UNCLASSIFIED

CONFIDENTIAL

PROJECT WHIRLWIND
(Device 24-x-3)

SUMMARY REPORT NO. 17

FEBRUARY 1949

Submitted to the

OFFICE OF NAVAL RESEARCH

Under Contract N5ori60

Project NR-048-097

SERVOMECHANISMS LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Cambridge 39, Massachusetts

Project DIC 6345

TABLE OF CONTENTS

	Page
FOREWORD	1
GENERAL STATUS	3
INSTALLATION AND TESTING OF WWI	3
SUMMARY SCHEDULE	4
LIFE OF VACUUM TUBES IN PULSED CIRCUITS	6
THE WHIRLWIND ELECTROSTATIC STORAGE TUBE	7
CHECKING AND TROUBLE LOCATION	12
Formation of Committee	
Test Problems	
Marginal Checking, Five-Digit Multiplier	
VISITORS	13
APPENDIX: Reports and Publications	15

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 original objective of the Project was the development of a device that would simulate airplanes in flight. An integral part of such a simulator is a digital computer of large storage capacity and very high speed, to provide continuous solutions to the equations of motion of an airplane.

As Project Whirlwind has evolved, applications to other types of simulation and to control have become important. Because the digital computer is basic to all these as well as to important applications in mathematics, science, engineering, and military problems including logistics and guided missiles, nearly all project resources are at present devoted to design of a suitable computer.

The Whirlwind Computers

The Whirlwind computers 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 developed, 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 will use 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. Five special orders expedite the subprogramming of multiple-length operations, so that coding is no more complicated than for single-length numbers, but computing time is substantially increased. 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

Summary Report No. 2, issued in November, 1947, was a collection of all information on the Whirlwind program up to that time. The present series of monthly reports is a continuation of the Summary Report series, designed 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 publications issued during the period covered by this Summary appears at the end as an appendix. Authorized personnel may obtain copies of any of them by addressing a request to the Office of Naval Research, Navy Department, Washington 25, D. C.; or where approval has previously been arranged, to Jay W. Forrester, Project Whirlwind, Servomechanisms Laboratory, Massachusetts Institute of Technology, Cambridge, Mass.

GENERAL STATUS

The WWI arithmetic element and arithmetic control have successfully performed all operations at designed speeds, as discussed in the next section. During March, circuits and voltage control panels will be installed to provide marginal checking in the arithmetic element, which will then be used to obtain data on reliability and operating tolerances.

The most interesting of the new information on the reliability of vacuum-tube computing circuits was obtained in a 25-day trial run on the 5-digit arithmetic element, as described in the section on Checking and Trouble Location. Eighteen days were error-free, and during one run of 9 consecutive days the equipment performed 10^{10} multiplications without errors from any source.

Project personnel and facilities are being concentrated on the completion of the WWI computer; for the present longer-range research is being postponed. Magnetic recording, which has been carried at a one-staff-member level (Summary Reports 3 and 8), has been terminated, and mathematics research has been curtailed in order to make staff time available for the design of trouble-location and test problems.

The Servomechanisms Laboratory has been asked by the Air Forces to study the use of high-speed digital computers in air traffic control. Some members of the applications and mathematics groups will be transferred to that work.

As the completion of WWI approaches, plans for its use must be formulated, and these will be discussed in future Summary Reports. An increasing proportion of the Laboratory effort will be devoted to research in the applications of high-speed digital computers, with special emphasis on control and simulation. Use of the equipment for scientific and engineering purposes will probably be on a cooperative basis with other groups interested in digital computer applications.

INSTALLATION AND TESTING OF WWI

During the month of February, system testing of the arithmetic element consisted of examination of individual arithmetic operations. Test control (see Summary Reports 13 and 15) provided two toggle-switch input registers and the necessary sequence of control pulses.

Two 15-digit binary numbers were successfully divided at a 1-megacycle pulse repetition rate. High-speed multiplication and division having been performed, the simpler arithmetic operations — shift-right, shift-left, add, and subtract — were done at normal operating speeds without difficulty. Only minor design changes were necessary to establish the correct operation of <u>scale factor</u>, which determines location of the first one to the right of the binary point, and <u>special add</u>, which permits the addition of double-length numbers. Thus all arithmetic operations have been found to function satisfactorily. A study to improve operation margins throughout the arithmetic element remains to be made.

