AN ELECTRONIC STIMULATOR

FOR MEDICAL RESEARCH

By

FREDDIE W. WENNINGER

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1959

Submitted to the faculty of the Graduate School of
the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1962

AN ELECTRONIC STIMULATOR

FOR MEDICAL RESEARCH

Thesis Adviser

Dean of the Graduate School

PREFACE

Electrical or electronic stimulation of animals is neither a new field of investigation, nor an old one where little is left to be accomplished. The first experiments were probably performed by Luigi Galvani, an Italian medical professor (1737-1798) when he discovered that a frog's leg could be made to kick by passing an electrical current through it. Since this meager beginning, investigators have used electrical stimulation as a basic tool in both research and therapy.

Various techniques have been devised in the past for electrical stimulation of the brain. The majority of these have utilized interconnecting wires from the stimulation source to the brain. The major disadvantage of this technique is that the subject is hampered in performing normal activities because of the interconnecting wires. Several investigators in the past have devised methods of remote stimulation[1,2,3,4,5,6]. However, these systems do not provide the necessary flexibility of stimulation control that is offered by systems utilizing interconnecting wires.

It is the purpose of this thesis to present a complete stimulation system that provides considerably more control of stimulation parameters than systems of the past. The system to be described has been designed as a general research instrument, offering high versatility of control and reliability of operation. The scope of this work is limited entirely to the design, development, and construction of the stimulation system. The basic specifications were provided by Dr. C. G. Gunn, Professor of Medicine, Oklahoma University School of Medicine, for whom this system was developed.

Complete design equations and analysis for all of the circuits in the stimulation system could easily fill several volumes. For this reason, only the basic principles of operation are discussed, although the complete circuit for the master control unit is presented in Appendix C. It is hoped that the reader who is not familiar with circuit details will gain a basic understanding of the system by reading Chapters I, II, and V. Chapters III and IV are devoted to explanations of the circuits presented in block form in Chapter II.

It is difficult to express in writing my sincere appreciation to Mr. J. E. Tompkins for the help and encouragement he gave during the months of this development. Mr. Tompkins was responsible for the radio frequency units in the stimulation system. He designed the radio frequency transmitter, antenna system and the radio frequency portion of the animal unit. In addition, he was responsible for the mechanical fabrication of the entire animal unit and provided many valuable suggestions for the layout and fabrication of the master control unit. I owe a debt of gratitude to my thesis advisor, Dr. Harold T. Fristoe, who has been most kind and cooperative in supplying advice and guidance throughout this work. In addition, special thanks are due

Dr. C. G. Gunn for his advice and understanding; Mr. Don Ryan for his assistance in the layout of the printed circuits; and Mr. Ray Magnuson, Research Engineer, General Electric Corporation, for his kind suggestions in the writing of the thesis.

Without the welcome advice and support of my parents and wife, this work would not have been possible and to them I owe my sincere appreciation and thanks.

TABLE OF CONTENTS

Chapter Page

APPENDIXES:

LIST OF ILLUSTRATIONS

Figure Page

Figure | Page

CHAPTER I

TERMINOLOGY AND SYSTEM SPECIFICATIONS

Definition of Terms

In the present system, there are two basic types of stimulation pulses, monophasic and biphasic. The terms monophasic and biphasic, while possibly misleading to people in the field of engineering, are standard in the medical profession and will be used extensively in the pages to follow.

A monophasic pulse is essentially a pulse in which the current flows in only one direction. Thus Fig. (1-A) is a positive monophasic pulse and Fig. (1-B) is a negative monophasic pulse.

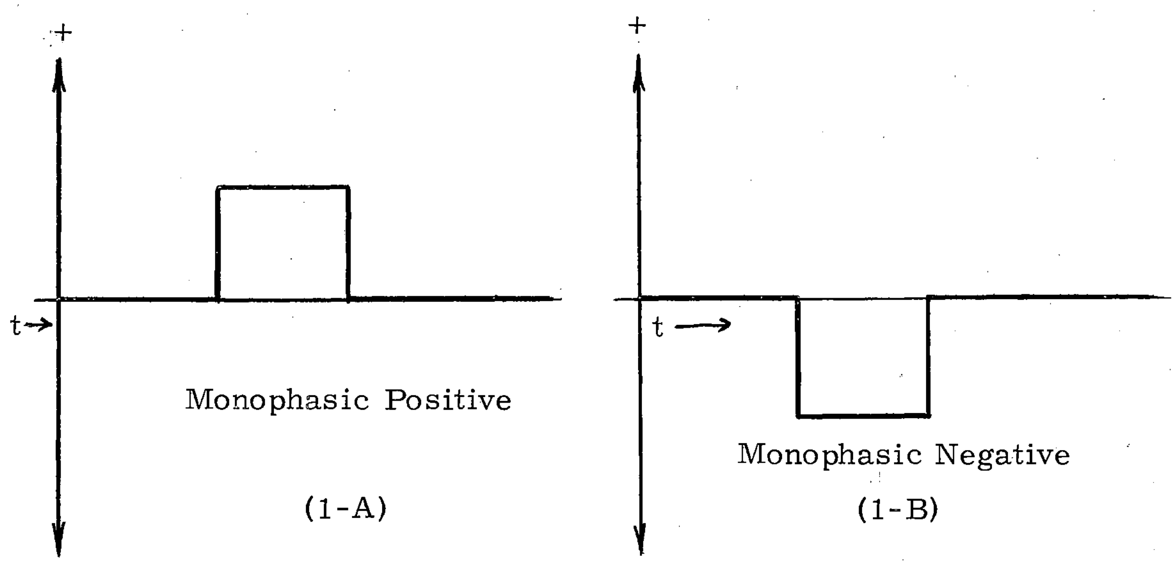


Fig. 1. Positive and Negative Monophasic Pulses

A biphasic pulse, Fig. 2, consists of a monophasic pulse followed by an equal monophasic pulse of opposite polarity.

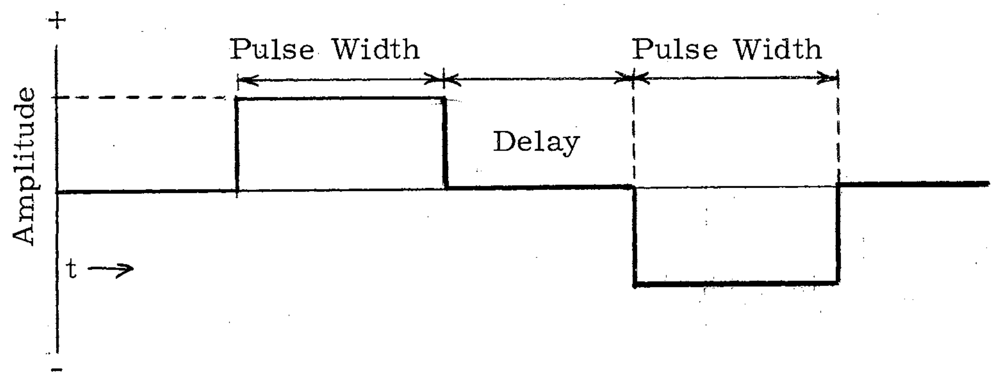


Fig. 2. Biphasic Pulse

The term "pulse width" refers to the time duration of a monophasic pulse; or, in the case of a biphasic pulse, the time duration of each of the two monophasic components. The term "delay" refers to the time delay between the two monophasic components of a biphasic pulse. The amplitude of a biphasic pulse is actually the peak amplitude, or the amplitude of one of the monophasic components.

It should be noted again, for clarity, that a biphasic pulse consists of two monophasic pulses equal in all respects, with the exception that they are opposite in polarity. Thus, if the pulse width or amplitude of a biphasic pulse is changed, both monophasic components must be changed equally. (Biphasic pulses generated by many systems of the past consist only of a differentiated rectangular pulse and do not offer the flexibility of adjustment available in the present system.) The stimulation frequency, as the term implies, is the number of monophasic or biphasic pulses generated per second.

In the present system, an electronic timer is included to turn the stimulation on and off for preselected times. The terms "burst width" and "burst spacing" (alternately, on time and off time) refer to the operation of this timer. See Fig. 3.

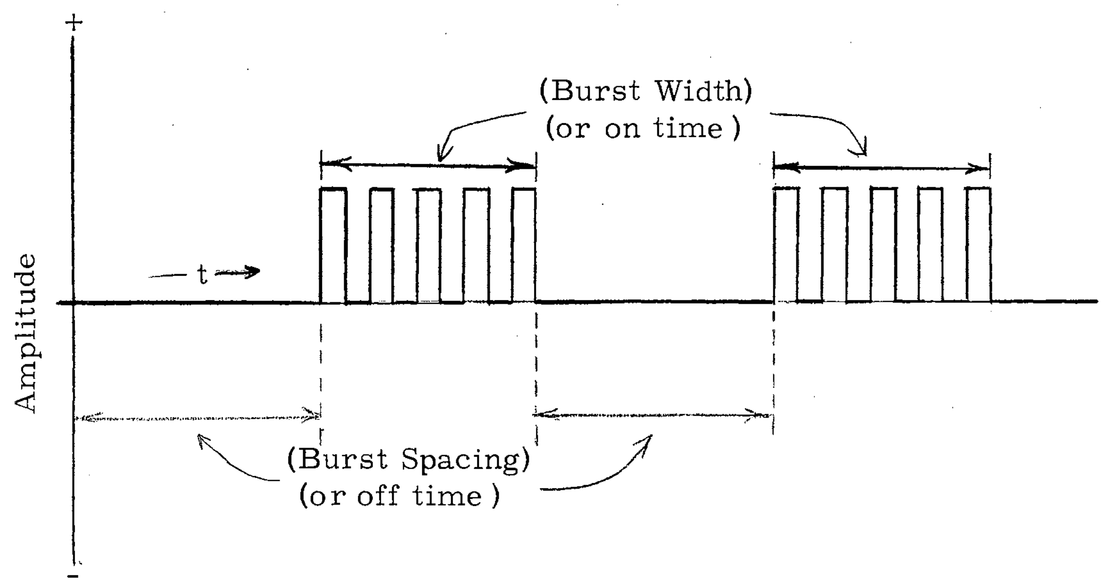


Fig. 3. Burst Width and Burst Spacing

System Specifications

The system consists of a master control unit, a radio frequency transmitter, and five miniature receivers. Direct coupled, positive or negative monophasic, and biphasic stimulation pulses are available at each of the receivers and at the master control unit. The stimulation parameters are controlled at the master control unit, with the exception that the stimulation amplitude is individually controlled at each of the receivers.

As can be seen in Fig. 4, the pulse width, delay, frequency, amplitude, burst width, and burst spacing are all adjustable and dial calibrations are linear. The pulse width and delay are adjustable in three decades from ten microseconds to ten milliseconds, while the frequency is adjustable in three decades from one cycle per second to one thousand cycles per second. The amplitude of the stimulation is adjustable from zero to ten volts at the master control unit and from zero to approximately two volts less than the battery voltage at each of the receivers. The burst width and burst spacing are adjustable in one-half second intervals from zero to nine minutes, fifty-nine and one-half seconds.

If the operator does not wish to use the timer, a lever switch provides two other alternatives; the output can be made either continuous or single-pulse. In the single-pulse position, a push button permits one stimulation pulse to be generated for each operation of the push button.

The choice of frequency as an independent variable, as opposed to time delay between individual pulses, is somewhat unfortunate for it is apparently possible to select a frequency and pulse width combination that will result in a duty cycle of greater than one hundred percent. This is, of course, impossible and causes erroneous results. For this reason, a duty-cycle meter is mounted on the front panel to show the operator the duty cycle of the combination of pulse width and frequency he has selected, and it provides an indication of an improper setting. In addition, a neon indicator lamp is mounted on the front panel and flashes each time a stimulation pulse is generated.

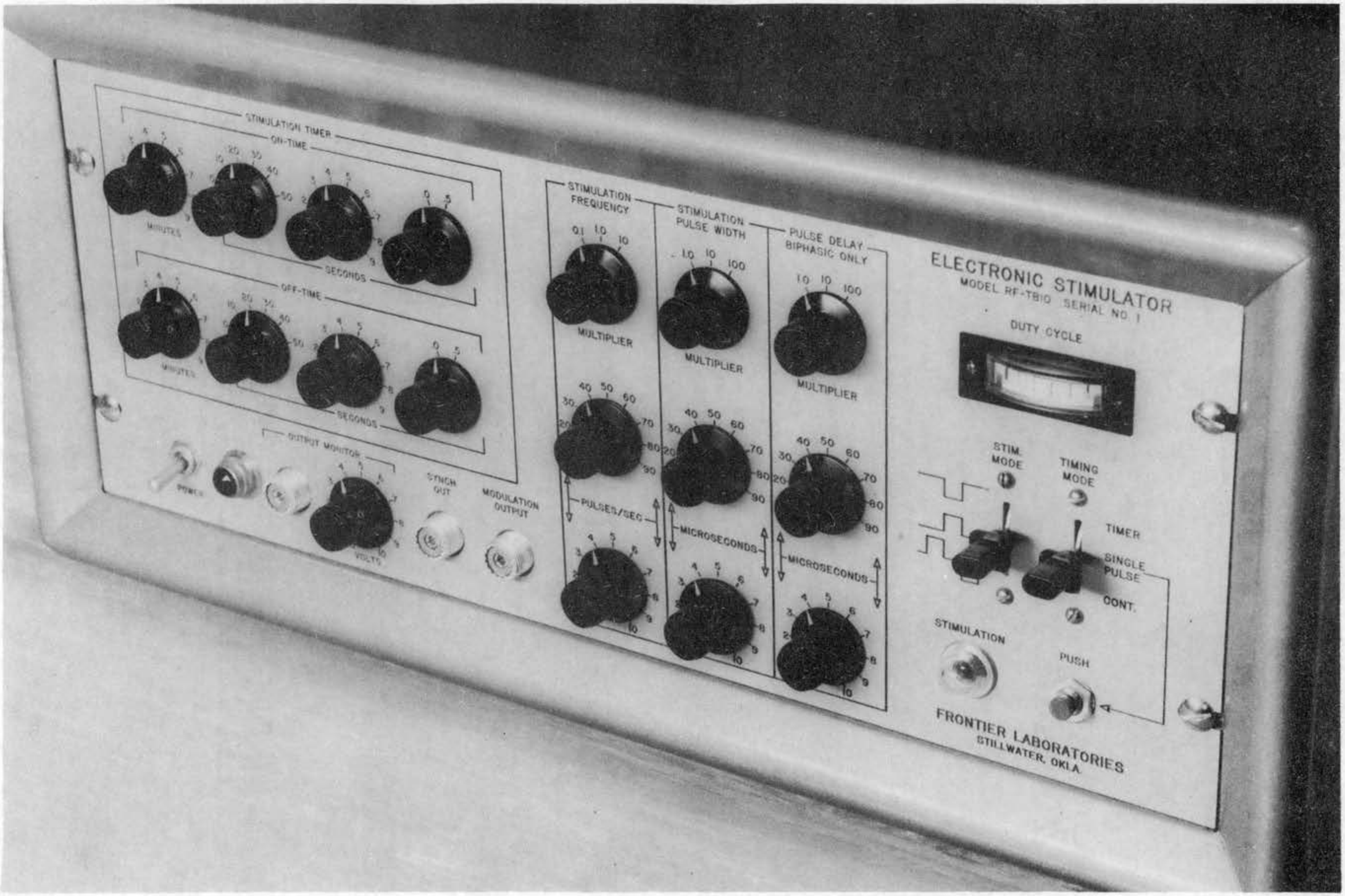


Fig. 4. Close-Up View of Stimulator

CHAPTER II

BASIC OPERATION OF SYSTEM

General

An elementary block diagram of the system is shown in Fig. 5.

