

UNCLASSIFIED

PROJECT WHIRLWIND
(Device 24-x-3)

SUMMARY REPORT NO. 13
OCTOBER 1948

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OFFICE OF NAVAL RESEARCH
Under Contract N5ori60
Project NR-720-003

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 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

All sixteen units of the arithmetic A-register have been delivered by Sylvania except for the zero digit panel, which is slightly different from the others. Construction of B-registers and accumulator panels is well advanced and most of the arithmetic control is under test.

Five of the eight direct-current power supplies have been received from the Power Equipment Company and are installed.

Continued tests show deterioration of certain types of vacuum tubes in circuits in which the tubes are non-conducting a large part of the time; see "Change in Tube Types for WWI" in Summary Report 9 for June 1948. One production lot of 7AD7 tubes shows decrease in steady-state plate current as did the 6AG7's, while another production lot appears entirely free of such trouble. Projects using vacuum tubes in computers and other pulsed circuits would be greatly benefited by an active study of factors affecting the life and stability of pulsed tubes. Vacuum tube designers and research laboratories might conduct such studies as part of their development programs on long-life vacuum tubes.

The time schedules posted to the end of October show a delay of about two weeks behind the July plan.

The first of the 5-inch storage tubes using a beryllium mosaic on mica shows better promise than previous tubes. Results are good enough to justify immediately undertaking the design of equipment to make realistic high-speed tests of tube operation and reliability. Such equipment may take several months to design and construct, and tubes may be ready for testing before the equipment is complete. A modulated intermediate frequency of a few megacycles per second rather than a gated video pulse may be used as a storage tube output pulse. These circuits and those for high-speed cyclic operation of several storage tubes in parallel are being designed.

VISITORS

During October the Laboratory had among its visitors the following:

Rear Admiral A. G. Noble, Chief, Bureau of Ordnance, USN; Rear Admiral M. F. Schoeffel, Deputy Chief, Bureau of Ordnance, USN; Capt. F. C. Manville, Section Chief, Bureau of Ordnance, USN; Capt. M. E. Murphy, USN; Capt. E. E. Mann, Senior Naval Officer at MIT; Cmdr. H. M. Mott-Smith, USN; and Mr. L. W. Sharpe, Project Meteor, MIT, to discuss application of digital computers to guided missiles.

Capt. J. R. Ruhsenberger, Director, Special Devices Center, USN; Mr. Henry C. Knutson, Mr. Charles H. Doersam, and Mr. John B. Thaler, all of Special Devices Center, USN; and Cmdr. W. L. Thompson and Dr. C. F. Muckenhoupt, both of Boston Branch, Office of Naval Research.

Dr. A. Wertheimer and Cmdr. G. T. Atkins of the Bureau of Ordnance, USN, to discuss digital computers and storage tubes.

Mr. F. W. Tietsworth and Mr. K. A. Waldron of the Tube Division of General Electric Company, who were interested in tube problems and tube requirements for high-speed digital computers.

Dr. E. P. Little, USAF, in charge of Air Force personnel training in the field of digital computing at Harvard University, and to be in charge of digital computer work at Wright Field.

Mr. A. H. Taub of the Mathematics Department of the University of Illinois, where a digital computer program is being started.

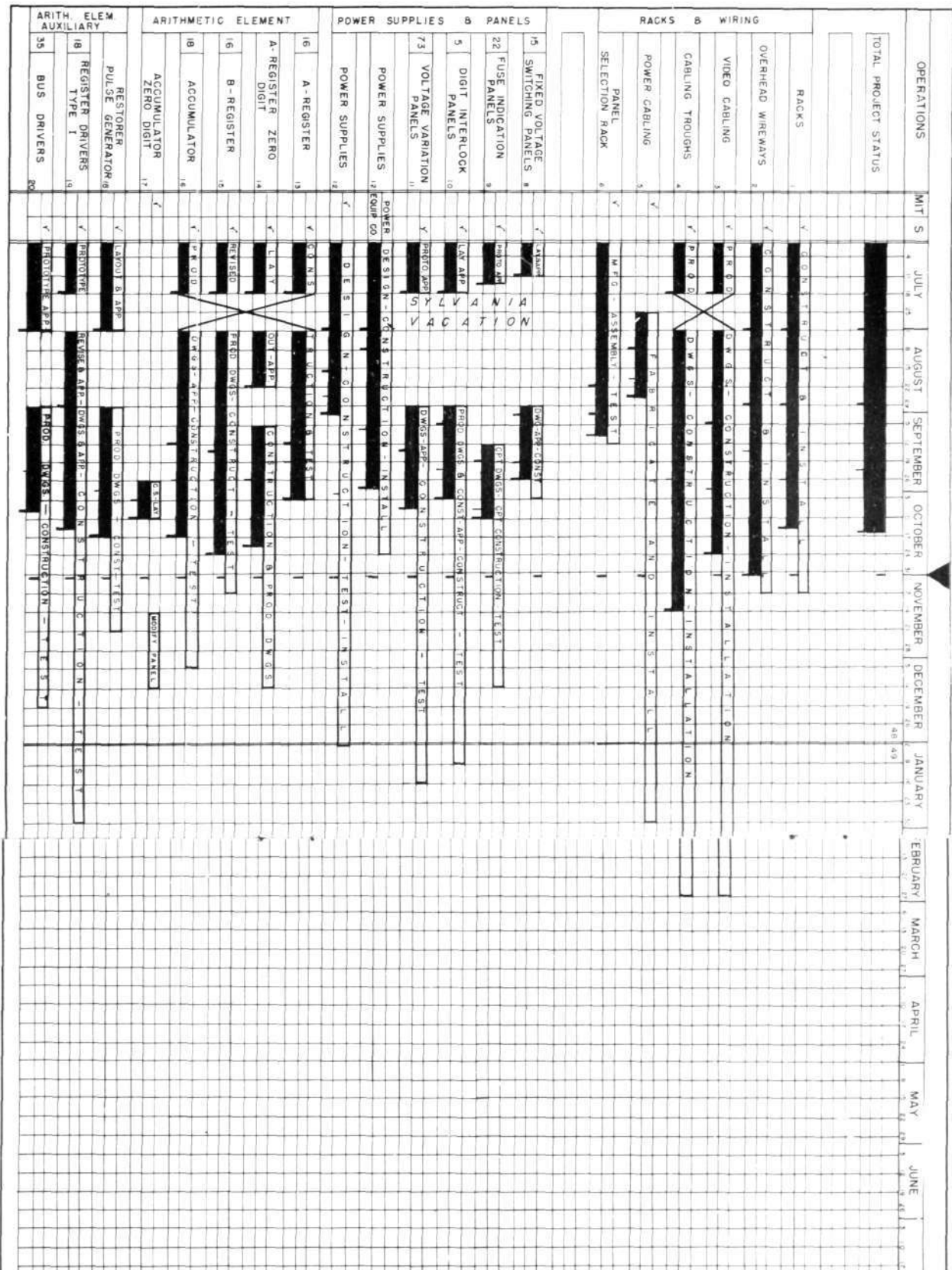
Mr. J. N. Davis and Mr. Paul G. Bohlke of the Kew Gardens, Long Island, laboratories of Sylvania Electric Products, Inc., to discuss storage tubes.