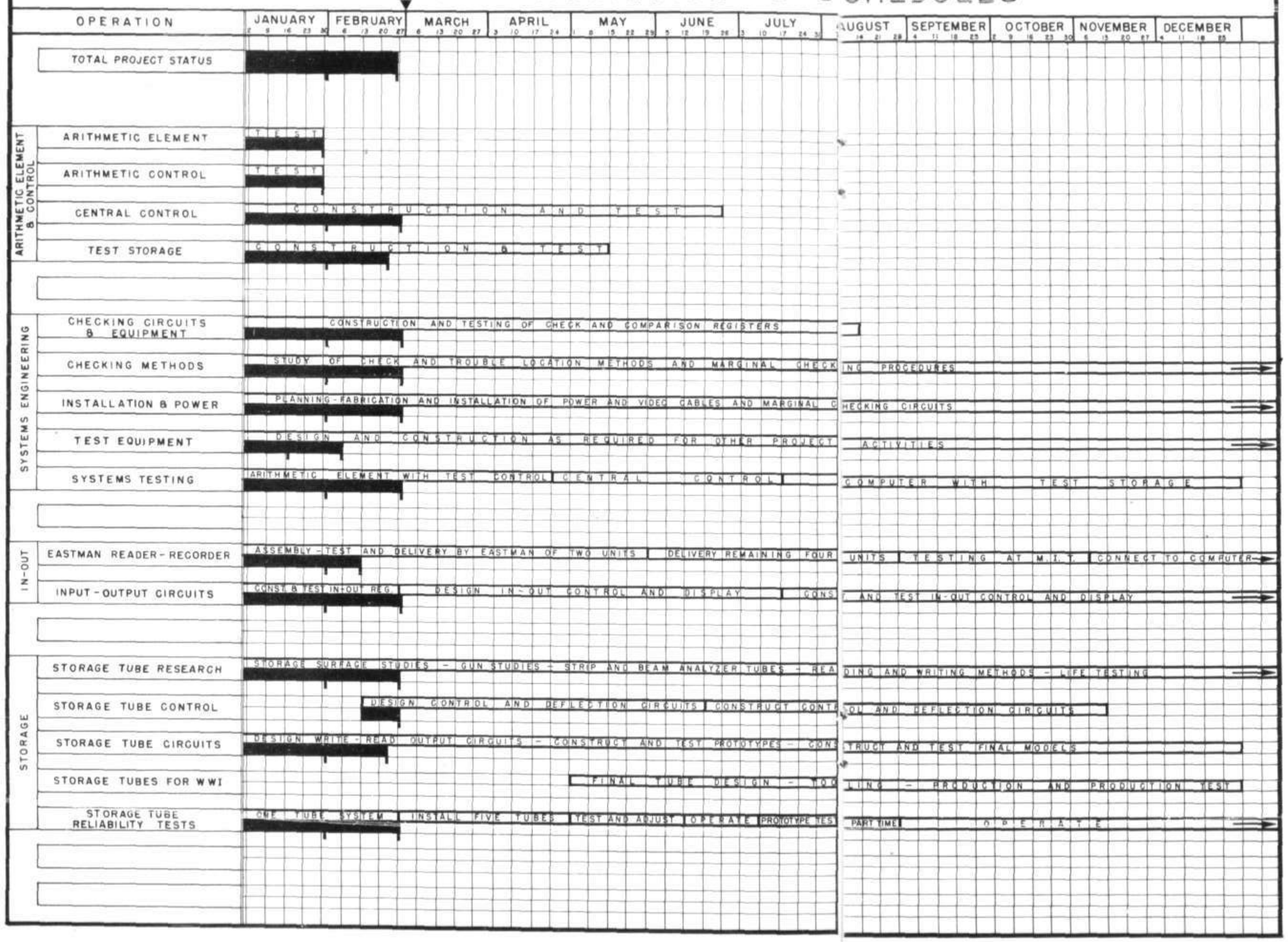
During the initial tests a single operation was followed by a long wait (about 1000 microseconds) which allowed the result to be read from indicator lights. During the wait period all circuits had ample time to recover from any possible effects of the short period of high-speed operation. A new phase of system testing was then undertaken: the performance of a series of high-speed operations without the waiting period. This required the provision of a means for checking the results of each solution of a series. The equipment which will be used to perform such checks in the final WWI was not yet available, but a temporary checking means using the program register as a comparator was set up. At first, errors occurred after the fifth multiplication in a series of high-speed multiplications. Normal operation of WWI will probably never be so severe, but it was thought that to provide a safety factor the circuits should be better than actually required.

Improvement of the band pass of certain circuits allowed the series to be greatly extended. During a one-hour test, over 150,000,000 successive multiplications of two 15-digit binary numbers were performed without error. Circuits used in the other arithmetic operations will be similarly tested.

continued on page 6

APPROVED FOR PUBLIC RELEASE. CASE 06-1104.

SUMMARY - WHIRLWIND I SCHEDULES



LEGEND

JANUARY

Period of one month, comprising the total number of days in the month.

PROTOTYPE

Operation to be performed, and the estimated time allotted for its completion. Estimates made in January 1949.

Indicates extension of the work into next year.

Work done. The ratio of the length of the solid bar to the length of the open bar above it shows percentage of completion at the end of the month.

▼

Date of the latest posting.

Summary line. Shows the overall status of the project.

While other tests are being made, data are being collected in concise diagram form to show the proper signal waveforms throughout the arithmetic element. These diagrams will be of great use in maintenance, in trouble location, and in detecting trends of component deterioration.

By the end of February the following WWI equipment had been installed:

1. The complete arithmetic element
2. The restorer-pulse generator
3. The program register.

Power wiring for the arithmetic element was complete, for flip-flop storage 60% complete.

