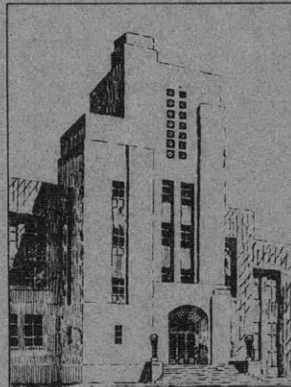# THE DAVID W. TAYLOR
MODEL BASIN

UNITED STATES NAVY

A MICROSECOND TIME-DELAY CIRCUIT

BY LIEUT. G. ROBERT MEZGER, USNR

RESTRICTED

MAY 1944   REPORT 525

NAVY DEPARTMENT
DAVID TAYLOR MODEL BASIN
WASHINGTON, D.C.

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REPORT 525

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DAVID TAYLOR MODEL BASIN

PERSONNEL

The instrument described in this report was developed by George W. Cook of the Electronics Section of the David Taylor Model Basin and was constructed by personnel of that section. The shock-wave photograph was made by Lieut. D.C. Campbell, USNR, of the Photographic Development Section. The report is the work of Lieut. G. Robert Mezger, USNR.

A MICROSECOND TIME-DELAY CIRCUIT

ABSTRACT

An electrical time-delay circuit is described which generates, at a prede-
termined time following the receipt of an initiating pulse, a sharp, electrical,
triggering pulse. The predetermined time delay is variable, in steps of one micro-
second, from 1 microsecond to 10,000 microseconds. The peak output potential is of
the order of 100 d-c volts.

The instrument is self-contained and in general is suitable for uses in
which the electrical control of time delay of a sequence of events may be required.

INTRODUCTION

The problem for the development of the circuit which is described in this
report was outlined to the Electronics Section of the David Taylor Model Basin by the
Photographic Development Section. The latter was engaged on the problem of photo-
graphing successive phases of high-speed, transient, physical phenomena. The method
employed was "microflash" photography, using the high-speed flash lamp developed by
Dr. H.E. Edgerton. The phenomena were originated by an electrical impulse, and if
some suitable method were available for photographing the phenomena in progressive
phases of development, by delayed firing of the flash lamp, useful information would
be achieved. It was to be the function of the time-delay circuit described in this
report to provide controllable delays of the desired duration.

Two units of this design have been built, and they have been used extensive-
ly at the Taylor Model Basin for the firing of microflash lamps for photographic stud-
ies of dynamic phenomena.

DEVELOPMENT OF THE CIRCUIT

The obvious development of a circuit to perform the functions described in
the foregoing would embody some type of resistance-capacitance discharge circuit,
which, when the potential across one of the elements of the circuit reached a partic-
ular value, would initiate some type of pulse-generating device. Devices of this kind
have been designed and built at the Taylor Model Basin, and a circuit which outlines
the general principles is shown in Figure 1 In this circuit, components may be so
arranged that the following action will take place: A positively polarized initiating
pulse applied to the grid circuit of the gas-filled triode V_1 will drive the grid of
V_1 positive and cause the tube to conduct. When V_1 conducts, a potential is developed
across R_1 which causes C_1 to charge through R_2. When the potential across C_1 rises
sufficiently to carry the grid of the gas-filled triode V_2 to the proper potential for
conduction, this tube will ionize, discharge the capacitor C_2, and develop a short,
sharp pulse across R_3. The elapsed time between the arrival of the pulse at the grid
of V_1 and the development of the pulse at R_3 will be determined by the values of R_2,
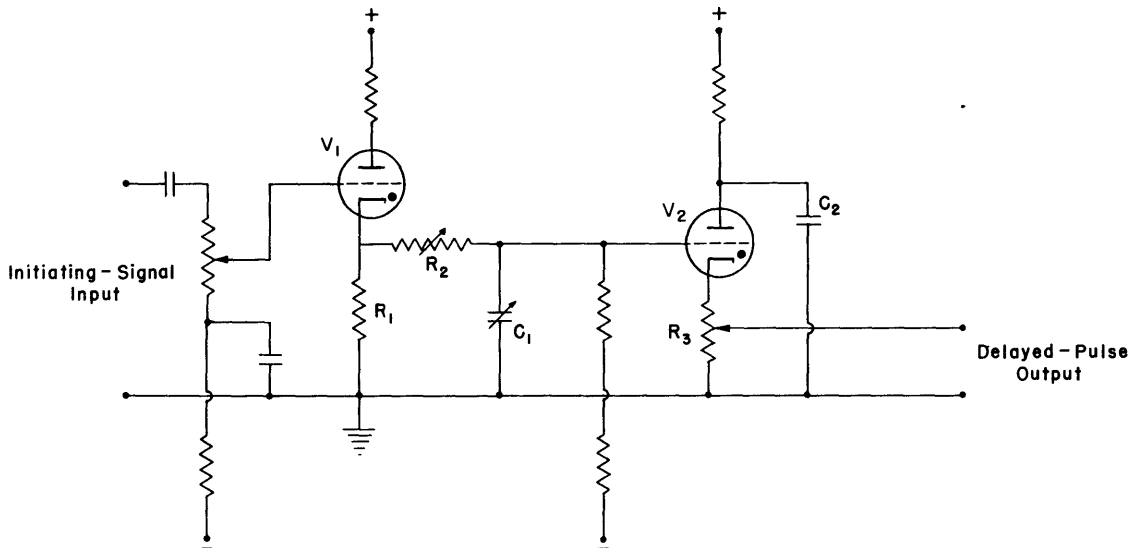
Figure 1 - Basic Type of Time-Delay Circuit

C_1, and the particular value of grid potential of V_2 for which the circuit was designed to cause ionization of V_2.

