

**THE DESIGN AND CONSTRUCTION OF A SINGLE CHANNEL  
" TIME ANALYZER**

by

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"

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## INTRODUCTION

The function of a time analyzer in counting circuits is to sort the pulses that meet some criterion in their time with respect to other pulses. There are numerous experimental situations requiring some means of time discrimination. The requirements for a particular time analyzer design are determined by the experiments to be performed.

In recent years, the use of time analyzers has been widespread in reactor and nuclear physics. They have also been used in various forms for the generation of marker pulses in radar(4).

The single channel time analyzer described herein has been designed and constructed as part of the counting equipment to be used in conjunction with the 250 kev Cockroft-Walton accelerator to perform pulsed-neutron-source experiments.

The purpose served by this time analyzer is to activate the register circuits at a definite time after a reference pulse from the target has been received. All pulses that occur within a certain known time interval, or gate, will be recorded by the register. Both the time of delay and the counting interval, or gate, are variable. The time of delay, or Delay, is continuously variable over a range from 10 microseconds to 100 milliseconds. The counting interval, or Gate, is continuously variable over the range from 10 microseconds to 10 milliseconds. These wide ranges in time are desirable, as may be seen from a typical experiment in which the pulsed-neutron-source technique has been applied to studies of neutron diffusion in graphite.

In this experiment(2), several graphite piles of varying dimensions were pulsed with a small 250 kev accelerator employing the  $H^3(d,n)He^4$  reaction, and the decay rates of the neutron flux were measured with a 25 channel time analyzer. Measurements of the flux decay rates extended from a few microseconds to beyond 10 milliseconds. From this information, the author obtained the values of the transport mean free path and diffusion length of the neutrons.

Gate widths of less than a few microseconds are not required because input pulses from the detectors are about one microsecond in duration. Gate widths of over 10 milliseconds would result in no significant discrimination of the time dependence of events.

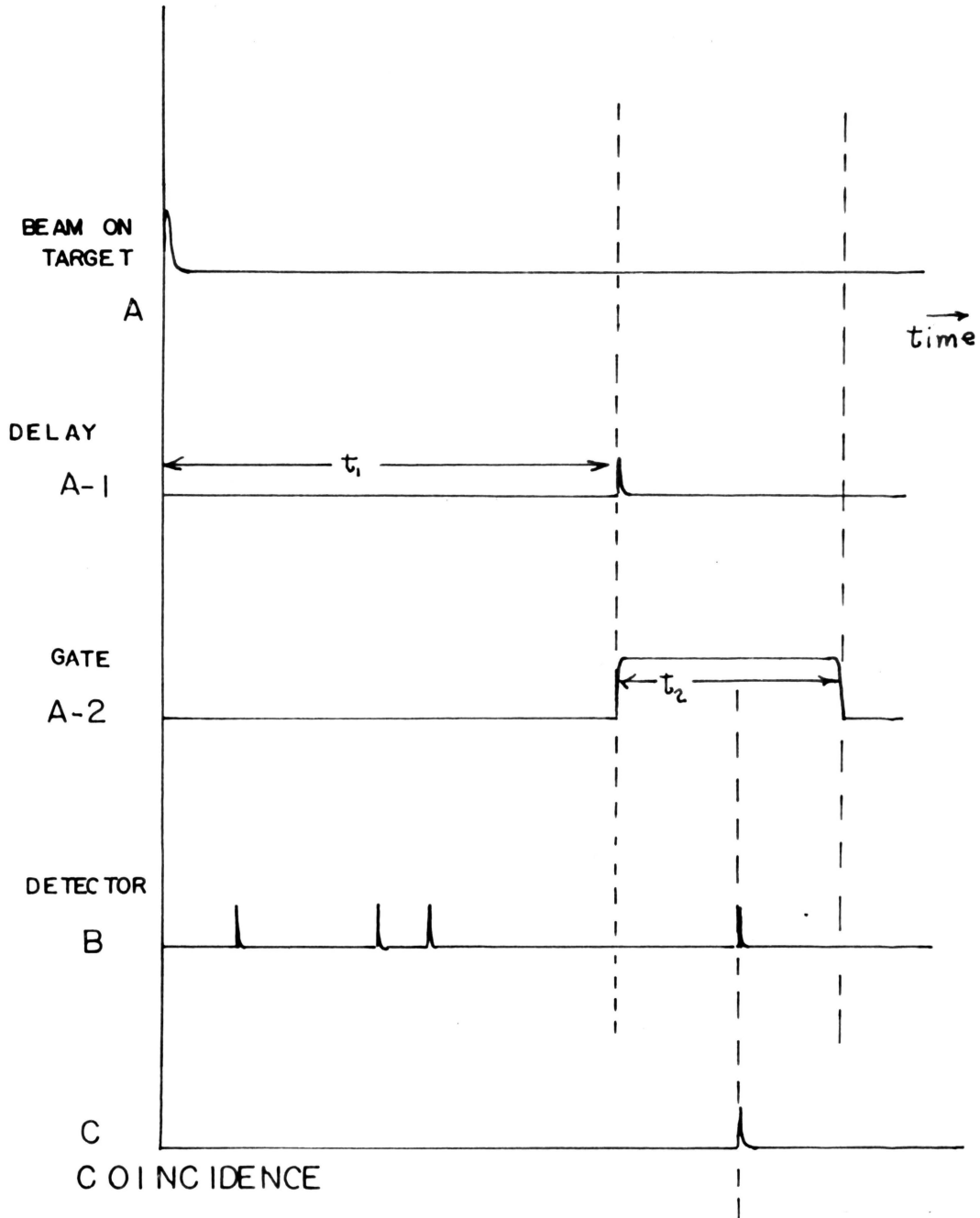
Both single and multichannel time analyzers play a vitally important role in pulsed-neutron-source investigations of reactor and nuclear physics. With this technique, a pulse from some periodic oscillator is applied simultaneously to modulate the beam of the accelerator and to initiate time analysis of the information from the detectors. Pulses from the detectors that have been delayed due to nuclear processes, times of flight, or diffusion processes are analyzed in the time analyzer circuits and sorted according to their delay times.

Related waveforms are presented in Figure 1 to illustrate the principle of time analysis. A more complete discussion of time analysis is found in the literature(6).

The pulses shown at A and B are from separate sources, the target and detector respectively. The pulses at A-1 and A-2 are derived from the pulse shown at A. When the gate and the detector pulses are applied

In proper manner to a coincidence circuit, the output pulses will appear as shown at C. If times  $t_1$  and  $t_2$  are variable, it is evident that the information at C may be recorded for a wide range in time with respect to  $t_0$ .

Within the past few years, much emphasis has been placed upon the design of multichannel time analyzers which permit a complete time spectrum to be recorded for each pulsing of the beam. Although these multichannel time analyzers are structurally different from the single channel type, the principle of operation is the same. Multichannel analyzers are, in general, single channel analyzers operated in sequence.



VARIABLE  
VARIABLE

FIG. 1 TIME ANALYSIS WAVEFORMS

It was decided to construct a single channel analyzer since only a limited number of scaling and recording circuits were available.

The operation of a single channel in a 10 channel time analyzer is discussed by Elmore and Sands(7).

A 10 channel time analyzer has been designed for determining half-lives of radioactivities in the range from a few microseconds to one second(9). Other investigators have discussed similar determinations of half-lives in this range(12).

A 40 channel time analyzer is discussed in detail by Von Dardel(14). Multichannel analyzers of this type have been employed by other investigators for diffusion studies(2).

Multichannel analyzers of 1000 time channels have been designed for use with neutron choppers capable of delivering bursts of less than one microsecond in duration(5).

In 1955, two single channel time analyzers were used to study the diffusion process by the pulsed-source technique(1). A somewhat different method was employed by Ramanna(11). Extensive investigations and the time analysis employed in the experiments at the Oak Ridge National Laboratories may be found in Campbell(3).

