be available from many different lots started on test at different calendar dates. The method of analysis must properly combine the data at corresponding ages for the different lots. As for a single test lot, the results from such an analysis can be plotted as a curve of survival percentage vs. length of service. The early life section of the curve is based on a larger sample of tubes than the later life sections, which do not include data from so many replacement tubes.

The data can be analyzed as follows to obtain the values for plotting the curve of survival vs. length of service. For each interval of tube life (say a thousand hours), the total number of tubes whose life reached the beginning of the interval is noted (not including tubes which are still alive and whose length of service lies within the interval). Also note the total number of tubes reaching the end of the interval. (The difference is, of course, the failures in the interval.) The number of tubes at the end of the interval is divided by the number at the beginning of the interval to give the survival ratio, S_n, for the nth interval. A survival ratio is thereby established for each time interval of tube life. Beginning with 100 percent tubes in service at zero hours, successive points on the curve are obtained by multiplying the preceding point by the survival ratio of the next interval. Each point on the final curve may be expressed mathematically as the finite product:

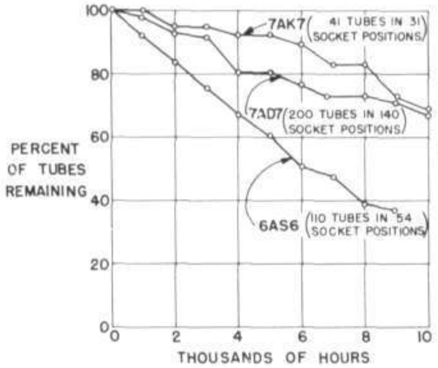
$$A_n = 100\,(S_1)(S_2)\ \ldots\ (S_n),$$

where A_n is the percent of tubes remaining after the nth time interval and S_n is the survival ratio for the nth interval.

The curves on page 14 show the life experience of the 7AK7, 7AD7, and 6AS6 tubes used in the multiplier. The figures in parentheses indicate the total number of tubes on which experience has been obtained. It can be seen that more than 65 percent of both the 7AD7 and 7AK7 tubes remain in service after 10,000 hours. This is encouraging informa-



tion, since according to previously formed impressions, commercially available tubes would not have this long a life.



Tube life in five-digit multiplier.

One reason for the higher failure rates for the 6AS6 type is that the circuits for these tubes do not have as wide operating margins as those for the other two types. In the design of circuits for the Whirlwind computer, the desirability of wide operating tolerances to allow for tube deterioration was recognized, so tube life in the computer should be at least as good as that of the 7AD7 and 7AK7 tubes in the multiplier.

3.22 WWI Computer

Only about 3000 hours of operating time has been accumulated on the Whirlwind Computer, so that an analysis of the life of its tubes would not be significant. However, an examination of the failures that have occurred shows that the performance of the 7AK7 and 7AD7 types, which comprise a large part of the computer tube complement, is comparable to what has been obtained in the multiplier. In the case of the 7AK7 gate tube, which was specially designed for the project and manufactured under pilot-plant conditions, only about one percent of the tube complement has been retired; more than half of these failures were because of mechanical defects and the rest because of changes in characteristics. Of the 7AD7 tubes, which were purchased from commercial production, about 5 percent of the complement has failed, the predominant reasons for failure again being mechanical defects and change in characteristics. The accompanying table lists the 49 tubes replaced during this quarter.

TUBE FAILURES IN WWI
January 1 - March 31, 1950

			Reason for Failure; Number Failed			
Type	Total in Service	Hours at Failure	Change in Characteristics	Mechanical	Burn-Out	Gassy
		0 - 100				
		100 - 500		1		
7AK7	1330	500 - 1000		1		
		1000 - 2000	1			
		2000 - 3000				
		0 - 100				
		100 - 500		1		
7AD7	1462	500 - 1000	3	1		
		1000 - 2000	9	2		
		2000 - 3000	17	6		
		0 - 100				
		100 - 500				
3E29	92	500 - 1000				
		1000 - 2000				
		2000 - 3000	1			
		0 - 100				
		100 - 500				
6Y6G	204	500 - 1000				
		1000 - 2000		1		
		2000 - 3000	4			
		0 - 100				
		100 - 500			1	
Gammatron	1	500 - 1000				
Type 24		1000 - 2000				
		2000 - 3000				

3.23 Life Tests

Controlled life tests conducted during the past quarter have been confined mainly to a study of methods for determining whether or not a given production lot of purchased tubes is liable to exhibit cathode interface deterioration. The results of these studies have been encouraging.

It has been found that operation at elevated cathode temperatures speeds interface formation; therefore an experiment was conducted to determine if a 500-hour life test under such conditions on samples from each production lot of tubes would give a satisfactory indication whether deterioration would occur within a few thousand hours of normal operation. A 500-hour period was chosen as being the longest practical test that could be performed by a tube manufacturer.

For the experiment, 7AD7 tubes from three production lots were operated for 500 hours at heater voltages of 8.0 volts. From experience in the multiplier and in the computer it was known that the three lots have widely different life characteristics; one lot has shown essentially no deterioration over a period of 10,000 hours, another has shown substantial interface formation in 1000 to 2000 hours, and the third has given intermediate performance. Measurements made at the end of the 500-hour test indicated excellent correlation between the interface deterioration in the samples and in normal use. Furthermore it was found that 500 hours is sufficient to develop measurable interfaces in tubes which are satisfactory for more than 5000 hours of normal operation; therefore it is felt that the measuring techniques have adequate sensitivity.

On the basis of the results obtained, it appears that an accelerated test for interface is a useful tool in selecting tubes for long life. Such a test is now being applied to samples of new lots of tubes that are purchased.

3.3 COMPONENT REPLACEMENT IN WWI

The number of components other than tubes and crystal diodes requiring replacement continues to be negligibly small. During the quarter, 84 crystal diodes were replaced as shown in the table on page 16. This rather large number resulted from the increasing activity in marginal checking and the effort to bring up all margins to liberal tolerances. The data gives no evidence of crystal deterioration with age.

