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PROJECT WHIRLWIND
(Device 24-x-3)

SUMMARY REPORT NO. 18
MARCH 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

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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 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 and construction 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 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

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, together with instructions for obtaining copies of them, appears at the end as an appendix.

NOTE

The Summary Reports will from now on be issued at quarterly intervals instead of monthly. Thus the next report will appear some time after June 30, covering the second quarter of 1949.

QUARTERLY REVIEW

Arithmetic Element and Arithmetic Control

During the first three months of 1949 the 16-digit arithmetic element and the arithmetic control of WWI have been installed and given extensive tests with a minimum number of voltage-variation circuits for marginal checking and trouble location. As described more fully in the section on Installation and Testing of WWI (and in the same section of Summary Reports 16 and 17), all arithmetic operations have been performed at design speed, and circuit performance has, in general, been very gratifying. Work remains to be done on the isolation and modification of certain signal channels which are sensitive to pulse repetition frequency. Simple circuit modifications already made to some of these channels have greatly improved their reliability, and no serious problems are anticipated in correcting others. Based on experience with the five-digit multiplier we are just beginning to apply to the whole arithmetic element the voltage-variation methods for the location of incipient trouble. This activity will continue over a period of several months and will establish the optimum method of connecting these flexible circuits as well as the choice of problems for checking and locating trouble.

Central Control

The construction of central control is now far enough along so that we can expect its completion in May. Differing from the arithmetic element, which lent itself to rather extensive individual testing of its component digits, the parts of central control are so interrelated that much less of this piecemeal testing can be done. There will thus be more unknowns connected with the incorporation of central control into the system. For example, although the 32-position control switch has been rather fully investigated (see R-123), it has driven only a load which simulates the control matrix, not the complete matrix itself.

Storage and In-Out Control

Electrostatic storage control and input-output control have not until recently received detailed attention. The block diagrams have now been established as described elsewhere in this Report. For electrostatic storage control we had the choice of doing a considerable amount of new circuit design and using tubes and panel space with maximum efficiency, or using existing spare arithmetic-element panels less efficiently. From considerations of time, reliability, and economy, we decided to use the existing panels. The decision on whether to replace these spare panels can be deferred until the computer is nearing actual use. Input-output control uses some circuits not found elsewhere in the computer but with which we have had considerable experience.

Electrostatic Storage

The first three months of 1949 have seen a change in the emphasis of the storage-tube program. Until the first of the year the emphasis was almost entirely on research. At that time it appeared that the major problem had been solved, at least in principle: tubes were being built which could be used for storage. Storage surfaces with the desired characteristics had been obtained, and construction techniques and testing techniques seemed to be well in hand. It became apparent that with properly directed effort a set of storage tubes suitable for first use with WWI, although probably with reduced speed and spot pattern specifications, could be developed and built by the end of 1949.

The decision to commit ourselves to such a time schedule required considerable reorganization and reorientation of the storage-tube group. A considerable part of the test personnel was diverted to the design of the circuits intimately associated with the tubes. It was necessary to make this diversion almost immediately if the necessary development, including prototype design and testing, was to be completed in time for the Project construction facilities to build, test, and install the repetitive elements by early 1950. The emphasis within the remaining group was placed on improving the test instrumentation facilities available for detailed investigation of improved tubes, on improving construction techniques to overcome the limitations and troubles with the partially developed tubes, and on studying the as yet uninvestigated life and reliability characteristics of the storage tubes.

This reorganization, naturally enough, resulted in a considerable slowing in the rate of progress last fall. The new test facilities have pointed up new troubles as well as given new information; changes in construction techniques have caused new difficulties and reduced the number of successful tubes turned out. An improved storage assembly has been designed and adopted for use in both storage and evaporation tubes. The greatest difficulty has been in making storage surfaces that are uniformly good over their entire surfaces. In general, all tubes built thus far have certain surface areas which will not store satisfactorily. More recently some trouble has been experienced with tubes which seemed to have very high leakage currents over the entire storage surface. This trouble has been partially traced to the recently introduced use of getters. Every effort is being made to overcome these surface troubles.

A unit for operating experimental tubes at high repetition rates, although with limited deflection flexibility, has been put into operation in the test laboratory. The standard TV test unit has been improved for more convenient use. A new TV unit using r-f beam modulation for improved definition is under construction. This unit will allow detailed visual investigation of the charge characteristics of individual mosaic squares. Special tubes and equipment for investigating current distribution in high-velocity and holding-gun beams have been built and put into operation.