The method of time analysis employed with the impulse technique to determine reactivities are discussed in King(10).

## THEORY OF OPERATION

### General Description:

A block diagram of the single channel time analyzer circuit is shown in Figure 2. Dotted lines indicate the circuits contained within the time analyzer itself. Appropriate waveforms are illustrated for each stage of the operation when a reference pulse is presented to the input.

Operation of the single channel time analyzer is as follows.

The pulse of current in the accelerator causes the target potential to increase. This change in potential is transmitted to the Reference Pulse Input. The pulse shown is a positive going square wave with  $t_0$  designating the instant that the pulsed beam strikes the target. The incoming pulse is coupled through a Pulse Shape switch, a differentiator and clipper, and is presented to the amplifier. Direct coupling to the amplifier is achieved with the Pulse Shape switch in the OFF position. Direct coupling to the amplifier is desirable when the reference pulse is one of fast rise time and a duration of the order of one microsecond. When the pulse of current on the target is longer than this, it is necessary to shape the reference pulse illustrated in Figure 2 to achieve an accurate time reference.

The amplified pulse is coupled to the first of two linear delay univibrators in the time analyzer circuit. The square wave output, or delay, of this first univibrator is continuously variable in duration throughout a range of 10 microseconds to 100 milliseconds by means of

delay controls on the front panel of the time analyzer.

The time of the trailing edge of the delay output is denoted by  $t_1$ , the delay in time with respect to the reference pulse from the target. This trailing edge of the delay forms the trigger pulse for the second linear delay univibrator, and the output of this univibrator is the gate. The gate pulse is continuously variable in duration throughout a range of 10 microseconds to 10 milliseconds by means of gate controls on the front panel of the time analyzer.

It is desired to count all the pulses from some detector that occur within the gate, after the beam has struck the target. The coincidence circuit serves this purpose. The detector pulses are, after suitable amplification, coupled through an attenuator and inverter to one input of a coincidence circuit. The gate is coupled to the other input of the coincidence circuit through a cathode follower. Output pulses will occur through the discriminator only for those detector pulses that occur within the specified time interval. These are coupled to the Output through a cathode follower and are transmitted to a counting circuit. The circuit is designed to accept pulses from the pulse height selector of a linear amplifier. It can easily be modified to accept other pulses.

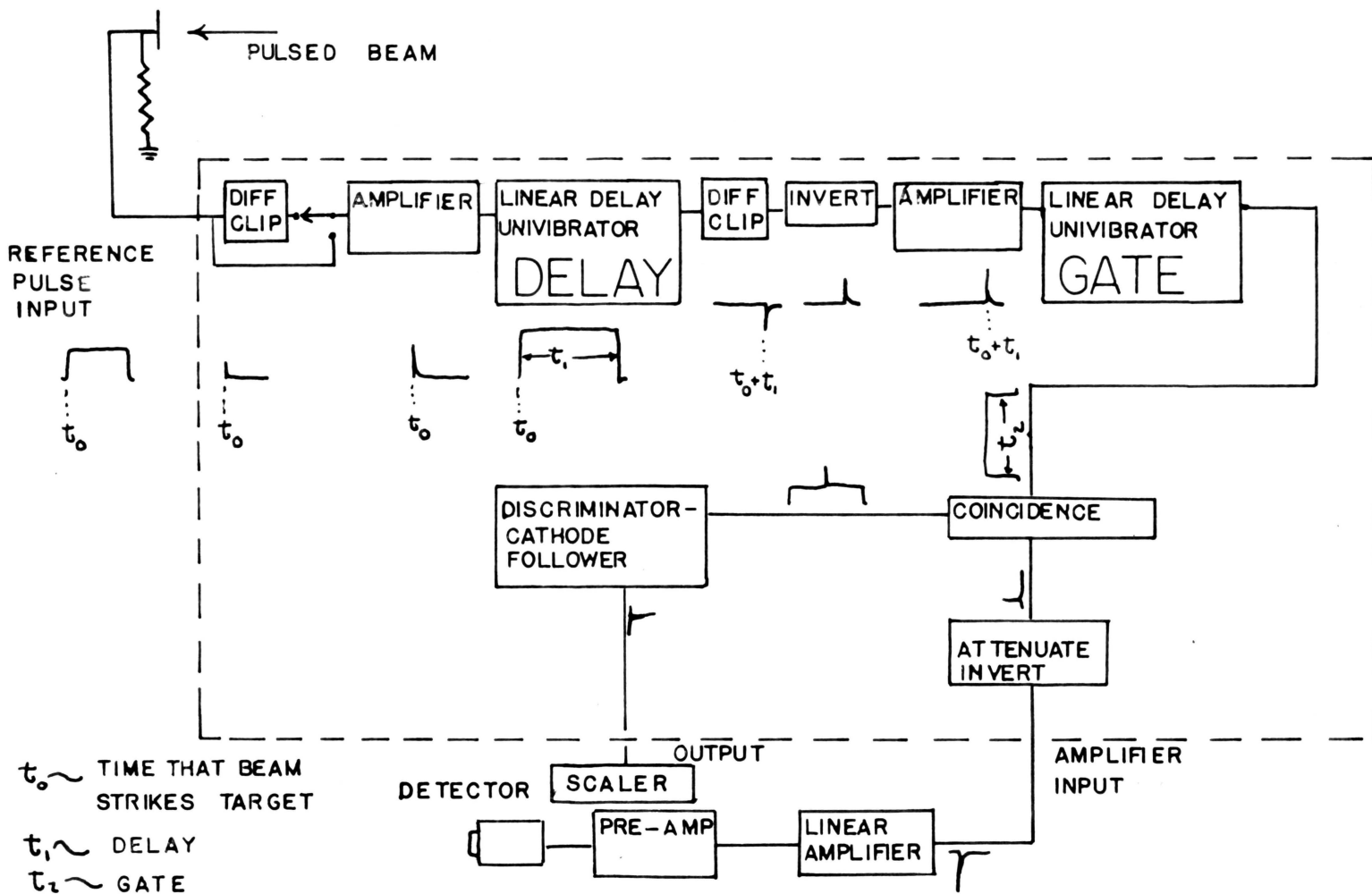


FIG. 2 BLOCK DIAGRAM OF SINGLE CHANNEL TIME ANALYZER

### Power Supply:

A circuit diagram of the power supply is shown in Figure 7. The power supply is a conventional electronic voltage regulator circuit. The operation is typical of the supply circuits discussed in Elmore and Sands (8). The output of the power supply is well regulated and is within 3% of 250VDC for an input variation of from 95 volts to 135 volts.

### Delay Circuit:

A circuit diagram of the delay circuit is shown in Figure 5. The delay circuit receives the timing pulse from the target at the Reference Pulse Input. The positive going square wave is differentiated by C1 and R1 and the negative going portion is clipped by the diode CR1. The choice of the leading edge of the beam current pulse as the reference time was arbitrary. The circuit could easily be modified to accept the trailing edge as the reference time.

The major component of the delay circuit is the linear delay univibrator. The schematic of a simple linear delay univibrator is shown in Figure 3. The theory of operation of linear delay univibrators is discussed in detail by Seely (13).

The operation of the cathode coupled delay univibrator is as follows: the d-c bias potential, E, is adjusted such that T1 will be cut off and T2 will be conducting. The cathode biasing resistor  $R_k$  is large enough so that T1 is held at cutoff by the voltage due to the plate current in T2. Tube T2 conducts until a positive trigger arrives at the grid of T1 causing a decrease in the plate voltage of T1. This voltage drop is transmitted by the capacitor, C, to the grid of T2, thereby reducing the current in T2.

Regeneration through the common cathode causes the plate voltage at T1 to further reduce.