However, the reliability of any circuit which embodies the principles of operation of the circuit outlined in Figure 1 is questionable. The timing is directly dependent upon the ionization potential of V_2, as reflected by the grid potential required for ionization. The grid potential for ionization of any gas-filled triode depends upon a number of factors, most of which are beyond the control of the designer. Significant among these are variation of gas pressure with age and cathode temperature, as well as ambient temperature. For these reasons, therefore, it was decided to employ a design which was not dependent for its time stability upon gas-filled triodes. The final circuit utilizes a conventional Eccles-Jordan trigger circuit. Time stability, therefore, becomes dependent upon the constancy of the parameters of high-vacuum tubes, which are much more stable.

A block diagram of the final design of the microsecond time-delay circuit is shown in Figure 2. In this circuit, the sequence of events, in general, occurs in the following manner. The signal potential which is to initiate the series of events is applied to the input circuit at the left-hand side of the diagram. This signal is employed to generate a pulse of the shape desired to initiate the action of the time-counting circuit. After the desired period of time has elapsed, a potential of the
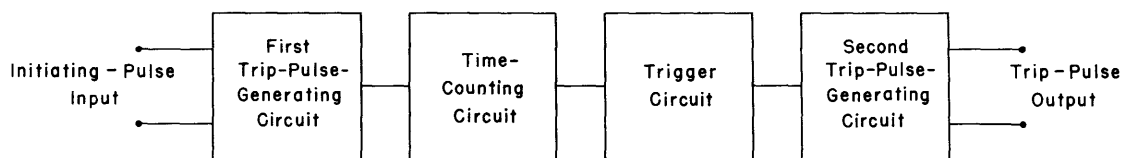

Figure 2 - Block Diagram of Microsecond Time-Delay Circuit

correct value is applied to the input of the trigger circuit, and the trigger circuit actuates a second trip-pulse-generating circuit which provides the output of the device.

CIRCUIT DETAILS

A complete schematic diagram of the circuit of the device in its final form is given in Figure 3. The circuit functions in the following manner:

The signal with which it is desired to set the circuit in operation is applied to the input terminals at the left-hand side of the diagram. A pulse-type signal of the order of 5 peak volts is adequate to initiate operation, but the signal must be positively polarized; that is, it must drive the grid of V_1 in a positive direction. Capacitor C_3 is fully charged to the potential level of the plate of the right-hand diode section of V_9 because the device has been energized previous to its operation. When the grid of V_1 is driven positive, the ionization potential of the tube is reduced below the potential to which C_3 is charged, and this capacitor is discharged through V_1. The circuit which consists of V_1 and its surrounding network constitutes the first trip-pulse-generating circuit of the block diagram of Figure 2. As the capacitor C_3 discharges, the plate potential of V_1 is decreased, thus carrying the grid of V_3 considerably beyond cutoff. This initiates the time-counting circuit which consists of V_2 and V_4 with their associated networks.

The latter circuit is so designed that, before the capacitor C_3 is discharged, the control grid of V_3 is maintained at the proper potential for C_5 to be charged and for the grid of the trigger-circuit tube V_5 to be at the proper potential for passage of current through V_5. The change in plate potential of V_1, however, alters these conditions by driving the grid of V_3 to cutoff and permitting the capacitor C_5 to discharge linearly through the constant-current device; this consists of V_2, V_4, and the resistors R_{13} and R_{14}.* As the capacitor C_5 discharges, its potential falls, and it carries the grid of V_5 in a negative direction. At this time, the grid of V_6 is beyond cutoff potential, and the change in grid potential of V_5, operating upon the plate potential of V_5, raises the grid potential of V_6 to the point where plate current begins to flow through V_6.

When the grid of V_6 rises to cutoff potential, conventional trigger-circuit action then occurs between tubes V_5 and V_6 with the result that the grid of V_7 is driven in a negative direction. The tube V_7 is cut off by the resulting negative voltage change which is applied at its grid, and it delivers a positively polarized voltage change to the grid of the gas-filled triode V_8. Raising the grid potential of V_8 reduces its ionization potential, discharges C_9 in exactly the same manner in which C_3 was discharged by V_1, and a pulse is developed across the cathode-load resistor R_{27}. The amplitude of the pulse delivered to the output terminals may be controlled by adjustment of the rotating arm of the potentiometer R_{27}.