The storage-tube reliability tester was modified during February and March to include the r-f read-out circuits described in Summary Report 15. The signals derived from the r-f circuits are more stable and reliable than those provided by the former video read-out circuits. We have had difficulty in reproducing the 16 × 16 cycled array described in Summary Report 16, and were not successful until the second week of April, when this Report was being written. Although positive conclusions would be premature, we believe the important factors in getting back to the 16 × 16 array were the adjustment of test equipment and the techniques used in getting an optimum setting of the focussing potential on the storage tube. Before continuing with the program (described in Summary Report 16) for installing five tubes, we plan to improve the reliability of the existing equipment. The program for five tubes is now three weeks behind the schedule set in January.

This report includes a section under Storage Tubes which describes investigations we have made in the past few months to determine the cause of some random spots on storage surfaces. The results have led us to further refine our precautions in maintaining cleanliness during the process of tube assembly. Also described is a storage-tube life-test rack which is now operating with four tubes and will shortly be expanded to include eight.

Vacuum Tubes

Summary Report 17 includes a summary of the studies of vacuum-tube life and deterioration made by the Project in the past year. This month, in the section on Vacuum Tube Life, we are including some further data and details of work which we have done on this subject.

Mathematics and Checking

In the past few months the efforts of the Project Whirlwind mathematics group have been largely devoted to a study of check and trouble-location problems for use in getting WWI into operation. Summary Report 16 discusses the coding of some other problems which were done previously. Checking and trouble-location methods are discussed in some detail in Summary Report 17. We have recently worked out some problems which can be done with the 32 registers of test storage which will be available in the next six months, before electrostatic storage is incorporated in the system. Engineering Note E-220 describes some such problems which turn out to be more sophisticated than we had anticipated.

INSTALLATION AND TESTING OF WWI

From March 7 to March 28, system testing of the arithmetic element was suspended and the computer inactivated. During this period the temporary power distribution, trouble indication, and power control systems were replaced by modified systems. Also, other WWI elements were installed at this time. Installation work was completed on March 22, and the remainder of the inactive period was expended in the testing of the recently added equipment.

The modified power distribution system consists of part of the permanent system plus an interim temporary system. Voltage variation has been provided for all flip-flop screen and gate-tube screen circuits in the repetitive elements and arithmetic control. This is a permanent installation and will facilitate an early examination of the efficacy of marginal checking in system testing. In addition, permanent installations were made of all non-variable distribution circuits supplying the repetitive elements and arithmetic control.

All circuits to repetitive elements, both temporary and permanent, have been installed in accordance with the final system plan, that is, by digit pairs. D-C power to any pair of digits separated by eight digits (0-8, 1-9, etc.) can be independently controlled by the automatic interlock system and/or the voltage variation system. The arithmetic control, excluding the step counter and step counter output, are wired as one digit, as are the register drivers.

The permanent wiring for control and indication between the individual power racks and between the power racks and computer racks was installed.

The internal power wiring for flip-flop storage was completed, including that for the flip-flop storage register drivers. In addition, all elements of flip-flop storage and associated register drivers were installed except the comparison register.

The power supply remote control was made operative, and manual operation of the marginal checking system made available for system testing.

Operation was resumed without difficulty after the installation period. Readjustment of signal amplitudes was necessary in only a very few cases. The program of widening operating margins in the arithmetic element was resumed.

CONTROL

Electrostatic Storage Control

The storage element in the Whirlwind computer contains all the information necessary to run the computer as well as the numbers used in a given computation. It is necessary, therefore, both to read the control information from this storage and to restore interim information during the computation of any given problem.

The means of communicating with the storage element is known as storage control. Only two basic orders — known as read and write — are needed for this function; but in order to carry out either of them, the present storage tube requires