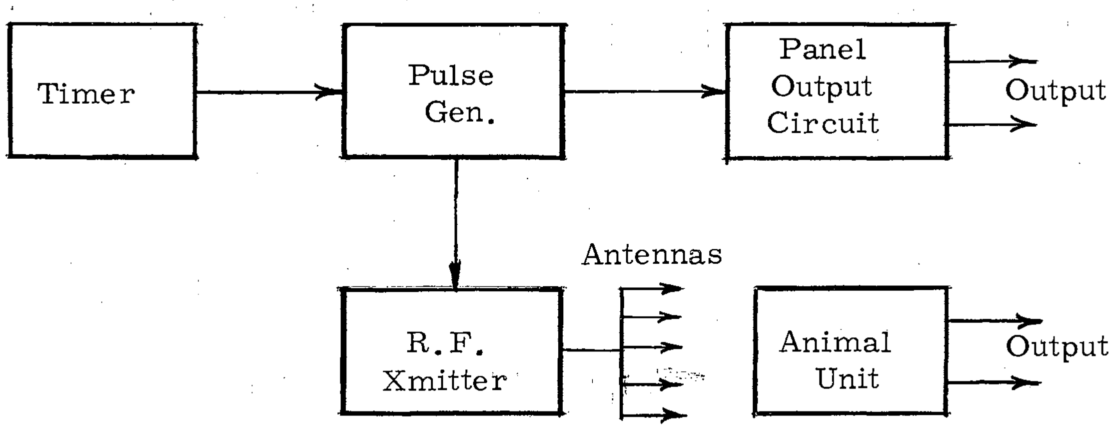


Fig. 5. Basic System Block

In operation, the timer gates the pulse generator on for the burst width and off for the burst spacing. When gated on, the pulse generator produces a chain of monophasic or biphasic pulses, depending upon the mode of operation. These pulses are then fed to a panel output circuit and to the modulator of a radio frequency transmitter. The transmitted signal is received by a small animal unit which then provides the stimulation output.

Timer Considerations

There are many possible schemes for achieving the timing operation. The long periods required, however, rule out the simple oscillator circuits such as a free-running multivibrator because of the lack of long-term stability. Recycling mechanical timers are unusable because the noise associated with these units could cause conditioning of the animal, and simple cam timers lack the flexibility of adjustment.

An electronic recycling preset counter, although more complex, has none of these disadvantages. Furthermore, by careful choice of components and proper design, this type of timer can be made both reliable and economical. Figure 6 shows a block diagram for this type of timer. Clock pulses, having a frequency of two pulses per second, are fed to a counter chain. The first counter counts the number of half-second intervals up to one; the second counter counts seconds up to nine; the third counts the number of ten-second intervals up to five; and the fourth counter counts the number of sixty-second intervals or minutes up to nine. Each counter provides a unique output for each number.

Through front panel selector switches, connections are made to both "and" circuits from the proper counter outputs. The outputs of the "and" circuits are fed to opposite sides of a flip flop. When the flip flop is triggered, it resets the entire counter chain through the "or" and reset circuits. Thus, one cycle through the counter chain produces a trigger to one side of the flip flop through the corresponding

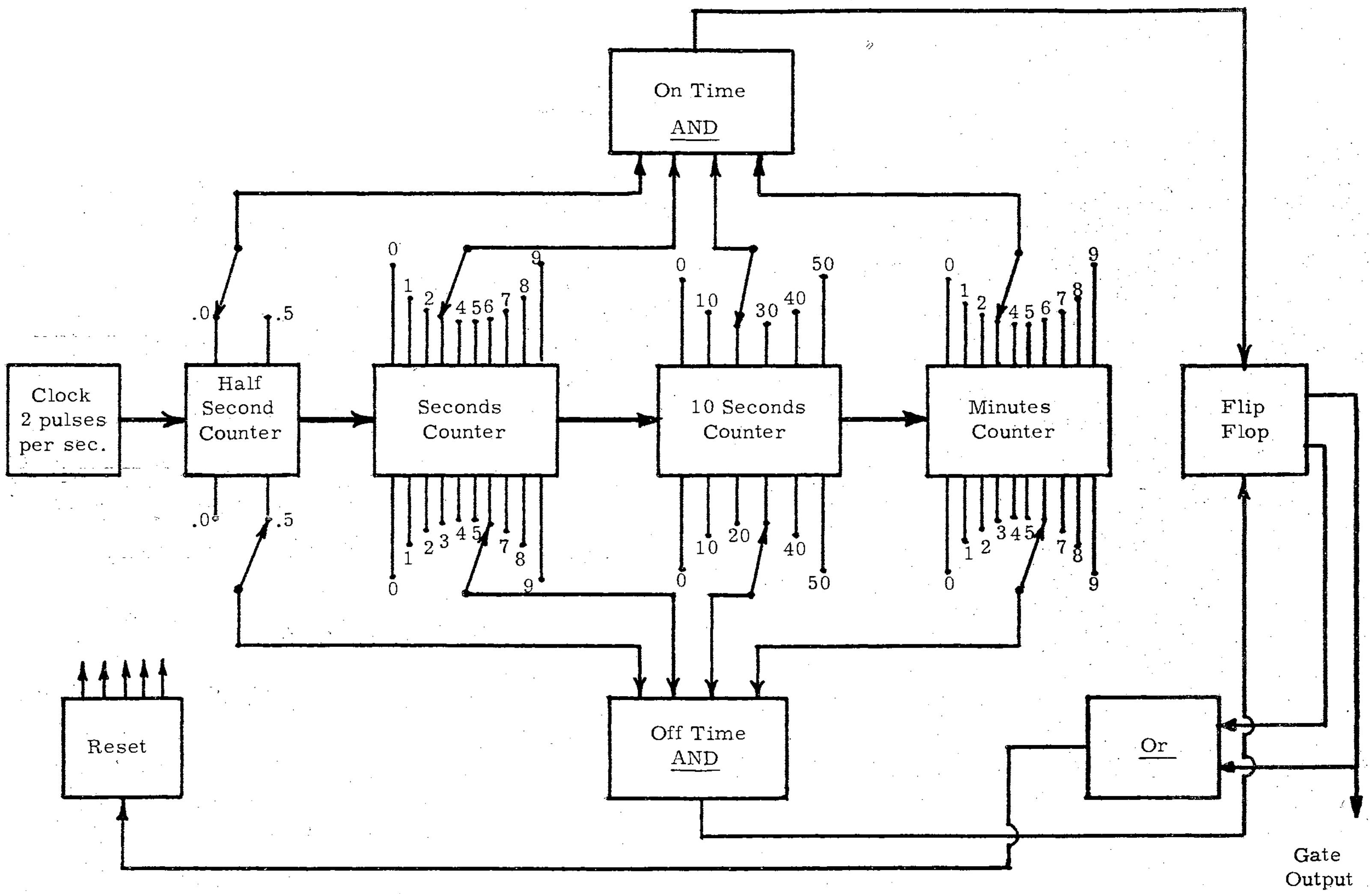


Fig. 6. Timer Block

"and" circuit. Then, on the next cycle through the counter, it counts until an output from the other "and" circuit triggers the opposite side of the flip flop. An output from the flip flop is then used to gate the pulse generator on and off for the preselected times.

As an example, the panel selector switches shown in Fig. 6 are set to provide a burst width of three minutes, twenty-three seconds, and a burst spacing of six minutes, thirty-six and one-half seconds.

Pulse Generator and Panel Output Block

The basic block diagram for the pulse generator is presented in Fig. 7. In operation, the variable frequency oscillator is turned on and off either manually, or by the timer, and its output triggers a variable pulse width generator. The trailing edge of the output from the variable pulse width generator triggers a flip flop. The previous state of this flip flop has been arranged so that when it changes state the variable delay generator is triggered. At the end of the delay, the variable pulse width generator is triggered again and, as before, it triggers the flip flop. However, the state of the flip flop is opposite to its previous state and hence the variable delay is not triggered. The system then remains at rest until it receives another trigger from the variable frequency oscillator. Thus, for every pulse from the variable frequency oscillator, two pulses, variable in width and time delay, are produced at the input to the pulse separator and inverter. Here, the two pulses are separated and the second pulse is inverted. The logic function which causes one pulse to be inverted is derived from the

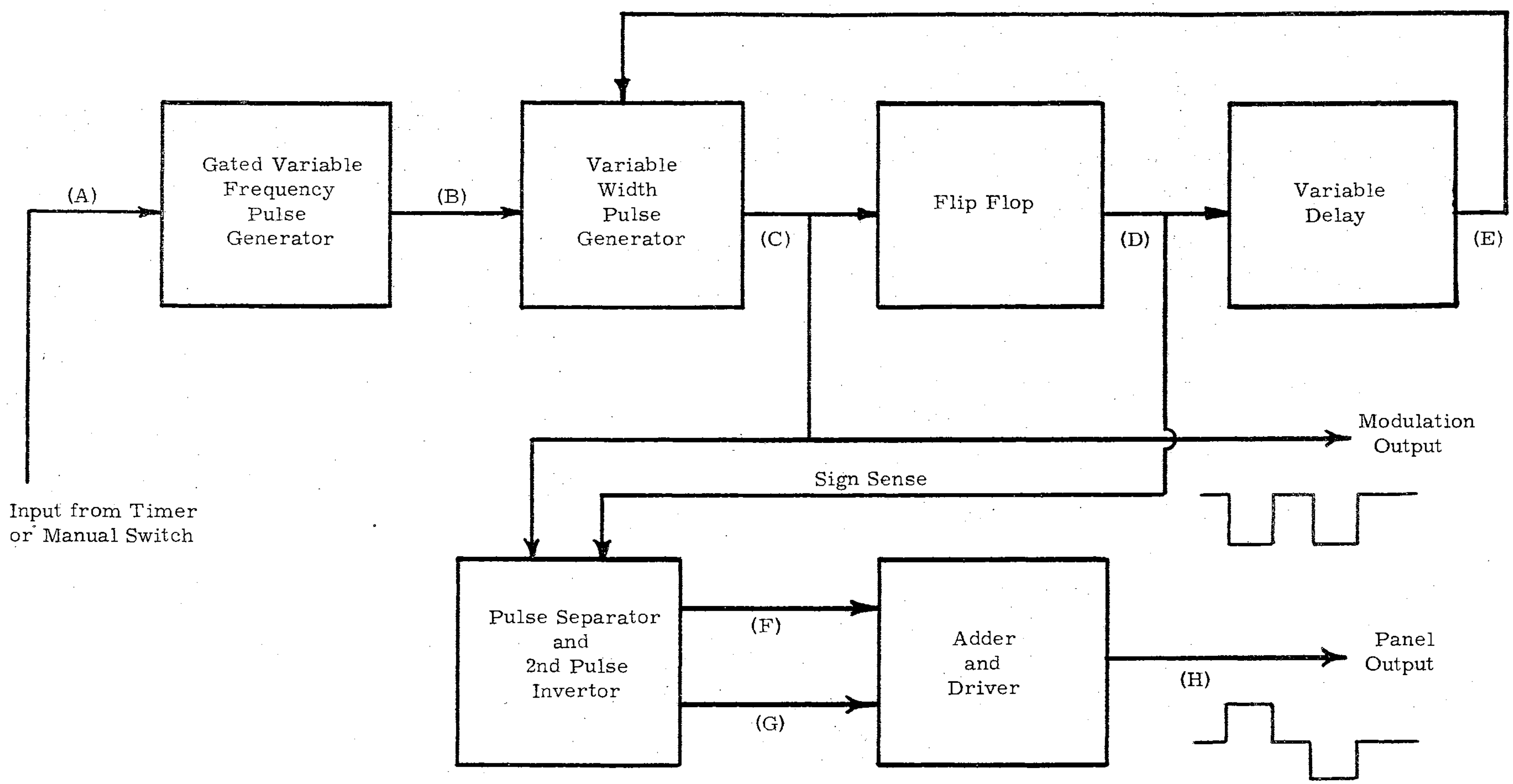


Fig. 7. Pulse Generator Block Diagram

state of the flip flop. The two outputs of the pulse separator and inverter are supplied to an adder-driver from which a variable amplitude biphasic pulse is obtained.

For monophasic outputs the flip flop is held in one state for positive outputs and in the other state for negative outputs. The modulation output, consisting of only negative pulses, is taken out ahead of the pulse separator and inverter.

Figure 8 illustrates the basic waveforms in the circuit.