This process continues until T2 is cut off and T1 is conducting. This transfer of conduction from T2 to T1 occurs in such a short time that there is no change in the potential of the capacitor. The capacitor discharges through the series path consisting of R1 and R<sub>g2</sub>. This discharge causes the T2 grid potential to increase exponentially toward a final value equal to the plate supply voltage. When the potential, with respect to the cathode, reaches such a value that T2 again conducts, the regeneration causes the conduction to transfer very rapidly from T1 to T2.

It is shown in Seely(13) that the time during which T1 conducts is given approximately by the following expression

$$T \approx aCR_{g2}E + b \quad (1)$$

where:

a and b are constants determined by the circuit parameters.

It is seen from this expression that the delay time is proportional to the d-c bias E which is controlled by the helipot.

The range of variability of E is limited, and the pulse duration is principally determined by the values of C and R<sub>g2</sub>.

It was, however, possible to design this time analyzer so that the variability of E would permit adjustment of the delay time and gate by a factor of 10 for several different values of the product CR<sub>g2</sub>. This permits calibration of the instrument so that its control setting may be immediately converted to time.

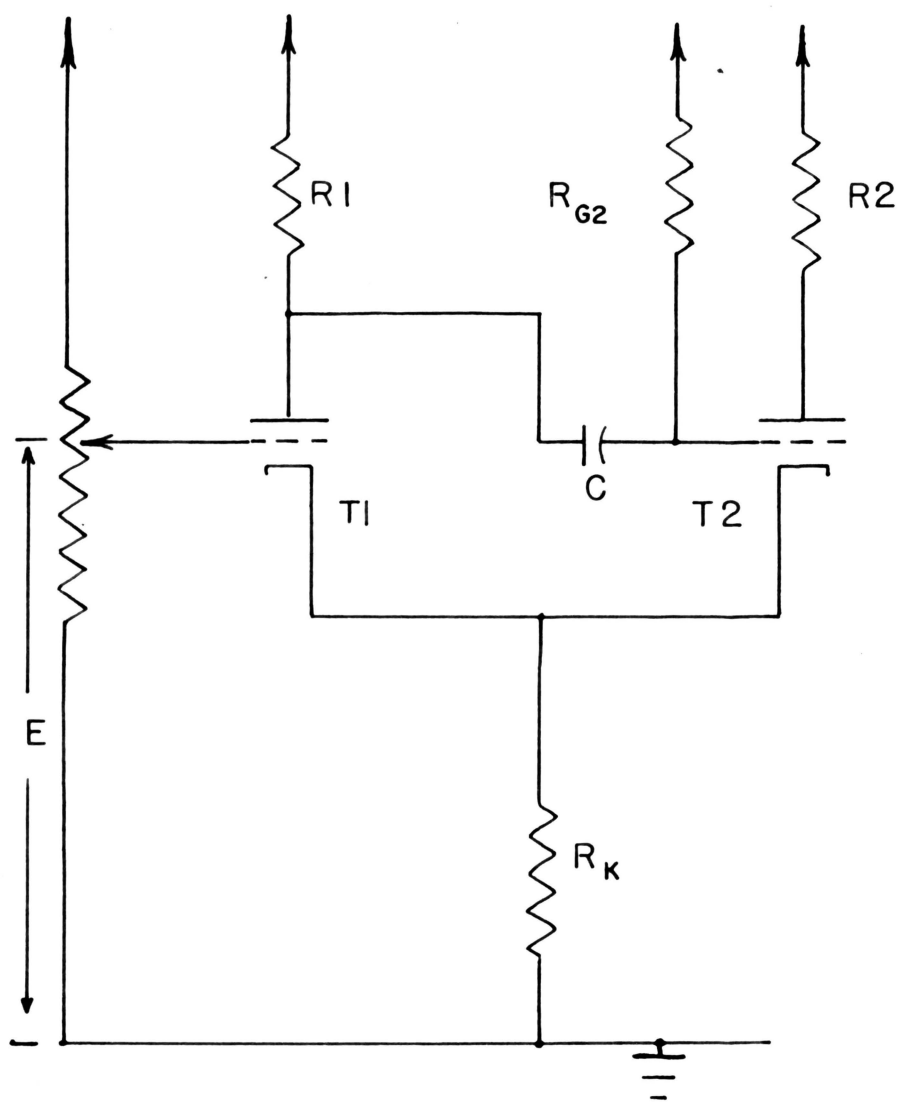


FIG. 3 SCHEMATIC OF A LINEAR DELAY UNIVIBRATOR

The linear delay univibrator incorporated in the time delay circuit of this time analyzer is identical in principle of operation to the one just described.

The delay univibrator is a twin triode 6SN7, V6A and V6B, Figure 8. The values of C are determined by the position of a three section multiple throw switch S2. The switch couples through a ganged connection, to a ten-turn helipot which controls the d-c bias voltage E. With the switch S2 in the position for delay times in the range from 10 to 100 microseconds, the bias E is determined by the calibration potentiometers R6 and R9 and the 100K helipot. With S2 set to the longer delays, the bias E is determined by R7, R10, and the 100K helipot. It is necessary to provide separate adjustment of the bias E in the shortest delay range to achieve a linear response. A detailed circuit diagram of the selector switch is shown in Figure 9.

The crystal diode CR2 in the input circuit of the delay univibrator serves to disconnect the delay univibrator from the trigger source until the next positive trigger arrives.

### Gate Circuit

A circuit diagram of the gate, or counting interval, circuit is shown in Figure 10. The trailing edge of the output delay pulse, which occurs at a known time  $t_1$  after the beam has struck the target, is the trigger for the gate circuit. The gate univibrator circuit is identical in design to the delay circuit, with the exception of the clipping polarity, the phase inverter V7, and values of the resistors and capac-

itors throughout the circuit. There are three gate intervals providing continuous variation throughout the range from 10 microseconds to 10 milliseconds. The controls are located on the front panel and are marked Gate.

### Coincidence Circuit

The purpose served by a coincidence circuit is to produce an output pulse only when suitable signals occur simultaneously at the inputs. A schematic of a simple diode coincidence circuit is shown in Figure 4. The operation is as follows

In the quiescent condition, T1 and T2 are both conducting. The potential at the common plate junction,  $V_p$ , is given by the following expression

$$V_p = V \frac{R_2}{(2R_1 + R_2)} \quad (2)$$

In deriving this expression, the small forward resistance of the diodes has been neglected. If a positive signal appears at either of the inputs, one of the diodes is cut off, which doubles the potential at the common junction. If large positive pulses occur simultaneously at the inputs, the rise in cathode potential is large. Both diodes will be cut off, and a large pulse will be produced at the common plates. The signal, smaller in voltage of the two pulses, determines the voltage of this pulse. Its duration is determined by the duration of the shorter pulse.