FAILURES OF COMPONENTS IN WWI
January 1 — March 31, 1950

Component	Type	Total in Service	No. of Failures	Hours of Operation	Comments
Capacitor	0.001	2900	1	543	(Mica). Internal unsoldered pig-tail connection caused intermittent operation.
Crystal Rectifiers	D-357	6400	1	100-500	Clamping crystal, excessive drift.
			6	500-1000	Grid crystals: 4, excessive drift; 2, low back resistance.
			7	1500-2000	Clamping crystals, excessive drift.
			2	2000-2500	Grid crystals, excessive drift.
	D-358	3100	1	0-100	Clamping crystal, excessive drift.
			3	100-500	2 clamping crystals, excessive drift; 1 switching crystal, low back resistance.
			32	500-1000	14 clamping crystals: 10, excessive drift; 3, shorted; 1, low back resistance. 18 switching crystals: 16, excessive drift; 2, shorted.
			2	1000-1500	Clamping crystals, excessive drift.
			19	1500-2000	Clamping crystals: 18, excessive drift; 1, low back resistance.
			8	2000-2500	Clamping crystals: 6, excessive drift; 2, low back resistance.
			1	2500-3000	Clamping crystal, excessive drift.
	D-359	446	1	500-1000	Output crystal, burned out.
			1	2000-2500	Bus driver crystal, open-circuited.
Delay Line	0.4μsec.	1	1	655	Open circuited.
Pulse Transformer	3:1	2500	2	1000-2000	Open secondary.
	5:1	300	1	1653	Open primary.
Resistors Carbon	220 ohms 1 watt	9000	1	1600	Open circuited.
			1	1894	Burned out.
			3	2000-3000	Burned out.
	680 ohms 1 watt	68	5	1000-2000	Overheating.
	1000 ohms 2 watt	56	1	442	Burned out.
Resistors Wire Wound	5000 ohms 8 watt	650	1	1786	Outside tolerance.

4. ELECTROSTATIC STORAGE

4.1 TUBE PROGRAM

The storage tubes built late in 1949 have been installed in the mount boxes, given dynamic operation tests in the reliability tester, and installed in the computer. Construction of 100-series tubes continued with a yield of about 1-1/2 good tubes per week.

Development work included the successful construction of two storage tubes with both guns in one neck and continued progress toward tubes of higher storage density.

4.11 Tube Production

The outstanding characteristic of the tube production record from January through March is the very low shrinkage. Twenty-nine storage tubes, either standard or special, were built; 27 of these passed initial test. One of the rejected tubes was successfully reprocessed; the net shrinkage (initial test) for the quarter was 1 tube in 29, or less than 4 percent. The production group is now able to schedule 3 tubes per week and to produce on the average 2-1/2 successful tubes per week. This production can be divided in any way desired between standard-model storage tubes and research tubes.

Figure 1 shows the tube production record for the first quarter of 1950. The accompanying table describes briefly the specialized characteristics of the research tubes listed.

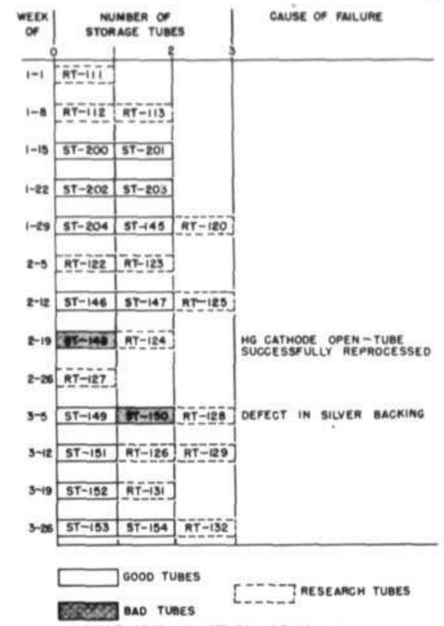


Fig. 1. Storage-tube production record.

The first few research tubes built during the quarter were short-throw tubes with various mosaic sizes, continuing the development begun in the

CHARACTERISTICS OF RESEARCH TUBES
January 1 - March 31, 1950

Research Tube Number	Description
RT111	Experimental 200-series; 40-mesh mosaic
RT112	Experimental 200-series; 40-mesh mosaic
RT113	200-series; surface 1/2 60-mesh and 1/2 100-mesh mosaic
RT120	200-series; 100-mesh mosaic
RT122	200-series; 60-mesh mosaic
RT123	200-series; 100-mesh mosaic
RT124	Two guns in one neck; 100-mesh; short-throw 3RP high-velocity gun
RT125	200-series; 100-mesh mosaic; collector-to-surface spacing varying from 0.002" to 0.020"
RT126	Two guns in one neck; 100-mesh; short-throw 5UP (standard) high-velocity gun
RT127	Variable-throw tube with surface tilted 20°
RT128	Reoxidized mosaic from standard storage tube
RT129	Variable-throw tube with surface tilted 14°
RT131	Heavily oxidized mosaic
RT132	200-series tube; 100-mesh mosaic on glass dielectric

last quarter of 1949. In the middle of January production was started on 200-series tubes (similar to the 100-series but with reduced high-velocity beam throw – see Summary Report 21 for details). Five of the 200-series tubes were built and the run was then ended. Detailed performance tests on both 100-series and 200-series tubes showed that the 200-series tubes were unable to operate reliably with 32 × 32 arrays. We therefore decided to resume production of 100-series tubes, thus insuring an adequate supply of identical tubes for use in the computer during debugging and initial operation. The production of a new series will be deferred until the development of higher-density tubes is complete.

Starting about the first of February, 100-series construction was resumed at a rate of about 1 tube per week. The rest of the production capacity was assigned to research tubes, some description of which will be found in Section 4.13.

ST148, built in the middle of February, had an open holding-gun cathode lead. This was the first tube failure since the first week of December 1949. The guns in ST148 were replaced; the tube was reprocessed and then accepted. The only other tube failure – ST150 – had a defective evaporated silver signal plate.

4.12 Dynamic WW Acceptance Tests

The following test sequence is run on all storage tubes before installation in WW:

a. Initial static testing in a TV setup.
b. A second static test (WWI acceptance test) run after a shelf life of 300 hours to check for gassiness.
c. Dynamic tests run in the reliability tester after installation in mount boxes.

Summary Report 21 describes the results of (b), the WWI static acceptance tests. The WWI dynamic acceptance tests, (c), have been run on all tubes for WWI during the past quarter.

The tubes passing WWI static acceptance tests are installed in the mount boxes and adjusted for uniform characteristics and r-f lineup. The resulting assemblies are interchangeable in the computer and operate with identical d-c supply voltages, deflection voltages, and video and r-f gates. The dynamic test consists of the following:

1. The tube and mount are placed in the reliability tester and standard voltages and gates applied.
2. The tube is then given a cycling test and checked for satisfactory operation, correct centering and deflection sensitivity, compensation, focus, r-f lineup, and sensitivity to shock.
3. If the tube operates satisfactorily under standard conditions, a determination is made of the maximum permissible range of each of the most important variables that will not affect the cycling of a standard array of alternate positive and negative spots.
4. Center values for the gun voltages are then set for each mount.

A typical test report is shown in Figure 2. The average ranges for the first 13 tubes tested are given instead of the range for any particular tube. The mount boxes must be interchangeable. The first five values listed are d-c voltages, individually adjusted within the mount. They can therefore be set to their optimum values, usually the centers of the ranges. The ranges for these variables are measured both as an aid in determining optimum setting and as an indication of tube characteristics and reliability.