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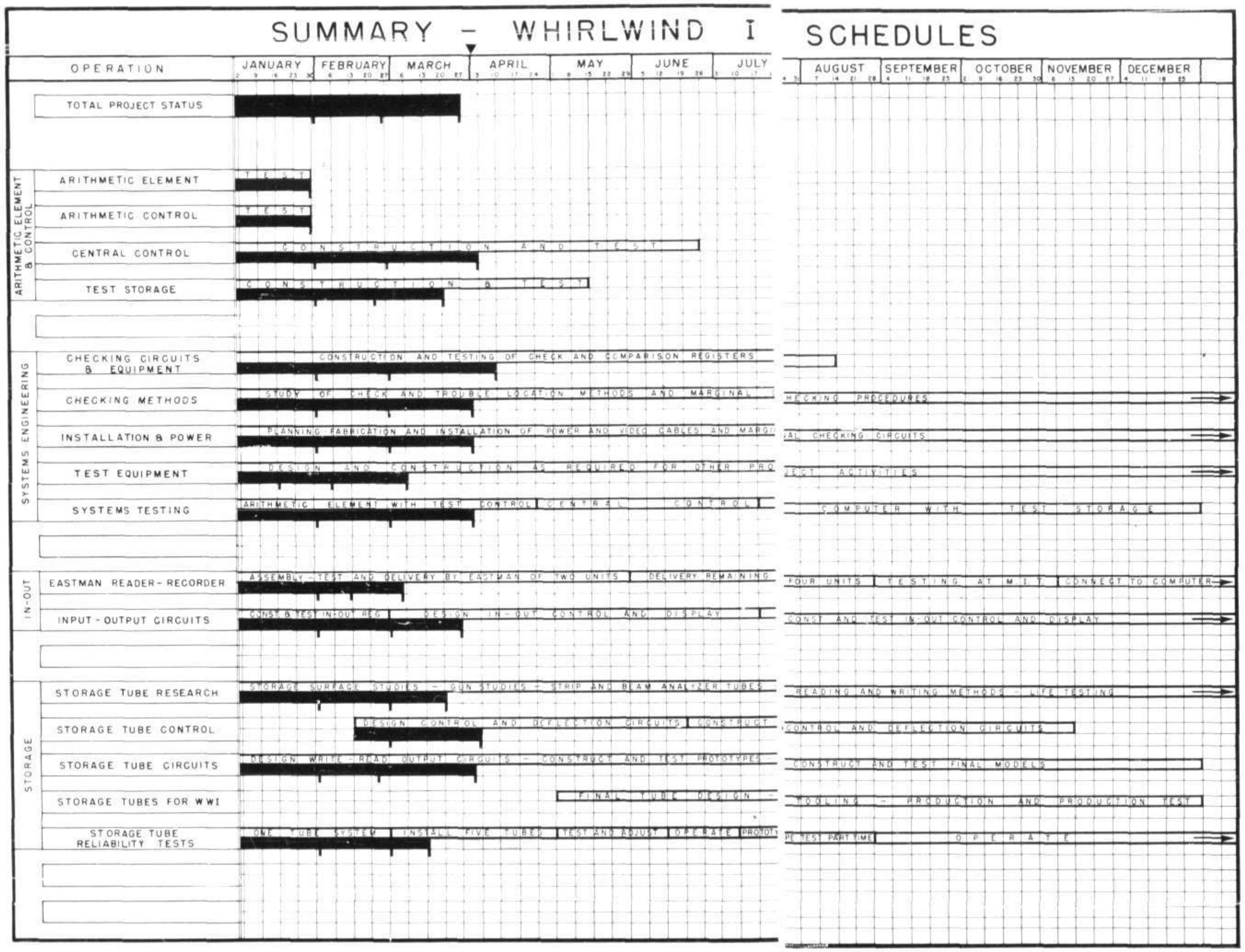


LEGEND

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.

seven pulses which must arrive on their prescribed lines at the proper time. Of the many possible ways to achieve this result, the one selected uses existing spare Whirlwind I panels, thus avoiding additional design, test, and construction. About three racks of equipment are required, including: 2 accumulators, 5 program counters, 2 B-registers, 1 A-register, and 4 standardizer amplifiers.

The system which has been laid out has the ability to do the following:

1. Accept a control order from the central control of the computer and return control to the computer after a storage operation has been performed.
2. Provide a sequence of 7 time pulses which can occur at intervals variable from 1 to 16 microseconds. This flexibility will allow the storage tube to work under optimum conditions for each type of operation, that is, reading or storing of positive or negative charges.
3. Allow for a selection to be made between two banks of storage tubes.
4. Provide for the separate control of the right 11 or the left 5 digits in order to make use of the transfer-digit order in computer programming.
5. Assure that the holding-gun action of the storage tube will be allowed sufficient time to restore charges between operations and that rewriting operations will be performed automatically after each read-out has been effected.