LIFE OF VACUUM TUBES IN PULSED CIRCUITS

At the beginning of WWI development the need for reliable tubes was recognized as basic. Information on tube life was lacking; therefore life tests on 100 6AG7 tubes, the type intended for use in flip-flops and buffer amplifiers, were begun in July, 1947. It was not until the five-digit multiplier had been operating for about 1500 hours, however, that any tube deterioration became apparent. At this time a flip-flop instability began to appear which was traced to a gradually increasing current unbalance in the two halves of the flip-flop. (See Summary Report 6, March, 1948).

The apparent cause of this deterioration was the gradual building up of an impedance, consisting of a resistance and capacitance in parallel, in the internal cathode circuit of the tube. This was demonstrated by pulse tests of the aged tubes; and the effects could be simulated by similar tests with external cathode networks on good tubes.

The life tests of the 100 6AG7 tubes had been going on all this time; but no significant deterioration in these tubes had been noted after several thousand hours. The differing results may be explained by the differing conditions of operation. The 100 tubes on life test operated at a 0.5 duty cycle, being turned on and off by a 60-cycle square wave on their grids. In the multiplier, one tube of a flip-flop was off about 90% of the time. Professor W. B. Nottingham, of the MIT Physics Department, has suggested that operation of tubes with plate current off for longer periods than it is on may produce a resistive barrier at the interface surface between the nickel sleeve of the cathode and its oxide coating. It might be expected that in buffer amplifiers with a duty factor of 0.02 or less (on only when passing 0.1-microsecond pulses) such deterioration would be even worse. This was indeed so in the five-digit multiplier. Typical average values for plate current in d-c tests of 6AG7 flip-flops and pulsed buffer amplifiers are presented below. (See Report R-139, "Vacuum Tube Life").

Operating condition	No. of tubes	Mean plate current: Initial	Mean plate current: 1500-hr	1500-hr current as percent of initial current
Flip-flops or cathode followers and buffer amplifiers connected to them.	37	42.2	27.2	64.9
Pulsed buffer amplifiers	17	42.5	13.9	32.5

It therefore appears that certain tubes deteriorate faster when used in pulsed circuits than when operated Class "A" (plate current always flowing) or at a high duty factor. Some tube types, however, do not exhibit this characteristic. In the multiplier the 6AS6, a Western Electric pentode, is used as a gate tube at the same low duty factor as the 6AG7 buffer amplifier. No serious decrease in plate current was noted for these tubes after about 2500 hours of operation. Chemical analysis shows no silicon in their cathode sleeves. This was thought significant, and accordingly, in June, 1948, it was decided to change the flip-flop and buffer amplifier tubes in WWI from the 6AG7, the cathode of which contained silicon, to the 7AD7, whose cathode nickel had greater purity. (See Summary Report 9, June, 1948).

During the past 8 months about 4000 hours of life testing have been accumulated on the 7AD7 tubes that replaced the 6AG7 tubes in the 5-digit multiplier. Tubes from two different Sylvania Electric Products Co. production lots were used.

Production lot B8B exhibited the same characteristic current deterioration in d-c tests as the 6AG7's they replaced, and pulse tests showed evidence of the same type of interface barrier. Little silicon, however, was found to be present in the cathode nickel of these tubes. Production lot L7P, on the other hand, showed excellent characteristics. In d-c tests at 2500 hours, 10 tubes from this lot used as pulsed buffer amplifiers, and 8 tubes used as flip-flops, manifested an average plate current decrease of only 4.6% from initial values. This is very heartening data, and much effort is now being put into investigations to find the cause of the difference in the two lots. Some of the studies being made are along the following lines:

1. Sylvania has found that both lots of 7AD7's were made with cathode nickel of low silicon content. The plates of the B8B lot, however, were made from aluminized steel, while the plates of the L7P lot were carbonized nickel-plated steel. This may be a significant factor.

2. Sylvania has completed a series of experimental 7AD7 tubes which it is hoped will point out the reasons for the differences noted. Groups of tubes each of which has a single change from the L7P lot are on life test.

3. During February, 1949, the five-digit multiplier was shut down and all tubes retested. Up to this time, 20 7AD7's had deteriorated to an unusable point, and most of these showed evidence of serious interface trouble. In cooperation with the MIT Physics Department and the Raytheon Manufacturing Company, spectrochemical analyses are to be made of the cathode-nickel surfaces in these tubes to determine just what this apparent interface barrier consists of.

4. In the hope of accelerating the formation of interface resistance for test purposes, a group of 10 7AD7's are currently being operated with 8 volts on their heaters. Five of these have 90 volts on their plates and screens, and zero bias; five have zero plate and screen voltage and a -5-volt bias. A control group of ten are being run under the same conditions, but with 6.3-volt heater voltage.

5. Contact has been made with a number of tube manufacturers. The problem has been presented to them, and they have shown much interest in it. Any useful solution obviously depends on their cooperation. Therefore the efforts of the Laboratory will be directed toward a practical solution, and close contact with the manufacturers will be maintained.

THE WHIRLWIND ELECTROSTATIC STORAGE TUBE

Physical Description

The electrostatic storage tube is a special cathode-ray tube in which binary digits are stored as charges on a dielectric surface. By electrostatic deflection of an electron beam, one of many storage spots on a dielectric plate can be selected (Summary Reports 7, 9). In each of the storage spots the tube can maintain either of two stable states of electrostatic potential. These two potentials, referred to as zero and negative, are taken to correspond to the binary digits zero and one. The tube provides high-speed access to stored information, and no erasing is necessary since new information is established in the tube independently of its prior condition.