Dr. J. R. Pierce of Bell Telephone Laboratories, to discuss storage tubes.

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SUMMARY - WHIRLWIND I SCHEDULES



LEGEND

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

PROTOTYPE

Operation to be performed, and estimated time allotted for its completion. Estimates made in July 1948.

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 latest posting.

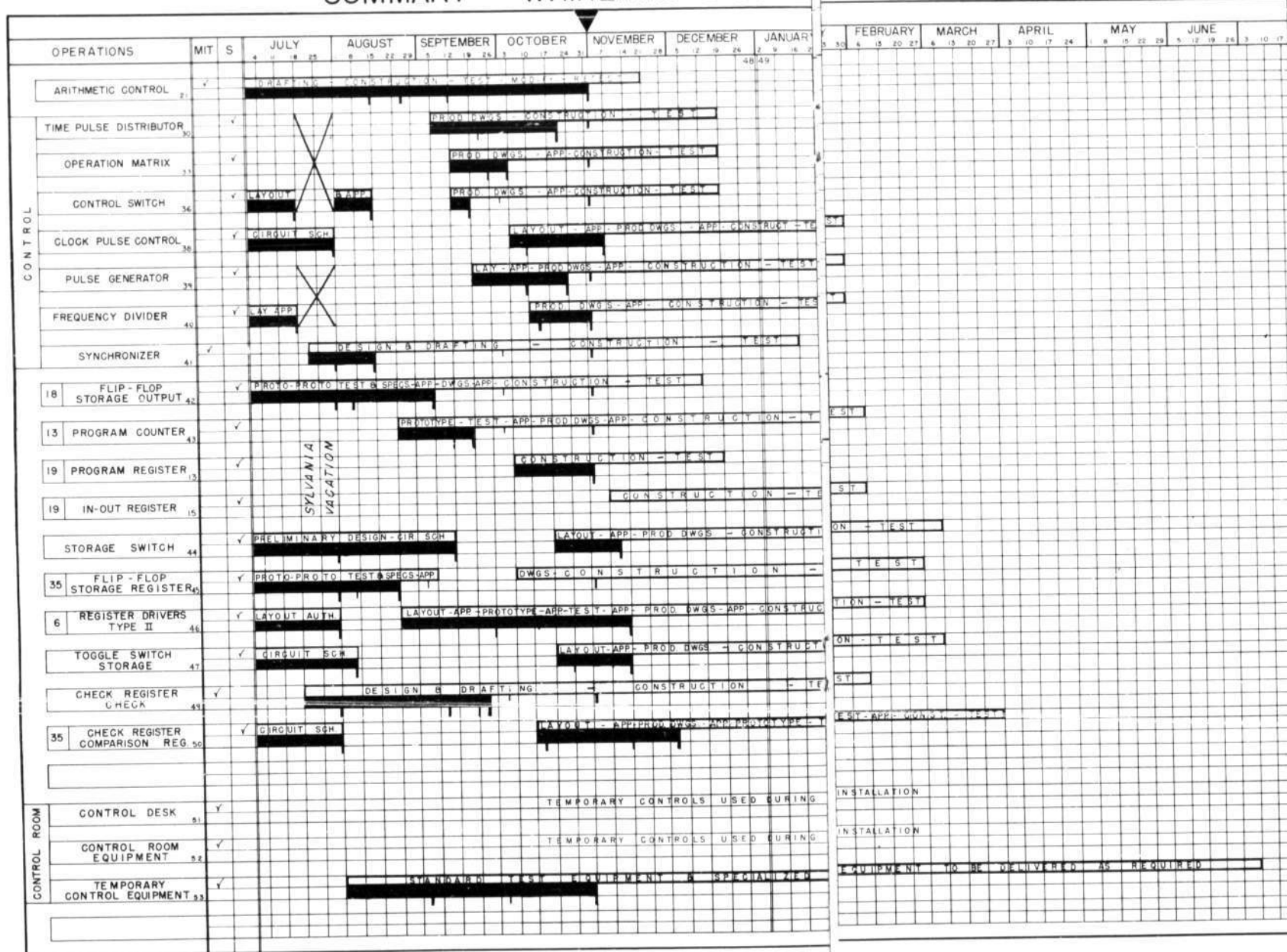
Summary line. Shows overall status of the project.

MIT S

Column showing whether M.I.T. or Sylvania will do major portion of the job.

For a long-range plan from 1944 to 1952 showing the relation of the detailed schedule to past and future work, see Summary Report No. 11, August 1948.