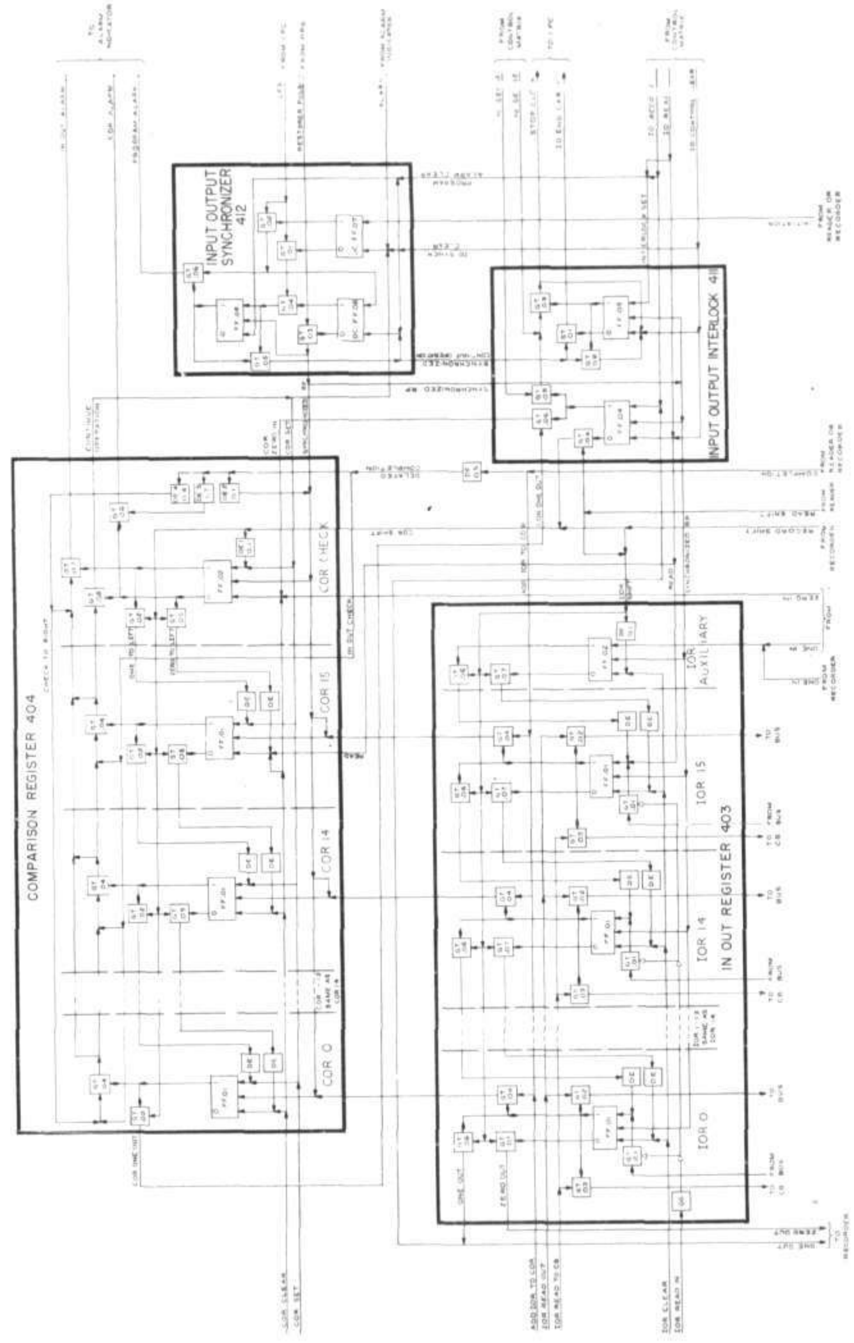
The system is designed with great flexibility. At a later date when operating margins with the storage tubes are well established, the system may well be simplified with some significant savings in equipment.

In-Out Control

A proposed block diagram of input-output control for Whirlwind I is reproduced herewith. The control is designed for the purpose of transferring numbers from the computer input-output register to the film-type recording units being built for this purpose by the Eastman Kodak Company, and for transferring numbers from the film-type reading units to the input-output register. The control also provides means for checking the number transfers in various ways. The control does not include any means of selecting among the possible types and numbers of readers and recorders external to the computer; this will be done by a separate electronic switch operated by the address section of the pertinent computer in-out order.

The functions to be taken care of by the in-out control are essentially:

1. Conversion between the serial-type, single-bus number transfer used by the film units, and the parallel-type, multiple-bus number transfer used by the computer. This is accomplished by reading the digits into one end of the in-out register and shifting the contents of the register as the digits are received. The register can then be read out into the parallel bus system. The scheme operates in both directions.
2. Checking of the transfer by reading both a number and its complement from the film during reading or by reading back the number recorded during recording. This is accomplished by means of the comparison register. During reading, the number on the complement line on the film is shifted into the comparison register. This number should be identical with the number shifted into the in-out register. The comparison is made by an operation consisting of an add without carry, which adds the contents of the in-out register to the comparison register, thus producing all 0's in the comparison register. This condition of all 0's is sensed by the comparison-register check circuit. During recording, the process is to compare the number read back into the in-out register from the recorder with the number previously added to the comparison register.
3. Synchronization of the control signals from the film units with the computer clock pulses. This is done by the in-out synchronizer circuit. This circuit uses a d-c-coupled flip-flop operating without restorer pulses to control a series of clock pulses which are



INPUT - OUTPUT CONTROL

externally stopped during restoration. These pulses in turn operate on a second d-c-coupled flip-flop which controls restorer pulses. Restoration is stopped during reading or recording. The flip-flop connections are designed to prevent the stopping of only one of a pair of restorer pulses and to prevent any trouble because of coincidence of computer and film unit pulses.