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* The theory of operation of this constant-current device is discussed in detail in TMB Report R-86 entitled "A Stable Direct-Coupled Amplifier." The tube V_2 functions here as a cathode-follower coupling circuit between the plate and the cathode of tube V_4.
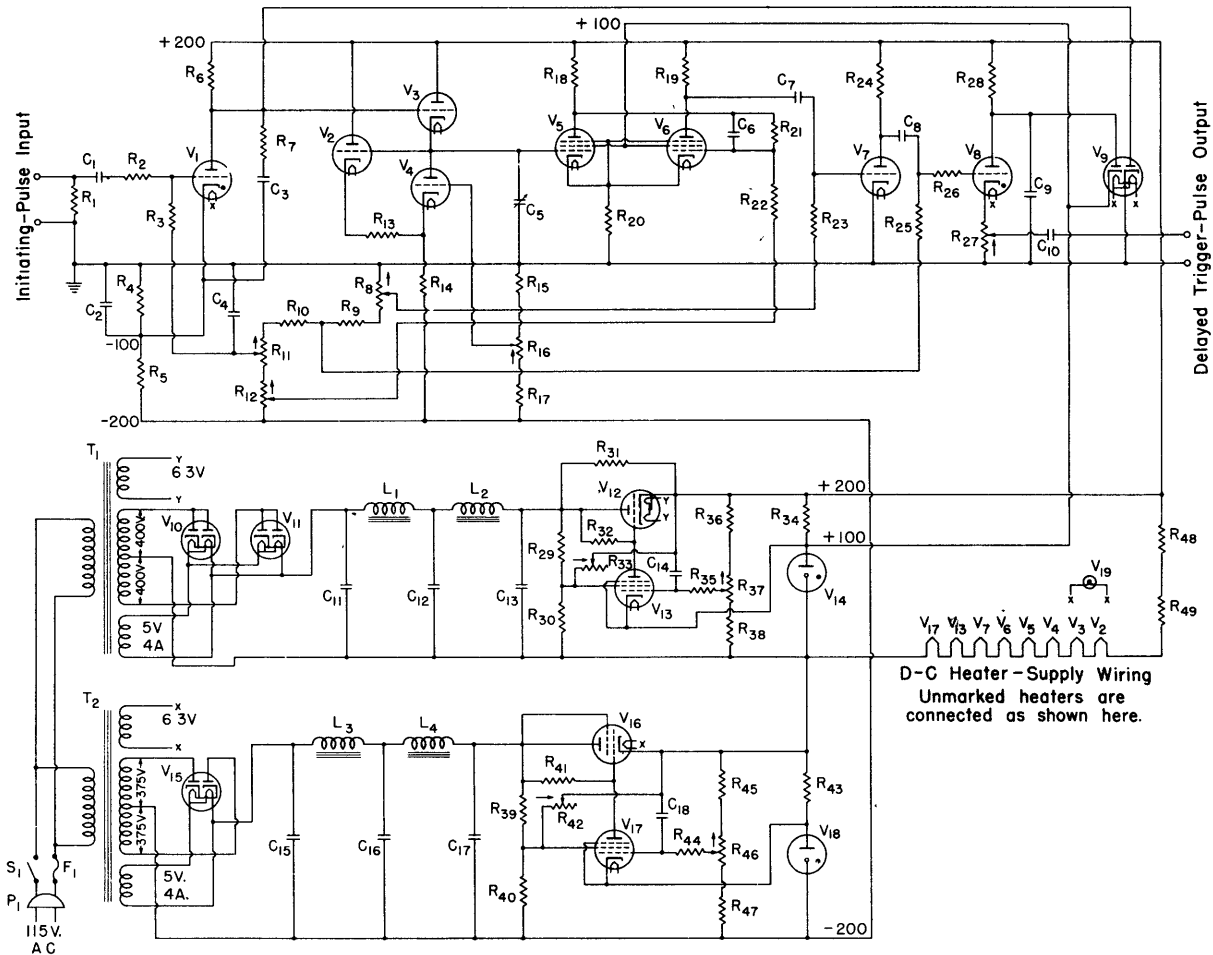
Figure 3 - Schematic Diagram of Microsecond Time-Delay Circuit

The Parts List gives the electrical ratings and characteristics of the various components.