Figure 1 is a diagram of the essential parts of the tube. The storage surface is separated by a thin dielectric from a signal plate. In front of the storage surface is a grounded collector screen for the control of secondary electrons. In addition, this screen prevents switching potentials applied to the signal plate from affecting the electrostatic fields inside the tube, and thus prevents interference with the deflecting force applied to the electron beam. The writing-reading gun is an ordinary type cathode-ray gun. It provides a current of 50 microamperes or more which can be directed at the desired location on the storage surface. A second electron source operated at low voltage provides a uniform flood of electrons over the entire storage surface. This holding gun (Summary Report 10) maintains the pattern of zero and negative charges on the storage surface as stable signals, and compensates for electron leakage among any of the charged spots. Current from the holding gun may be as great as 5 milliamperes.

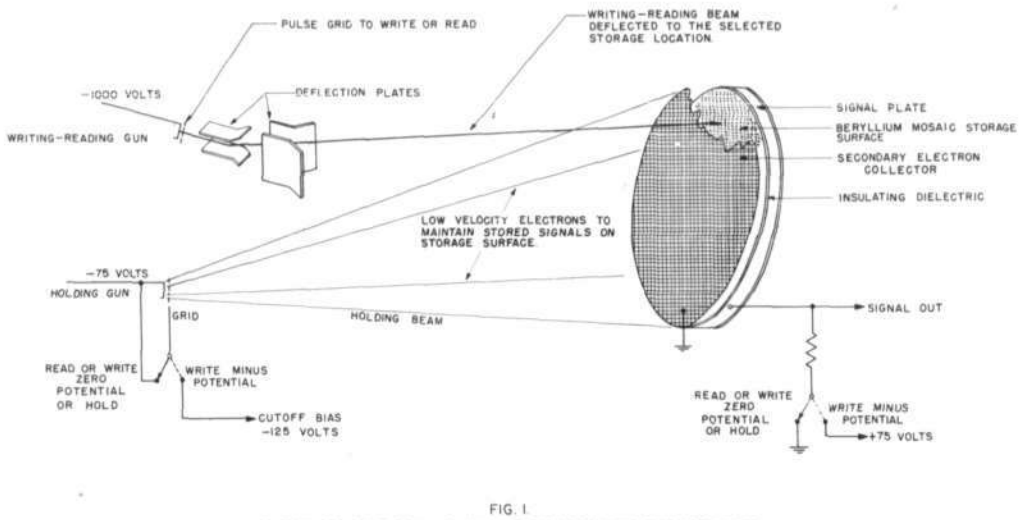


FIG. 1
ELEMENTS OF THE WHIRLWIND ELECTROSTATIC STORAGE TUBE

The storage surface on top of the insulating film is made of a mosaic of small squares of conducting material. In the present tubes this mosaic of about 40 squares per linear inch is made of beryllium evaporated through a wire mesh (Summary Report 12). The writing-reading gun covers many of these squares at one time, so that a single binary digit is stored on a spot consisting of 10 to 20 adjacent squares. The surface is thus essentially continuous (Summary Report 9), so that the deflection system need not be constructed to aim the beam at a predetermined point on the dielectric; it must only make the beam return for reading to the same spot where a signal was written.

Capacity

Research and design have been directed toward a tube which will store 1,024 binary digits per tube as a 32-by-32 array on a portion of the surface 3-3/4 inches in diameter. Tests to date have satisfactorily demonstrated a 16-by-16 array, or 256 points per tube, and storage patterns 11-by-11 on only a small part of the surface show that the 32-by-32 density can probably be obtained.

Speed

The goal for total access time has been 6 microseconds, including the time required to set the deflection circuits as well as the time required for tube read-out. Access time of present tubes ranges from 10 to 25 microseconds. Writing a new number at present requires a few microseconds longer than reading a number.

Life

Life tests are only beginning, but tubes have operated some 500 hours without any apparent change in characteristics. The life of a storage tube can probably equal that of a cathode-ray tube.

Construction Program

In the process of the work to date, 46 research tubes have been made for studying storage surface and electron guns. To provide evaporated surfaces for tests and for storage tubes, 115 evaporation tubes have been processed. Forty-five storage tubes have been constructed for test purposes. Of these the last 12 have been of the type described here and illustrated in Summary Report 12. Defective tubes due to mechanical causes (poor vacuum, open and shorted leads, etc.) have numbered only about 11%, which is very low, even though nearly all tubes have been dissimilar and of special design for differing tests.