The next three values are video gate amplitudes. These are not adjustable in the mounts but can be independently set in each digit column; therefore, it is possible to set the optimum values for each tube. Such a procedure is not desirable, however, since the mount boxes would then not be strictly interchangeable. It is preferable to have the gate amplitudes the same in all digit columns. The importance in measuring these ranges is to determine the overlap or range in which all the tubes will operate. The center values of these ranges can then be set, once and for all, in all digit columns.

The last two values are writing gate lengths. Since these are determined by the storage control they must be the same for all tubes. The ranges are measured to determine the overlaps, margins of operation, and optimum values. The increment supply voltages to the deflection decoders are varied in order to find the minimum area in which a 16 × 16 array may be cycled. The equivalent array density for the entire surface is listed.

The ranges of the important quantities is gratifyingly large. The overlap or range of gate amplitudes and lengths for which all tubes will operate (listed below) is satisfactory.

Quantity	Operating Range for all Tubes
W-SPG (Write minus signal plate gate)	115 to 125 volts
RSPG (Read signal plate gate)	54 to 87 volts
HV Video Gate	56 to 92 volts
T+ (Write + gate length)	9-1/2 μs or greater
T- (Write – gate length)	13-1/2 μs or greater

Average readings of 13 tubes passed up to noon 3/24/50

WWI MOUNT CHECKOUT ON STRT

___ PASSED
___ REJECTED
___ Storage Tube
___ Mount Box

MOUNT SER.# ____________

ST ____________

TIME ____________

DATE ____________

V'_K = +90V. (to gnd.) V_K = -1820V. (to gnd.) OPERS. ____________

V'_{A_1}, A_2 = +500V. (to HGK) V_{A_2} = +125V. (to gnd.) ____________

	PARAMETER (Adjusted in order listed)	INITIAL VALUE	RANGE FOR CYCLING A 16 x 16 ALTERNATE ARRAY WITH A 40 μsec. PERIOD	FINAL VALUE
SIMPSON #345-5044	HV BIAS SUPPLY	-180V.	------------------	-180V.
	V_F	+500V. (to HVK)	370V. to 625V.	500V.
	V_B	-80V. (to HVK)	-72V. to -100V.	-80V.
	V_{HG}	+100V. (to HGK)	74V. to 110V.	93.5V.
	V_{A_3}	+100V. (to HGK)	< 70V. to > 150V.	100V.
SIMPSON #345-5048	W - SPG	120V.	105V. to > 133V.	120V.
	RSPG	70V.	14V. to 95V. except ST136R1 = 52, ST142 = 56	70V.
	HV VIDEO GATES	85V.	38V. to > 95V.	85V.
	T+	12 μsec.	4 μ sec. to > 16 μ sec.	12 μ sec.
	T-	15 μsec.	8 3/4 μ sec. to > 16 μ sec.	15 μ sec.
SIMPSON #SM-3552	V INCREMENT SUPPLY	-44.5 V.	-33.5V; EQUIVALENT ARRAY DENSITY 20 x 20	
	H INCREMENT SUPPLY	-51.5V.	-40.5V.	

D. C. LEVEL OF DEFL. BUS LINES FOR CENTERED ARRAY: V - 1 ________ V. - 2 ________ V. H-3 ________ V. -4 ________ V. [TO GROUND]

ADJUSTMENTS REQUIRED AND COMMENTS:

Fig. 2. Typical test report.

The narrowest range, that of the W-SPG, is a function of V_{HG} for each tube. If V_{HG} were made the same for each tube (which is possible) the W-SPG range would be wider. The range is satisfactory as is, however.

Nineteen tubes in mounts were given dynamic tests during the quarter. Sixteen of these passed test and were turned over to the computer group to form the first storage-tube bank. Three tubes were rejected, one for susceptibility to shock and two for bad areas on the surface. These areas did not show up in TV tests; under dynamic tests, however, they would not give satisfactory operation.

4.13 Storage-Tube Development

4.131 Construction of Simplified Tubes

We are now able to make 18-pin hard-glass stems in whatever quantity we may need. Using these stems, two single-neck tubes were made during the quarter. The first of these, RT124, contained a 100-mesh mosaic and a 3RP, instead of the usual 5UP, high-velocity gun. This tube, shown in Figure 3, was made from a transmitter-tube envelope blank to reduce glasswork. Although successful, this blank is too thin for safe use, and thicker blanks will be procured in the future. The second tube, RT126, had a 5UP gun and a built-up envelope, but otherwise it was identical to RT124. Both of these tubes had about the same performance as equivalent two-neck tubes. This method of construction will probably be used in new-model tubes.

4.132 Storage Density Research

Storage density research may be divided into two parts:

1. Gun Studies

Work continues on measuring current distribution and deflection defocusing for high-velocity guns. Tests have not revealed any great advantage of the 3RP and 7GP guns over the standard 5UP gun. The use of multiple holding guns to obtain greater and more uniform holding-current density is being investigated.

A thesis has been undertaken to investigate the effect of angle of incidence and deflection angle on the read-out signal from storage tubes. This investigation is being made on special tubes with movable surfaces.

2. Mosaic Studies

Several research tubes of the 200-series type but with 60- and 100-mesh mosaics have shown improvements in spot uniformity and static storage ability over the 40-mesh tubes. Their dynamic storage ability, however, is not very much better than that of the 40-mesh tubes. A detailed study of the dynamic density limitations in both short-throw, fine-mesh tubes and the standard long-throw, coarse-mesh tubes is now under way in the reliability tester.

An attempt is being made to isolate the several effects of mosaic square size, width of mica between squares, and percent beryllium on the surface.

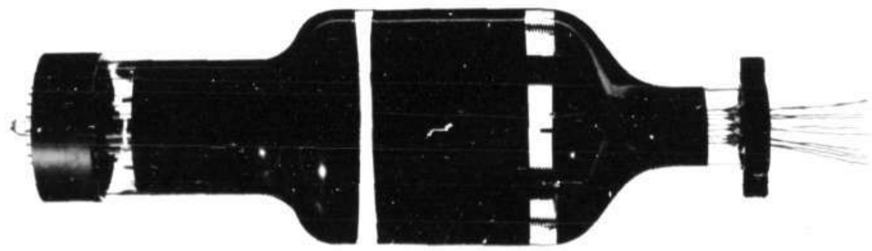


Fig. 3. Experimental single-neck storage tube.