4. Provision of an interlock circuit that will prevent the computer from ordering another in-out operation before the film units have completed a previous order. This is accomplished by the in-out interlock. If the computer tries to order an in-out operation while the film units are operating, a sense pulse will pass the interlock circuit and stop the computer. Upon completion of a film-unit operation, the interlock is cleared and then, if a sense pulse has passed through the interlock and stopped the computer, a pulse is sent out to start the computer.

The accompanying block diagram of the in-out control includes the input-output and comparison registers also. All signals to and from the film units are shown at the bottom of the drawing; the computer signals are shown on the left. The computer uses five newly devised orders, each of which involves execution of a number of individual commands, to control the operation of in-out control:

1. rf - run forward
2. rb - run backward

One of these two orders is always used to start a reading or recording process. The film unit specified in the address section of the order is started in the direction specified (recorders are used in the forward direction only), and the proper pulses are sent to in-out control to put it in the condition for reading.

3. rd - read

This order is used to remove from the input-output register the word deposited there by a reader, and store it in the storage register specified in the address section of the order. The order then puts the in-out control back into the condition for reading. The reading unit runs continuously until ordered to stop, and the rd orders must be performed between the time the film unit has completed the reading of one word and the time it starts the reading of the next word.

4. rc - record

This order is used during the recording process to insert into the input-output register the word to be recorded, that is, the one stored in the storage register specified in the address section of the rc order. The rc order must occur before the recorder starts to operate on the input-output register each time; therefore, it must follow immediately after an rf order which specifies a recorder. The rc order puts the in-out control in the position for recording.

5. rs - reader or recorder stop

This order is used to stop the film unit after the desired number of words have been read or recorded.

Checking of the reading and recording transfers is extensive but not perfect; there are a few specific errors which in conjunction with coincidence of certain pulses, and the production of specific numbers, will go undetected. The probability of the error passing undetected is extremely small.

For greater detail, see Memorandum M-818, "In-Out Control," and Engineering Note E-225, "A Study of Input-Output checking." A general description of the operation of the Eastman Kodak Company film reader-recorders is given in Summary Report 13.

STORAGE TUBES

Spots on Storage Surface

In the television display of storage surfaces of some of the more recent storage tubes there appeared a few small spots distributed at random over the surface. These spots appeared first at low holding-gun voltages (about 15 volts) and increased in number and size as the holding-gun voltage was raised. This meant that as the potential between collector screen and storage surface was increased, spots on the storage surface stayed at collector potential, and that the number of these spots increased with increasing potential difference between collector and storage surface.

Some of the spots could be made to disappear if the collector screen was set into vibration by application of audio-frequency voltages. From this evidence it was conjectured that the spots represented actual short circuits between screen and storage surface — shorts which were probably caused by pieces of conducting material bridging the narrow gap (10 to 20 mils) between the two elements.

At first it was assumed that conduction was being caused by irregularities in the surface of the beryllium mosaic. It was observed that there were some tiny mounds of beryllium raised just high enough above the surface to make contact with the screen; such mounds are known to occur as a result of too violent evaporation of beryllium. The evaporation surfaces of the next tubes were very carefully examined for the purpose of eliminating any such mounds. Once or twice mounds appeared and were removed. However, tubes with these surfaces showed more spots than previous tubes, so that irregularities in the evaporating surface could no longer be assumed as the primary cause of the spot.

As a next attempt to get evidence, the appearance of a storage surface in the television display was carefully mapped. Then the storage tube was opened while precautions were taken to have the air seep in at such a slow rate that the assumed cause for the observed contacts would not be disturbed. The storage assembly was then examined microscopically. For every spot mapped in the television display there was found a corresponding particle — apparently carbonized lint — stuck in the collector mesh and contacting the storage surface. Very possibly excessive examination of the storage surfaces to insure cleanliness had only contributed to the formation of the spots. Although the operations were performed in a dust-controlled room, small lint threads from the cotton gloves used in handling the surfaces had gotten into the assembly. These tiny threads could be detected only under the microscope. They had a charred appearance, so they probably were carbonized and made conducting during heat treatment of the tube.

Tube-construction procedures were immediately revised. Assembly of the storage elements was performed in the exhaust air stream of an electric precipitator and subsequent examination under the microscope was performed under glass cover. Cotton gloves were replaced by rubber gloves. These precautions seem justified, because the latest storage tubes appear to be free from spots on the storage surface.