SUMMARY - WHIRLWIND I SCHEDULES CONT.



LEGEND



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



Operation to be performed, and estimated time allotted for its completion. Estimates made in July 1948.

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 latest posting.

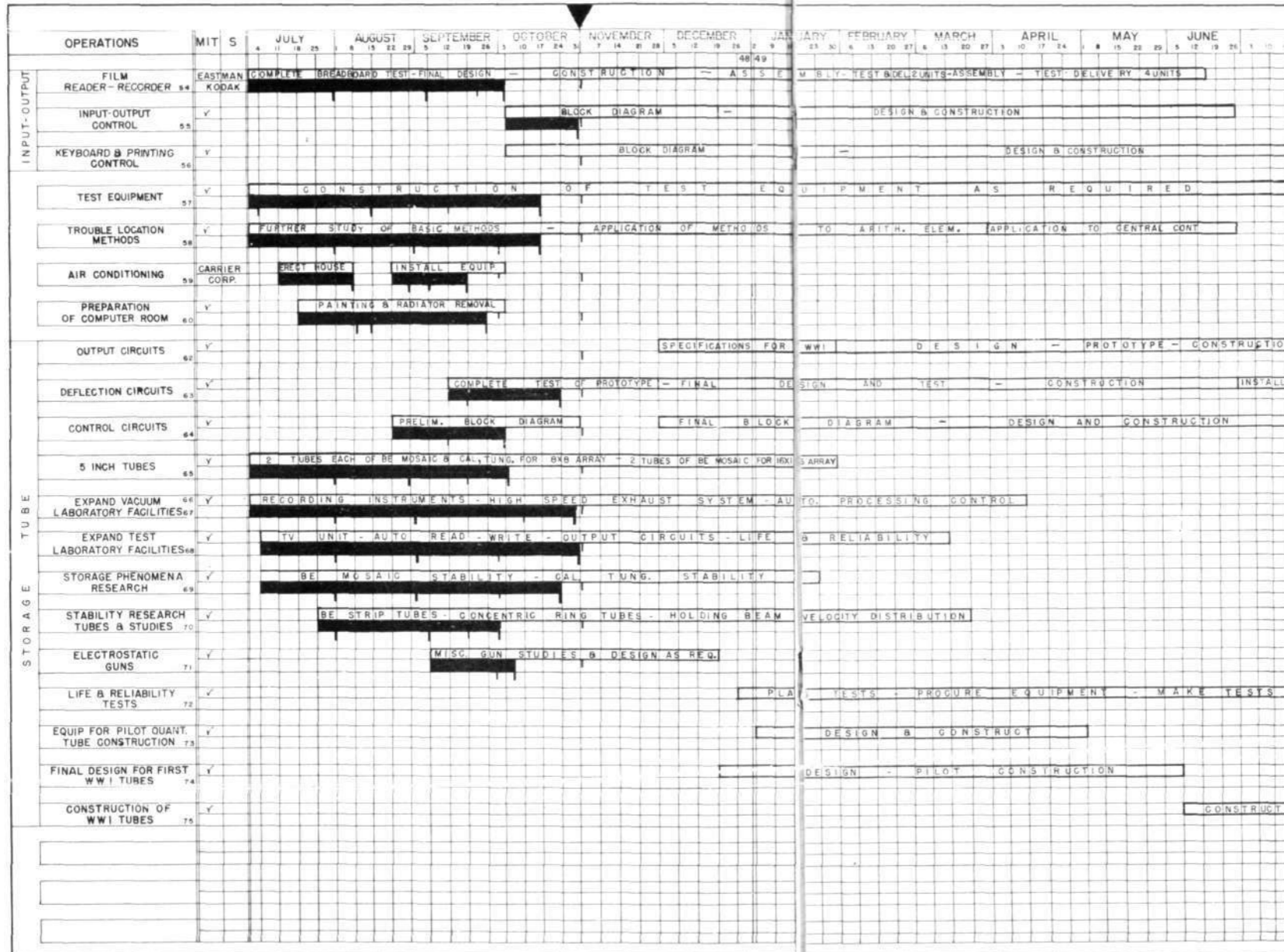
Summary line. Shows overall status of the project.



Column showing whether M.I.T. or Sylvania will do major portion of the job.

For a long-range plan from 1944 to 1952 showing the relation of this detailed schedule to past and future work, see Summary Report No. 11, August 1948.

SUMMARY - WHIRLWIND I SCHEDULES -CONT.



LEGEND

JULY
1 10 25

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

PROTOTYPE

Operation to be performed, and estimated time allotted for its completion. Estimates made in July 1948.

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 latest posting.

Summary line. Shows overall status of the project.

MIT S

Column showing whether M.I.T. or Sylvania will do major portion of the job.

For a long-range plan from 1944 to 1952 showing the relation of this detailed schedule to past and future work, see Summary Report No. 11, August 1948.

FILM READER-RECORDER

Eastman Kodak Company has almost completed development of the film reader-recorder unit mentioned in SR-3, and the prototype model is undergoing tests at the ~~Eastman Kodak Company~~.

The unit will record on 35-mm film binary numbers received from the in-out register of WWI; with slight changes in the optical system, it will read binary numbers from a previously exposed film to the in-out register of WWI.

The recorder, shown schematically in Fig. 1, exposes the film to the light generated by the trace on a cathode-ray tube as the trace sweeps across the tube in response to an instruction to record. The face of the cathode-ray tube is covered by a mask in which are cut two horizontal rows of sixteen rectangular holes corresponding to the sixteen digits of WWI; see Fig. 2. The image of these holes is focused upon the film. The top row of holes records the number itself; the bottom row records the complement of the number to be used for checking purposes.