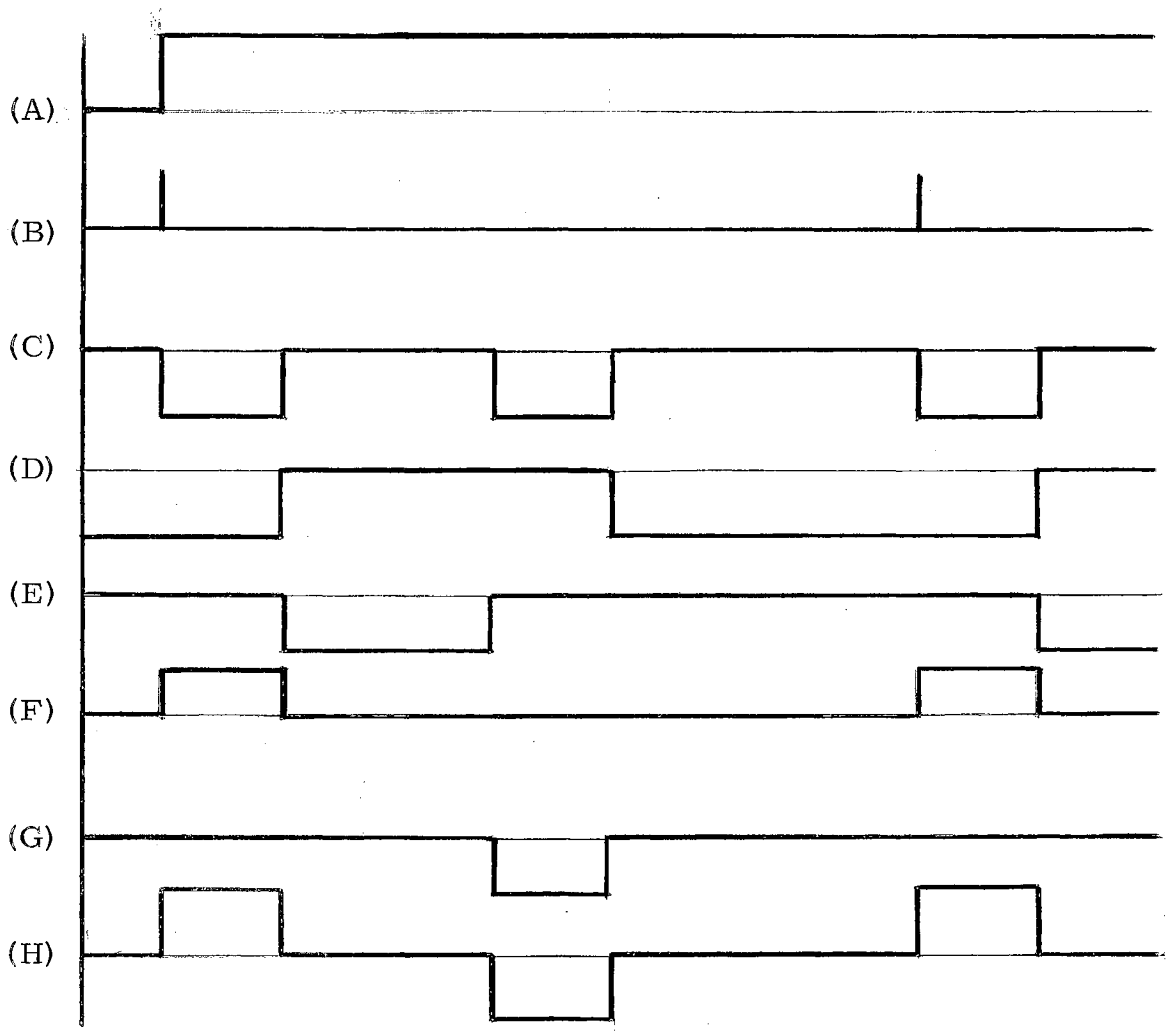


Fig. 8. Basic Waveforms in Pulse Generator

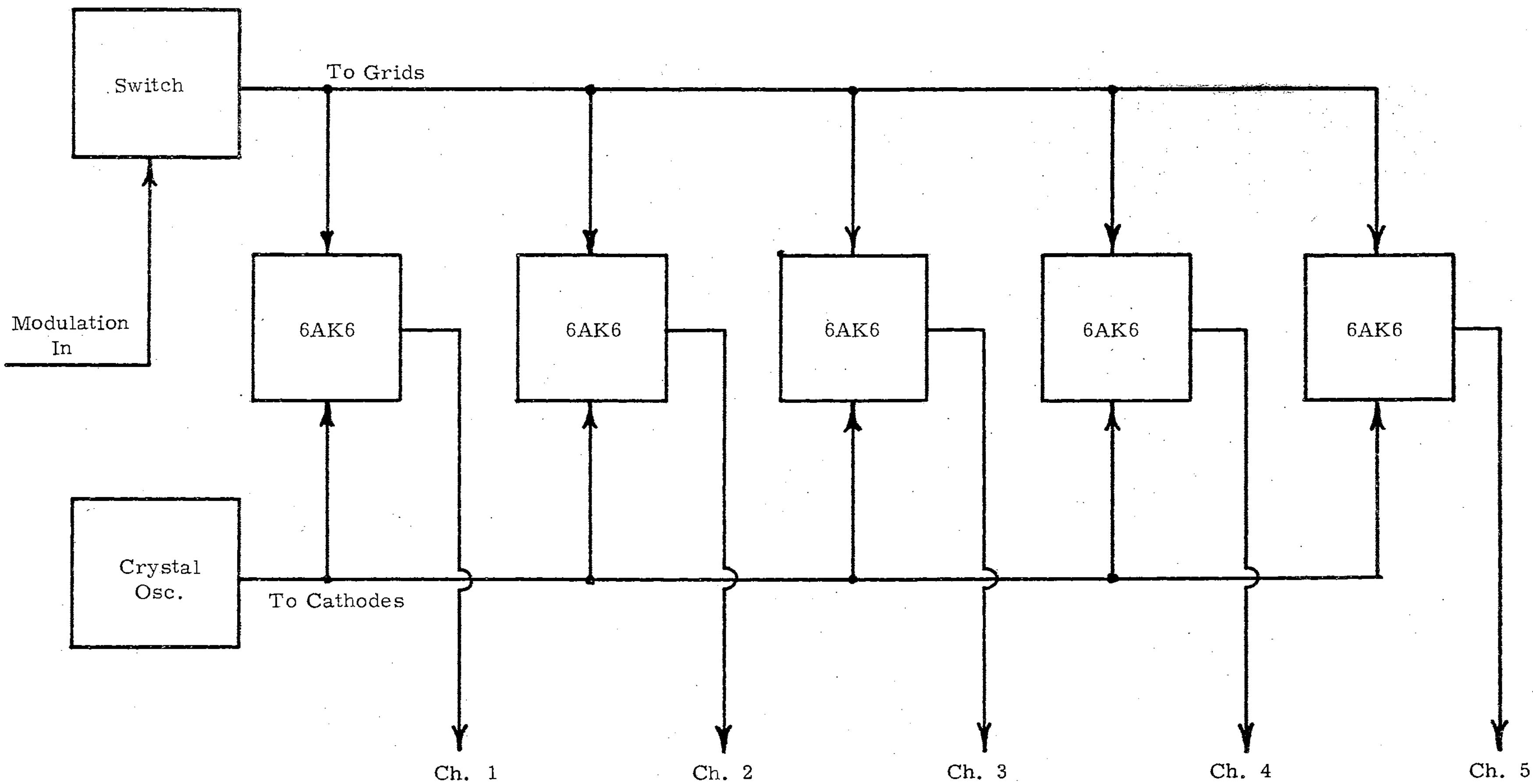


Fig. 9. Transmitter Block Diagram

Radio Frequency Transmitter

The basic block diagram of the transmitter is shown in Fig. 9. A 27 megacycle oscillator drives the cathodes of five 6AK6 pentodes. These tubes are held off by a large negative grid voltage in the absence of a modulation pulse. A modulation pulse operates a transistor switch which grounds all grids. A radio frequency output of 1 watt across 50 ohms is then produced at the output of each channel. The transmitter output is cabled to cages and is radiated inside the cages.

Animal Unit

Figure 10 shows the basic block diagram for the animal unit. Radiated signals from the transmitter are detected and amplified in the receiver unit. The receiver unit, in turn, operates a switch transistor whose output is similar to the modulation pulses fed to the transmitter. The output and logic circuits then transform these pulses to biphasic or monophasic stimulation pulses.

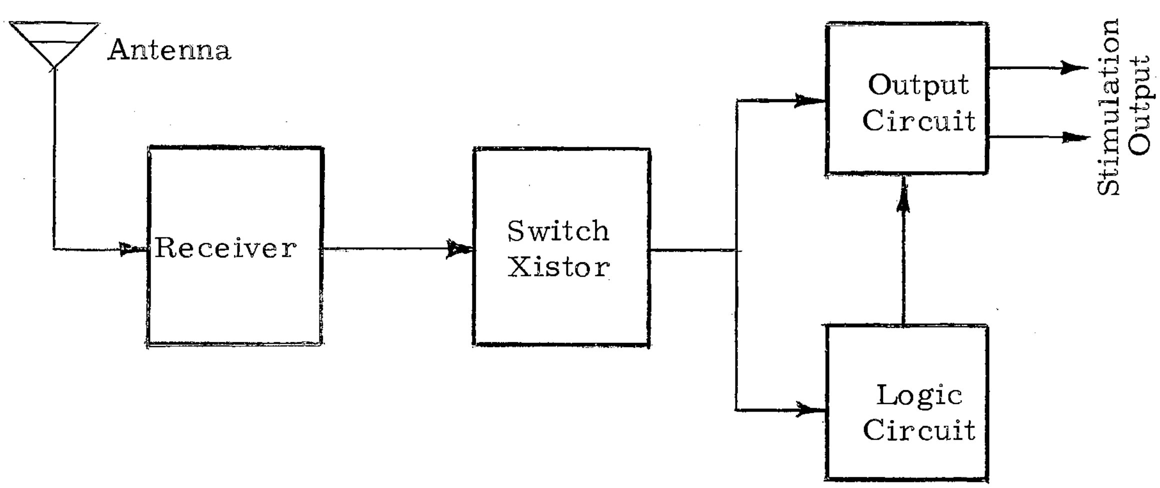


Fig. 10. Animal Unit Block Diagram

CHAPTER III

MASTER CONTROL UNIT CIRCUIT DETAILS

Timer Circuit

The first consideration for design of the timer is a source of clock pulses. Inasmuch as the stimulation system is to be operated from standard 110 volt, 60 cycle line voltage, a logical choice of time base is the line voltage itself. For reasons of economy and reliability, the two cycle per second standard is derived from a light chopper driven by a synchronous motor. Figure 11 shows the circuit.

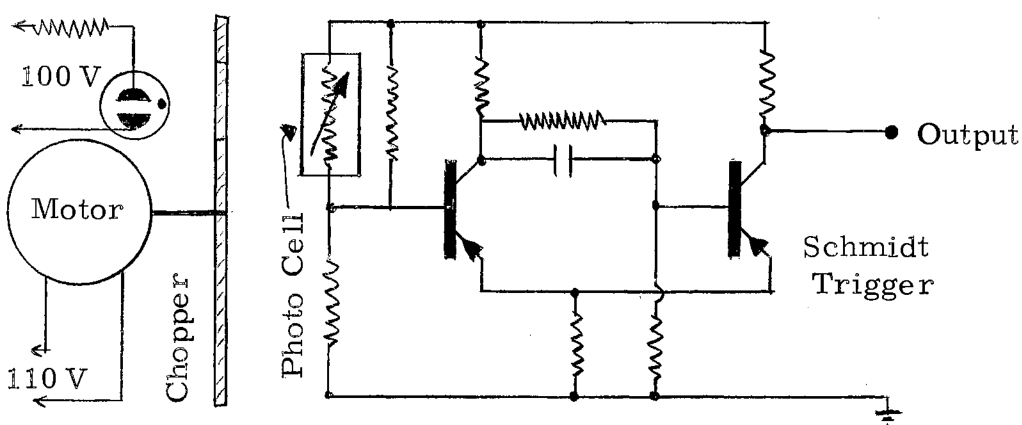


Fig. 11. Time Base Circuit

The second and more difficult consideration is the choice of counter to be used. Space does not permit a complete discussion of the many different types of counters developed during the past decade. However, the requirements of long-term reliability, availability, and economy narrow the choice considerably.

A counter utilizing transistor flip flops and resistor logic was designed and constructed. However, this circuit was rejected in favor of a counter employing Burroughs' Beam-X counter tubes. For this application, the small size and low power capabilities of the transistor circuit were offset by the inherent reliability of the Beam-X tubes (expected life is 50,000 hours, or approximately 5 years of continuous operation) and a reduction in the number of circuit components due to the operation of Beam-X tubes.

The theory of operation of Beam-X tubes is covered in the literature and will not be duplicated here. Let it suffice to say that the Beam-X tube is a 10 position, high vacuum, electronic switching tube. Quoting from Burroughs' brochure BX535:

> The Beam-X switch consists of ten identical sections or arrays arranged symmetrically about a central cathode. Each array comprises a spade element for beam forming and locking; a target element to provide constant current output; and a switching grid which is used to switch a beam from position to position. ..... in a typical ten-position switching application, the Beam-X switch eliminates the 90 transistors, diodes and resistors which must be used with binary logic and achieves superior results. This major reduction in components helps to eliminate the multicomponent unreliability.
>
> The Beam-X switch has useful constant current outputs, positive switching elements and memory in each of its ten positions. It may remain in one position indefinitely or switch at speeds from DC to 10 megacycles either sequentially or at random; it may be interconnected as a distributor of any number of positions less or greater than 10, and be preset to any position and reset in less than a microsecond. Operating flexibly and efficiently with respect to B plus voltages, it can be utilized equally well in

high or low voltage systems. In vacuum tube circuits, outputs as high as 200 volts can be obtained, while in transistorized systems it can be operated by 12 volt signals directly from the solid state circuitry. The Beam-X switch is constructed to withstand shock and vibration, and to be insensitive to temperature extremes.

Figure 12 shows the basic Beam-X circuit used in the counter. The resistor values were obtained from a graphical analysis of the Beam-X characteristic curves, and were verified experimentally.

In operation, an input pulse from the preceding counter triggers a flip flop. The outputs of both sides of the flip flop are differentiated by the RC networks R_{28}, C_{12} and R_{29}, C_{13} and clipped by diodes D_7 and D_8. Thus a negative pulse is alternately applied to the even and odd grids, which in turn advances the electron beam one position for each trigger pulse.

When the DC supply voltage is first applied to the Beam-X circuit, the tube normally remains in its cleared or cut-off state. In order to initially form the beam to the zero position, the zero spade must be lowered to below the first intersection of the load line with the static space characteristic curve. At the same time, the flip flop must be set to the appropriate state so that the first input pulse which triggers the flip flop produces a negative pulse from the flip flop to the even grids to advance the beam from zero position.

In order to reset the beam to zero from any position, the tube must first be cleared as the beam will not step backwards within the tube. After clearing, the reset pulse may be applied to the zero

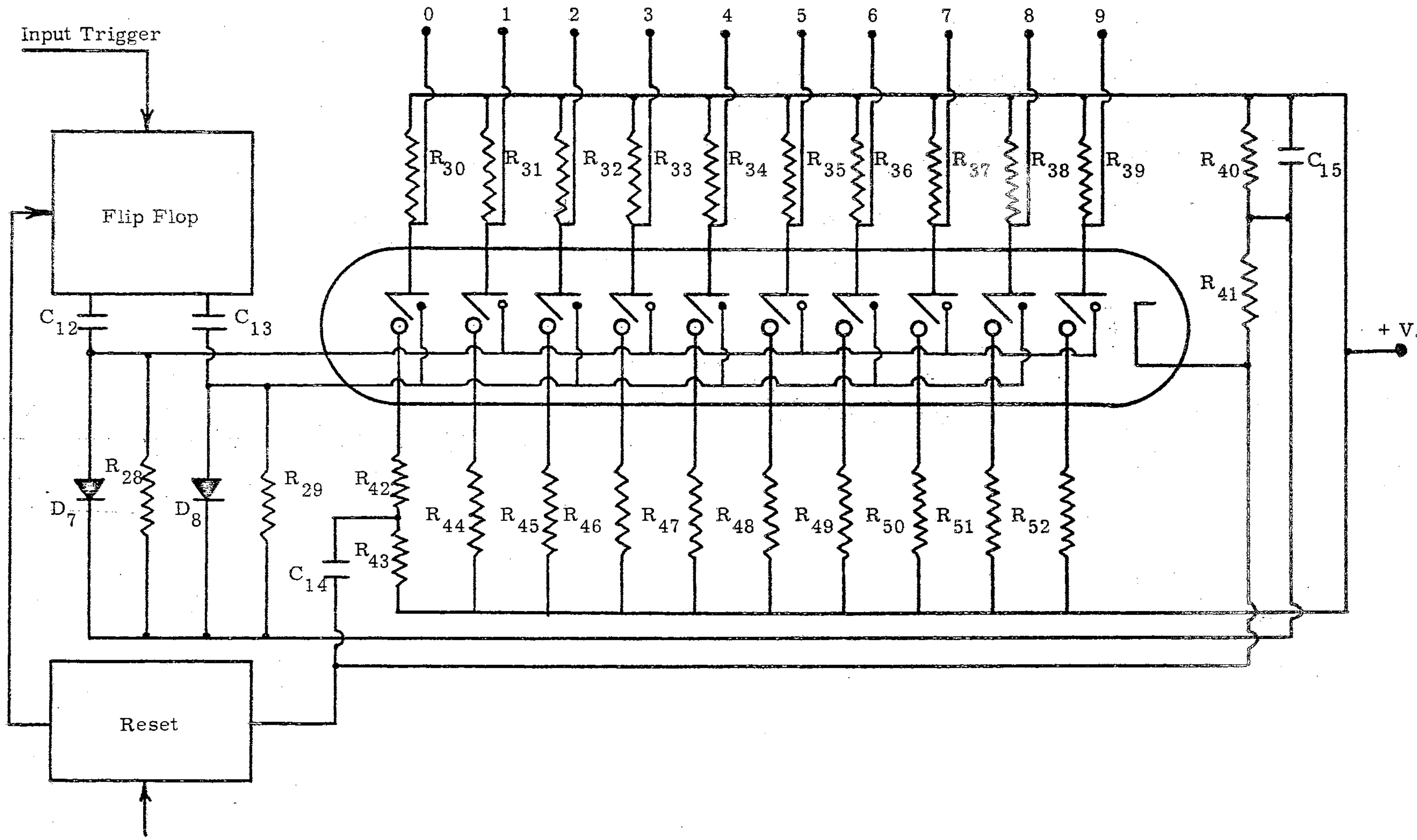


Fig. 12. Basic Beam-X Circuit

spade, thereby resetting the tube to zero.

The function of clearing and resetting is done simultaneously in the circuit of Fig. 12. The reset pulse is applied to the cathode of the Beam-X tube and raises its potential to that of the target and spade voltage, thus clearing the tube. During the reset pulse, capacitor C_{14} discharges through R_{43}. When the reset pulse vanishes and the full supply voltage is again applied to the tube, the junction of R_{42} and R_{43} remains at the cathode potential due to the action of C_{14}. This causes the beam to be formed at position "0" as C_{14} charges exponentially toward the supply voltage.

The third consideration for design of the timer is the choice of coincidence or <u>and</u> circuit to be used. Inasmuch as the <u>and</u> circuits are connected to the counter by selector switches, the inputs to the circuit must be isolated from each other in order to prevent undesirable feedthrough which would result in erroneous counts for certain combinations of switch settings.

Transistors TR_{24}, TR_{25}, TR_{26}, and TR_{27}, in Fig. 13, perform the dual function of serving as logic elements and providing isolation between inputs. Inputs B, C, and D connect through selector switches to the Beam-X counter tubes. Input A connects to the collector of the .5 second counter, transistor TR_{28} serving as a constant current coupling device. When signals are present at all four inputs, transistor TR_{23} is saturated and a pulse is fed to the flip flop.