Parts List

C_1 - 0.001 μf, 400 v

C_2 - 40 μf, 50 v, electrolytic

C_3 - 0.1 μf, 400 v

C_4 - 40 μf, 150 v, electrolytic

C_5 - Four-section, decade capacitor.
Cornell-Dubiler Capacitor,
Model CDB3 0 to 1 μf in 10 steps and 0 to .1 μf in 10 steps

Model CDA5 0 to .01 μf in 10 steps and 0 to .001 μf in 10 steps

C_6 - 50 $\mu\mu$f, mica

C_7 - 0.25 μf, 400 v

C_8 - 0.01 μf, 400 v

C_9 - 0.01 μf, 400 v

C_{10} - 0.001 μf, 400 v

C_{11} - 8 μf, 450 v, electrolytic

C_{12} - 8 μf, 450 v, electrolytic

C_{13} - 8 μf, 450 v, electrolytic

C_{14} - 1 μf, 600 v, paper, hermetically sealed

C_{15} - 8 μf, 450 v, electrolytic

C_{16} - 8 μf, 450 v, electrolytic

C_{17} - 8 μf, 450 v, electrolytic

C_{18} - 1 μf, 600 v, paper, hermetically sealed

Parts List (continued)

R_1 - 100 K, 1/2 w

R_2 - 10 K, 1/2 w

R_3 - 50 K, 1/2 w

R_4 - 100 K, 1 w

R_5 - 100 K, 1 w

R_6 - 10 M, 1 w

R_7 - 200 ohms, 1 w

R_8 - 2 M, potentiometer

R_9 - 15 K, 1 w

R_{10} - 75 K, 1 w

R_{11} - 50 K, potentiometer

R_{12} - 50 K, potentiometer

R_{13} - 2 M, 1 w

R_{14} - 100 K, 1 w

R_{15} - 75 K, 1 w

R_{16} - 50 K, potentiometer

R_{17} - 75 K, 1 w

R_{18} - 50 K, 1 w

R_{19} - 20 K, 1 w

R_{20} - 5 K, 1 w

R_{21} - 200 K, 1 w

R_{22} - 50 K, 1 w

R_{23} - 5 M, 1 w

R_{24} - 50 K, 1 w

R_{25} - 50 K, 1 w

R_{26} - 10 K, 1/2 w

R_{27} - 1 K, potentiometer

R_{28} - 10 M, 1 w

R_{29} - 125 K, 1 w

R_{30} - 125 K, 1 w

R_{31} - 2.5 K, 10 w

R_{32} - 750 K, 1 w

R_{33} - 50 K, potentiometer

R_{34} - 5 K, 10 w

R_{35} - 1 M, 1/2 w

R_{36} - 75 K, 1 w

R_{37} - 50 K, potenticmeter

R_{38} - 75 K, 1 w

R_{39} - 125 K, 1 w

R_{40} - 125 K, 1 w

R_{41} - 750 K, 1 w

R_{42} - 50 K, potentiometer

R_{43} - 50 K, 10 w

R_{44} - 1 M, 1/2 w

R_{45} - 75 K, 1 w

R_{46} - 50 K, potentiometer

R_{47} - 75 K, 1 w

R_{48} - 350 ohms, 10 w

R_{49} - 350 ohms, 10 w

Note: K corresponds to a multiplying factor of 10^3. M corresponds to a multiplying factor of 10^6. The unit for all resistances given in this table is ohms.

V_1 - 884

V_2 - 12SF5

V_3 - 12J5

V_4 - 12J5

V_5 - 12SJ7

V_6 - 12SJ7

V_7 - 12J5

V_8 - 884

V_9 - 6H6

V_{10} - 5Z4

V_{11} - 5Z4

V_{12} - 6A5G

V_{13} - 12SJ7

V_{14} - VR105/30

V_{15} 5Z4

V_{16} - 6L6

V_{17} - 12SJ7

V_{18} - VR105/30

V_{19} - 6.3 v, 0.15 amp pilot lamp

S_1 - SPST toggle switch

F_1 - 3.0 amp fuse

L_1 - Thordarson filter choke T-67C49, 12 h at 0 ma, 5 h at 200 ma, 80 ohms

L_2 - Thordarson filter choke T-67C49, 12 h at 0 ma, 5 h at 200 ma, 80 ohms

L_3 - Thordarson filter choke T-47C07, 20 h at 0 ma, 12 h at 75 ma, 410 ohms

L_4 - Thordarson filter choke T-47C07, 20 h at 0 ma, 12 h at 75 ma, 410 ohms

T_1 - Thordarson power transformer T-13R16, 180 va, 400-0-400 v, 200 ma, 5v - 4 amp, 6.3 v - 5.14 amp, center-tapped

T_2 - Thordarson power transformer T-13R15, 140 va, 375-0-375 v, 150 ma, 5v - 4 amp, 6.3 v - 5.0 amp, center-tapped

The time taken to reach the critical grid potential of V_6 is determined by the capacitance of C_5 and the current through tube V_4. The time required for C_5 to change its potential from its initial level to the potential which produces the critical conducting potential for the grid of V_6 constitutes the time-counting function of the circuit. This time may be varied most conveniently by variation of the capacitance of C_5, and since the discharge current is maintained linear by V_4, a series of decade capacitors may be employed to vary linearly the time interval which is obtained.

The time which is required for C_5 to change its potential from its higher to its lower critical value actually is dependent not only upon the magnitude of the current passing through C_5 but also upon the constancy of the grid cutoff potential of V_6. This constancy is insured by operating the heaters of V_5 and V_6 from a regulated d-c power source and by adjustment of the bias of V_6 to the desired value by potentiometer R_{12}. Adjustment of this potentiometer determines the particular grid potential of V_6 which will make the time scale correspond properly with the decade capacitance scale.