5. INPUT - OUTPUT

5.1 PROPOSED TERMINAL EQUIPMENT

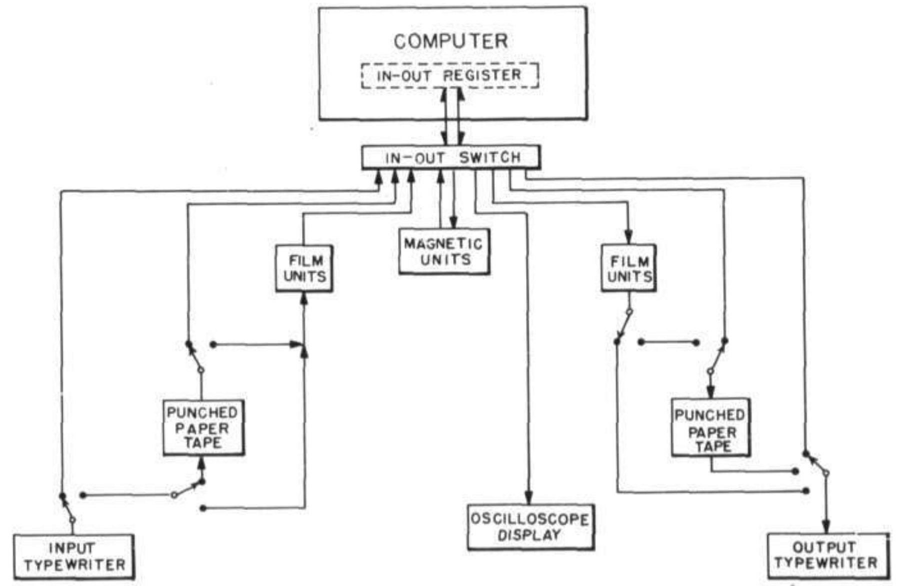
The integration of terminal equipment with the Whirlwind computer will continue for the next year. Certain terminal devices are necessary to perform any useful work with the system and will be installed first; additional equipment will serve to increase the flexibility of the computer or to adapt it to a particular problem.

The input-output requirements have been studied and a proposal has been made for the minimum amount of terminal equipment needed to make the computer useful in handling general problems. Input equipment for the minimum system (see the accompanying figure) includes (1) a typewriter for inserting orders and numbers into Whirlwind storage, (2) film units for recording orders and numbers on film from a typewriter and for reading the film at a later time into the computer storage, and (3) apparatus for preparing a punched paper tape from a typewriter, and for reading the tape onto film or into storage at a later time. The output equipment includes (1) a film recorder, (2) a typewriter, (3) a paper-tape punch, and (4) a versatile oscilloscope display.

Either the recorded film or the punched tape could be used at a later time for preparation of typed copy. At least three oscilloscopes would be provided, two for visual display and one for photographic recording. They would be capable of tracing lines, circles, and ellipses of controllable size at any point on their screens, so that complex plots including coordinates could be shown. An erasable magnetic-type storage would provide an intermediate-speed high-capacity memory. In general, all communication with the computer would be by means of the input-output register, and the proper terminal unit for a given transfer would be selected by a suitable crystal-matrix switch.

5.2 INTERIM SYSTEM

Since sufficient manpower was not available for immediate work on the design of the complete minimum system outlined above, an interim system has been defined which is scheduled to be completed in the summer of 1950. This includes (1) equipment for preparation of checked punched paper tape from a typewriter keyboard, (2) facilities for reading this paper tape either into Whirlwind storage or onto film by means of the in-out register, (3) equipment for preparing punched tape or typed copy of computed results, (4) one film unit to be used as a reader and one as a recorder, and (5) a



PROPOSED MINIMUM SYSTEM OF INPUT-OUTPUT TERMINAL EQUIPMENT display oscilloscope in which the computer can control both the horizontal and the vertical deflections.

Design work is being carried out on both the input tape-preparation equipment and the output typewriter and tape-punching equipment. Flexowriter automatic typewriter equipment with suitable controls will be used for these functions. Work on other units of the minimum system will be undertaken as manpower permits. It is recognized that priorities for these units will be determined largely by the applications to be studied.

5.21 Tape Preparation

Flexowriter equipment uses a 7-hole tape (not counting the feed hole), in which 6 holes will be used to form codes for the typewriter characters and the seventh for control purposes. In transferring Flexowriter code, rather than binary, into Whirlwind storage, two 6-digit Flexowriter code groups will be inserted into one register, so three 16-digit Whirlwind registers will be required to store either an order (2 alphabetical characters and 4 decimal characters) or a number (sign and 5 decimal characters) before conversion to binary. It is planned that the final input punched tape will be prepared in such a way that all operations are checked and as many sources of error eliminated as possible. This corrected tape will be obtained as follows:

a. An initial punched tape will be prepared by an operator at a standard Flexowriter typewriter and punch.
b. The initial tape will be compared line-by-line with a second typing by a second operator at a second typewriter. Only if the two characters agree will a final tape be punched.
c. To provide checks on the final punching operation and also on the subsequent reading of this corrected tape, the complement of each character will be automatically punched in the line following that of each corrected code group. Two lines of holes, therefore, are required for each character.

The typewriter input system is being designed to handle pure binary numbers as well as coded characters, so that words which do not require conversion can be inserted into the computer. Two methods will be provided for doing this. In the first, one typing operation and hence one 6-hole group, or two lines on the corrected tape, will represent one binary digit. Only two of the keys on the typewriter, 0 and 1, will be used, but 16 typing operations will be necessary to record information for filling one Whirlwind register. In the second, one typing operation, or one 6-hole group, will contain 4 binary digits. In this case, 16 typewriter characters will be needed to represent all the binary numbers, but only 4 typing operations will be required to make up a 16-digit binary word.

The design of the tape-preparation equipment described above is now essentially complete. Relay circuits for controlling the action of a tape reader in scanning the initial tape, and for controlling a perforator in punching word and complement groups in the final tape, have operated satisfactorily in breadboard tests.

5.22 Tape Reading

Since an Eastman-Kodak film recorder requires that single words be transmitted to it at a video rate determined by the unit itself, a high-speed shifting register is required for this type of recording. For the initial system, then, the corrected punched tapes will be read into the Whirlwind in-out register. Once data are in this register, they are available to the computer as direct input or they can be recorded on film for later input. The transfer of data from punched tape to the in-out register will be checked by reading the complement code groups into the comparison register following each transfer to the in-out register and determining that the contents of the two registers agree. The tape-reading equipment will utilize a Flexowriter tape reader with associated control circuits for handling either binary numbers or coded typewriter characters.

5.23 Output Printing

Other equipment is being designed to allow transfer of data from the in-out register to a Flexowriter printer or to a tape punch. With this equipment, information can be brought out directly from the computer or it can be obtained from a recorded film. Two modes of operation are being provided, one for handling Flexowriter characters whose codes have been previously formed within the computer by a suitable conversion program, and another for handling pure binary numbers, printing them in binary form. The output punched tape will contain both word and complement codes for each character represented, so that it can be used later for an input tape, if desired.