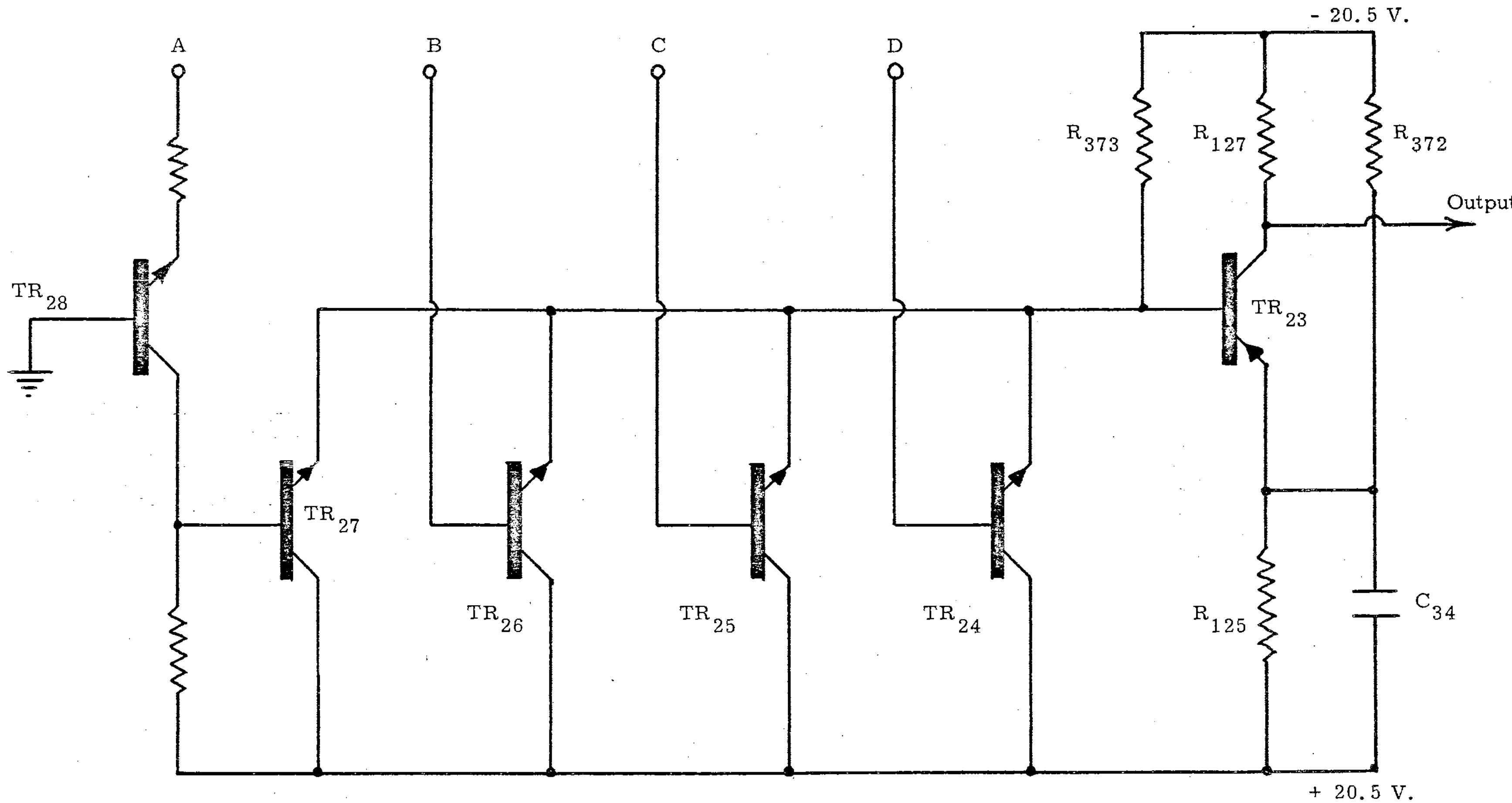


Fig. 13. AND Circuit

As explained in Chapter I, each time the flip flop changes state, the entire counter chain is reset. Figure 14 shows the complete or and reset circuit.

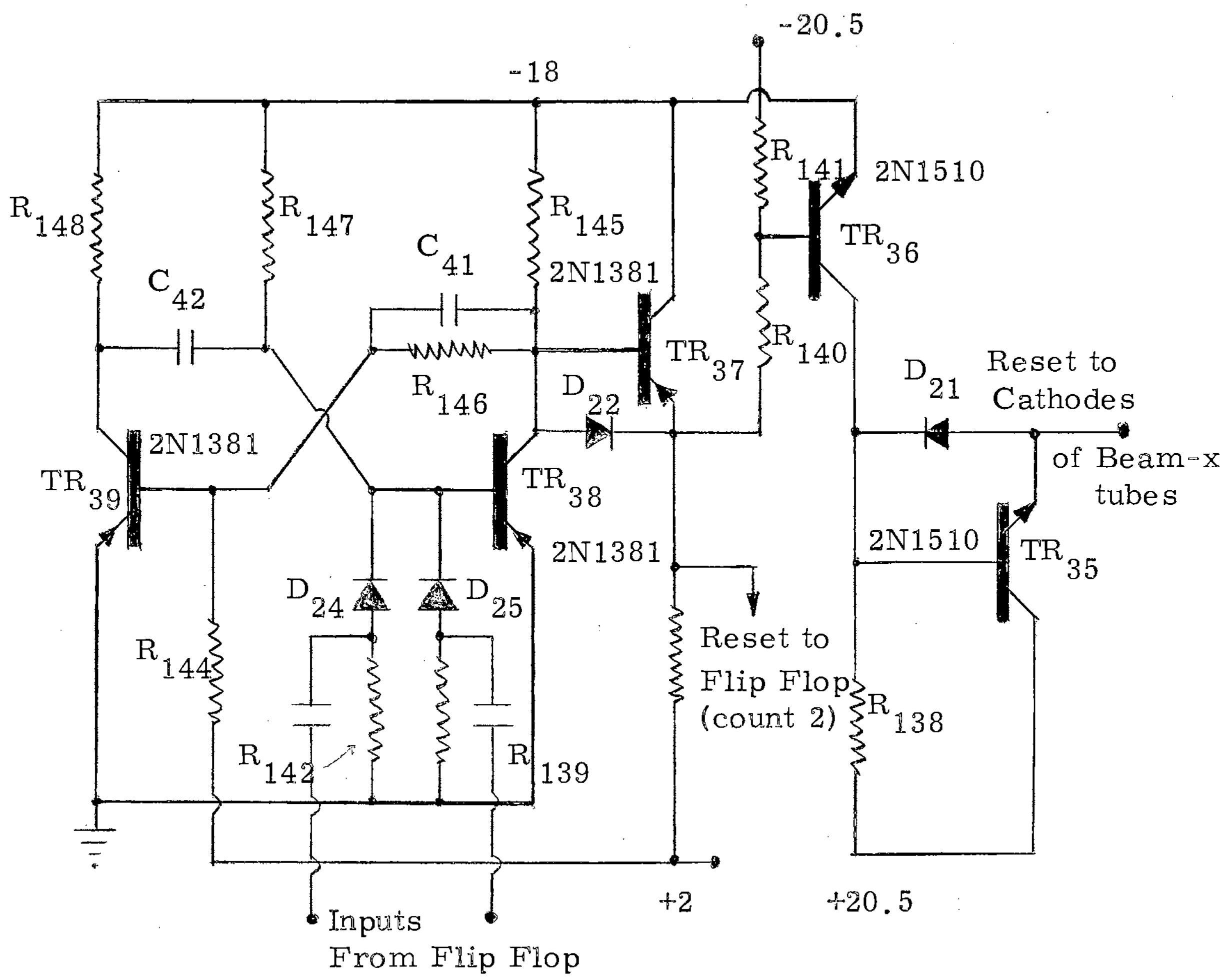


Fig. 14. or and Reset Circuit

In operation, TR_{38} normally rests on. This, in turn, causes TR_{36} to be saturated and the cathodes of the Beam-X tubes are held at -18 volts by diode D_{21}. When a pulse is received from the flip flop the one-shot multivibrator (TR_{39} and TR_{38}) is triggered. This, in turn, cuts TR_{36} off and its collector falls from -18 volts to + 20.5 volts. The cathodes of the Beam-X tubes are thus returned to the target supply. TR_{35} is an emitter follower to supply sufficient drive to the reset line. At the completion of the one-shot multivibrator's cycle, the circuit returns to normal and the counter chain is reset.

Pulse Generator

The variable frequency oscillator, pulse width generator, and delay circuit are all similar in operation. Figure 15 shows the basic principle of operation of these circuits. When an input is received, the flip flop is triggered and in turn cuts TR_{42} off, which allows the capacitor C to be charged by a constant current from TR_{41}. This produces a ramp function at the collector of TR_{42} which is fed to a comparator. When the ramp reaches the level necessary to trip the comparator, a trigger is produced which resets the flip flop and clamps the capacitor back to ground.

By changing the reference voltage, a variable pulse width may be produced which varies linearly with the reference. In the same fashion a variable delay may be obtained, and the same fundamental circuit can also be used as a variable frequency oscillator by allowing it to retrigger itself.

Variable Frequency Oscillator

It has been mentioned earlier that the front panel controls have linear dial calibrations. The following brief analysis will indicate how this is achieved in the case of the variable frequency oscillator. A more complete analysis is given in Appendix A.

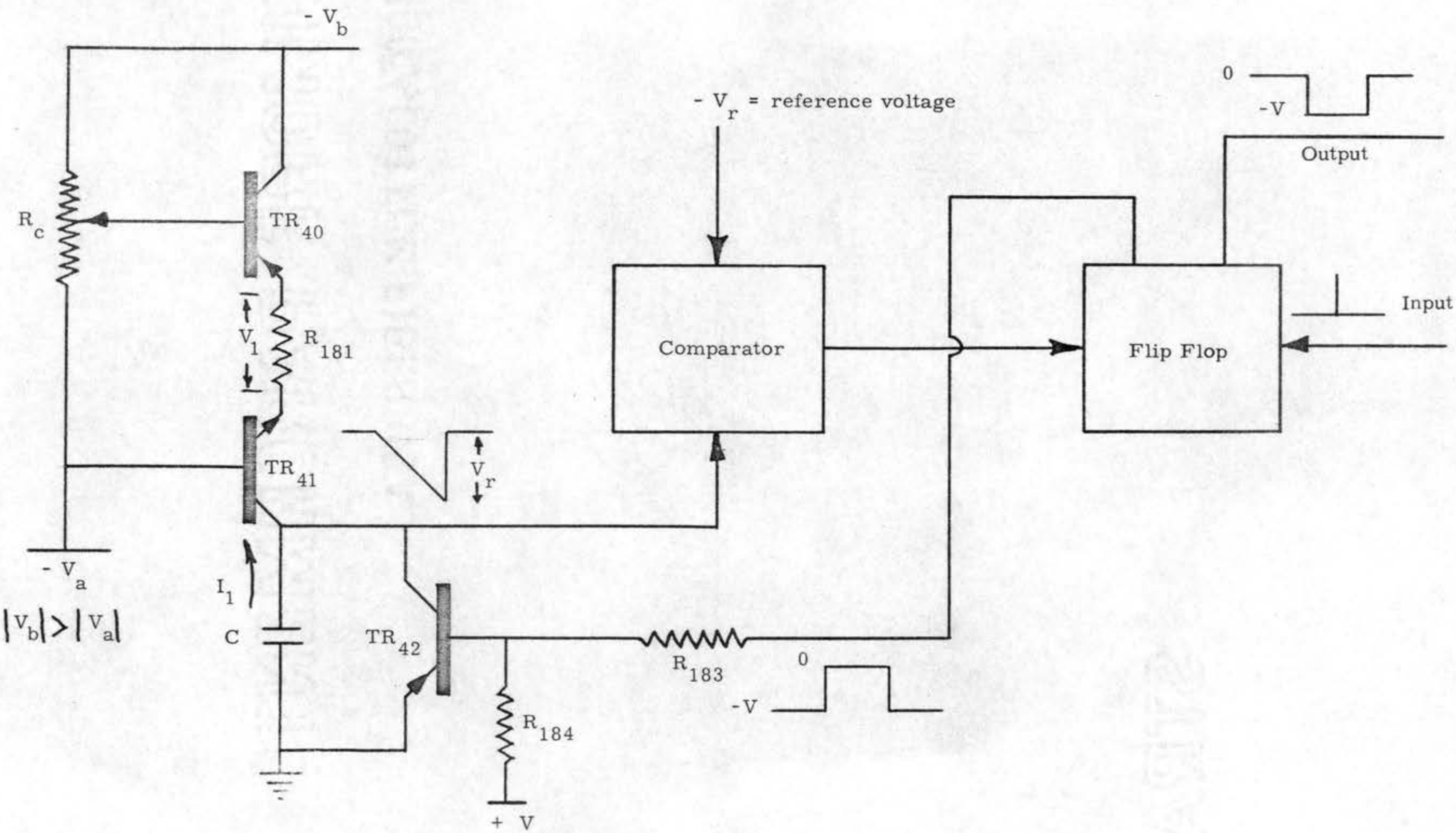


Fig. 15. Variable Pulse Generator

With reference to Fig. 15, we know that $CV_r = I_1 T$ or

$$T = \frac{CV_r}{I_1}$$

where

T = period of oscillation

C = capacity

V_r = amplitude of ramp function $\doteq$ reference voltage

I_1 = current in capacitor.

Now, since the frequency F is equal to $1/T$, we have $F = \frac{I_1}{CV_r}$

but $I_1 = \frac{V_1}{R_{181}}$ so that $F = \frac{V_1}{R_{181} CV_r}$. By making $R_{181} CV_r$

constant $= \frac{1}{K}$ we have $F = KV_1$. V_1 is proportional to the arm setting of R_c so that the frequency is a linear function of the dial setting. Transistor TR_{40} is an emitter follower whose function is to reduce the loading of R_c due to the current flowing in the emitter of TR_{41}.

The complete variable frequency oscillator circuit is shown in Fig. 16.

Transistors TR_{40}, TR_{41}, and TR_{42} are the same as in Fig. 15. TR_{43} and TR_{45} are the comparator shown in block form in Fig. 15. The reference voltage V_r of Fig. 15 is derived from the voltage divider R_{185} and either R_{187}, R_{188}, or R_{189}, depending upon the setting of the switch S_1. Transistors TR_{47} and TR_{48} are the flip flop of Fig. 15 and TR_{50} is an emitter follower to supply sufficient

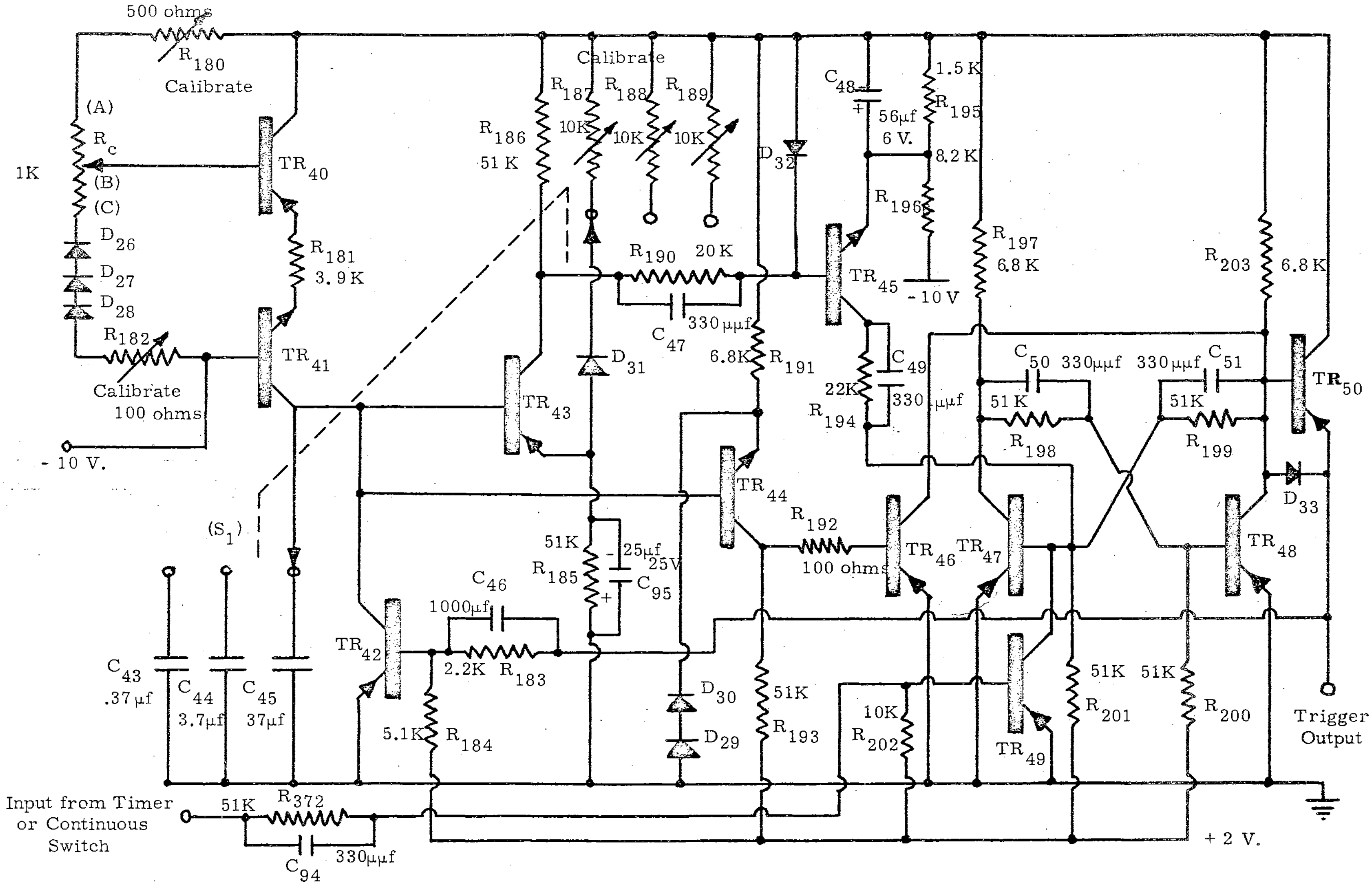


Fig. 16. Variable Frequency Oscillator

drive to the clamp, TR_{42}. TR_{44} and TR_{46} enable the circuit to recycle by resetting the flip flop after the timing capacitor C_{43}, C_{44} or C_{45} (depending upon the setting of S_1) has been discharged by TR_{42}. When a signal is received from the timer, TR_{49} stops the circuit by holding the flip flop in one state. Diodes D_{26}, D_{27}, D_{28}, D_{31} and D_{32} are for temperature compensation, and R_{180}, R_{182}, R_{187}, R_{188}, and R_{189} are for calibration. R_{180} and R_{182} are adjusted so that the frequency varies over a ten to one range in each decade and R_{187}, R_{188} and R_{189} are used to calibrate each range.