As the trace sweeps across the tube it is deflected vertically so that it strikes a hole in the top row if the digit to be recorded is a one, or the corresponding hole in the bottom row if the digit is a zero. The recorder actually reads only the contents of the rightmost digit of the in-out register, but each time the beam sweeps across a hole in the mask, a portion of the resultant light is used to generate a pulse that shifts the contents of the in-out register to the right one digit. Thus the next digit is inserted in the recorder and the trace is deflected vertically in accordance with the contents of the new digit. This all happens before the trace has reached the next hole in the mask.

This process continues until the trace has swept across the length of the mask and all digits have been shifted out of the in-out register. The pulse that initiates the sweep is generated by light passing through slits in a timing disk which rotates as the film moves, thus spacing the numbers properly on the film. This pulse starts the sweep of the trace. Before the trace reaches the row of holes in the mask, it strikes a narrow slit in the mask. The image of this slit is focused on the film

as a reference mark to be used later when the developed film is read into the computer. The light producing this reference mark is also used to generate the initial shift-right pulse applied to the in-out register, thus shifting the first digit into the recorder.

The film moves continuously past the recording head during the recording process, and the distance required for the trace to sweep across the mask is short enough so that the film moves a very short distance during the recording of a number. The resultant skew is negligible.

The reading operation of the reader-recorder is very similar to recording; the arrangement is shown schematically in Fig. 3. The mask over the face of the cathode-ray tube is replaced by a mask having only one row of holes and having no reference slit; see Fig. 4. In front of the cathode-ray tube is a beam-splitting prism that splits up the light from the mask into two beams, the two beams being focused onto the film as two rows of spots. The film contains rows of clear and opaque spots representing numbers and their complements, and one of the split beams is focused along a row representing a number, the other along the complement of this number. Behind the film are located three photoelectric cells, one to pick up light coming through the number row on the film, one to pick up light through the complement row, and the third to pick up light from a steady light source focused on the reference marks along the edge of the film.

As the film moves, either forward or backward as directed by the computer, light passes through the reference mark to the third photo tube and a pulse is generated that starts the sweep of the trace across the face of the cathode-ray tube. The light of the trace as it passes across the holes in the mask will cause a pulse to be generated by either the first or second photo tube, depending upon whether the film holds a one or a zero in that particular digit. The signals from the first photo tube, or "one" tube, cause a one to be shifted into the leftmost digit of the in-out register and cause the register to shift right one digit. The signals from the second, or "zero", photo tube generate the same action except that a zero is shifted into the leftmost digit of the in-out register. In this manner the number on the