As with the input-tape preparation and reading equipment, all information transfers will be thoroughly checked insofar as practicable. In the output printer this checking will be carried only as far as the solenoids which activate the key levers on the instrument. It is felt that, at present, the added accuracy that might be obtained by including the mechanical action of the printer in the checking loop would not justify the extensive modification to the instrument that would be required.

Detailed circuit design of the output printing and tape-punching system is nearly complete, but no breadboard tests have been made. Construction of the control equipment needed and initial tests on the system will be accomplished during the next quarter.

5.3 ANALOG-DIGITAL CONVERSION

A recent master's thesis describes two analog-digital conversion devices developed for use with high-speed digital computers: a coder which converts shaft positions into binary pulse-coded numbers, and a decoder which converts binary pulse-coded numbers into voltage amplitudes.

The coder performs its conversion in three steps:

1. The shaft position is converted into a phase-modulated signal by a synchro control transformer.
2. The phase-modulated signal is converted to a pulse-position-modulated signal (PPM) by electronic clipping and peaking circuits.
3. The PPM signal is converted into a binary pulse-coded number through the use of a binary counter. Tests indicate that the coder will convert a shaft position into the corresponding binary number in 250 microseconds.

Accuracy of one part in 360, sensitivity of one part in 1000, and good reliability are achieved.

The decoder operates in four steps:

1. The binary number is converted to a PPM signal by the use of a binary counter.
2. The PPM signal is "held" by regenerating pulses in two special multivibrator circuits.
3. The held PPM signal is converted into a gate-width-modulated signal.
4. This signal is integrated by a low-pass filter to obtain a voltage amplitude which is proportional to the binary number to be decoded.

The decoder also has provision for electronic switching, so that the equipment needed for step 1 can be common to a large number of output channels. The total decoding time is at least 150 microseconds. The decoder will hold the number for periods up to five hours. It has an accuracy of one part in 250.

6. MATHEMATICS, CODING, AND APPLICATIONS

6.1 STANDARD AUTOMATIC SUBROUTINES

6.11 Built-In Operations

A digital computer is theoretically capable of performing any task which can be described by a program of arithmetical and logical (yes-no) operations. Before the program can be carried out by the computer, it must be translated, or coded, into a series of orders, or coded program, which the computer can interpret. Each different order instructs the computer to perform some one function, e.g., add, subtract, transfer to storage, transfer control. Only a few such orders are indispensable. In fact, a single two-address order, properly chosen, is sufficient to code any program. In the usual order code (list of operations which the computer is capable of performing), however, a fairly large number of different orders are included to facilitate the coding and to speed up the computer.

In Whirlwind I an order is represented by 16 binary digits, 5 to determine the operation to be performed and 11 to determine the storage register involved. The 5 digits of the operation section permit distinguishing between at most $2^5 = 32$ different operations, of which 25 have already been definitely assigned (cf. Section 6.3). The present code (see Summary Report 21) includes not only basic orders such as addition, subtraction, and comparison, but also multiplication, division, and multiplication by a power of 2 (i.e., shifting). All of the latter can be synthesized out of the more basic operations of addition and subtraction, so that their inclusion as built-in operations to be performed automatically in response to one order is a matter of convenience and time saving rather than logical necessity.

6.12 Programming the Operations Not Included in the Order Code

Other frequently-needed operations such as square-rooting, evaluation of trigonometric, logarithmic, and exponential functions, integration, and the like, have not been built in. Any of these operations can be synthesized from the built-in operations just as multiplication can be made up out of additions. For examples, routine methods for evaluating square root, sine and cosine, and exponential and logarithm have been coded in detail and are described in C-70, C-77, and E-170 respectively. In principle, then, no difficulty arises from the omission of some frequently-needed operations from the order code (and of course some must be omitted if the order code is to be of any reasonable length and the computer of any reasonable size). But in practice the necessity for writing down a long sequence of orders every time such an operation is needed is wasteful of a programmer's time and patience.

6.13 Standard Automatic Subroutines

Many of the advantages of having a built-in order for the evaluation of any frequently-used function can be had at little cost if the routine for evaluating each such function can be written once and for all and made available automatically to any given program. Standard forms of such routines which will be automatically available for use as subordinate parts of larger main programs are known as standard automatic subroutines. A standard automatic subroutine can be written to direct the computer to perform any computational chore. Once written, the subroutine can be used almost as easily as an equivalent built-in order, with resultant saving in the programmer's time. In effect, the use of standard automatic subroutines gives the person doing the coding an opportunity to select for himself from a practically limitless group of subroutines, and with practically no effort, an "order code" suited to the problem at hand. If the subroutine he wants is not available, he may quite easily write it himself or request that it be written. The steps required of the programmer are described in the examples in Section 6.15. The means by which the selection and use of standard subroutines have been made automatic are summarized briefly following the example.

6.14 Comparison of the Three Methods

Standard automatic subroutines have much to recommend them, so much in fact that extensive use will undoubtedly be made of them in programming for Whirlwind I. In all fairness, however, it should be realized that a standard automatic subroutine has some drawbacks when compared to the two other possible ways of achieving the same result — i.e., compared to a built-in operation or compared to writing down the sequence of orders each time it is needed.

From the point of view of computing time, the automatic subroutines are least efficient. Programmed evaluation of a function is necessarily more time-consuming than built-in evaluation if only because more storage access times are required to get at the several orders in the sequence than to get at the single built-in order. Furthermore, the process of making the subroutine automatic (i.e., the red-tape orders involved) makes the time required for a reference to an automatic subroutine even longer than would be required if the evaluation sequence were written out in full every time it was needed.

Looked at in terms of the storage capacity required, a standard automatic subroutine comes out second best. Since the orders in the subroutine must be stored in some group of registers, the subroutine naturally requires more storage than a built-in operation; but because a subroutine need be stored only once, it uses less storage than if it were written out and stored in full in several different places in a program.

From the programmer's point of view the standard automatic subroutine is as easy to use as a built-in order and incomparably easier to use than a sequence which must be written out in full each time.

In the few special applications in which computing time and/or storage capacity are of paramount importance, more tedious programming or a more elaborate computer may be required, for here the standard automatic subroutine is *not very helpful.*

But for a general-purpose computer, the programmer has first priority — the whole purpose of such a computer is to reduce human effort. Since including all possible operations in the computer order code is obviously out of the question, there can be little doubt that use of standard automatic subroutines is of great value.