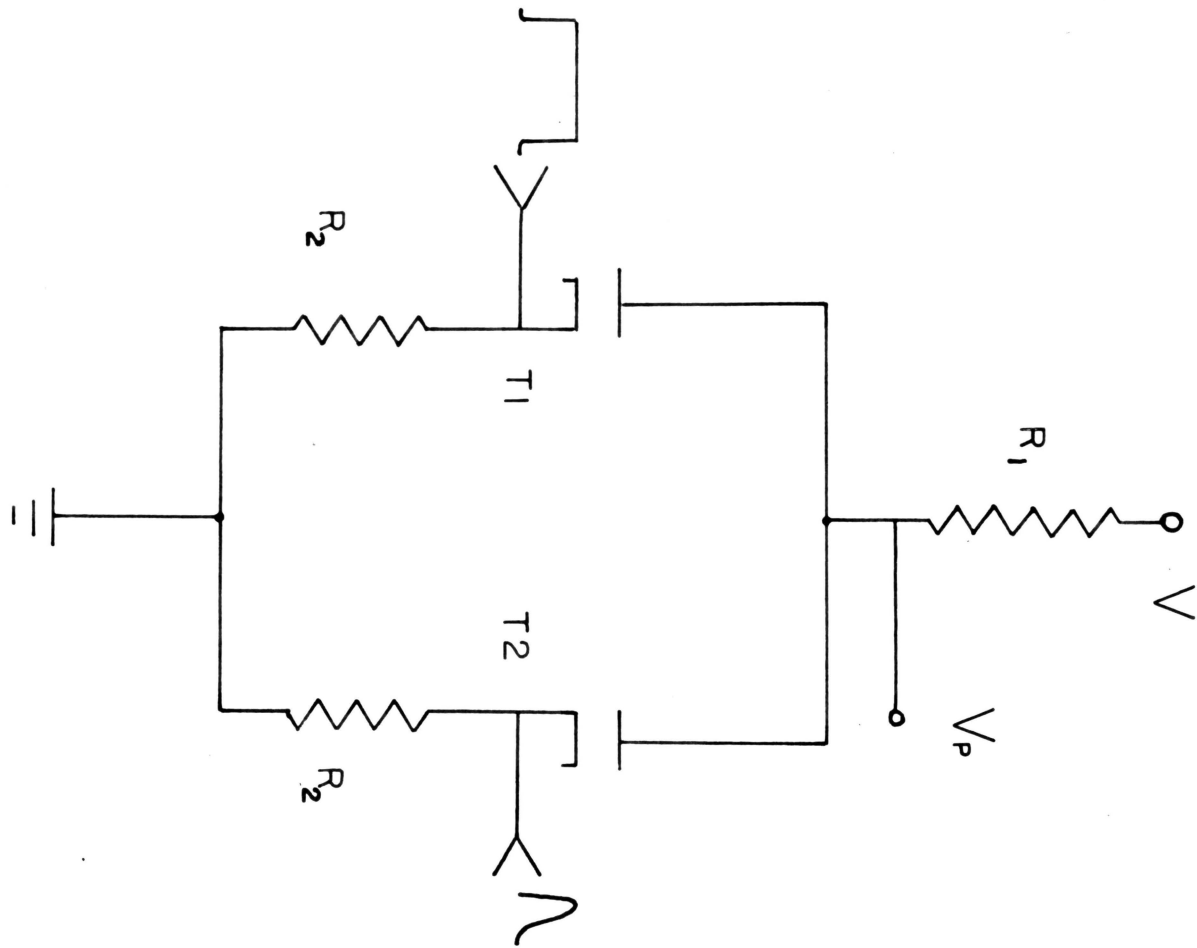


FIG. 4 SCHEMATIC OF A SIMPLE DIODE COINCIDENCE CIRCUIT

This diode coincidence circuit as incorporated in the time analyzer is shown in Figure 11. The coincidence output is easily discriminated by V12 which is biased to pass only the coincident pulses. The coincident pulses are inverted in V12 and coupled through the cathode follower V13 to the Output connection.

The detector pulses are externally amplified and arrive at the Amplifier Input connection of the single channel time analyzer. The time analyzer is designed to accept pulse-height-selector pulses from the Model A-1 Linear Amplifier. These pulses are 60 volt negative pulses and are attenuated and then inverted in V11B. The output of the phase inverter applied to the cathode of CR2 is a fast rising positive pulse of a few microseconds duration.

The pulses at the Output of the time analyzer are negative pulses. This is desirable since some of the available scalers are designed to accept only negative pulses and others are designed for input pulses of either polarity.

### Performance

The single channel time analyzer is constructed as a single unit. The completed instrument is shown in Figure 12. Vacuum tubes are oriented and located on the chassis to accommodate short grid connections. Filament leads are twisted and routed to prevent noise, and the high voltage and ground connections are distributed on busbars.

Voltages throughout the analyzer circuit are listed in Table I. Table II contains measurements of the delay time, and gate time, as a

function of Delay duodial setting for each position of the selector switches. Figure 5 shows the Delay time as a function of duodial setting. Figure 6 shows the Gate time as a function of duodial setting. Both the Delay times and the Gate times are shown for each position of the switch and throughout the range of the duodials, to be superimposed. The largest variation between points on the several curves is less than the width of the line. Figure 13 shows waveforms at the critical points of the circuit.

Delay times were measured by visual comparison with the sweep times of Model 545 Tektronix oscilloscopes. No means of more accurately determining delay times in the single channel analyzer is currently available.

The time jitter; i.e., the variation in delay time of the uni-vibrators at a fixed position of the controls; in outputs of Delay and Gate intervals needs to be measured with better accuracy. The oscilloscope observations indicate that jitter is not more than a few percent of the delay time at any delay setting.

TABLE 1

Voltages Throughout the Circuit

All voltages measured with VTVM to ground.

Pin numbers in parentheses.

All values listed are volts d-c.

Power Supply

<u>Tube</u>	<u>Control Grids</u>	<u>Plate</u>	<u>Cathode</u>
V1	(3)246	400	(4)250
V2	(4)68	(8)246	(5)82
V3		(5)82	(2)0

Delay Circuit

<u>Tube</u>	<u>Control Grids</u>	<u>Plate</u>	<u>Cathode</u>
V4	(1)0	(5)225	(7)3.5
V5A	(2)0	(1)165	(3)5.5
V5B	(7)55	(6)250	(8)67
V6A	(1)29	(2)250	(3)55
V6B	(4)55	(5)160	(6)55

Delay Duodial

<u>Duodial</u>	<u>Helipot</u>	<u>100msec. to 100microsec. Ranges</u>	<u>100microsec. Range</u>
10	Wiper	29	31
	Bottom	21	22
	Top	29	31
1	Wiper	22.5	24

TABLE 1 (Cont'd)

<u>Gate Circuit</u>			
<u>Tube</u>	<u>Grids</u>	<u>Plate</u>	<u>Cathode</u>
V7	(2)0	(1)230	(3)15
V8	(1)0	(5)190	(7)15
V9A	(2)0	(1)115	(3)5
V9B	(7)52	(6)250	(8)63
V10A	(1)33	(2)250	(3)62
V10B	(4)62	(5)165	(6)62

<u>Gate Duodial</u>			
<u>Duodial</u>	<u>Helipot</u>	<u>10msec. to 100 microsec. Ranges</u>	<u>100microsec. Range</u>
10	Wiper	33	38
	Bottom	23.5	24
	Top	33	38
1	Wiper	28	29

<u>Coincidence Circuit</u>			
<u>Tube</u>	<u>Grids</u>	<u>Plate</u>	<u>Cathode</u>
V11A	(7)16	(6)250	(8)21
V11B	(2)0	(1)180	(3)3
V12	(1)0	(5)250	(7)19
V13	(7)0	(6)250	(8)250
CR1		(P)21	(C)21
CR2		(P)21	(C)21

TABLE 11

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Delay Time and Gate Time as a Function of Duodial Setting

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Range: 100 msec.		Range: 10 msec.	
<u>Duodial</u>	<u>Delay Time (msec)</u>	<u>Duodial</u>	<u>Delay Time (msec)</u>
1	9.90	1	1.0
2	19.9	2	2.0
3	29.9	3	3.0
4	40.0	4	4.0
5	50.0	5	5.0
6	60.0	6	6.0
7	70.0	7	7.0
8	80.0	8	8.0
9	90.0	9	9.0
10	100	10	10

Range: 1msec.		Range: 100 microsec.	
<u>Duodial</u>	<u>Delay Time (microsec.)</u>	<u>Duodial</u>	<u>Delay Time (microsec.)</u>
1	100	1	10
2	200	2	20
3	300	3	30
4	406	4	40
5	510	5	50
6	610	6	60
7	710	7	70
8	810	8	80
9	910	9	90
10	1000	10	100

TABLE II (cont'd)

Range: 10msec.