The potentiometer R_c of Fig. 15 is actually the equivalent resistance of the network shown in Fig. 17.

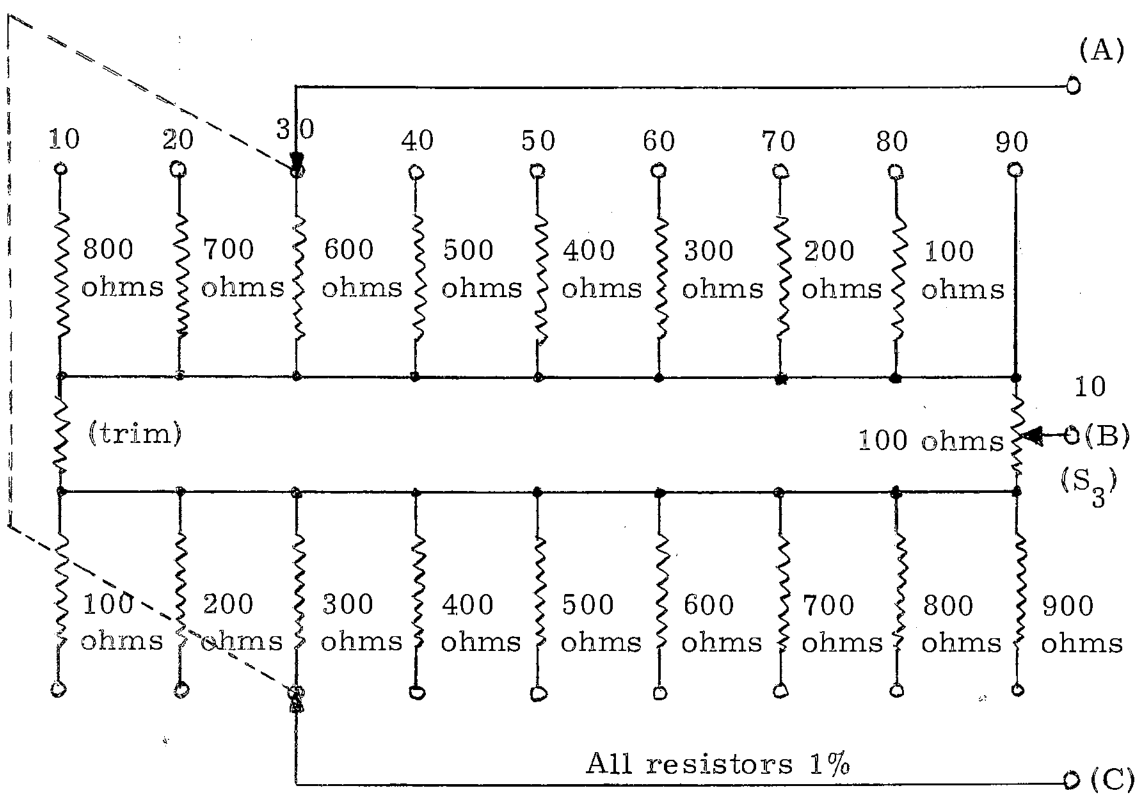


Fig. 17. Equivalent Network for Potentiometer

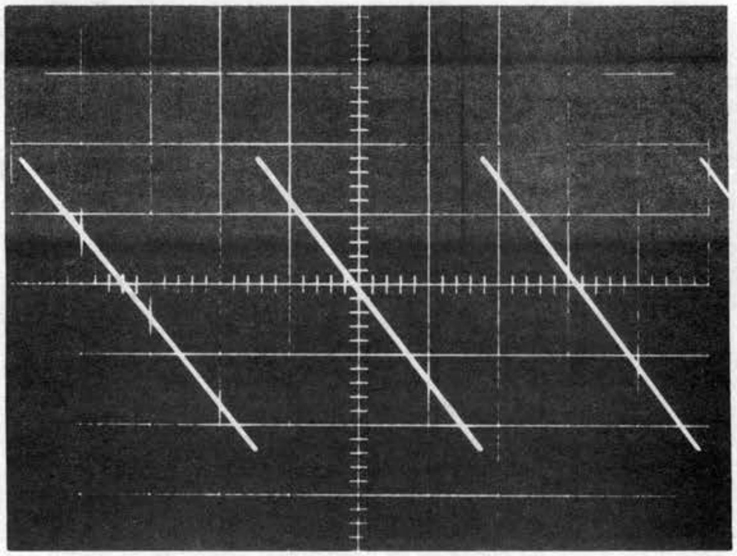
The network of Fig. 17 presents a constant resistance of 1000 ohms between points (A) and (C). Switch S_2 varies the resistance between points (B) and (C) in increments of 100 ohms from 100 ohms to 900 ohms and potentiometer S_3, serving as a vernier, varies the resistance over the range of zero to 100 ohms.

With reference to Fig. 4 of Chapter I, this network and S_1 of Fig. 16 comprise the front panel controls of the variable frequency oscillator.

It should be noted in passing that the circuit of Fig. 16 is sufficiently accurate to permit the replacement of R_c or the network of Fig. 17 with a ten turn potentiometer, the frequency of the circuit being accurate to within the three place calibration of the ten turn potentiometer dial. However, the network of Fig. 17 was chosen over the ten turn dial because of operator preference.

Figure 18 is a photograph of an actual ramp function at the collector of TR_{41}, and Fig. 19 is an expanded view of the same waveform. Figure 20 shows the output trigger of the circuit at the emitter of TR_{50}. The width of this pulse is the time required to discharge the timing capacitor C_{44}. Figure 21 shows the actual discharge waveform.

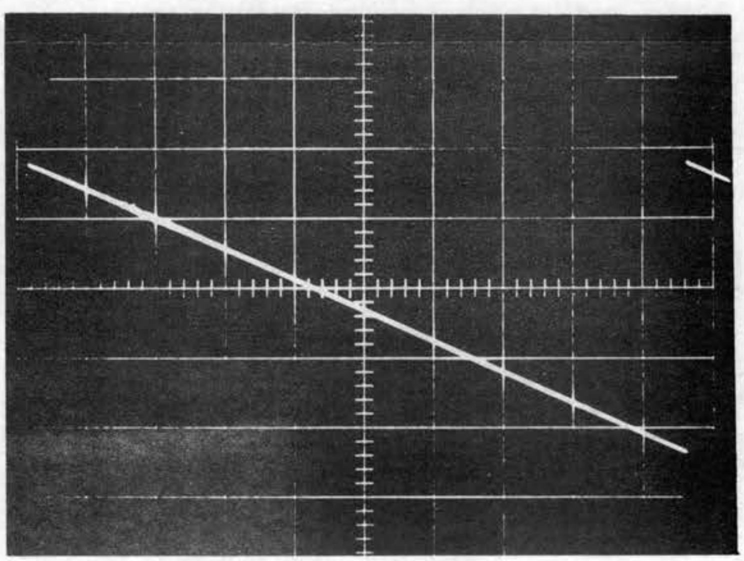
With reference to Fig. 19 and Fig. 21, a simple calculation shows that the discharge time of the sawtooth waveform is approximately .15% of the total period. A discussion of the error caused by this discharge time is included in Appendix A.



2V/cm Vertical

5ms/cm Horizontal

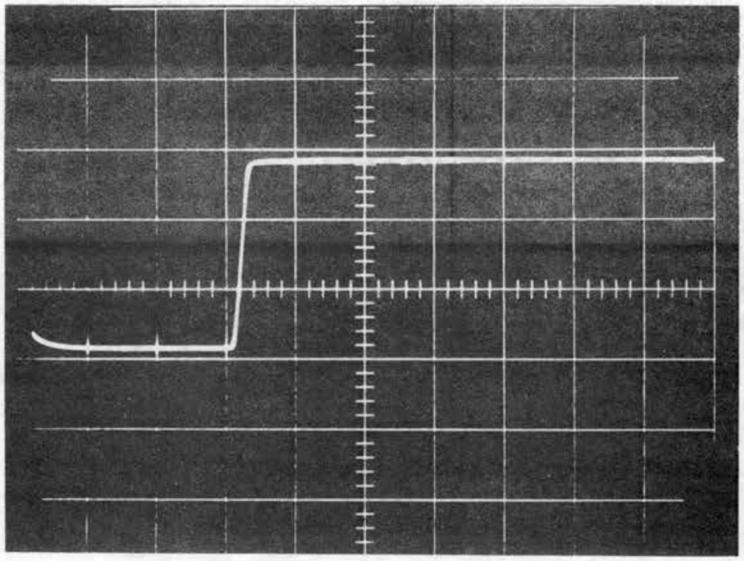
Fig. 18. Waveform at Collector of TR_{41}



2V/cm Vertical

2ms/cm Horizontal

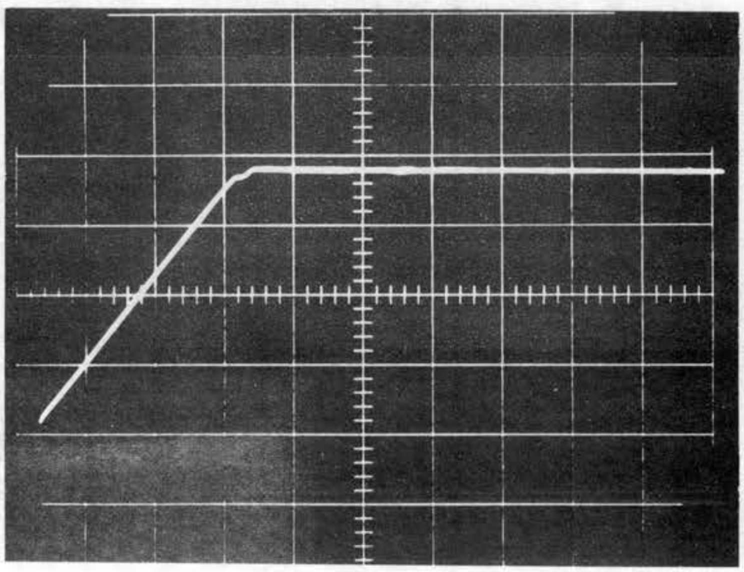
Fig. 19. Expanded View of Waveform of Fig. 18



10μsec/cm Horizontal

5V/cm Vertical

Fig. 20. Output Trigger Pulse



10μsec/cm Horizontal

2V/cm Vertical

Fig. 21. Discharge Waveform

Pulse Width and Delay Circuits

The pulse width and delay circuits are identical and are very similar to the variable frequency oscillator, the difference being that the circuits are not permitted to retrigger themselves at the completion of each pulse.

The complete pulse width circuit is shown in Fig. 22. Transistors TR_{58} and TR_{59} are the flip flop of Fig. 15. TR_{59} normally rests in the cutoff state causing the timing capacitor C_{54}, C_{55}, or C_{56} (depending upon the position of S_1) to be clamped to ground by TR_{55}. When a trigger pulse is fed to the circuit, the flip flop changes state, cutting TR_{55} off and allowing TR_{53} to charge the timing capacitor with a constant current. When the ramp function at the collector of TR_{53} reaches the reference voltage determined by the arm of potentiometer R_c, transistors TR_{54}, TR_{56}, and TR_{57} reset the flip flop. The timing capacitor is then reclamped to ground and the circuit remains at rest until another trigger pulse is received. The negative output pulse of the circuit appears at the emitter of the emitter follower TR_{93} , its duration being a linear function of the reference voltage.

As in the frequency circuit, the potentiometer R_c is actually the equivalent resistance of the network of Fig. 17. With reference to Fig. 4 of Chapter I, switch S_1 of Fig. 22 and the network of Fig. 17 comprise the front panel controls of the pulse width and delay circuits.

Figure 23 is a photograph of the ramp functions in the pulse

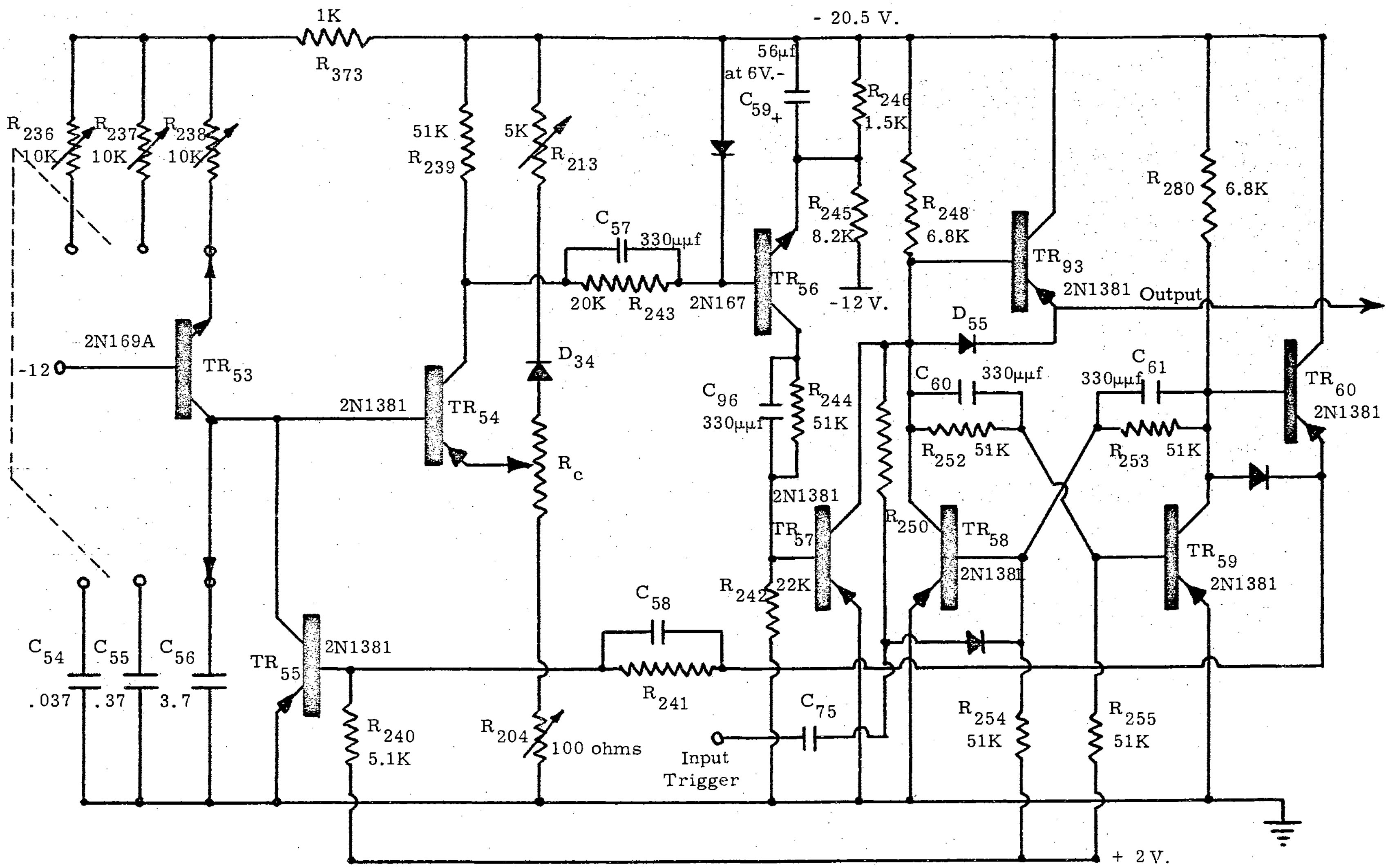
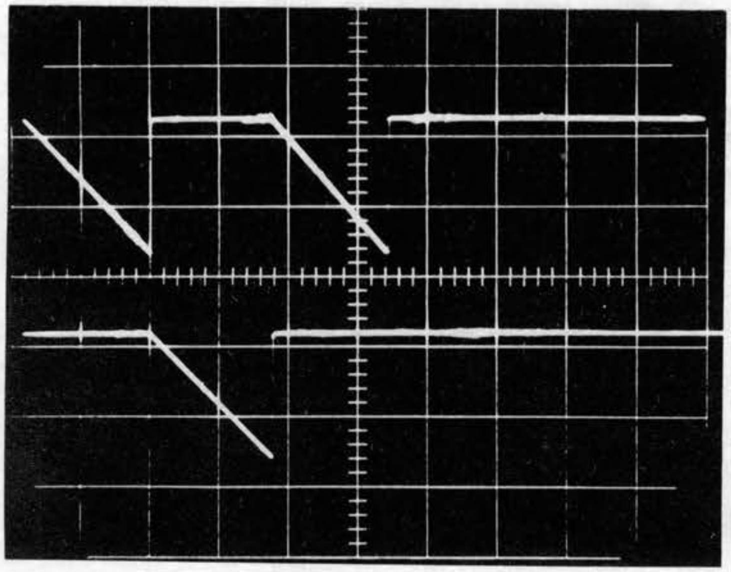


Fig. 22. Pulse Generator

width and delay circuits during a biphasic pulse.