6.15 Examples of the Use of Standard Automatic Subroutines

In actual practice for the Whirlwind computer, standard automatic subroutines will be written as needed, and once written will be recorded on photographic film by an Eastman-Kodak recorder. A catalog of the various subroutines available in the library, each with its own catalog number, will be maintained. The catalog will include all the details — the length of the subroutine in terms of storage and time, the information to be supplied to it, and the result which may be expected. For *example, one listing might be:*

#37 — Evaluation of sin x for x in revolutions

Data:	x in revolutions assumed to be in AC, $-1 < x < +1$
Results:	sin x to be left in AC (± 1 to be represented by $\pm 1 \mp 2^{-15}$)
Accuracy:	$\pm 2^{-14}$
Length:	52 registers; 28 operations

If a programmer needed to evaluate sin x at some point in his program he would first determine the catalog number (in this example, #37) of the desired subroutine. He would note that 52 storage registers are required and he would reserve a space of 52 consecutive storage registers (say, for example, 926 to 977) to accommodate the subroutine. He would make special note of the address of the first register of the 52 reserved registers — namely 926. At the end of the coded program he would write

A 0926

S 0037

which indicates that standard automatic subroutine #37 is to be selected automatically by the computer from the library film and stored automatically beginning at register 926.

Any program, even a subroutine, must originally be written as if it were to be stored in some specific group of registers, and the address sections of most of the orders will refer to other orders or numbers within the subroutine. Consequently, if a subroutine written to be stored in a specific group of registers is to be stored instead in some arbitrary group of registers, the address sections of all the orders must be examined and changed if necessary to adapt the subroutine to its arbitrarily assigned location. Thus the computer must perform not only selection of the desired subroutines but also adaptation of them. But none of these complications need concern the programmer using the standard automatic subroutines.

First Example

Assume that the hypothetical programmer in our example has noted down the A 0926, S 0037 *symbols and that his program has reached the stage* at which x is in the accumulator (AC) and sin x is wanted. He then need only write down the one order

sp 926

and the job is done. The result of this order is the same as if he had ordered "find the sine of the contents of AC". The sp order transfers control to register 926, where the sine of x is evaluated. Provision is made within the subroutine to return control to the proper point in the main program — i.e., to the register next after the register which contained the sp 926 order. The return of control is made correctly regardless of the number of different places in the main program at which the subroutine is referred to (i.e., regardless of how many different times the sp 926 order is used). Notice that if the programmer had decided to reserve registers 1389 through 1440 rather than 926 through 977 for the subroutine, the order for finding the sine would be sp 1389 rather than sp 926.

Second Example

Suppose, though, that a subroutine is desired to find the product of two double-length numbers (a double-length number is a 30-binary-digit number stored with the leftmost 15 digits in one register and the *rightmost 15 digits in the next register).* The multiplier, multiplicand, and product each occupy two registers, so that none of them may be stored in AC. In this case, it is possible either (1) to store the multiplier and multiplicand in two prearranged pairs of registers and to expect the product in a third prearranged pair, or (2) to leave the multiplier and multiplicands in whatever two pairs of registers are convenient and to expect the product in a third arbitrarily assigned pair of registers (i.e., any or all of these registers may be assigned differently at each new use of the subroutine). The second alternative is quite obviously more flexible than the first, but it requires supplying the necessary addresses to the subroutine each time it is used. A subroutine which must be supplied with three arbitrary addresses is called a 3-address subroutine (by analogy, the subroutine like the one for finding the sine is called a 0-address subroutine, and of course there may also be 1-address, 2-address subroutines, etc.). Suppose, for example, that the multiplier is stored in registers 762 and 763 and the multiplicand in registers 846 and 847, and the product is wanted in registers 114 and 115. Suppose, further, that registers 950 to 991 are reserved for double-length product subroutine. The only orders necessary to initiate the double-length multiplication are

```
sp 950
ri 762
ri 846
ri 114
```

As before, the order sp 950 transfers control to the desired subroutine, which has been stored in registers 950 to 991 automatically by the computer when the problem was set up. The three orders following the sp 950 are dummy orders (operation ri is ordinarily used only for setting up the computer for a new program — it is used here because its 5-digit representation is 00000). Only the address sections of the orders are meaningful. The subroutine itself contains the orders which take these addresses and put them into the proper orders further along in the subroutine. In other words, the programmer need not provide means to put the arbitrary addresses into the subroutine; he need only write the addresses down in a location uniquely defined for each sp order — i.e., i[illegible] the storage registers next after each sp order.

6.16 Mechanization

The detailed mechanics of the programs needed to make automatic the selection, adaptation, and use of standard automatic subroutines are being described in a series of Engineering Notes (e.g., E-329: Techniques for Using Standard Automatic Subroutines).

Adaptation is facilitated by writing every standard automatic subroutine as if it were to be stored in consecutive registers starting at register 1024 with all orders at the beginning and numbers at the end. Furthermore, each subroutine when stored on film will be preceded by three recorded words giving the catalog number, the total number of words, and the total number of orders in the subroutine. Since the first so-many words of the subroutine are orders, the adaptation program can then examine each order in turn. If the address section of the order is less than 1024, that address evidently refers to a number of shifts or to some external device and not to a storage register associated with the subroutine. Therefore, if the address is less than 1024, the order should not be changed. If the address is 1024 or greater, the address is adapted by subtracting 1024 (the address at which the subroutine was first intended to start) and adding the number of the register in which the subroutine is now to start.

In the use of standard automatic subroutines, it is assumed that each subroutine will have available the correct return address each time that subroutine is referred to from any arbitrary point in the main program. This is mechanized in WWI by a special feature of the sp operation which stores the address of the register next after the one which contains the sp order itself in the A register (AR). A ta order can then be used at the beginning of the subroutine to transfer the address from AR to any desired location within the subroutine. Without this feature of the sp operation, it would be necessary for the programmer actually to send the return address to the subroutine before transferring control to the subroutine. The process of storing extra addresses in dummy orders in the registers immediately following the sp order can, however, be used without any special operations in almost any computer.

6.2 PROGRAMS PERFORMED USING TEST STORAGE

6.21 Investigations

Because of the limited capacity of the 32 registers of test storage now available, no very ambitious programs are being performed on Whirlwind I as yet. Several simple programs, described in Summary Report 21, were written some time ago to provide a demonstration and to provide experience in using the computer. At present, methods are being worked out to give a preliminary solution of problems to serve as a guide in writing finished programs. If the general behavior of a solution can be determined in advance, the programmer is greatly aided in adjusting scale factors and the like. Consequently, approximations to various differential equations by crude but simple extrapolation methods and evaluation of common functions through their difference equations (e.g., $e^{nh} = e^{h}e^{(n-1)h}$) have been used quite successfully to obtain the desired quick approximations.

6.22 Practical Problems

A program was written to obtain a plot of a

fourth-degree polynomial and hence the approximate roots which a member of this Project happened to need. Other simple practical algebraic problems proposed by people at MIT as well as at this Project will be undertaken shortly.