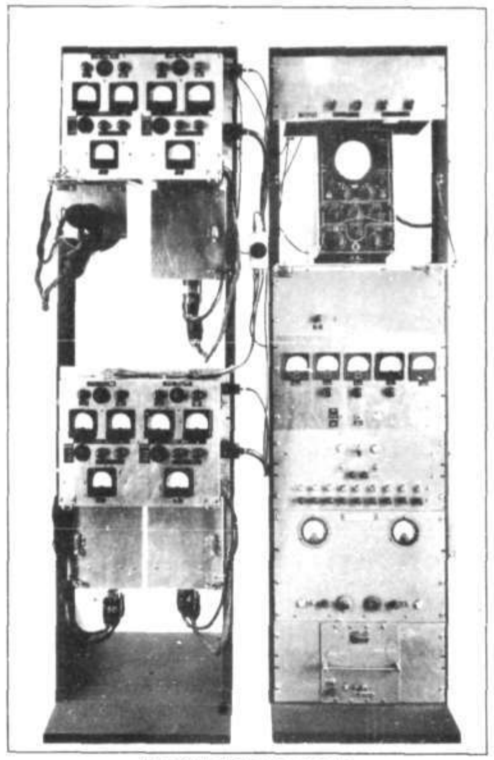
This experience is an additional proof that storage tubes can be produced only under conditions of extreme cleanliness. In particular, construction of a storage tube is even more critical than of an orthicon or Iconiscope because of the presence of a fine-mesh screen which readily acts as a catcher for small particles in front of the storage surface.

Storage Tube Life Tester

Satisfactory operation of the storage tube to be used in the Whirlwind computers depends to a large extent upon the secondary-electron emitting properties of the storage surface and the currents obtained from both electron guns. A storage-tube life tester has been constructed to facilitate study of storage-tube life, particularly as influenced by these factors.

The tester provides for setting up static storage patterns and storing them for extended periods of time with a minimum of idle equipment. Each storage tube is removed from the life tester at periodic intervals and put through a series of standard tests to obtain information concerning surface characteristics and gun operation.

Eight storage tubes may be placed on life test, four on each side of the equipment and power-control rack in the center. In the accompanying photograph, which shows only four of the eight tubes, one of the tube mounts is shown in the horizontal position for loading a storage tube, the other three in the vertical or operating position. The two protruding chasses contain two identical sets of meters and controls for the two associated storage tubes. Meters for each storage tube indicate the cathode



STORAGE TUBE LIFE TESTER

current of the holding gun and cathode current and grid-bias voltage of the high-velocity gun. The voltages for the high-velocity guns of all eight tubes are supplied by a common source; however, each gun is controlled individually by the controls at each storage-tube position. The holding-gun voltages for all eight tubes are supplied by another common source, but are controlled and metered in parallel at the center panel in the equipment and power-control rack. The remaining units in the equipment rack from the top down are the sweep adapter and centering unit, a cathode-ray oscilloscope, and a video amplifier. The video read-out system was included in the life tester to give a check on the patterns set up on the storage tubes.