Pulse Width Ramp

5ms/cm Horizontal
5V/cm Vertical

Delay Ramp

Fig. 23. Ramp Functions in Pulse Width and Delay Circuits

Single Pulse Circuit

As was mentioned in the system specifications of Chapter I, the pulse generator may be triggered either by the variable frequency oscillator or by a push button. In order to produce a single pulse for each operation of the push button, it is necessary to eliminate the effect of contact chatter in the switch. A brief search of the literature indicated that standard practice is either to filter the chatter or to employ a one-shot multivibrator whose period is greater than the duration of the chatter.

The circuit of Fig. 24 appears to be a superior solution in this application. It requires few components, may be operated as rapidly as desired, and produces no false triggers.

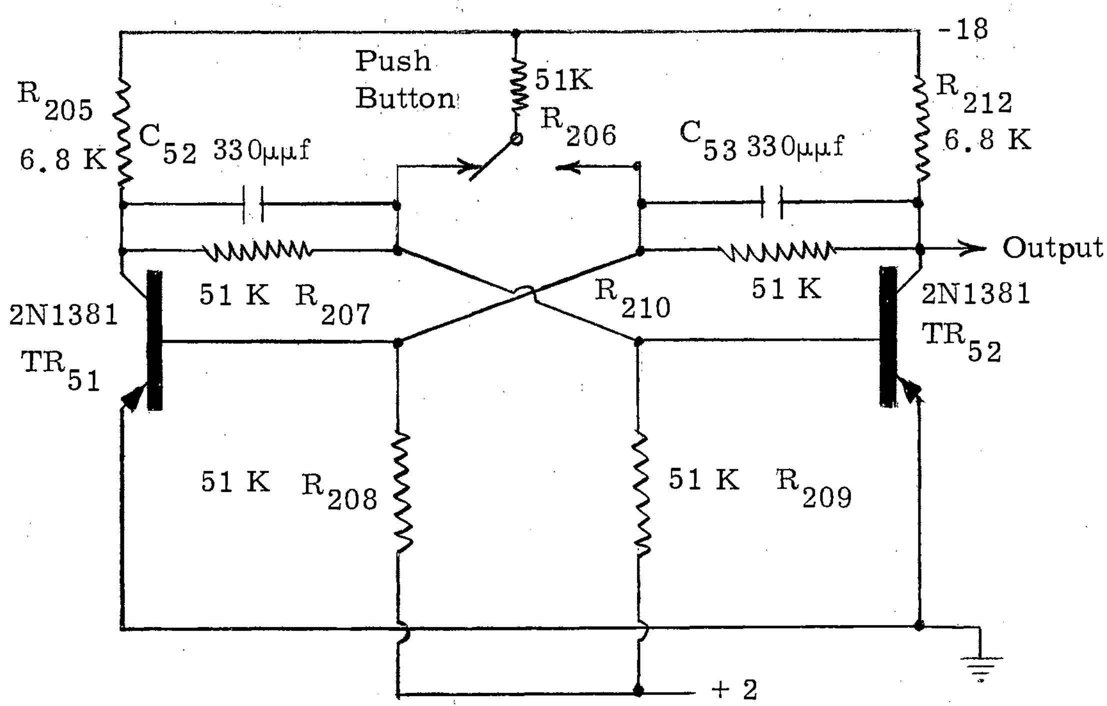


Fig. 24. Single Pulse Circuit

The circuit is essentially a flip flop with the bases of both transistors connected to a single pole, double throw, non-shorting, push button switch, the arm of the switch being connected to the collector supply voltage through R_{206}. TR_{52} is normally held in the saturated state by virtue of current through R_{206}. When the switch is operated, R_{206} is momentarily disconnected from the circuit but the flip flop remains in its normal state due to the current in R_{207}. When the switch contact lands in the second position, or makes the first bounce, the flip flop is triggered and TR_{52} is cut off. TR_{52} remains cut off, regardless of the number of contact bounces, until the push button switch is released and returns to its original position. Thus, for each operation of the push button, either a positive or negative going step is generated depending upon which side of the flip flop is used.

Pulse Separator and Inverter Circuit

In order to obtain a biphasic pulse at the output of the master control unit, it is necessary to invert one of the two monophasic components generated by the pulse generator. As was explained in Chapter II, the logical function or sign sense signal necessary to discriminate between the two components is derived from the state of the flip flop of Fig. 7. The complete pulse separator and inverter circuit is presented in Fig. 25.

Consider first the case when a negative voltage is present at the sign sense input. Transistor TR_{71} is then in the saturated state because of the current in R_{324}, and TR_{72} is cut off. Thus, when a negative pulse from the pulse generator appears at the input, no signal is fed to transistor TR_{74} because TR_{71} is saturated. However, the negative input signal turns transistor TR_{73} off, and, since TR_{72} is cut off, the collector of TR_{73} approaches the positive 12 volt supply. TR_{75} is then turned on by virtue of the current in R_{327} and R_{316}. This in turn saturates TR_{77} because of the current in R_{314} and point (A) goes from zero volts to positive 10 volts. A positive output signal of zero to 10 volts, depending upon the position of the amplitude control R_{309} is then obtained at the junction of R_{307} and R_{308}, transistors TR_{78} and TR_{79} being a complementary emitter follower output stage.

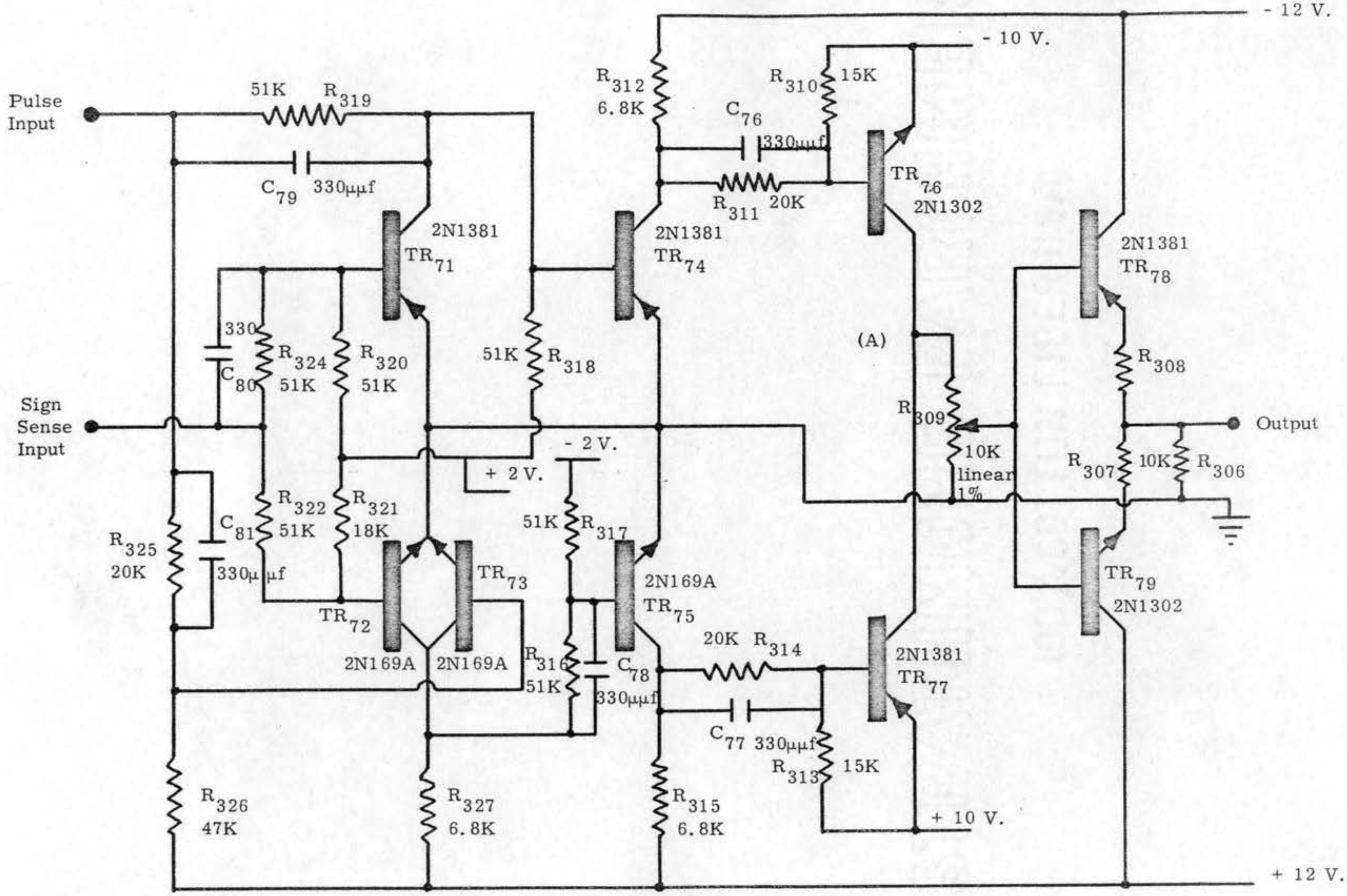


Fig. 25. Pulse Separator and Inverter

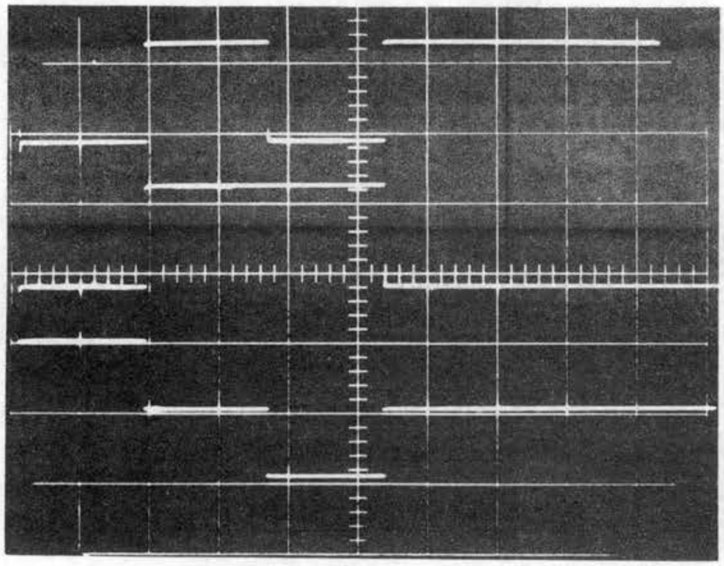
Next consider the case when there is zero voltage at the sign sense input. TR_{71} is now cut off and TR_{72} is saturated because of the current in R_{321}. When a negative pulse is present at the input, the collector of TR_{73} does not swing positive as before because it is clamped by TR_{72}. However, since TR_{71} is cut off, a negative pulse is fed through R_{319} to the base of TR_{74} and its collector voltage falls to zero. This in turn saturates TR_{76} because of the base current in R_{311}. Thus point (A) goes from zero volts to -10 volts, and a negative pulse having the same amplitude as the previous positive pulse appears at the output.

When no pulse is present at the input, both TR_{76} and TR_{77} are cut off and point (A) rests at ground because of R_{309}. Transistor pairs TR_{76} and TR_{77}, and TR_{78} and TR_{79}, are selected to have equal or nearly equal leakage currents to insure an output resting level of zero volts. In the actual circuit, this is achieved to within a few millivolts over the range of normal operating temperatures.

Figure 26 shows the input and output waveforms of the circuit and Fig. 27 is a larger view of a typical biphasic pulse output.

Neon Indicator Circuit

The neon indicator circuit is presented in Fig. 28. Transistors TR_{80} and TR_{81} form a one-shot multivibrator and TR_{82} is a high voltage driver stage. In operation, TR_{81} is normally saturated by virtue of current in R_{335}, and TR_{80} is cut off. When a negative trigger pulse is received, the states of TR_{80} and TR_{81} reverse