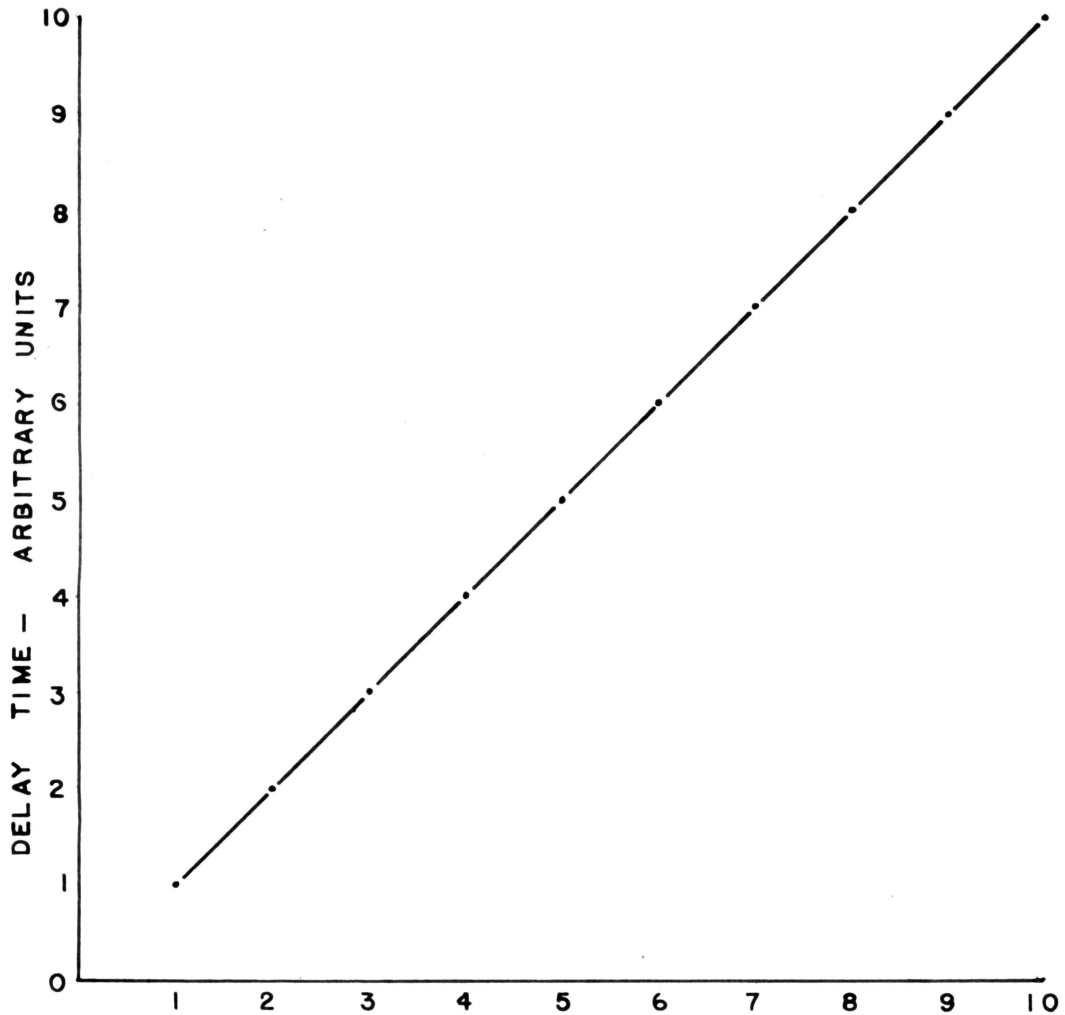
<u>Duodial</u>	<u>Gate Time(msec.)</u>
1	1.0
2	2.0
3	3.0
4	4.0
5	5.0
6	6.0
7	7.0
8	8.0
9	9.0
10	10

Range: 1msec.

<u>Duodial</u>	<u>Gate Time(microsec.)</u>
1	100
2	200
3	300
4	400
5	500
6	600
7	700
8	800
9	900
10	1000

Range: 100 microseconds

<u>Duodial</u>	<u>Gate Time (microseconds)</u>
1	10
2	20
3	30
4	40
5	51
6	61
7	71
8	81
9	91
10	101



DUODIAL SETTING

CURVES 1,2,3,4 ARE SUPERIMPOSED

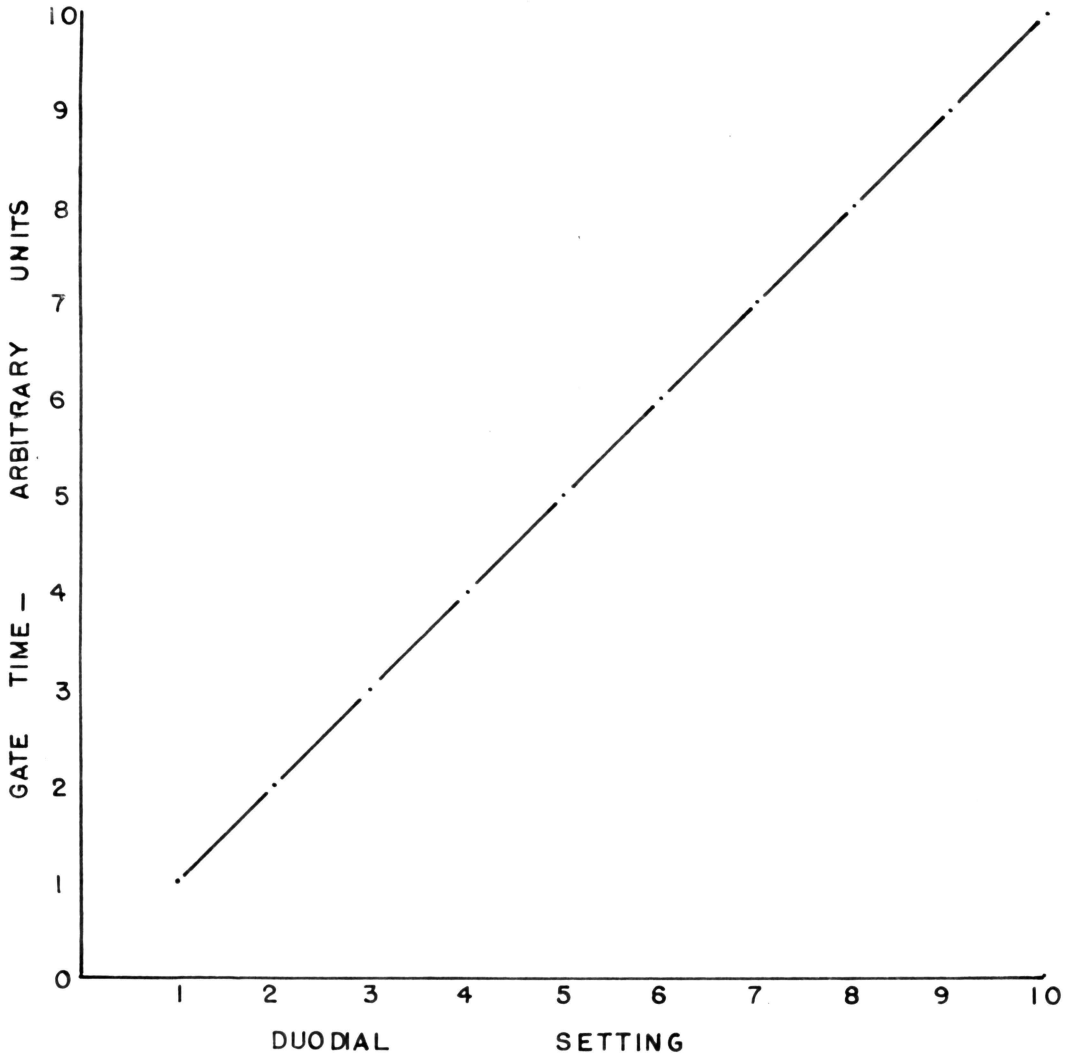
CURVE 1- MSEC  $\times 10$

CURVE 2- MSEC  $\times 1$

CURVE 3- MICROSEC  $\times 100$

CURVE 4- MICRO SEC  $\times 10$

FIG. 5 DELAY TIME AS A FUNCTION OF DUODIAL SETTING



CURVES 1,2,3 ARE SUPERIMPOSED

CURVE 1- MSEC x 1

CURVE 2- MICROSEC x 100

CURVE 3- MICROSEC x 10

FIG.6 GATE TIME AS A FUNCTION OF  
DUODIAL SETTING

CALIBRATION PROCEDURE

Calibration of Delay Duodial

1. Connect a square wave generator to the Reference Pulse Input and use an oscilloscope to trace the waveforms at each stage of the time analyzer.
2. Measure the power supply output with a VTVM. This should be 250 VDC. The HIGH VOLTS ADJUST potentiometer is located on top of the chassis.
3. Connect oscilloscope probe to pin 5, V6B, to obtain the delay waveform.
4. Set the Delay controls as follows and note the Delay Time indicated on the scope TIME/CM dials.