6.23 Confirmation

To obtain a confirmation of the method to be used in a standard automatic subroutine for evaluating the square root by three iterations of Newton's method, the programmer who worked out the subroutine wrote a special version which would fit into 32 registers and which would direct the computer to evaluate the square root of x, square the result, subtract x, and take the magnitude of the difference. The program then caused the computer to perform this task for all values of x between 1/2 and 1, in steps of 2^{-15}, and to keep count of the magnitude of the difference between x and $(\sqrt{x})^2$ in each case. For the 16382 numbers tried, 9015 gave a difference of 0×2^{-15}, 7226 gave a difference of 1×2^{-15}, and 141 gave a difference of 2×2^{-15}. The total computation, including counting the errors, took 8.3 seconds to perform, using the test storage with an access time shorter than that of the initial electrostatic storage.

6.24 Displays

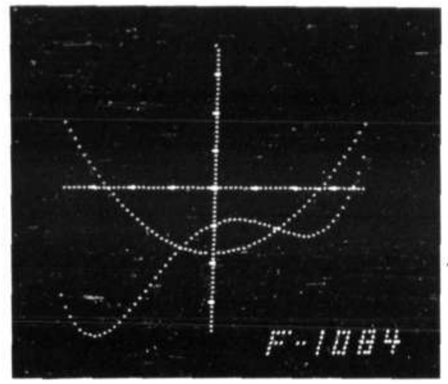
In order to investigate and to demonstrate how cathode-ray-tube displays can be made quite useful, programs were written to plot calibrated axes and to write letters and numbers on the scope face, all under the direct control of the computer (i.e., each point was plotted separately by the computer). One need hardly point out the value of using such axes to provide accurate scales and of writing letters and numbers to identify displays and make them readily intelligible. A photograph of two simple curves with these added features shows the effectiveness of the cathode-ray tube used as a high-speed plotting table by a computer.

6.3 ADDITIONS TO THE ORDER CODE

6.31 Operation ck: Check

One new order has been added to the order code during the past quarter. This is operation ck (check), which has been in use on a temporary or trial basis (called qc) for some time and has proven its usefulness. It will be needed in many programs such as the initial conversion program and consequently is given permanent status at this time.

Operation ck uses the check register to perform an identity comparison of the content of the accumulator with the content of the storage register indicated in the address section of the ck order. While such a comparison could be performed in other ways (in the accumulator, for instance), the



Curves, axes, and identifying symbols
on display scope

The 32 registers of test storage are s[illegible]ficient only to generate the axes and solve the equations of the curves. The legend was generated by a separate program and two exposures superposed.

simple and direct procedure used here seems highly desirable, since it saves operations and time and also minimizes the amount of equipment which must be relied upon in performing the check.

If the content of the accumulator is not identical with the content of the indicated storage register, the result is a transfer check alarm which stops the computer. There is no need to provide a special alarm light for this operation, as the nature of the alarm can be readily determined from the settings of the control switch, time-pulse distributor, program counter, etc., which are left unchanged when the computer stops.

The check order has been of great value already, as is illustrated, for example, in Test Program I (E-295) and Test Program II (E-296), in both of which check orders (then called qc) make up about 30 percent of the program.

6.32 The Temporary Operations

For purposes of testing and display, several different operations have been temporarily wired into Whirlwind I, using some of the seven as-yet-unassigned positions of the 32-position control switch (which selects the desired operation). For various reasons these operations may not be retained permanently. Hence temporary operations must not be used in any productive program (i.e., a program intended to yield useful results) unless circumstances are such that the programmer knows for certain that the temporary operation will be retained long enough to avoid the need for rewriting his program.

All temporary operations are distinguished by a first letter q in the two-letter code designation.

Because these orders are used in test and display programs, their functions are summarized in the table below, along with operation ck. The order code as described in Summary Report 21 and in E-235 is unchanged except for these additions.

ADDITIONS TO THE ORDER CODE

The code as summarized in Summary Report 21 is unchanged except for these additions.

Permanent order:

Order	Operation			Function
	Name	Code		
		Decimal	Binary	
ck x	check	11	01011	Stop the computer and ring an alarm if the contents of register x is not identical with the contents of AC; otherwise proceed to next order.

Temporary orders now in use, but not to be used in final coded programs:

Order	Operation			Function
	Name	Code		
		Decimal	Binary	
qh x	h-axis set	6	00110	Transfer contents of AC to register x; set the horizontal position of the display scope beam to correspond to the numerical value of the contents of AC.
qd x	display	7	00111	Transfer contents of AC to register x; set the vertical position of the display scope beam to correspond to the numerical value of the contents of AC; intensify the beam to display a spot on the face of the display scope.
qe x	exchange	13	01101	Exchange the contents of AC with the contents of register x (original contents of AC to register x, original contents of register x to AC).

NOTES:

Check order. This order cannot be used for anything but an identity check. It is intended primarily for use in special test problems and in spot-checking to assure reliability, especially in handling film units.

Display orders. The qh operation sets horizontal deflection and leaves it set until the next qh. A new vertical deflection must be provided each time a spot is displayed by qd. The qd operation can be used without a qh operation by allowing the horizontal deflection to be provided by a linear time-base sweep generator in the display scope, in which case computed values can be synchronized with the sweep by allowing each new sweep to cause the computer to start over at the beginning. In any one program either the qh or the time-base (not both) is used, the proper one being chosen by manually setting a switch. The temporary display orders will be replaced later by using operation rf to select the device and rc to put the number into it.

7. APPENDIX

7.1 VISITORS

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

Dr. C. B. Tompkins of George Washington University and Cmdr. A. T. Magnell of the Office of Naval Research, to discuss the application of digital techniques to the problem of logistics.

Mr. J. Presper Eckert, Jr., and Mr. J. R. Weiner, of Eckert-Mauchly Computer Corporation.

Dr. G. C. Comstock, Mr. J. W. Marchetti, Maj. D. T. Cella, Mr. A. F. Donovan, Maj. T. F. Walkowicz, and Prof. G. E. Valley, Jr. representing the Air Force's Scientific Advisory Board.

Mr. C. O. Beum of the Bureau of Personnel, U. S. Navy, whose work includes both personnel bookkeeping and psychometry.

Mr. J. D. Noe of the Stanford Research Institute, interested in automatic trouble location and maintenance.

Dr. G. A. Korn and Mr. W. W. Lindsay, Jr., of Lockheed Aircraft Corporation, who were investigating simulation techniques.

Sir Charles Wright of the British Joint Services Mission.

Dr. John von Neumann of the Institute for Advanced Study, Mr. W. A. Bruce of the Carter Oil Company, Mr. T. V. Moore of Standard Oil Development Company, and Professor W. K. Lewis of MIT, whose interest is in calculations on reservoir problems in the oil industry.

A group from Professor Kopal's (MIT) class in numerical methods.

Mr. J. Katz of the University of Toronto, where a small, general-purpose electronic digital computer is being designed and built.

Dr. Warren Weaver of the Rockefeller Foundation.