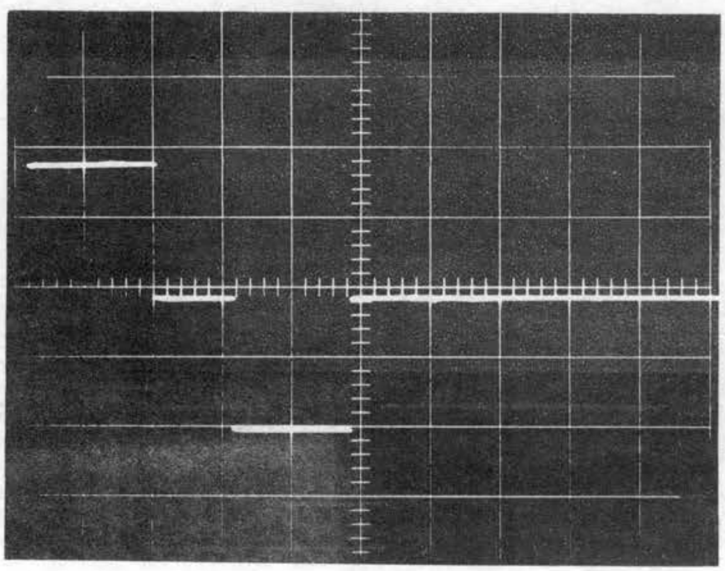
Pulse Input

Sign Sense Input

Biphasic Output

5 ms/cm Horizontal
10V/cm Vertical

Fig. 26. Basic Waveforms in Pulse Separator and Inverter Circuit



10V/cm Vertical

5ms/cm Horizontal

Fig. 27. Typical Biphasic Pulse Output

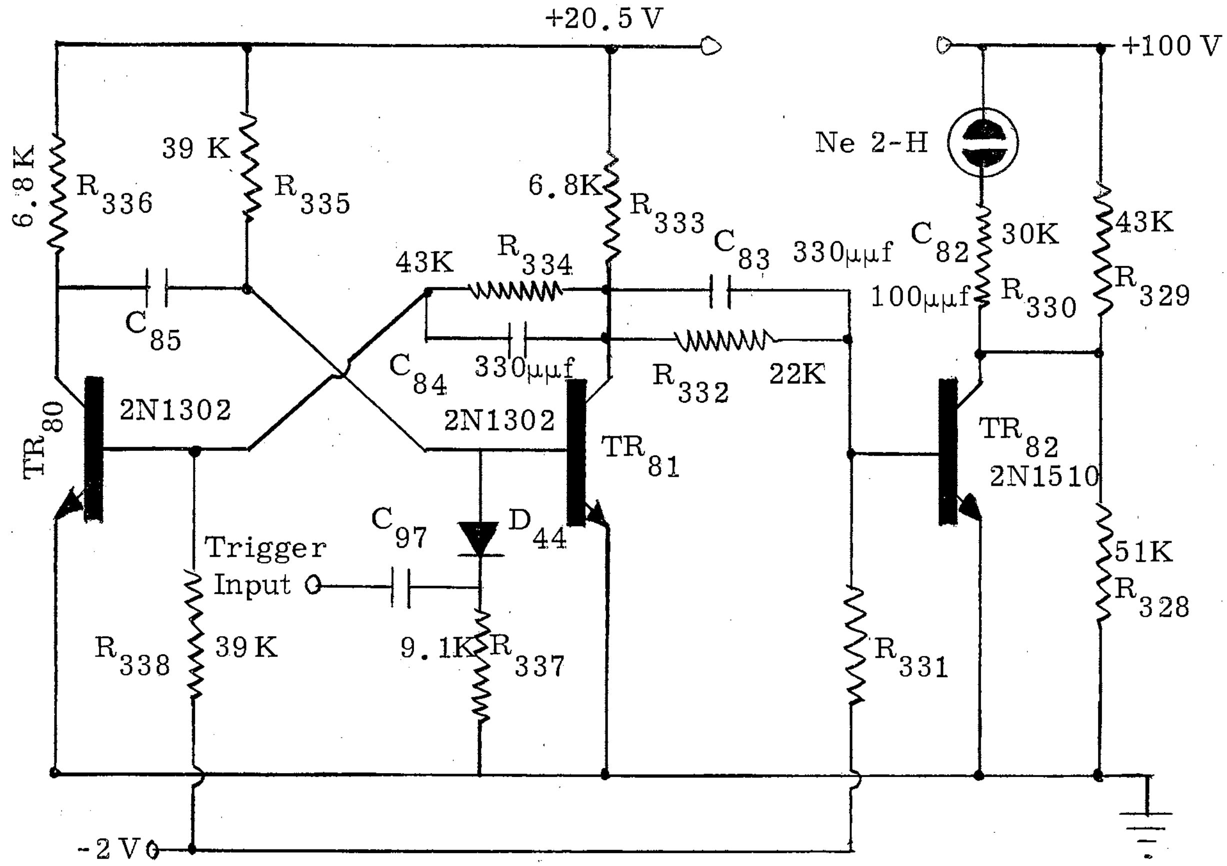


Fig. 28. Neon Indicator Circuit

and TR_{82} is driven into saturation by current in R_{332}. This in turn fires the neon and the circuit returns to rest after C_{85} has discharged sufficiently through R_{335}, the total period being given approximately by $T = .7 R_{335} C_{85}$.

The reader may wonder why the drive for TR_{82} could not be derived directly from the output of the pulse generator, thereby eliminating the one-shot multivibrator. The reason for the multivibrator is to insure reliable firing of the neon for short pulse widths since there is sometimes a considerable delay (depending upon the previous state of the neon) between the time the voltage is applied to the neon and the time it fires. The period of the one-shot multivibrator is made large in order to minimize this problem.

Power Supply

The power requirements of the master control unit are not stringent and the design of the power supply was very straightforward. The circuit of Fig. 29 provides negative voltages of -20.5 volts, -18 volts, -12 volts, -10 volts, and -2 volts. The same circuit is made to supply positive voltages of +20.5 volts, +12 volts, +10 volts, and +2 volts by changing the position of the ground to the emitter of TR_{90}.

Transistor TR_{92} serves as a voltage amplifier and TR_{91} is an emitter follower that permits an increase in the collector resistance of TR_{92}, thereby increasing the gain of the amplifier while still allowing sufficient drive for TR_{90}. TR_{90} is the pass transistor and TR_{89} is an emitter follower that allows the 20.5 volts to be dropped to 18 volts without losing significant regulation of this voltage.

Complete Master Control Unit Circuit

In order to facilitate a clear understanding of the master control unit, the complete circuit is presented in Appendix C. This circuit shows all of the interconnections between individual circuits and presents some circuits not included in the text, such as flip flops, duty cycle meter, switches, etc. The component designations are the same as the corresponding designations in the text so that a quick reference between circuit explanations in the text and Appendix can be easily made.

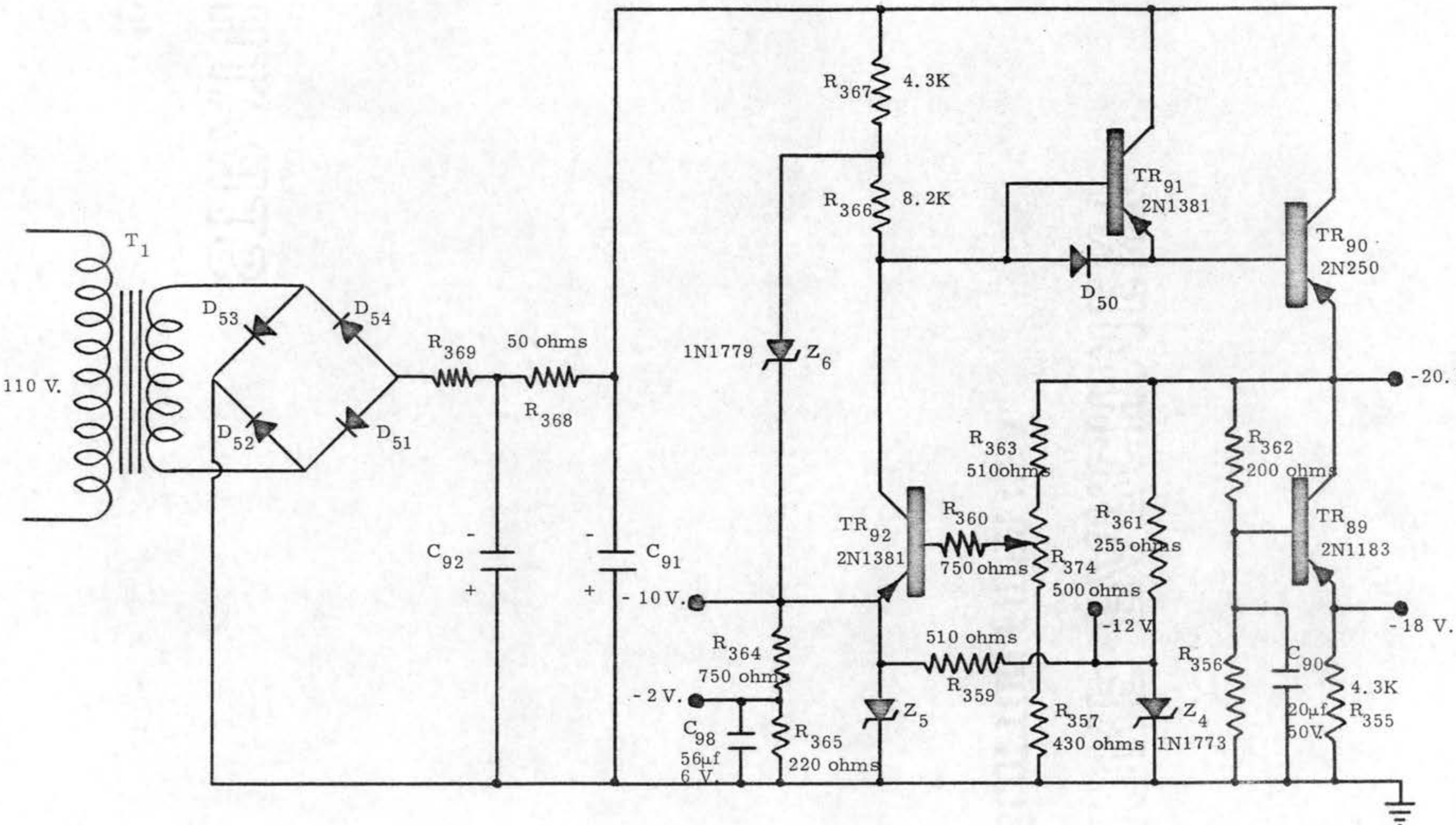


Fig. 29. Master Control Unit Power Supply

CHAPTER IV

RADIO FREQUENCY TRANSMITTER AND ANIMAL UNIT

Radio Frequency Transmitter

The experimenter may wish to stimulate several animals, each in a separate cage, during an experiment. Inasmuch as the cages may be dissimilar, a unique antenna system may be required for each cage. For this reason each antenna system is driven by a separate output tube and transformer to facilitate transmitter and antenna adjustments.

The complete radio frequency transmitter is shown in Fig. 30. Tubes V_1, V_2, V_3, V_4, and V_5 are the output tubes and T_1, T_2, T_3, T_4, and T_5 provide a 50 ohm output impedance for each channel. In operation TR_1 normally rests off, causing the output tubes to be cut off by the -25 volt grid voltage. Thus no radio frequency output is obtained until a negative pulse appears at the modulation input. When this occurs, TR_1 saturates and grounds the grids of the output tubes. Thus, during the pulse, the output tubes become grounded grid amplifiers with the output of the International Crystal oscillator being coupled directly to the cathodes of the output tubes.

Figure 31 shows the complete transmitter power supply. As

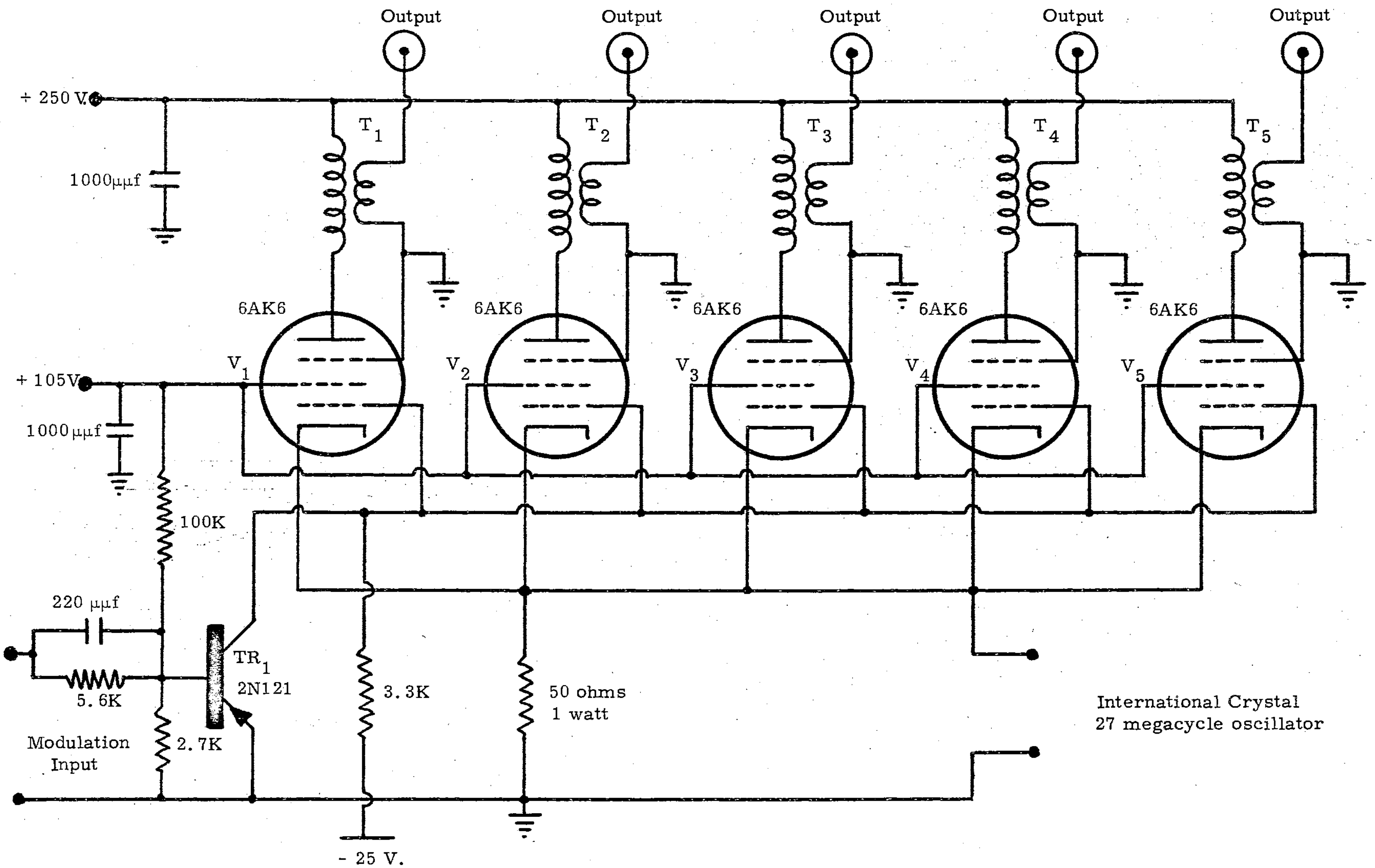


Fig. 30. Radio Frequency Transmitter

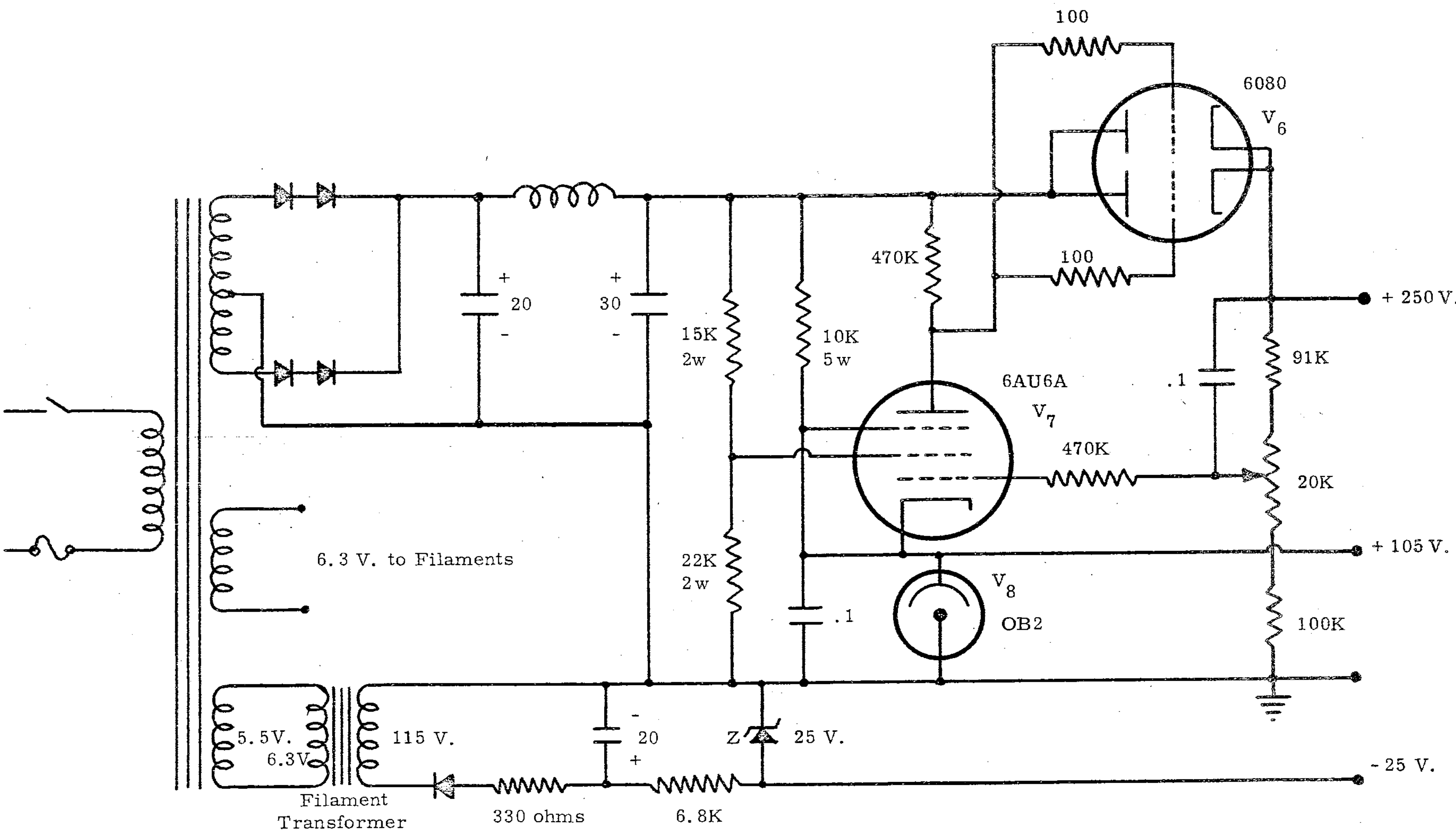


Fig. 31. Transmitter Power Supply

with the master control unit, the power supply requirements are not stringent and the circuit of Fig. 31 provides adequate regulation. The 250 volt output is regulated to within one-tenth percent for line voltage changes of $\pm$ ten volts and to within one-half percent during a stimulation pulse.