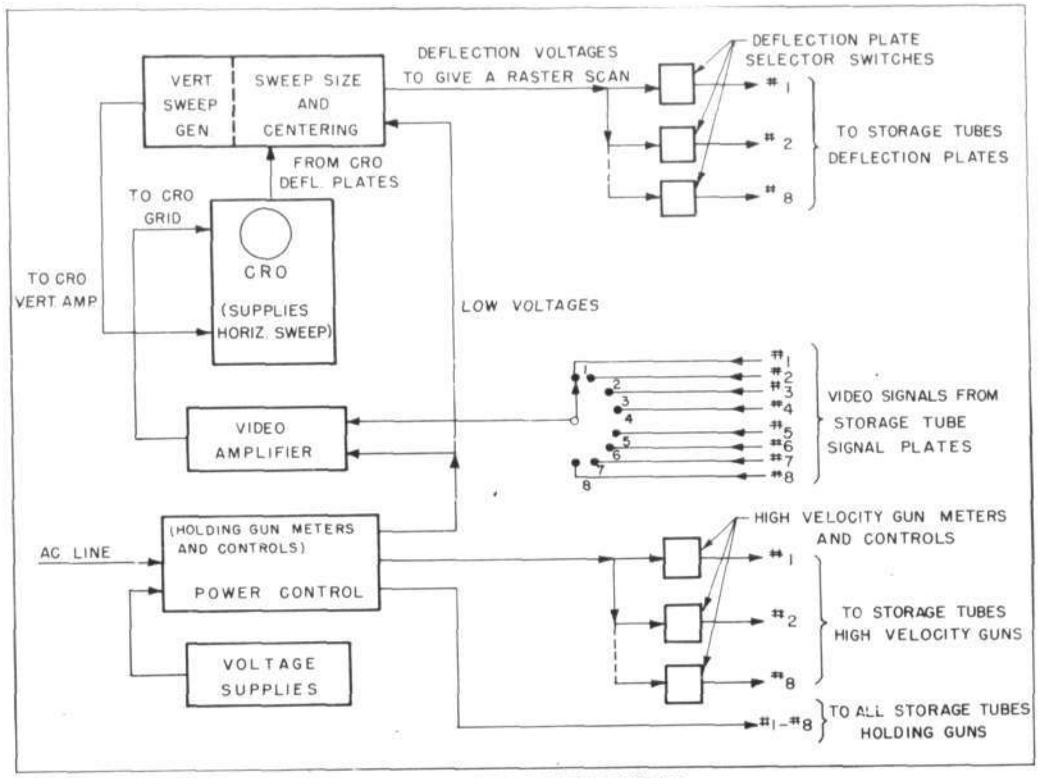
Referring to the block diagram, it is seen that a television or raster-type scan is applied to the deflection plates of the cathode-ray tube and to any of the storage tubes. The pattern stored on any storage tube is observed by setting the deflection-plate switch of that tube to the scanning voltages and setting the video-amplifier input-selector switch to the appropriate position. A pattern is "written" into a storage tube by stabilizing the entire surface at the negative potential and then setting the deflection-plate switch to apply scanning voltage to the vertical deflection plates only. As the high-velocity beam is moved up and down on the storage surface, it is able to overcome the action of the holding beam, and a vertical line on the surface switches to the positive stable potential. Areas on the surface may be put at the positive stable potential by shifting the horizontal position of the vertical line at a rate slow compared with the vertical sweep rate.

A convenient pattern to set up, and one which it is felt will lead to useful test results, is one with half the surface made positive, the other half remaining negative. Provisions have also been made for storing a static array of spots. To do this, however, requires an external deflection source supplying a desired number of spot position voltages and a pulse unit supplying writing pulses to the high-velocity guns.

To date, the storage-tube life tester has operated satisfactorily with four tubes for approximately five hundred hours. Mountings and associated equipment for the remaining four tubes were just recently completed.

VACUUM TUBE LIFE

Of the 4,000 tubes to be used in the Whirlwind I computer, approximately two-thirds will be 7AD7 pentodes or 7AK7 gate tubes. The long life and the reliability of these two types are of particular interest to the Project; therefore, a considerable effort is being expended to study these factors. One of the problems which is most difficult to surmount in life studies is the length of time necessarily involved to obtain results. Three to four months very often elapse before a new set of sample tubes can be tested.



STORAGE TUBE LIFE TESTER

As described in Summary Reports 9 and 17 and Report R-139, certain 6AG7 and 7AD7 tubes used in Whirlwind circuits have exhibited a tendency to deteriorate with age. This deterioration, manifested by a large decrease in static plate current, has been associated with an effective internal resistance in series with the cathode, which has been ascribed to the formation of an interface barrier between the cathode sleeve and the oxide coating. Of two lots of Sylvania 7AD7 tubes, those of lot B8B have been subject to this apparent cathode interface, which makes them unsatisfactory for use in the Whirlwind computer, while those of lot L7P are very satisfactory.

Spectrochemical analysis of the cathodes from aged 7AD7 tubes from the five-digit multiplier has revealed that (1) the cathode sleeves from the B8B and L7P lots are very nearly identical; (2) the cathode coating materials differ markedly in silicon and iron content, tubes of lot B8B having several times as much of these two elements as the L7P tubes. An effort will be made to discover the source of the impurities in the coating material of the B8B tubes. These spectrochemical tests were made by Mr. James Cardell of Raytheon Manufacturing Company in cooperation with the MIT Physics Department.

In addition to these efforts to investigate the 7AD7, both the Sylvania Company and RCA have submitted special pentodes made from selected materials of very low impurities. These tubes are being studied by the Project engineers to determine whether the life characteristics have been improved by these precautionary measures.

The 7AK7 tube, which is of equal importance, presents a much more favorable picture. Experience with this tube in the five-digit multiplier indicates that we may expect 4,000 to 5,000 hours of reliable operation from the tubes we are now receiving.

A number of 6AS6 tubes used in the five-digit multiplier failed during the month of March. The cause of failure appeared to be low cathode emission, without any formation of interface as occurs in 7AD7 and 6AG7 tubes. A modified marginal checking procedure (see Summary Reports 15, 17) using low filament voltage was found to be very effective in locating these tubes before failure.