<u>Duodial</u>	<u>Switch Position</u>	<u>Delay Time</u>
10-----	100msec.	----- 100msec.
1-----	100msec.	----- 10msec.
10-----	10msec.	----- 10msec.
1-----	10msec.	----- 1msec.
10-----	1msec.	----- 1msec.
1-----	1msec.	----- 100microsec.
10-----	100microsec.	----- 100microsec.
1-----	100microsec.	----- 10microsec.

5. Should the delay ranges be out of adjustment, it will be necessary to adjust the d-c bias voltage E by the following procedure. Set the Delay Duodial at 10 and the Delay Selector switch at 100msec. All Delay range calibration potentiometers are located on top of the chassis and labeled DELAY ADJUST. It is not necessary to adjust R17 unless the 6SN7, V6, is replaced. Adjust R7 so that Delay Time is

100msec. Set Duodial at 1 and adjust R10 so that Delay Time is 10 msec. Repeat this procedure until Delay Time is within 1% of Duodial setting throughout the range of the dial.

6. Set Duodial at 10 and switch at 100 microsec. Adjust R6 so that Delay Time is 100 microsec. Set Duodial at 1 and adjust R9 until Delay Time is 10 microsec. Repeat until Delay Time is within 1% of Duodial setting throughout the range of the dial.

7. Plot the Delay Time versus Duodial Reading throughout the range of the Duodial for each of the switch positions. The instrument is calibrated when the curves indicate that the Delay Time is, within 1%, a linear function of the Duodial Setting.

#### Calibration of Gate Duodial

The calibration adjustments for the Gate circuit are located on top of the chassis and are marked GATE ADJUST.

Connect oscilloscope probe to pin 5, V10B, and obtain the gate waveform.

2. The calibration potentiometers for Gate Times in the range from 10 to 100 microsecond are R6 and R9. For Gate Times in the range from 100 microseconds to 10 milliseconds adjust R7 and R10. The same conditions govern the adjustment of R17 as are set forth in step No. 5 in the calibration procedure for the delay circuits with the exception that R17 in the GATE ADJUST should be adjusted to give a 62volts on the VTVM at pin 3, V10.

3. Except for conditions set forth in steps 1 and 2 above, the calibration procedure for the Gate Duodial is the same as for the Delay Duodial.

#### ACKNOWLEDGMENTS

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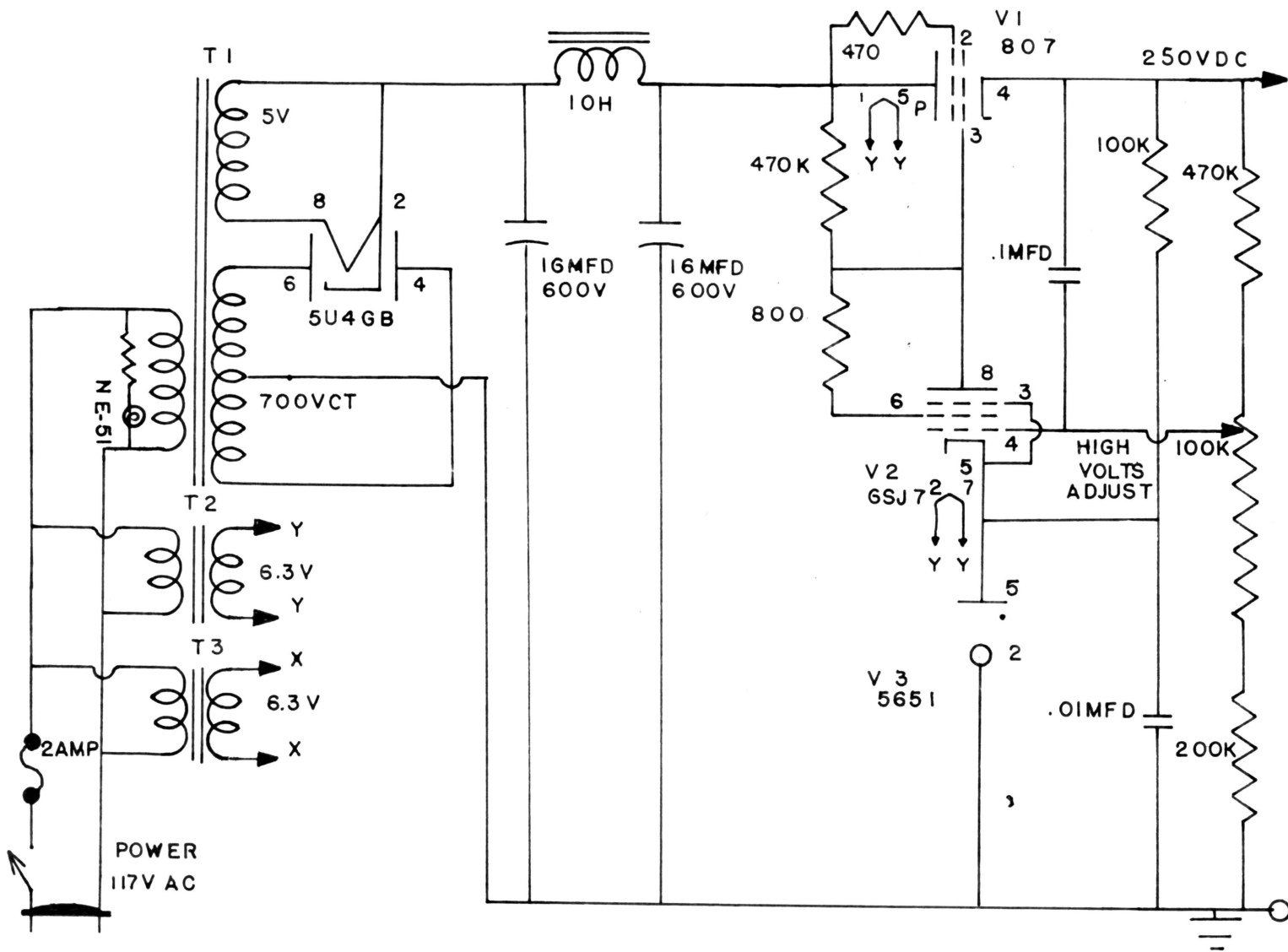