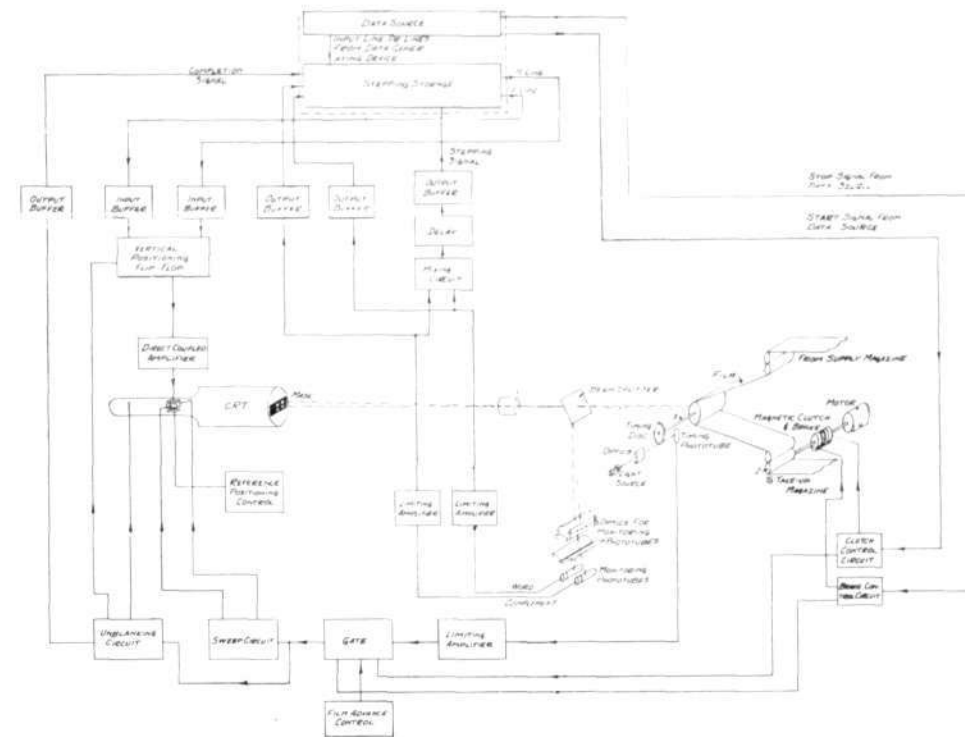


FIG. 1. RECORDER

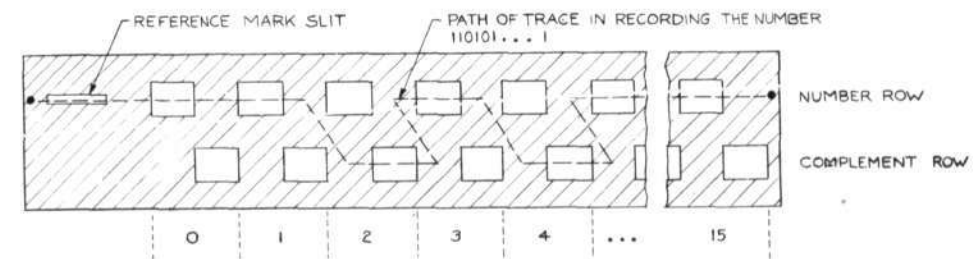


FIG. 2. SCOPE MASK USED FOR RECORDING

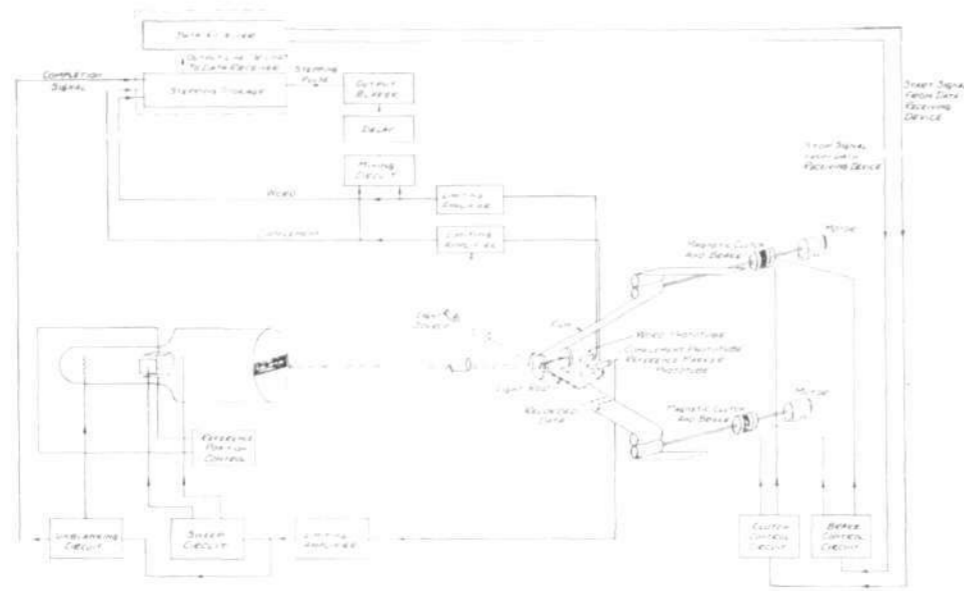


FIG. 3. READER

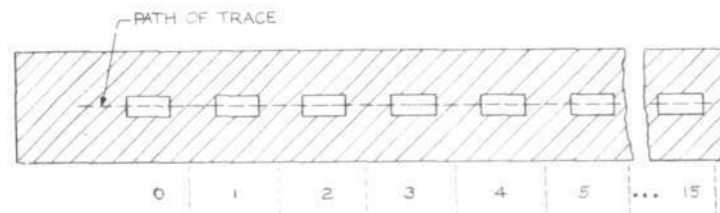


FIG. 4. SCOPE MASK USED FOR READING

film is shifted into the in-out register as the trace sweeps across the mask.

The above description is considerably simplified; the checking and control phases have been omitted; also, the spots representing the complement are placed between the spots of some other number so that no space on the film is wasted, and each number and its complement occupy a total of one line on the film.

The film drive mechanism is arranged so that data may be read or recorded in groups of numbers, with the film stopping between groups, or the unit can read or record line-by-line, with the film stopping between individual lines of data. The data are always read or recorded while the film is in motion. The normal speed of the film is about 20 inches per second and the lines are spaced about 100 per inch.

Six of the reader-recorder units are to be built by the Eastman Kodak Company. They will each handle up to 1000 feet of film and can be used as either readers or recorders. The Eastman Kodak Company is also building a high-speed automatic developing unit for the exposed film from the recording units.

TEMPORARY CONTROL AND OPERATOR'S CONSOLE

The Whirlwind I arithmetic element, which comprises the A-register, B-register, accumulator, arithmetic control, and a number of bus and register drivers, will be installed in the computer room in December. During early 1949, exhaustive tests will be made to assure the fulfillment of all requirements, both logical and engineering. Other parts of the computer will be integrated with the arithmetic element as they become available. (See Long-Term Schedule in SR-11).

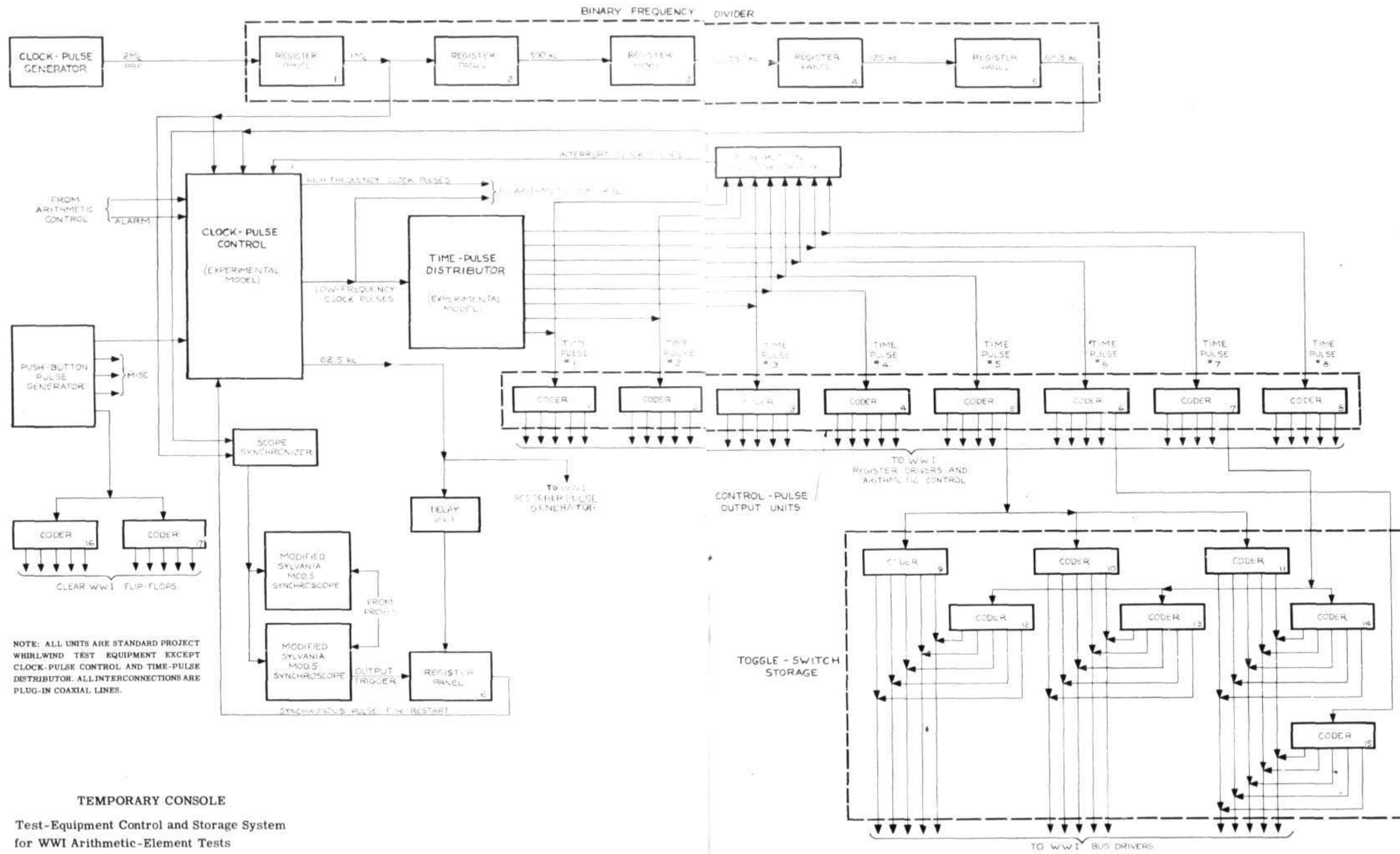
Testing of the arithmetic element will require simulation of functions of other parts of the computer which will not at first be available. This simulation is to be accomplished by means of the standard test equipment developed by the Project for such purposes (see SR-10); the system to be used is shown in the accompanying schematic.