When the capacitor C_3 is discharged to the extinction potential of V_1, this tube deionizes and C_3 begins to recharge through R_6 to its original potential. As C_3 charges, the grid of V_3 is carried back into the plate-current-conducting region, the potential across C_5 begins to rise as it charges through V_3, the control grid of V_5 is carried positively again to cutoff and beyond into the conducting region, and a reverse trigger-circuit action occurs between V_5 and V_6. C_3 and C_5 continue to charge until C_3 attains the potential to which it is limited by the right-hand diode section of V_9. At the same time, C_9 recharges in exactly the same manner as described for C_3. When these actions are completed, the circuit is again ready for operation.

The time necessary for C_3 to charge positively to the grid cutoff point of V_3, however, is longer than the longest time interval which is produced by the unit, so that this operation does not interfere with the accuracy of the time-counting circuit. This is accomplished by keeping both R_6 and C_3 large in value. After the circuit has delivered one delayed trigger pulse, it cannot deliver another pulse until sufficient time has elapsed for the charge on C_3 to rise to the potential at which it will cause the trigger circuit to reverse. Spurious trigger-pulse generation and erratic action thereby are prevented. This feature of the circuit has proved an advantage for the type of work which is conducted at the Taylor Model Basin, inasmuch as many of the circuits which deliver input pulses into this equipment cannot be controlled to limit their output to one and only one pulse.

The diode sections of V_9, which are connected to V_1 and V_8, operate so that C_3 and C_9 charge to a fixed potential, at which potential all subsequent current through the circuits is drawn by the diodes. The right-hand diode section of V_9 determines exactly the potential of the grid of trigger tube V_5 at the start of the time measurement. This diode, therefore, directly controls the accuracy of the instrument, and it is responsible to a great extent for maintaining this accuracy. The second

diode section available in the Type 6H6 which is used in the position of V_9 provides a convenient control for the magnitude of the trigger pulse delivered to the attenuator R_{27}.

ADJUSTMENT OF THE CIRCUIT

Potentiometer R_{11} determines the grid-bias potential which is applied to V_1. This potential is adjusted so that an input signal of approximately 5 d-c volts will, cause ionization of V_1.

Potentiometer R_{16} is provided to control the current passing through V_4 by adjustment of the grid-bias potential of this tube. This control will determine the time interval between steps on the capacitor C_5 by determining the magnitude of the constant current through the current-limiting circuit. Once adjusted, this circuit should be independent of tube changes, and it should exhibit good long-time stability. R_{16} should be adjusted, by the use of a cathode-ray oscillograph as described later, to give the correct time intervals between steps.

The potentiometer R_8 furnishes the proper grid-bias potential to the grid of the amplifier V_7. It should be adjusted so that a plate-terminal potential of approximately 100 volts is obtained on V_7.

The potentiometer R_{12} determines the grid-bias potential of V_6, and by so doing, it controls the grid-signal potential of V_5 at which the trigger circuit switches. That is, this control determines the specific potential across C_5 which causes the trigger circuit to switch. It amounts to a "tracking" control which causes the decade time scale to follow exactly the decade capacitance scale of C_5. This feature adds much to the convenience of design of the instrument as well as to its convenience of operation.

To adjust R_{16} and R_{12}, the output of the microsecond time-delay circuit is connected to the input of the Y-axis deflection circuit of a cathode-ray oscillograph. X-axis deflection is provided on the cathode-ray oscillograph by a linear single-sweep circuit, the writing rate of which has been accurately calibrated by an oscillator. An initiating pulse then is applied simultaneously to the single-sweep initiating circuit and to the input of the time-delay trigger circuit, and the time of arrival of the delayed trigger pulse is observed on the screen of the cathode-ray tube. It is desirable in making this adjustment to employ a repetitive pulse so that the pattern on the screen of the cathode-ray tube will appear recurrent rather than transient. After the potentiometer R_{12} has been adjusted to give the correct time delay for one setting of the capacitor C_5, this capacitor should be adjusted to a new and slightly different value, and the correct time interval between the old and the new settings of C_5 should be adjusted by the potentiometer R_{16}. This adjustment is illustrated graphically in Figure 4. It will be desirable to check these adjustments at two or three widely-spaced points over the control range of the instrument, so that a minor discrepancy in the setting of R_{16}, which may not be obvious over a short time interval, will become evident.
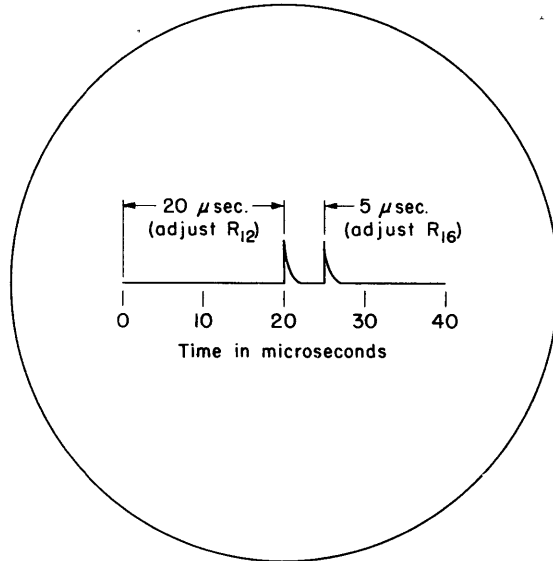
Figure 4 - Oscillographic Method for Calibration of Timing