Dr. G. W. Patterson, Mr. S. E. Gluck, and Mr. H. J. Gray of the University of Pennsylvania, who discussed components of computing machinery.

Professor P. L. Morton and Mr. D. R. Brown of the computer project at the University of California at Berkeley.

A group under Cmdr. H. A. Arnold from the David Taylor Model Basin, who were interested in the possibility of solving one of their problems on Whirlwind I.

Mr. E. G. Gaylord and Mr. R. E. Lack of the California Research Corporation, who discussed applications of digital computers to oil production problems.

Mr. E. S. Farrow of Eastman-Kodak, Mr. B. E. Smith of S. Morgan Smith Company, Mr. J. W. Crowley of the National Advisory Committee for Aeronautics, Dr. Irvin Stewart of West Virginia University, Mr. F. H. Wells of Aircraft Marine Products, Mr. Isaac Harter of Babcock-Wilcox Tube Company, and Mr. T. H. West of the Draper Corporation, all representing MIT's Visiting Committee for the Division of Industrial Cooperation.

Lt. Cmdr. R. M. Isaman of the Office of Naval Research.

Mr. S. Van Mierlo, Mr. M. Bataille, and Mr. G. Phelizon of the Paris Office of International Telephone and Telegraph.

Dr. Max Knoll and Dr. Paul Rudnick of RCA, to discuss holding-gun design.

Mr. H. T. Engstrom and Mr. W. W. Stifler, Jr., of Engineering Research Associates.

Mr. R. F. Clippinger of Aberdeen Proving Ground.

Dr. J. E. Gorham of the Signal Corps Engineering Laboratories (Camp Evans), interested in our progress in storage tubes and the computer.

Mr. Archibald Brown of Cambridge University, England, whose field is astronomy.

Professor S. G. Lutz, head of the Department of Electrical Engineering of New York University, interested in digital computation in connection with his research work.

Dr. W. Grattidge of the University of Missouri, who discussed cathode interface problems.

Col. A. C. Gay of the Equipment Laboratory at Wright Field.

7.2 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 first quarter of 1950.

No.	Title	No. of Pages	Date	Author
SR-20	Summary Report No. 20, Third Quarter, 1949	48		
R-173	Project Reports of Current Interest (Includes M-936 to M-945)	20	12-1-49	J. N. Ulman
R-174	Mosaic Characteristics of the MIT Storage Tube: SM Thesis (Abstract in E-325)	64	1-23-50	C. Corderman
E-316	The Significance of a Shorter Beam Length for the Whirlwind Storage Tube — Part I: Experimental Results with RT67	3	12-21-49	H. Klemperer H. Rowe
E-317	Flip-Flop Balance Checking in WWI	5	2-23-50	G. Sumner
E-318-1	Tests on a 3JP1 Cathode Ray Tube	2	12-30-49	H. Rowe
E-319	The Significance of a Shorter Beam Length for the Whirlwind Storage Tube — Part II: Fundamental Limitations on Spot Size and Current Density	7	1-3-50	H. Klemperer
E-320	Display Program No. IV: Non-Homogeneous Second-Order Differential Equation	11	1-30-50	C. Adams
E-321	Storage of Pulse-Coded Information (Abstract of SM Thesis)	2	1-10-50	A. Lephakis
E-323	Standard Operating Conditions for 100-Series Whirlwind Electrostatic Storage Tubes	5	1-19-50	R. Everett S. Dodd
E-324	Characteristics of 5UP and 7GP Electron Guns	2	1-24-50	H. Rowe
E-326	Power Distribution, Variable-Voltage Circuits, WWI	14	1-25-50	H. Lee
E-327	Standard Tests for Storage Tubes, Second Division	4	1-25-50	M. Florencourt
E-328	Pulse Transformers and Interstage Coupling in Whirlwind I	11	1-31-50	C. Rowland
E-329	Techniques for Using Standard Automatic Subroutines	15	2-10-50	C. Adams
E-333	Whirlwind I Order Code as of March, 1950	4	3-24-50	C. Adams
E-335	Operation of the WWI Storage Tube Power Supply Control	10	3-22-50	C. Watt
M-936	Project Reports of Current Interest: I. General — Introductory	1	12-1-49	
M-937	Project Reports of Current Interest: II. Systems Work — Block Diagrams	1	12-1-49	
M-938	Project Reports of Current Interest: III. Circuits and Components	3	12-1-49	
M-939	Project Reports of Current Interest: IV. Storage	2	12-1-49	
M-940	Project Reports of Current Interest: V. Test Equipment	1	12-1-49	
M-941	Project Reports of Current Interest: VI. Mathematics	3	12-1-49	

No.	Title	No. of Pages	Date	Author
M-942	Project Reports of Current Interest: VII. Programming and Application Studies	4	12-1-49	
M-943	Project Reports of Current Interest: VIII. Checking and Trouble Location	1	12-1-49	
M-944	Project Reports of Current Interest: IX. Input and Output	1	12-1-49	
M-963	Vacuum Tube Failures During December, 1949	3	1-3-50	H. Frost
M-967	Electrostatic Storage Tube to Program Register Transfer Check	5	1-13-50	R. Mayer
M-969	Accelerated Life Test for Cathode Interface	5	1-19-50	E. Rich
M-976	Collector Interception of Electron Beam as a Function of Angle of Incidence	2	1-24-50	M. Florencourt
M-977	Vacuum Tube Failures During January, 1950	2	2-3-50	H. Frost
M-981	Progress From Storing 16 × 16 to 32 × 32 Arrays	3	2-8-50	H. Klemperer
M-982	Aging of Beryllium Mosaic as Observed on ST112 Life Test	2	2-14-50	H. Klemperer
M-989	SR-1407 Tube Development: Tests on Lots C-9186 and C-9188	3	2-24-50	E. Rich
M-999	Vacuum Tube Failures During February, 1950	3	3-13-50	H. Frost
M-1000	A Proposed Binary to Analog Converter	4	3-6-50	K. McVicar
M-1001	SR-1407 Tube Development: Tests on Lot C-9402	4	3-7-50	E. Rich
M-1012	Nomogram for Calculating Area Ratio of Square Mosaic Patterns	1	3-30-50	R. Shaw

7.3 PROFESSIONAL SOCIETY PAPERS

During the quarter N. H. Taylor delivered a paper on "Marginal Checking as an Aid to Computer Reliability" before the IRE National Convention in New York City. This paper has been published as Project Whirlwind Report R-178.

A paper on the Project Whirlwind electrostatic storage tube by S. H. Dodd, H. Klemperer, and P. Youtz was presented by P. Youtz at the IRE National Convention, and a similar paper was presented by S. H. Dodd at the 1950 North Eastern District Meeting of the AIEE in Providence. These papers were combined into Report R-183.