Except for the clock-pulse control and the time-pulse distributor, which are experimental WWI panels, all blocks in the diagram represent units of standard test equipment. When installed in temporary racks in the control room, this equipment will provide:

1. A temporary operator's console, which will probably be a basis for design of the permanent console.
2. All timing and control pulses necessary for accurately simulating selected Whirlwind arithmetic operations.
3. Three temporary toggle-switch storage registers.
4. Means for observing performance of all circuits.

The test system will permit operations to be performed either at high speed or at a push-button rate. During high-speed operation, a given Whirlwind arithmetic operation will be repeated cyclically about 1000 times each second to permit continuous display of pulse waveforms and flip-flop performance on the synchrosopes. Since the arithmetic operations require only between 8 and 40 microseconds for completion, there will be a long delay between executions of the operation. Provision is made for interposing this delay between any two consecutive steps of the operation. Thus standard indicator-light panels, which show essentially the average positions of flip-flops, can be made to indicate flip-flop positions after any selected time pulse despite the fact that each flip-flop is actually responding to pulses during the small fraction of a cycle required for performance of the operation. This method provides the advantage that not only the final results of an operation, but also all partial results can readily be observed without the more involved interpretation of synchroscope waveforms.

In the diagram, standard register panels 1 through 5 make up a frequency divider which divides the 2-megacycle prf from the clock-pulse generator to 1 megacycle and 62.5 kilocycles for use by the clock-pulse control, which in turn provides pulses to the computer at these frequencies when required. The time-pulse distributor distributes clock pulses on parallel lines which normally cause coders 1



TEMPORARY CONSOLE
Test-Equipment Control and Storage System
for WWI Arithmetic-Element Tests

through 8 to be pulsed one at a time at 1-micro-second intervals. Pulses appear at the coder output terminals only if individual toggle switches are properly set. Manual selection of these toggle switches corresponds to the automatic selection of gate tubes by the WWI operation-control matrix switch, which is not yet available. Correct space and time distribution of pulses for the performance of any given arithmetic operation can be achieved in this manner. Introduction of the long delay after, some arbitrary time pulse during cyclic high-speed operation, as discussed in the above paragraph, is accomplished by proper setting of the push-button selector switch into which all time-pulse distributor output lines are fed.

Coders 9 through 11 represent a 15-digit toggle-switch storage register in which a number to be operated upon can be held. Coders 12 through 14 provide similar storage facilities, and Coder 15 provides one-third of a toggle-switch register which holds a 5-digit number to be sent to the WWI step counter. The binary number corresponding to the selected output switches of one such coder register can be "read out" to the arithmetic element by pulsing the inputs to each of the 3 coders simultaneously.

A gate-and-delay unit is used to provide delayed 62.5-kc pulses to register panel 6, which in effect exchanges the variable-delay output trigger pulse from one of the synchrosopes for the next following 62.5-kc pulse. The resulting single synchronous pulse is then sent to clock-pulse control, where it causes a new operation cycle to begin at a time such that the resulting waveforms can be observed with either synchroscope.

The push-button pulse generator will provide pulses to clock-pulse control whenever push-button operation is more desirable than high-speed cyclic operation. Outputs from the push-button pulse generator can also be used for such auxiliary purposes as clearing selected WWI flip-flop registers (in conjunction with coders 16 and 17), and complementing all WWI flip-flops (by feeding a single pulse to the restorer-pulse lines).

A number of pulse standardizers which provide amplification, polarity inversion, and independent

amplitude control of signal channels, as well as the waveform standardization for which they were primarily designed, were omitted from the diagram for simplicity. Several other test-equipment items not fundamental to the system were also omitted.

Although the connections between units are plug-in cables which are easily removed or interchanged, the system shown will require no recabling during the arithmetic element tests. All necessary manual signal routing is accomplished by means of toggle switches.