Here, the linear single sweep circuit has been adjusted to give a linear sweep of 2 inches in 40 microseconds, i.e., the spot has a horizontal time rate of travel of $2/40 \times 10^{-6} = 0.05 \times 10^6$ inches per second. With R_{12} set to the correct grid-bias potential for V_6, the spot will travel exactly 1 inch before the delayed pulse appears when the capacitor C_5 is set for a delay of 20 microseconds.

With the calibrated linear single-sweep circuit applied to the x-deflection axis of the cathode-ray tube, and with repetitive pulsing, R_{12} is adjusted until the pulse occurs exactly 1 inch horizontally from the start of the sweep. Capacitor C_5 then is adjusted to give a delay of 25 microseconds; with R_{12} untouched, R_{16} is adjusted until the pulse appears exactly one-quarter inch beyond its previous position. When the absolute time has been adjusted accurately at one point by R_{12}, and when the time interval between steps of C_5 has been adjusted accurately by R_{16}, the instrument will deliver accurately delayed pulses over its entire scale range.
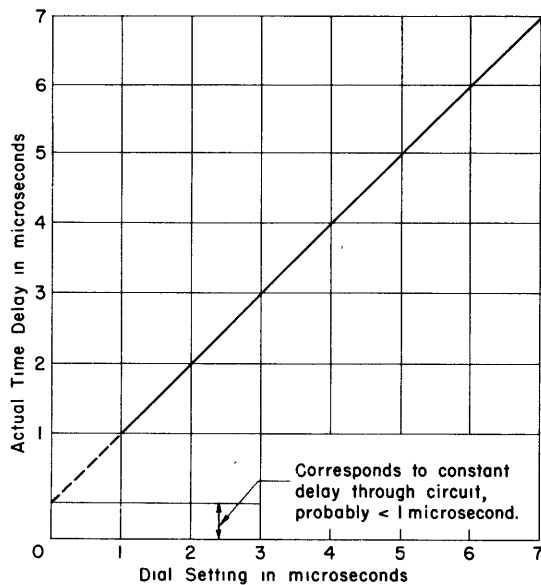

Figure 5 - Initial Time Delay
of the Instrument

When the adjustments which have been described in the foregoing have been completed, the instrument will deliver accurately delayed pulses, within the limits of its inherent stability, over its entire range with the exception of an initial and unavoidable zero error. This error is a constant time delay, for all ranges of the instrument, which is due to the time taken for the circuit to operate. It is illustrated graphically in Figure 5.

The error introduced by this initial delay becomes a decreasing percentage of the absolute time delay as the time delay becomes greater. The magnitude of the initial delay is believed to be 1 microsecond or

less. The magnitude of this initial delay is not changed by changing the time delay of the instrument.

The only remaining adjustments for the circuit are the balance and potential controls for the regulated power supplies. These are discussed in the next section of this report.

POWER SUPPLIES

The instrument is designed to operate from 115-volt, 60-cycle, single-phase alternating-current power. The power supply is self-contained within the equipment, and no batteries are required.

Two power supplies are utilized in the instrument. One provides a regulated potential of +200 volts with respect to ground, and the other provides a regulated potential of -200 volts with respect to ground.

The positive-potential power supply provides current for operation of the heaters to tubes V_2, V_3, V_4, V_5, V_6, V_7, V_{13}, and V_{17} as well as current for other electrodes of the vacuum tubes in the circuit. The use of regulated, direct-current power for heater circuits has been found to contribute materially to the stability of the circuit. In particular, the time-accuracy of the circuit depends directly upon the response of V_5 to the control-grid potential at which the trigger circuit is to switch. Vacuum-tube parameters, in a given tube, are affected probably more by cathode temperature and emission than by any other single factor, and it is believed that the excellent short-time and long-time stability of the heater-current power source contributes much to the overall stability of the unit.

The power supplies are conventional electronically regulated units.[*] The short-time stability of the regulator is good, and satisfactory long-time stability of output potential has been assured by operation of the heater circuit of each regulator-amplifier tube from the same d-c heater-current circuit which is used to supply the tubes of the time-delay circuit.

MECHANICAL DETAILS

The construction of the instrument is shown in Figures 6, 7, and 8. Figure 6 shows the external appearance of the instrument from the front. Figure 7 is another view from the front but with the protective hood removed from the chassis. Figure 8 shows the appearance of the under side of the chassis. Input circuits are at the right of this illustration, and output circuits are at the left-hand side.