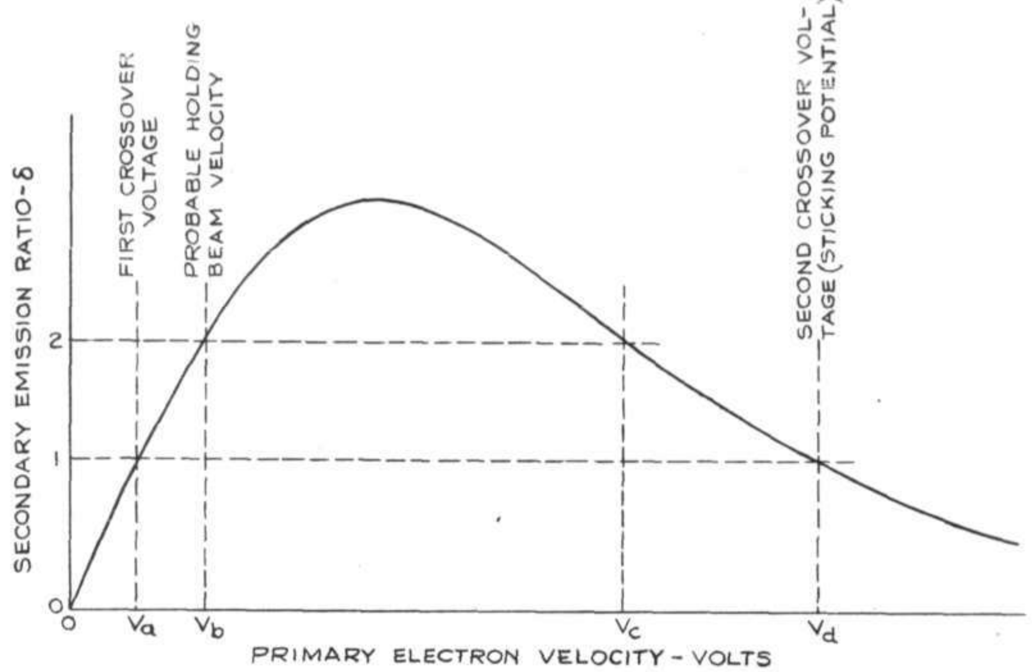


FIG. 2.
TYPICAL SECONDARY EMISSION CURVE

Operation: Basic Secondary Emission Phenomena

When electrons strike a solid surface, low-energy secondary electrons are released. The secondary emission ratio is the ratio of the number of secondary electrons leaving the surface to the number of primary electrons striking the surface. A typical curve of secondary emission ratio as a function of the primary electron velocity is plotted in Figure 2. Below the first crossover voltage the primary electrons have such low velocity and low energy that the number of secondary electrons released is less than the number of primary electrons. Above the first crossover voltage is a wide range in which the number of secondary electrons released is greater than the number of primary electrons. For a satisfactory storage-tube surface, the secondary emission ratio should reach a value greater than 2; and the tube will not function unless the secondary emission ratio is greater than 1.

The behavior of a secondary emitting surface behind a collecting screen presents four possible conditions of importance. These conditions correspond to primary electron velocities less than and greater than the first secondary-emission crossover voltage; and to collector potentials which are positive or negative with respect to the storage surface.

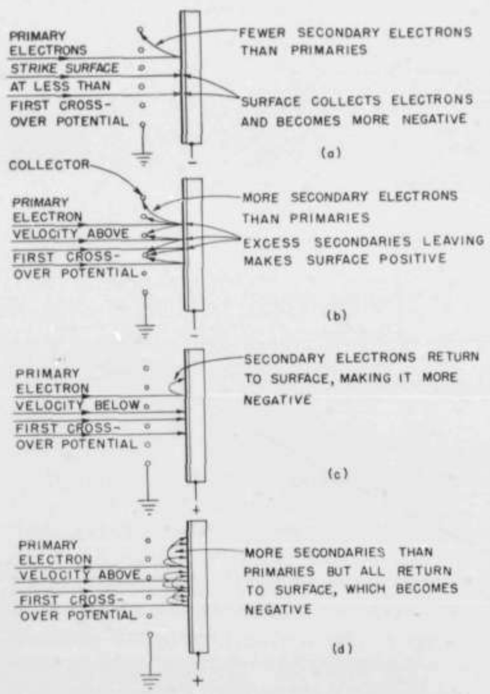


FIG 3
SECONDARY ELECTRON FLOW

Figures 3a, 3b, and 3d correspond to conditions for the holding beam of the storage tube, and Figures 3b and 3d correspond to conditions for the writing-reading beam. In Figure 3a the low-velocity primary electrons release fewer secondaries than their own number. The excess primary electrons remain on the surface and drive the surface more negative, toward the potential of the electron source. When the surface reaches the potential of this source there will be no net accelerating voltage for electrons and they will no longer reach the surface. In Figure 3b the primary electrons are at *higher velocity than first crossover* and release more secondaries than their own number. Enough of the secondaries are collected by the screen to leave a deficiency of electrons at the secondary-emitting surface, which becomes more positive, until it reaches the potential of the collecting screen. In 3c few electrons are liberated by the low-velocity primaries, but those that are liberated are returned to the emitting surface because they are repelled by the field between collector and surface. In Figure 3d the high-velocity electrons release an excess of secondaries. The secondaries are emitted at low velocity and are repelled by the decelerating field between emitting surface and collector so that they are returned to the emitting surface. The surface, therefore, becomes more negative at the rate permitted by electron supply in the primary beam. When the surface of either 3b or 3d reaches collector potential, conditions will be half way between those shown in the two cases, and the secondary electrons collected by the screen will just equal the number of primary electrons striking the emitting surface. It is to be noted that high-energy electrons always change the potential of the emitting surface in the direction of the collecting screen potential as shown in Figures 3b and 3d.