POWER SUPPLIES AND DISTRIBUTION

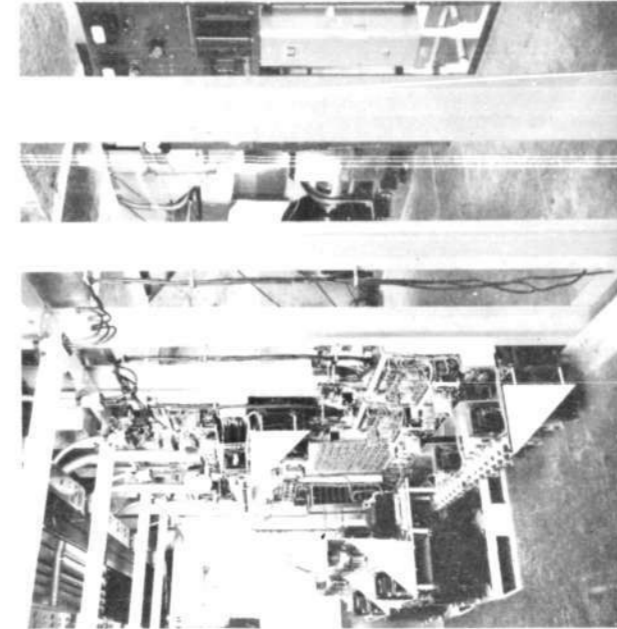
Supplies

The WWI computer is being provided with power which is regulated at various voltage levels to insure reliable performance of computer circuits. Studies have been made to determine computer power requirements, and the resulting d-c power supply specifications are shown in the accompanying table (high-voltage supplies for electrostatic storage tube power are not included). The relatively small number of supply voltages required for this computer may be attributed to the use of a-c coupling and the standardization of circuits.

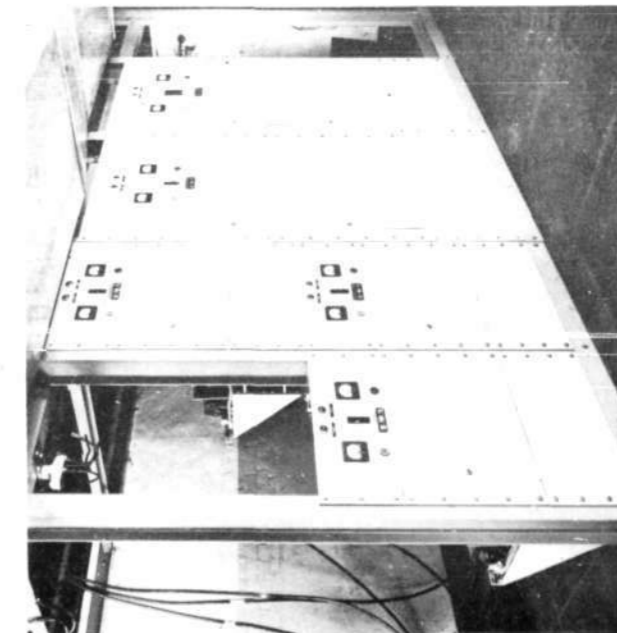
WWI D-C POWER SUPPLY SPECIFICATIONS

Nominal supply voltage	Current rating	Nominal power output	Maximum ripple	Maximum dynamic regulation
volts	amperes	kilowatts	volts, rms	volts
+ 48	50	2.4	-	-
+250	50	12.5	0.1	2.5
+150	50	7.5	0.1	1.5
+120	10	1.2	0.1	1.2
+ 90	10	0.9	0.1	0.9
-150	10	1.5	0.1	1.5
- 30	6	0.18	0.02	0.30
- 15	6	0.09	0.02	0.15

In order to make the power supplies adaptable to future alterations or additions in the computer, the supply voltages may be changed by $\pm 10\%$ of nominal voltage, and the current ratings are somewhat



REAR VIEW OF D-C POWER SUPPLIES



FRONT VIEW OF D-C POWER SUPPLIES

higher than will be required immediately. The specification for maximum dynamic regulation defines the maximum allowable change in instantaneous voltage following a sudden change in load current of 5% of the rated supply current.

These supplies have been ordered from the Power Equipment Company of Detroit. All except the + 48, - 30, and - 15-volt supplies have been installed, as shown in the accompanying photographs. The remaining three supplies are scheduled for delivery late in November.

The + 48-volt supply will furnish power for numerous relays in the computer, and is not critical with regard to ripple and dynamic regulation. It is a dry-disc rectifier, automatically regulated by means of saturable reactors.

The - 30 and - 15-volt bias supplies will have single-phase full-wave thyatron rectifiers. Automatic regulation is accomplished by grid-control of the thyratrons in conjunction with high-vacuum shunt tubes across the output.

The remaining 50-ampere and 10-ampere supplies are six-phase grid-controlled thyatron rectifiers with automatic regulation accomplished by control of the conducting period of the thyratrons.

The a-c power supply for the rectifiers is a 31-kva, 3-phase, 120/208-volt alternator driven by a synchronous motor. This system is used to reduce voltage transients caused by fluctuations of the commercial power lines, which are severe in an industrial district.

Filament power for WWI will be supplied from a 50-kva, single-phase, 120-volt alternator driven by a synchronous motor. The alternator will have a voltage regulator to maintain constant voltage within $\pm 1\%$ or better. In normal operation, the filament voltage will be increased from zero to rated value (or reduced to zero) over a period of five to fifteen minutes to avoid thermal shock in the tubes. The filament motor-generator bed is installed, and all major parts except the drive motor are on hand. The installation of major components will be completed shortly after the drive motor is delivered. An emergency source of filament power direct from the primary lines and a magnetic contactor for throw-over will be provided.