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[*] A complete description of the operation of the regulated power supplies used in this instrument is given in TMB Report 502, "An Electronic Voltage Regulator."
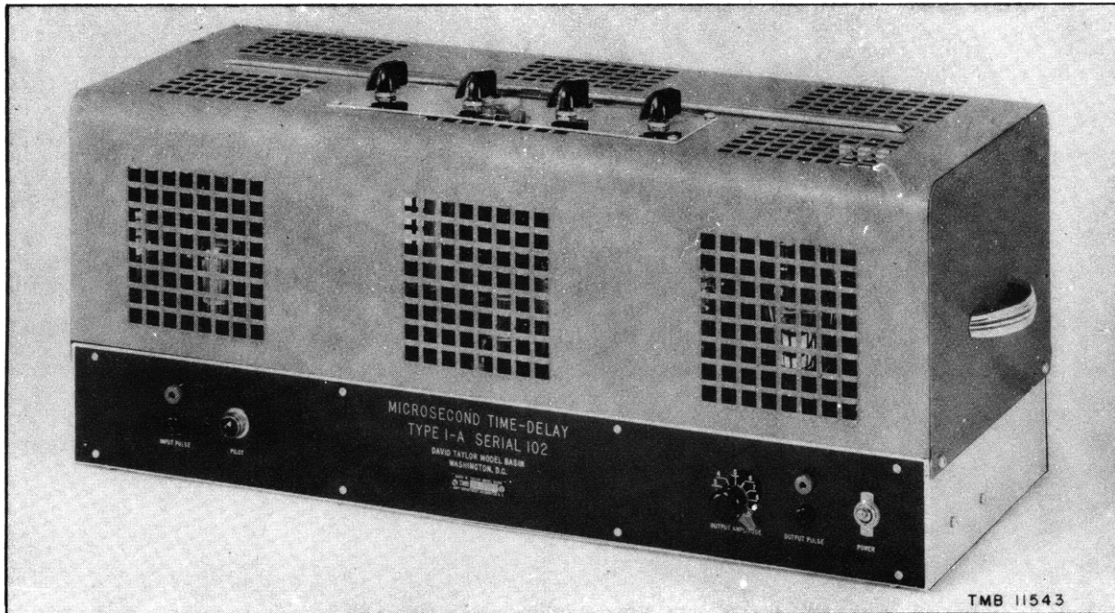
Figure 6 - External Appearance of the Microsecond Time-Delay Unit

Input circuits are at the left, output circuits at the right.

Figure 7 - Microsecond Time-Delay Unit

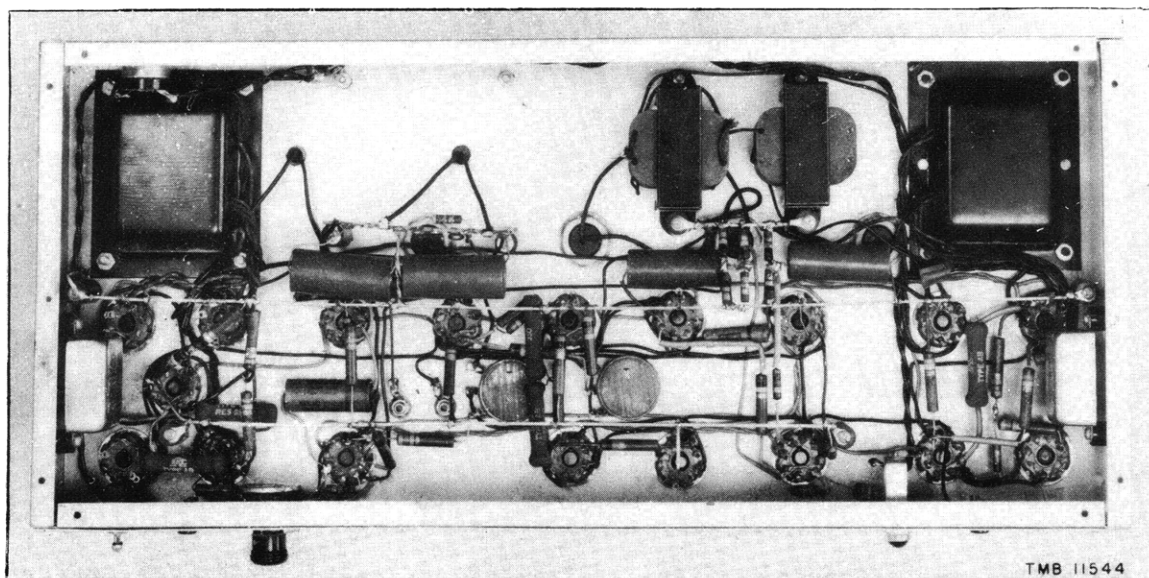View from the front with the chassis-protecting hood removed.

Figure 8 - Microsecond Time-Delay Unit

The photograph shows a view of the underside of the chassis. The front
of the unit is at the bottom of the illustration.