Stored binary digits are represented by spots on the storage surface at potentials of zero and minus 75 volts respectively while the signal plate is connected to ground. If the signal plate is now switched to plus 75 volts, the potential of each spot corresponding to a stored digit rises by 75 volts. In general, the storage surface follows approximately the voltage variations of the signal plate because of the capacitive coupling which exists across the thin dielectric. It is thus possible to change momentarily the potential of the storage surface with respect to the collector screen by switching the signal plate.

Writing

In the writing of zero and negative charges on the storage surface, voltages on the deflection plates of the writing-reading gun first are set corresponding to the location of the spot where a digit is to be written.

Writing of a zero charge: The storage surface will, under bombardment by high-velocity electrons, be brought to the potential of the collecting screen, which is always at zero, or ground, potential. If the storage surface was negative, the high-velocity beam will change it to zero potential. If the storage surface was previously at zero, however, no change will result.

Writing of a negative charge (i.e., the digit one): The signal plate is first changed to a positive voltage. This changes the original negative and zero voltages to zero and positive voltages with respect to the collector screen. The high-velocity beam now brings the storage spot to the screen potential. No change results if the chosen spot was originally negative (zero after signal-plate switching). The spot discharges to collector potential if it was formerly zero (positive after switching). Thus the selected storage spot is established at zero, regardless of its previous potential, and becomes negative when the signal plate is switched back to ground.

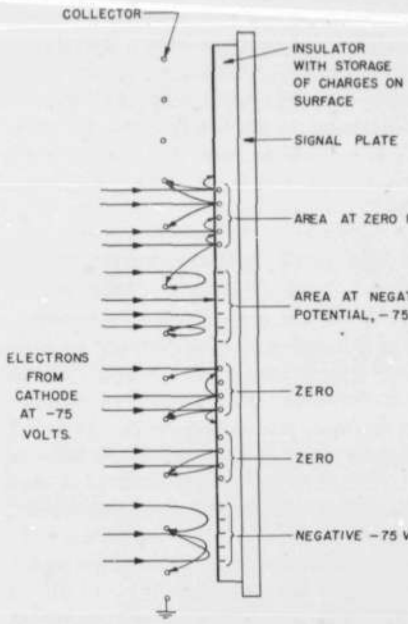


FIG 4
OPERATION OF HOLDING ELECTRONS

Holding

If there were not some mechanism for restoring leakage and compensating for other disturbances, the stored signals would soon disappear. Figure 4 shows several negative and zero spots under the influence of the holding electron beam. These electrons come from a cathode whose potential with respect to the collecting screen is negative by about twice the first crossover voltage on the secondary emission curve for the storage surface. On Figure 2 this holding-beam potential is shown as V_b. In Figure 4 both the zero and negative spots represent stable surface potentials.

Should a spot of zero potential become slightly positive, the conditions of Figure 3d would apply and electrons would be collected until the area returned to collector potential. Should this spot become slightly negative, the conditions of Figure 3b would apply, and electrons would be lost until the surface reached collector potential. It is seen, then, that the zero potential is stable and that any deviations will be corrected.

A negative spot is correspondingly stable. Since it tends to be at the same potential as the holding-gun cathode, electrons will be decelerated as they approach and will arrive with low or zero velocity. If the negative spot becomes slightly more positive than the holding-gun cathode, the conditions of Figure 3a will apply. Primary electrons will strike at a very low velocity, liberating few secondaries, and the collected primaries will drive the spot more negative, toward the potential of the holding-gun cathode. On the other hand, if the negative spot has become more negative than the holding-gun cathode, it then reflects all primary electrons, since they have not enough velocity to reach the surface; and the negative spot will gradually become more positive as leakage to other parts of the tube occurs. Thus the negative spot is likewise stable, and leakage can be compensated by the holding-gun electrons.

During the operation of writing a negative signal, the electrons from the holding gun are cut off momentarily so that they will not disturb the charges on the remainder of the storage surface. If the holding gun were left on during this period, it would tend to change the zero signals to negative signals in the tube.

Reading

Reading is accomplished by deflecting the high-velocity beam to the desired point and examining the change in signal-plate potential when the beam is pulsed. When a zero signal is being read, no change occurs on the storage spot, and no output signal is obtained. When a negative signal is being read, however, conditions correspond to those in Figure 3b, and electrons flow away from the storage spot. By capacitive coupling through the dielectric, the signal plate is made positive and the displacement current is detected as a positive output signal. The video output signal can ideally be as high as 0.75 volt, but may be less than one-tenth this value depending on the nature of the output coupling circuit.

CHECKING AND TROUBLE LOCATION

Formation of Committee

In order to develop effective procedures for use on WWI, a committee has been formed to study methods of checking and trouble location. Tentative staff assignments have been made to investigate the following interrelated phases of this work: (1) checking sequences to determine if the entire computer is operating satisfactorily, (2) trouble-location problems for the isolation of permanent faults, (3) marginal checking procedures to find deteriorating components, and (4) demonstration problems for use with test storage and oscilloscope display which may provide a type of smoothness check. In these studies emphasis is to be placed on the devising of test sequences which are automatic and which require no additional equipment.