FIG. 7 CIRCUIT DIAGRAM OF POWER SUPPLY



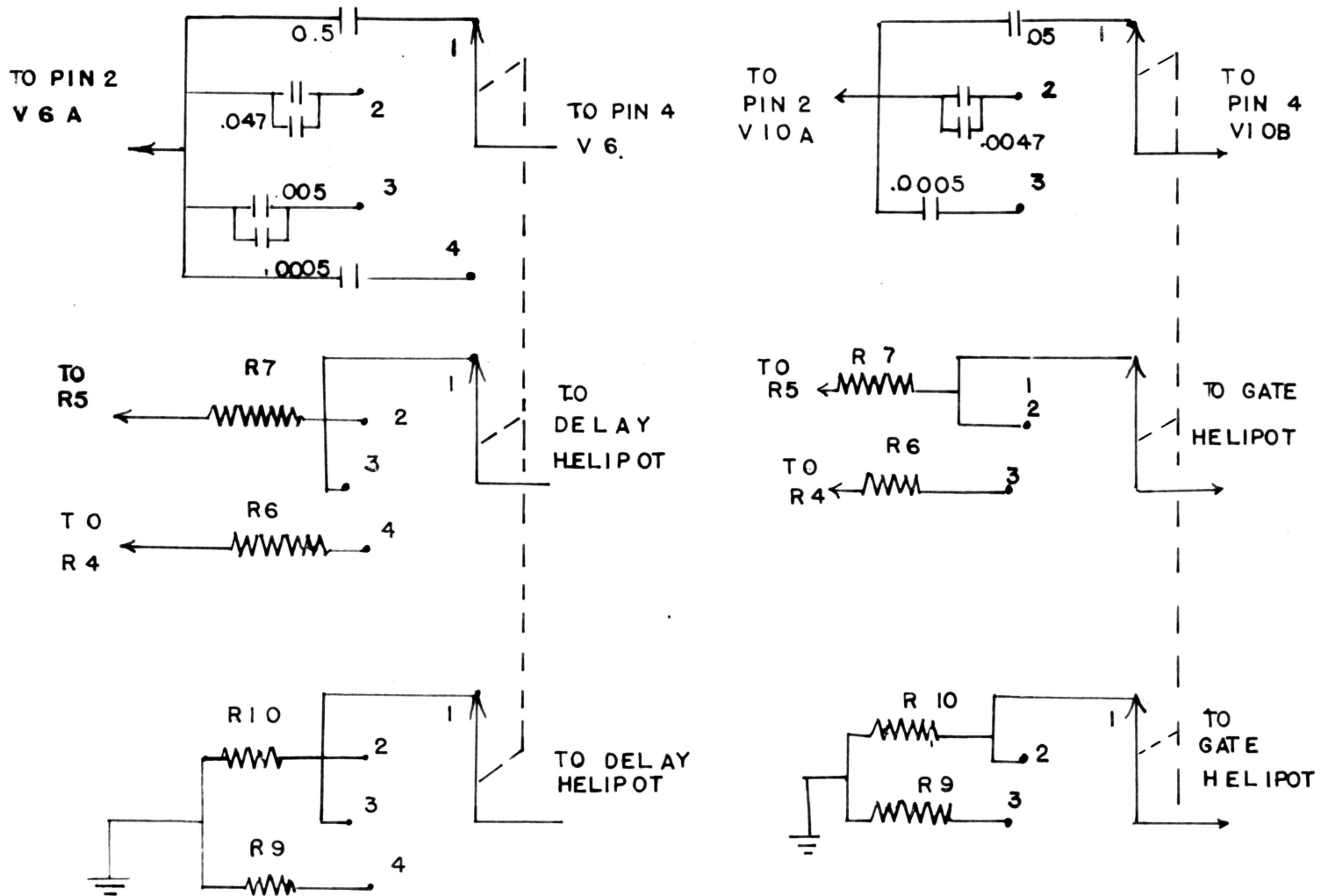


FIG. 9 DETAIL CIRCUIT DIAGRAM OF SELECTOR SWITCHES



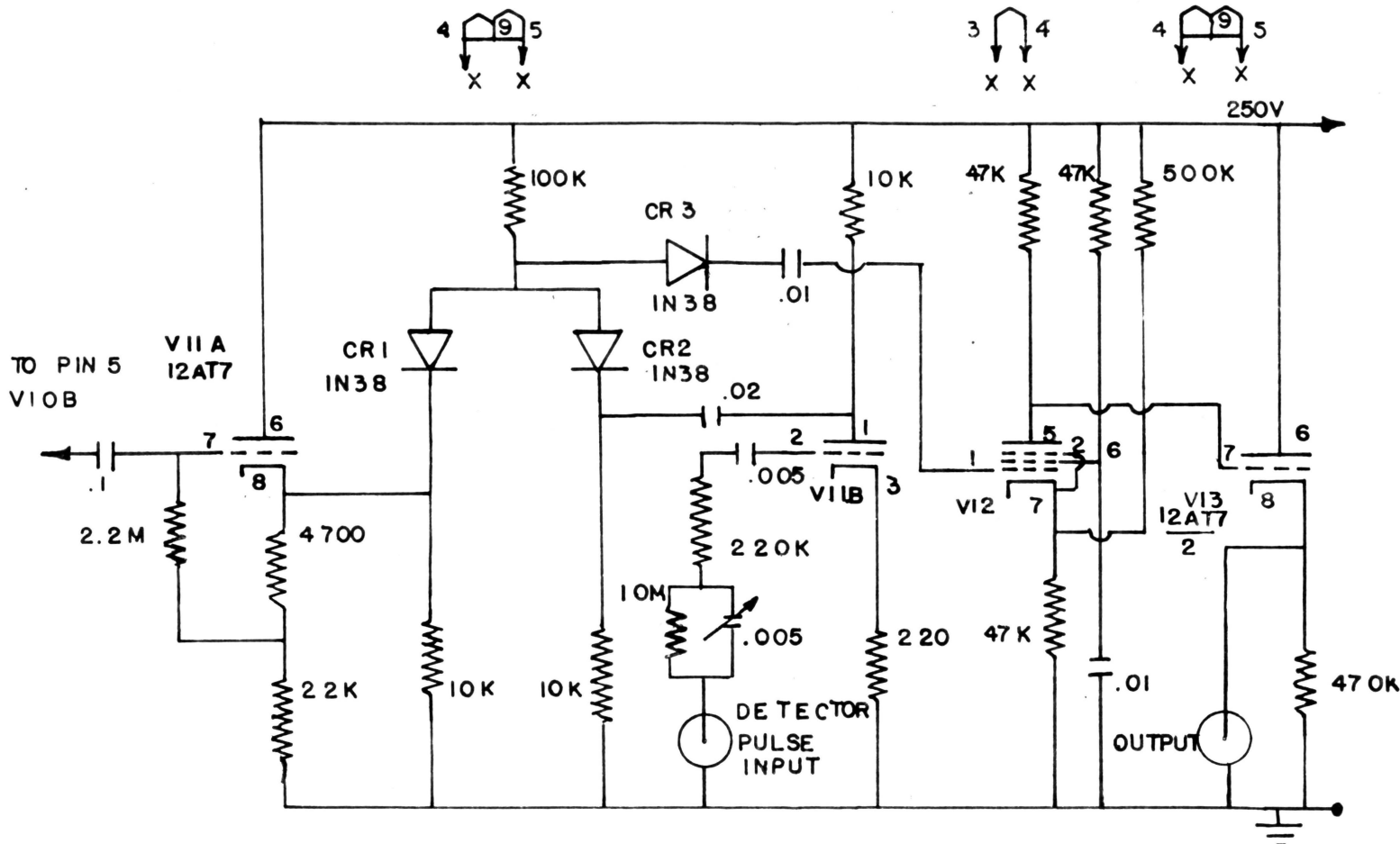


FIG. II CIRCUIT DIAGRAM OF COINCIDENCE CIRCUIT

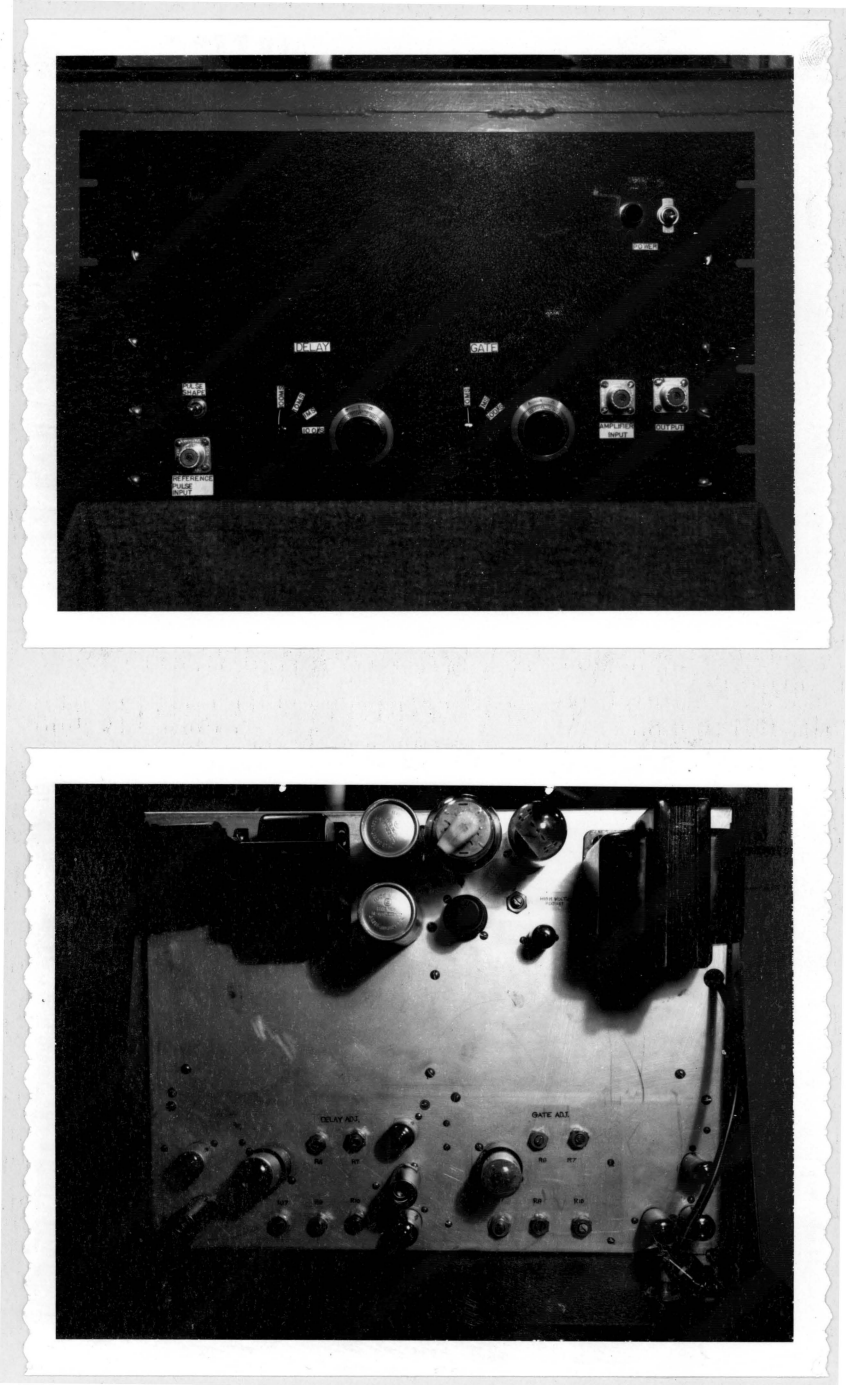


Fig. 12 Completed Unit-Single Channel Time Analyzer

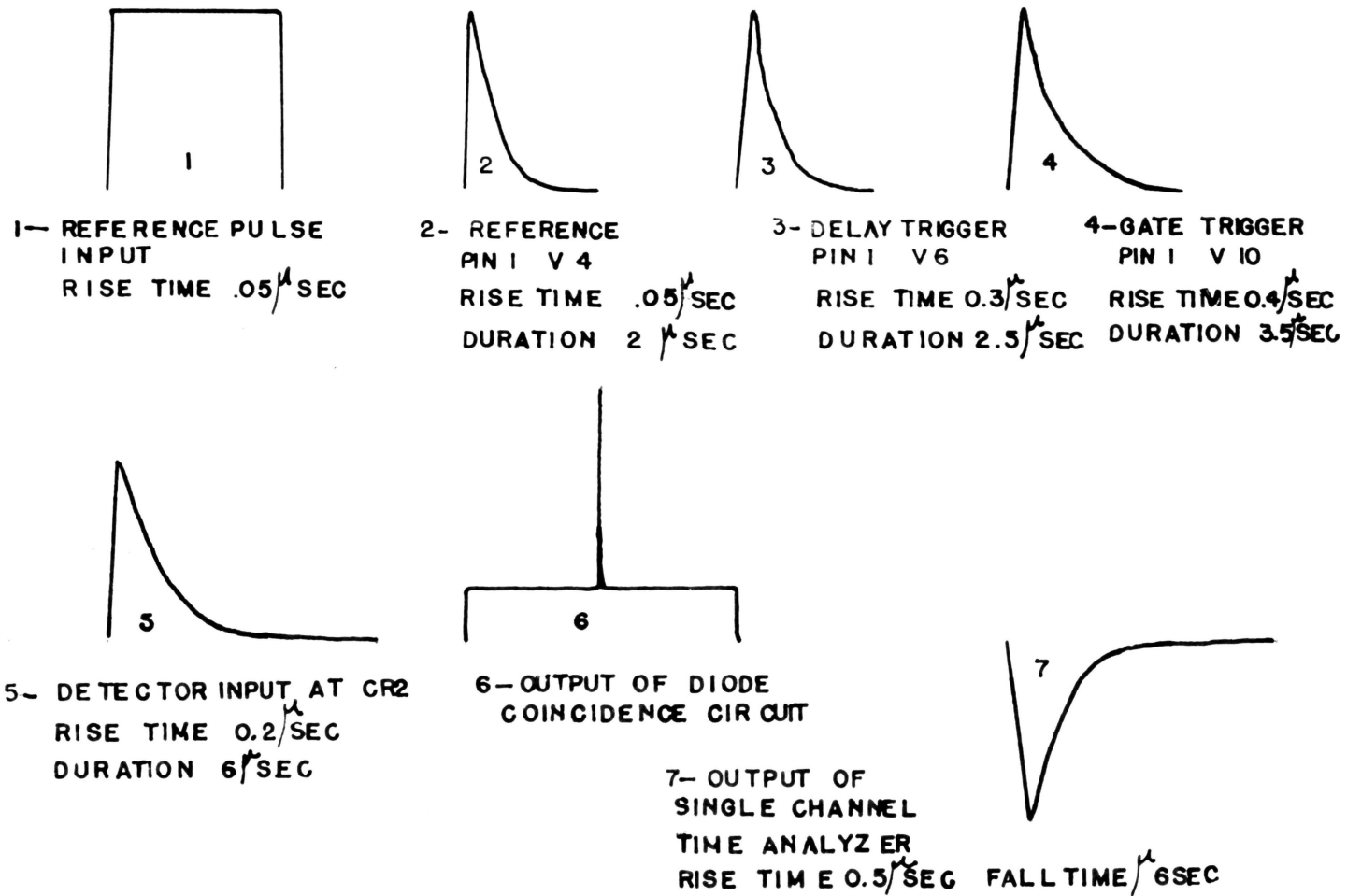


FIG. 13 PULSE OUTPUT AND INPUT WAVEFORMS

## ABSTRACT

The Virginia Polytechnic Institute 250 kev Cockroft-Walton electrostatic accelerator is being constructed under the direction of Dr. A. Robeson. The emphasis of the experiments to be performed with this machine will be placed upon those experiments which involve the use of a pulsed beam.

This thesis describes the author's contribution to the Cockroft-Walton project through the design and construction of a single channel time analyzer.

The time analyzer will detect the pulse of beam current on the target and, after a fixed delay time, will open a channel to record the pulses from a detector.

The delay time is continuously variable from 10 microseconds to 100 milliseconds. The duration of the counting interval is continuously variable from 10 microseconds to 10 milliseconds.

When the time analyzer is operated in conjunction with other equipment, it will be possible to perform such experiments in nuclear or reactor physics as measurements of the decay rate of neutron flux in moderators or other materials.