The other tubes in the Whirlwind I system — 6Y6, 6SN7, 829, 6AK5, 6L6, 2C51 — are used in much smaller quantities than the 7AD7 and 7AK7. Our experience with these types is less extensive than with the others, but the circuits in which they are used do not in general demand high tube performance, and indications are that we may expect satisfactory results.

Performance in Whirlwind I is encouraging but very preliminary in nature. After 350 hours of operation of 1,000 tubes, two 6SN7 tubes developed grid-to-cathode shorts. One 7AK7 was retired very early because of a mechanical defect.

VISITORS

During March the Laboratory had among its visitors the following:

Mr. A. H. Lundstrom, Mr. G. D. Johnson, Mr. P. H. Thayer, and Mr. R. G. Stephenson of Bell Telephone Laboratories and Mr. J. R. Marvin of the Bureau of Ordnance to discuss applications of digital computation techniques to naval fire control.

Prof. P. J. Rulon of Harvard University.

Mr. Perry Crawford of the Research and Development Board.

Mr. Perry Luth of North American Aviation, interested in circuit and component problems.

Mr. J. J. Pastoriza and Mr. H. P. Pacini of the Cambridge Field Station and Mr. A. R. Foley and Mr. D. R. Weller of Griffiss Air Base, to discuss air traffic control.

Mr. D. B. Houghton of the Franklin Institute, interested in the possibility of a centralized problem-preparation facility.

Mr. K. D. Swartzel of Cornell Aeronautical Laboratories, to discuss the air intercept problem.

Dr. John von Neumann of the Institute for Advanced Study.

Mr. L. P. Tabor and Mr. R. H. McClarren of the Franklin Institute.

Among visitors especially interested in storage tubes were the following:

Mr. Joseph Kelar of Engineering Research Associates.

Mr. F. K. Willenbrock and Mr. J. R. Hooper, Jr., of Harvard.

Mr. M. Baller, Mr. John Dillon, Mr. R. B. Palmiter, and Mr. B. M. Marshall of the Cambridge Field Station, USAF.

APPENDIX

REPORTS AND PUBLICATIONS

Project Whirlwind technical reports and memorandums are routinely distributed to only a restricted number of people who are known to have a need for detailed information on the Project. Other authorized personnel who are interested in particular phases of the work may obtain copies of individual reports by making specific requests for them. Requests for classified material should in general be addressed to the Mathematics Branch, Office of Naval Research, Navy Department, Washington 25, D. C. Requests for unclassified material, or requests for classified material where approval has been previously arranged, should be addressed to Jay W. Forrester, Servomechanisms Laboratory, 211 Massachusetts Avenue, Cambridge 39, Massachusetts.

The following reports and memorandums were among those issued during March:

No.	Title	Classification	No. of Pages	Date	Author
R-156	Intact Stability Study Programmed for a Digital Computer (S.M. Thesis: Abstract in E-210)	-	113	3- 7-49	C. W. Adams
R-157	A High-Speed Multi-Position Electronic Switch (S.M. Thesis: Abstract in E-211)	-	39	3- 7-49	D. R. Brown
E-204	Conversion of Binary Pulse Code to Voltage Amplitude (Abstract of Master's Thesis)	-	2	2-24-49	E. W. Sard
E-207-1	Nomogram for Determining Thickness of Beryllium Film	-	2	3-22-49	R. Shaw
E-208	Storage Tube ST73: Construction, Processing and Initial Testing	-	3	2-28-49	M. Florencourt
E-209	Storage Tube ST65: Construction, Processing and Initial Testing	-	2	3- 4-49	M. Florencourt
E-212	Storage Tube ST57: Construction, Processing and Initial Testing	-	2	3- 8-49	M. Florencourt
E-213	FF Sensitivity in WWI	-	2	3-10-49	R. L. Best
E-214	Storage Tube ST77: Construction, Processing and Initial Testing	-	2	3-17-49	M. Florencourt
E-216	Holding-Beam Trajectories and Potential Fields Near the Storage Surface	-	2	3-18-49	H. E. Rowe
E-219	Electrostatic Storage Control	-	7	3-25-49	S. H. Dodd N. H. Taylor R. R. Everett J. A. O'Brien R. P. Mayer
E-220	Demonstration Problems for Whirlwind I with Test Storage	-	16	3-30-49	G. Cooper
M-766	Anodizing Procedure	-	5	12-30-48	J. S. Palermo
M-792	Tables of Binary and Decimal Numbers	-	5	2-23-49	R. P. Mayer C. W. Adams
M-796	Bi-Weekly Report, Part I, 3-4-49	Restr.	17	3- 4-49	
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