In order to coordinate the program with other activities, interested staff members in addition to those assigned to active work on the problem will meet periodically for group discussions of the work in progress.

Test Problems

Problems to be used in testing WWI may be divided into two classes: check problems to tell whether a trouble exists, and trouble-location problems to isolate a trouble once it is known to exist. Each of these classes may be further subdivided into those used in connection with static faults and those used in connection with dynamic faults.

It is comparatively simple to establish the presence of a fault in multiplication or division by a set of three to five problems which when performed in WWI use every stage in the multiplying or dividing circuits. Such problems can be called static check problems, since they check the computer only for steady-state troubles equivalent to the removal of a tube from a socket or a cable from a jack. Marginal checking is intended to transform incipient and intermittent failures into steady failures, thus permitting the check problems to pick up such bothersome troubles.

Dynamic faults which result from rapid repetition of similar operations (so-called pulse-repetition-frequency or prf sensitivity) require a second type of check problem in which certain operations are repeated at the highest possible rate over a long period of time. Such checking requires use of a larger number of different problems than static checking; just how large a number has not yet been determined, but about twenty different problems will probably suffice.

The length of a trouble-location sequence will vary considerably, depending on how closely the scheme is intended to isolate the trouble and also how much additional equipment is used. It seems likely that even with relatively short programs, and with no extra equipment, a fairly satisfactory location of trouble can usually be obtained.

Test problems which have so far been worked out in detail for WWI have not covered trouble location, but have been restricted to problems for

checking the arithmetic element in conjunction with the temporary test control and storage. For this purpose it has been found convenient to check the results of individual steps of multiplications and divisions rather than final answers. In multiplication a complete static check can be obtained by using five problems and checking three or four steps in each. The operands are chosen with more regard to a simple binary form for easy insertion and checking than to ultimate efficiency in reducing the number of problems. Division can be checked by solving four problems and checking the results, the numbers again being chosen for simple binary form. In later check-problem sequences with test storage or electrostatic storage, it may be necessary because of storage limitations to choose efficient problems without regard to binary simplicity, but at present the use of simple numbers seems to be extremely desirable.

It is interesting to note that a problem which turns out to make the most rigorous demands possible on the high-speed-carry circuit is to all appearances such a simple one — the division of one-quarter by one-half — that it was chosen accidently by the systems engineers as the first division ever to be performed on the Whirlwind computer.

Marginal Checking, Five-Digit Multiplier

The initial life run on the five-digit multiplier to test the marginal checking procedures (see Summary Report 15) was started on January 25 and ended on February 18. During this period a total of 505 operating hours was accumulated. About 50 hours (1 to 2 hours per day) was spent in marginal checking, servicing, and study, and there was a 25-hour shutdown period because of a filament-power failure.

The multiplier, which uses 200 vacuum tubes, was solving the problem 31×31 periodically at the rate of 15,000 multiplications a second. At least 18 of the 25 days included in the initial test were completely errorless. Of these, the maximum number of successive errorless days was 9. Some 10^{10} complete multiplications were performed during this period, or about 10^{13} vacuum-tube operations (counting each transit of a pulse through a tube or each triggering of a flip-flop as one operation).

During the test 16 error counts were recorded; of these, at least 5 occurred non-consecutively. Nine errors were traced to transients introduced into the arithmetic element by failure of d-c power indicator lights. One of these occurred the first day of the test, and eight occurred over the week-end which included the 5th, 6th, and 7th days.

Four errors occurred on the 11th and 12th days, and were traced to improper operation of the filament voltage regulator. Three failures during the last 5 days were due to marginal operation of associated test equipment. This marginal operation had been detected before it caused errors, but was not corrected at the time, since it was planned to make some alterations in this equipment at the end of the test.

The indicator lights whose failures caused errors — 4-watt, 110-volt incandescent lamps — were connected to the +150-volt source through a series resistor located at the source end of the line to the lights. This voltage is used on the plates of flip-flops and gate tubes and on the screens of buffer amplifiers. Wires leading to the indicator light and to the terminal strip which distributes power to the tubes on a given digit panel are laced together in a cable for a distance of about two feet. Considerable capacitance exists, therefore, between the indicator-light and the d-c power-distribution circuits. Failure of an indicator light caused the voltage on the wire leading to the light to jump from 110 to 150 volts as the current through the dropping resistor was interrupted, so that a high-frequency transient was capacitively coupled into the power-distribution circuits. This difficulty was corrected by inserting the dropping resistor directly at the indicator light.

VISITORS

During February the Laboratory had among its visitors the following:

Mr. Dwight Ashley, Mr. Ray Bowman, Mr. Kirk Bell, Mr. Howard Barlow, and Mr. Frank Mitchell of the Army Security Agency, who were generally interested in our work and experience.

Mr. John W. Sheetz, Assistant to Dr. Waterman of ONR.

Mr. E. B. Callick of the British Navy Staff, Mr. A. W. Lines of the Telecommunications Research Establishment of the Ministry of Supply, and Mr. C. F. A. Wagstaffe of the Ministry of Supply, who were interested in our vacuum, construction, and processing techniques for storage tubes.