TYPICAL APPLICATION

        The microsecond time-delay circuit has proved itself of value in making photographs of shock-wave patterns. A shock wave in air, which was produced by an electrical spark, is shown in Figure 9.

        A diagram of the setup of equipment which was used in making the photograph of Figure 9 is shown in Figure 10. It is obvious that with a series of such photographs the propagation of the shock wave could be studied easily.
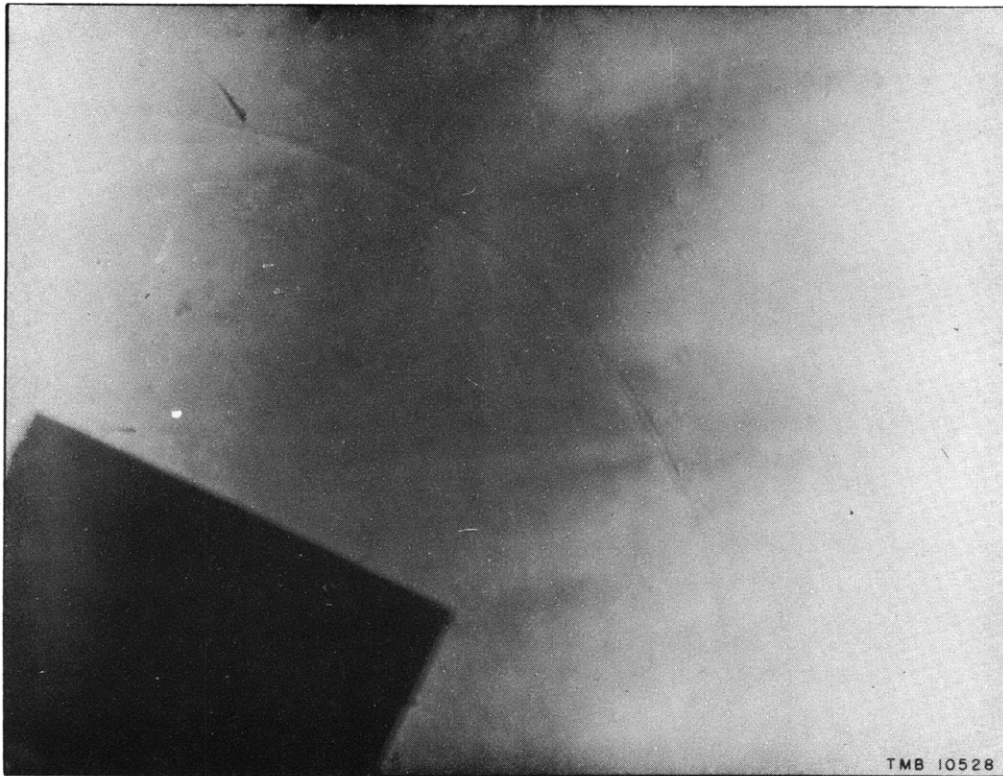
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Figure 9 - Photograph of a Shock Wave in Air

This is a photograph of a shock wave in air, generated by an electrical spark. The dark
area in the lower-left corner is the shadow cast by the light shield which was necessary
to prevent the light from the spark from over-exposing the film. This photograph was made
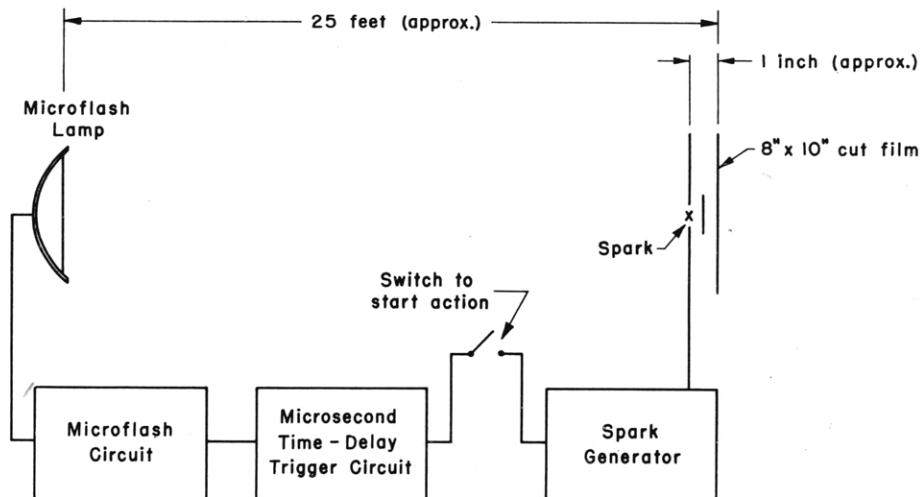using the setup shown in Figure 10. The time delay was 200 microseconds.

Figure 10 - Diagrammatic Sketch of Setup Employed for the
Shock-Wave Photograph of Figure 9

Eastman Super Panchro Press film was used for this work.