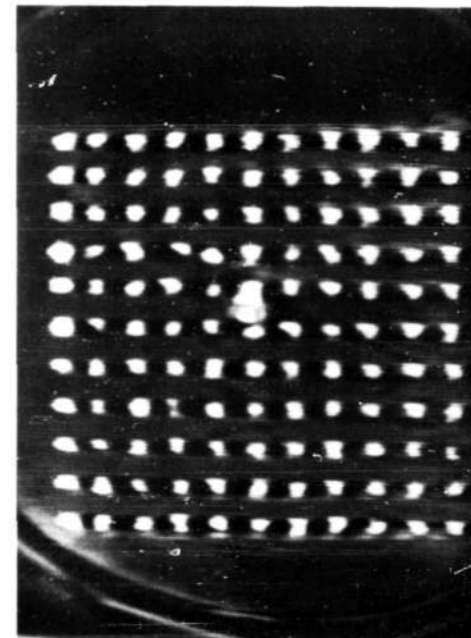
Distribution

The computer power is transmitted from the power supply room in the basement to the computer room on the second floor over conductors housed in five steel wireways. In order to minimize wiring inductance and mutual coupling among supplies, each supply has its own return conductor. In addition, a-c power, d-c plate power, d-c bias lines, and control lines are segregated in separate wireways. The return lines for all supplies are connected to a common bus in the computer room. This bus is grounded to the building water mains through a removable link so that the system may be operated grounded or ungrounded as desired. This wiring has been completed except for connections to those power supplies which have not yet been delivered.

STORAGE TUBES

Breakdown of the aluminum oxide dielectric has occurred in some storage tubes recently, as described in Summary Report 12, September 1948. Previously planned experiments with mica and glass dielectrics in place of aluminum oxide were therefore initiated. During October two large storage tubes with beryllium mosaic storage surfaces on mica were constructed and tested. Experimental results have been good - much better than those obtained with tubes containing storage surfaces of beryllium on aluminum oxide. Positive or negative spots may be written on a background of either polarity, and stability of stored areas is good. A reliability tester is under design to test a group of these tubes under approximately the conditions that will exist in the computer.

The accompanying photograph shows the television picture-tube representation of an 11 x 11 array of negative spots on a positive background stored on one of these new tubes. The area is 3-3/4 inches in diameter and consists of a beryllium mosaic surface on mica. The uneven bright area in the center of the picture is caused by a support post inserted between the target and screen to give increased support to the wire mesh screen; storage assembly designs are being developed to eliminate this post.



TELEVISION PICTURE-TUBE REPRESENTATION OF 121 NEGATIVE SPOTS STORED ON A POSITIVE BACKGROUND -- 3-3/4-inch-diameter portion of a beryllium mosaic on mica dielectric.

The testing which has been done up to this time indicates that this storage is extremely stable at holding-gun accelerating velocities substantially lower than those required for the tubes with aluminum oxide dielectric. The best holding-gun potential is about 75 volts, while previous tubes varied in the range of 150 to 700 volts. This smaller value of holding-gun potential requires smaller potential changes on a spot during writing,

and therefore results in shorter writing times. Indications are that this surface will give adequate operation with writing times of the order of 10 microseconds or less and reading times of the order of 2 microseconds. This is a substantial improvement over previous tubes.

Difficulty was encountered in the first tube because the nickel signal plate was not shielded and was subject to some direct pickup of electrons from the holding gun. Direct pickup of stray electrons can be avoided if the signal plate is coated with a dielectric; therefore, in the second tube an anodized aluminum backing plate, stripped on its front surface, was used as the signal plate (not as the storage dielectric). Another undesirable feature of the first tube was that small output signals, of the order of 30 millivolts, were obtained. It was felt that this might be caused by inadequate coupling between the dielectric surface and the signal plate. Therefore, the back side of the mica surface in the second tube was coated with silver paint to ensure complete electrical contact between the dielectric and the signal plate.

In the second tube, storage near the center of the surface was substantially the same as in the previous tube, but storage near the outside edge required higher values of holding-gun voltage. Test results on this tube indicate that adequate reproducibility can be obtained and that the difference between storage conditions in the second tube and in the first tube was probably due to evaporation of the binder from the silver paint and consequent contamination of the outer parts of the storage surface.

A third tube is now being constructed with adequate baking of the silver paint on mica before the mosaic is evaporated and inserted in the tube. It is expected that this prebaking will correct the difficulties encountered with dielectric contamination.

APPENDIX

REPORTS AND PUBLICATIONS

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

No.	Title	No. of Pages	No. of Drwgs.	Date	Author
R-144	The Variable-Frequency Clock-Pulse Generator (Model 2)	11	9	9-20-48	R. R. Rathbone
E-148	The Solution of Systems of Linear Algebraic Equations by Successive Approximation	36	-	9-29-48	E. Reich
E-149	History of Storage Tube Program	5	-	9-30-48	(S. H. Dodd (M. I. Florencourt
E-150	Filament Voltage Regulator for Five Digit Multiplier	2	-	10-5-48	J. J. Gano
E-151	Voltage Regulation of Laboratory Central D-C Power Supplies	2	-	10-5-48	C. R. Wieser
E-153	Flip-Flop Operation in WWI Circuits	2	1	10-11-48	R. L. Best
E-154	Further Development of Beryllium Evaporation Tubes	4	2	10-1-48	(H. Klemperer (M. Florencourt
E-156-1	Natural Frequency of Vibration of Grid of E. S. Storage Tube	3	-	10-20-48	M. Daniloff
E-157	Natural Frequency of Transverse Vibration of Square Grid of E. S. Tubes	2	-	10-25-48	M. Daniloff
M-217-1	Description of WWI Codes	14	-	10-11-48	C. W. Adams
M-617	931-A Life Tests	7	9	9-20-48	W. J. Nolan
M-626	Staff Indoctrination Program	6	-	9-29-48	J. C. Proctor
M-629	Conferences at Power Equipment Co., Detroit, 8-13 and 9-28	2	-	9-30-48	H. R. Boyd
M-630	Bi-Weekly Report, Part I, 10-1-48	11	-	10-1-48	
M-631	Bi-Weekly Report, Part II, 10-1-48	17	-	10-1-48	
M-633	Clock Pulse Control, Addition of a Tube to Circuit Schematic R-31916	1	-	10-4-48	J. A. O'Brien
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