Mr. James Cardell and Mr. R. L. McCormack of Raytheon, and Mr. C. F. Stromeyer and Mr. J. C. Harmony of Hytron, interested in the cathode interface problem.

Mr. Jesse Y. Bowman of North American Aircraft.

Mr. T. C. Chen of Edvac of the University of Pennsylvania, to discuss Whirlwind circuit techniques and test equipment especially.

Mr. W. M. Richardson and Mr. M. C. Long of ONR, and Mr. R. J. Bergemann and Mr. R. W. Hart of the Boston Branch of ONR, to consider vacuum-tube life problems with representatives of this Project and Prof. Wayne B. Nottingham of MIT.

APPENDIX

REPORTS AND PUBLICATIONS

The following reports and memorandums on Project Whirlwind work were among those issued during February:

No.	Title	No. of Pages	No. of Drwgs.	Date	Author
SR-15	Summary Report No. 15	25	-	12-48	
R-143	Specifications for Standard Test Equipment	28	-	1-18-49	R. R. Rathbone
R-153	Electrostatic Storage Tubes for Digital Computers and Other Information Processing Systems (Abstract in E-200)	16	16	1-24-49	J. W. Forrester
R-154	Outlook for Electronic Digital Computers - The Scope of the Engineering Involved (Abstract in E-201)	7	-	2-16-49	J. W. Forrester
E-169	Electrostatic Storage Tube Demonstrator.	23	2	2-49	J. S. Rochefort
E-185	Beryllium Strip Tubes, Test Results on RT 37, RT 38, and RT 41	10	22	12-16-48	J. McCusker
E-187	Influence of Ions on Holding Beam in Storage Tubes	4	1	1-28-49	H. Klemperer
E-189	A Method of Determining Tube Types for Digital Computers	4	1	2- 2-49	H. Kenosian
E-191	Research Tube 50: Construction and Processing	2	-	1-31-49	M. Florencourt
E-192	Testing of Storage Tube 69	2	-	2- 9-49	H. E. Rowe
E-193	Storage Tube 67: Construction and Processing	3	-	2- 9-49	M. Florencourt
E-194	Vertical Parabola through n- Points	2	-	2-14-49	P. Franklin
E-195	Status of Research on Magnetic Recording	8	11	2-14-49	G. Cooper
E-196	Storage Tube 71: Construction, Processing and Initial Testing	3	-	2-14-49	M. Florencourt
E-197	An Investigation of Basic Circuit BA-2	3	5	2-16-49	H. B. Frost
E-198	Storage Tube 64: Construction, Processing and Initial Testing	3	-	2-16-49	M. Florencourt
E-199	Storage Tube 51: Construction, Processing and Initial Testing	3	-	2-18-49	M. Florencourt
M-768-1	Navy Logistics: - Note for Members of the ONR Committee Studying the Application of Computers	7	-	2- 4-49	W. Welchman
M-774-1	Tube Conferences - January 31, 1949	2	-	2- 7-49	E. S. Rich
M-775	Bi-Weekly Report, Part I, 2-4-49	14	-	2- 4-49	
M-776	Bi-Weekly Report, Part II, 2-4-49	16	-	2- 4-49	
M-779	Testing of Storage Tubes 40 and 48	7	-	2- 1-49	C. Corderman
M-780	Study of Checking and Trouble Location Methods	2	-	2-10-49	J. W. Forrester
M-781	Progress Report: A Dual-Triode Capacitively-Coupled Flip-Flop	2	-	2-10-49	M. H. Hayes

No.	Title	No. of Pages	No. of Drwgs.	Date	Author
M-783	Envelope Dagging	2	-	2-10-49	J. S. Palermo
M-785	Progress Report: The Solution of Power Network Performance on Large-Scale Digital Computers	3	-	2-14-49	P. A. Fox
M-786	Physical Electronics Seminar - February 9, 1949	2	-	2-15-49	E. S. Rich
M-788	Suggestions for Mental or Manual Binary Conversion	3	1	2-16-49	C. W. Adams
M-789	Bi-Weekly Report, Part I, 2-18-49	18	-	2-18-49	
M-790	Bi-Weekly Report, Part II, 2-18-49	18	-	2-18-49	
M-791	Tube-Life Investigations	2	-	2-21-49	E. S. Rich
M-794	Conference on Vacuum-Tube Problems - February 17, 1949	2	-	2-24-49	E. S. Rich
C-81	Solution of Problems Stated in C-78	5	-	2-14-49	W. Welchman
C-86-1	Applications Study Group Working Notes, January 4 to January 11	4	-	1- 6-49	W. Welchman
C-94	Example of Coding Procedure	11	-	2-14-49	W. Welchman
C-95	Applications Study Group Working Notes, February 8 to February 15	2	-	2-11-49	W. Welchman
C-97	Applications Study Group Working Notes, February 15 to February 29	2	-	2-17-49	W. Welchman
C-98	Ballistic Problem, Simplified Flow Diagram for Runge-Kutta Method	4	-	2-18-49	T. W. Hildebrandt