Animal Unit

The animal unit, although small in size, is a major component in the stimulation system. It must receive the transmitted signal and provide an accurate reproduction of the master control unit output. In addition, since the transmitter produces only pulsed radio frequency energy, it must invert one of the monophasic components during a biphasic pulse.

It would appear that in order to obtain a biphasic pulse of magnitude, say 10 volts, a battery voltage of at least 20 volts would be required (since the peak to peak voltage of the pulse would be 20 volts). A circuit was developed, however, that requires a battery voltage only slightly higher than the maximum biphasic output voltage, and in addition provides the logic necessary to invert one of the monophasic components of a biphasic pulse. The basic elements of the circuit are presented in Fig. 32.

In operation, TR_3 is normally held off by a positive voltage from the receiver, allowing TR_4 and TR_6 to be held off by the -8.4 volt supply through R_5 .

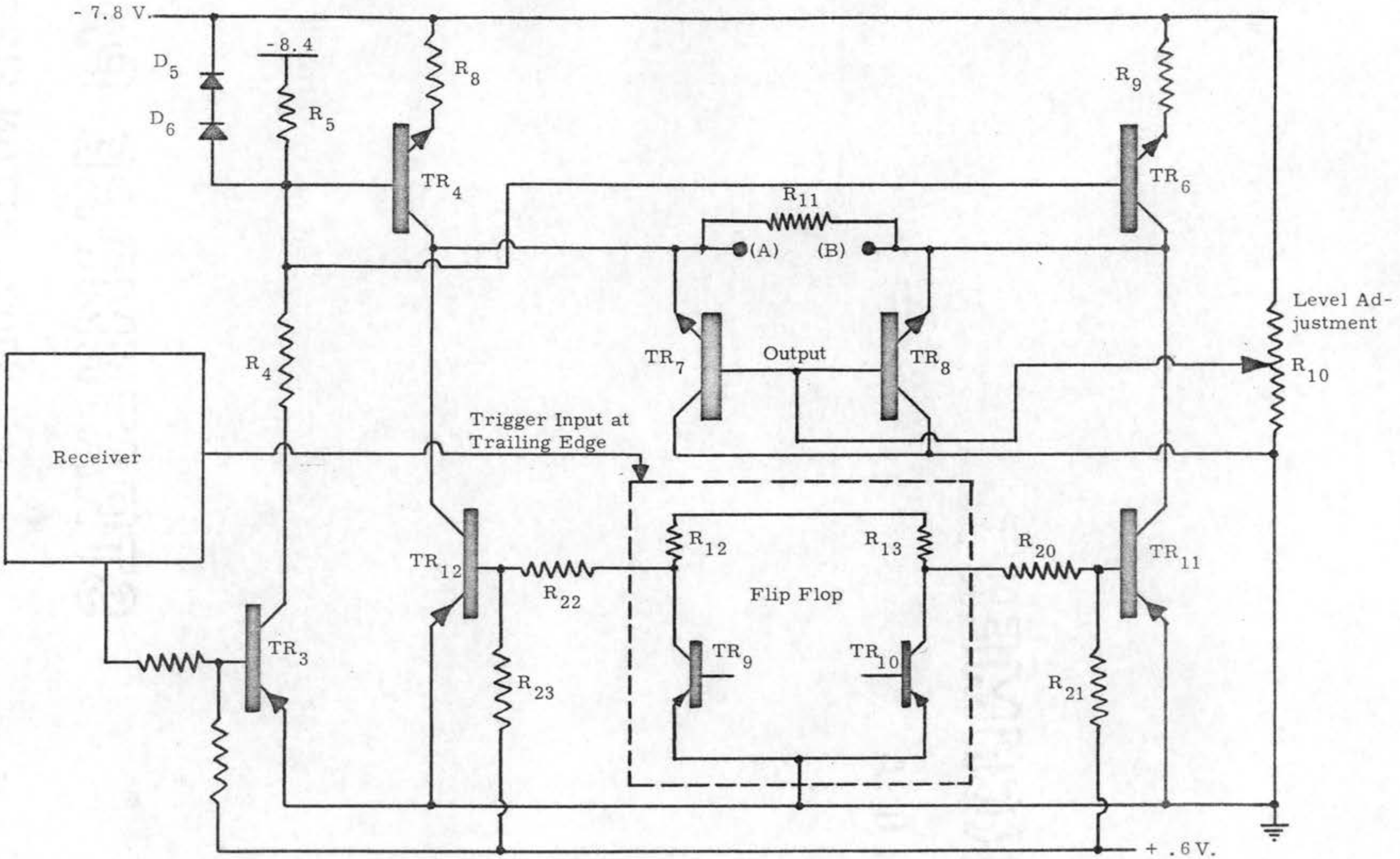


Fig. 32. Output Section of Animal Unit

In addition, depending upon the state of the flip flop, one of the pair of transistors TR_{12} and TR_{11} is saturated while the other is cut off. Assume for the moment that TR_{12} is saturated and TR_{11} is cut off. Since TR_4 and TR_6 are cut off, the voltage at the output terminals will rest at zero. A negative pulse from the receiver will saturate TR_3 causing the junction of R_4 and R_5 to swing from -8.4 volts to approximately -6.6 volts where it is clamped by diodes D_5 and D_6. This in turn will place a voltage of approximately .9 volts across R_9 and R_8, causing transistors TR_4 and TR_6 to conduct. Since TR_{12} is heavily saturated the output terminal (A) remains at ground while terminal (B) goes negative until it is clamped by the emitter follower TR_8, the clamping voltage being determined by the potentiometer R_{10}. At the end of the pulse output terminal (B) returns to ground and a trigger is fed to the flip flop causing it to change state. Thus when the next pulse is received, TR_{11} is saturated and TR_{12} is cut off so that point (B) remains at ground and terminal (A) goes negative until it is clamped by TR_7.

At the end of the pulse, output terminal (A) returns to ground, a trigger is fed to the flip flop causing it to change state, and a biphasic pulse is completed. For monophasic pulses, the flip flop is held in one state and of course only monophasic pulses are transmitted from the master control unit.

Inasmuch as either TR_{11} or TR_{12} must be heavily saturated during a pulse, it would seem that a significant steady state current should be maintained in the flip flop in order to supply drive to these transistors. A circuit was devised, however, that supplies additional drive to either transistor TR_{11} or TR_{12} during a pulse while reducing the steady state current. In addition, the circuit provides a means of triggering and steering the flip flop. This circuit is shown in Fig. 33.

The circuit is designed so that the steady state flip flop supply voltage, determined by R_7, rests at 3.3 volts. This results in a steady state current of about 385 microamperes, of which approximately 173 microamperes flows into the base of either TR_{12} or TR_{11}. Let us assume for the moment that TR_9 is saturated and TR_{10} is cut off.

When a pulse is received, transistor TR_5 is turned on and the flip flop supply voltage rises to -7.8 volts, causing the base drive of TR_{13} to rise to 435 microamperes. Additional drive is also supplied to transistor TR_9 causing it to remain saturated under its increased collector current. At the completion of the pulse, TR_5 is turned off and the collector supply voltage steps positive toward its resting level of -3.3 volts. Since capacitor C_2 has charged during the pulse, a portion of this positive step is applied to the base of TR_9, cutting it off and turning TR_{10} on. At the completion of the next pulse, TR_{10} is cut off, TR_9 is turned back on, and the cycle is complete.

The complete circuit for the animal unit is shown in Fig. 34. It was necessary to limit the sensitivity and hence complexity of the receiver, in order to keep the size of the unit to a minimum. The R.F.

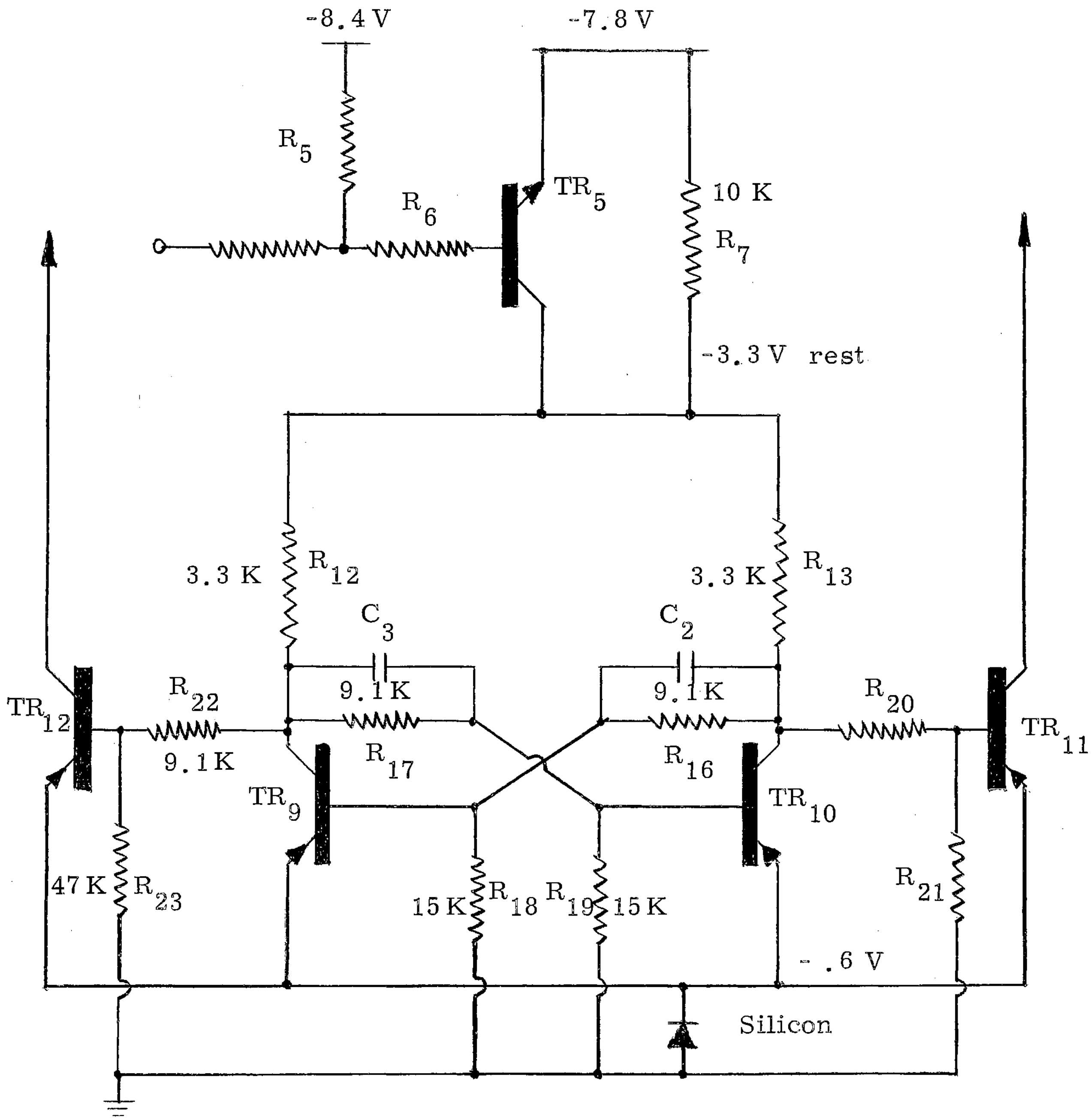


Fig. 33. Details of Logic Circuit

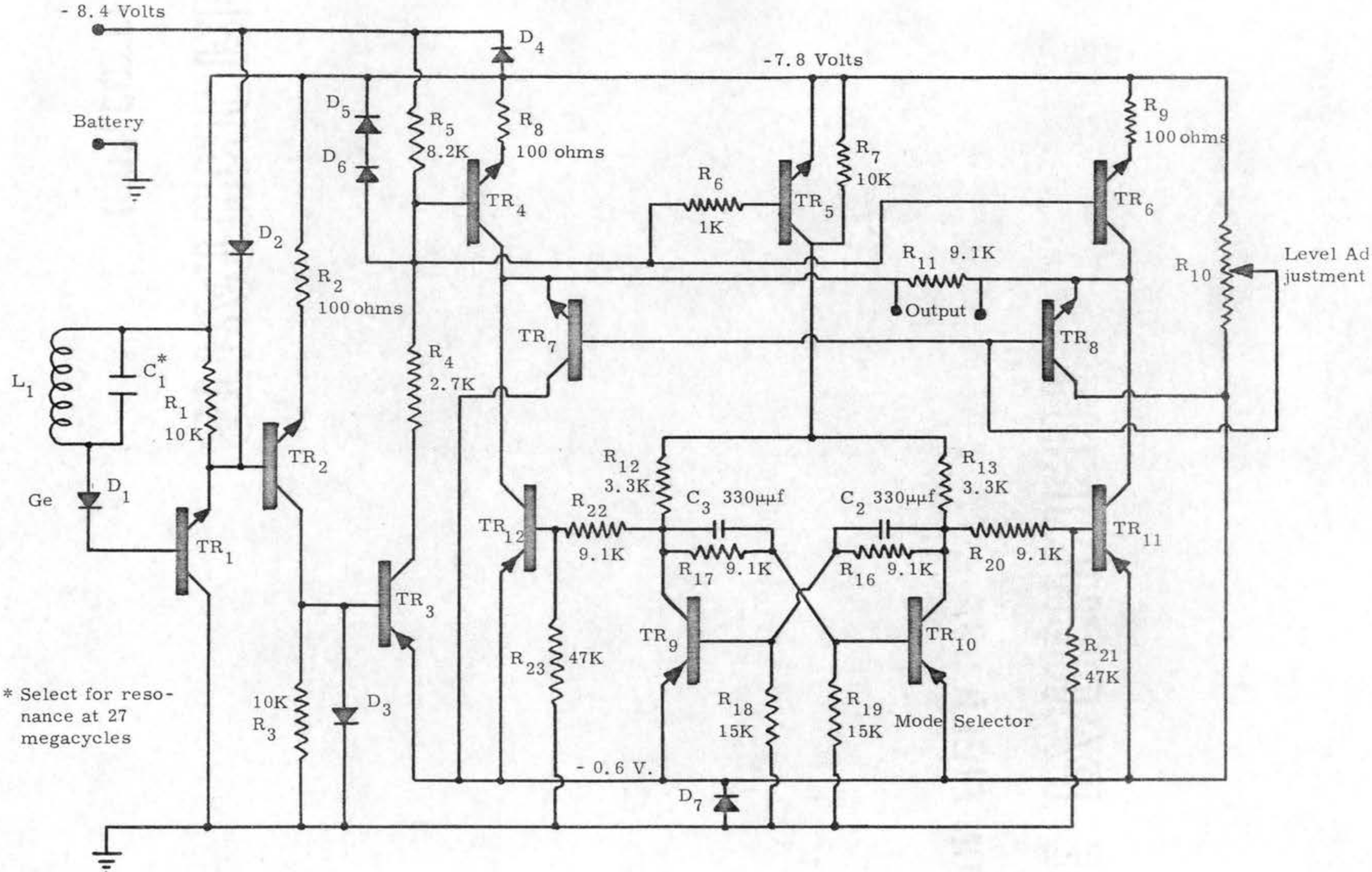


Fig. 34. Complete Circuit for Animal Unit

appearing across the tank circuit $C_1 L_1$, is rectified by diode D_1. Transistor TR_1 is an emitter follower that decreases the load on the tank circuit, thereby increasing its Q.

TR_2 is a simple common emitter amplifier and TR_3 is the switch transistor. The transistors in the rest of the circuit are the same as those in Fig. 33 and Fig. 32 and their operation has been discussed previously. Diodes D_2 and D_3 are for temperature compensation, while diodes D_4 and D_7 are used to obtain bias voltages for the rest of the circuit. With a Burgess type H 146, 8.4 volt battery, the animal unit is capable of supplying stimulation pulses having a maximum amplitude of 7.2 volts and a maximum current of 10 milliamperes. Battery life is dependent upon the stimulation parameters although with no stimulation the battery life is approximately 4 weeks. Figure 35 shows the completed animal unit.

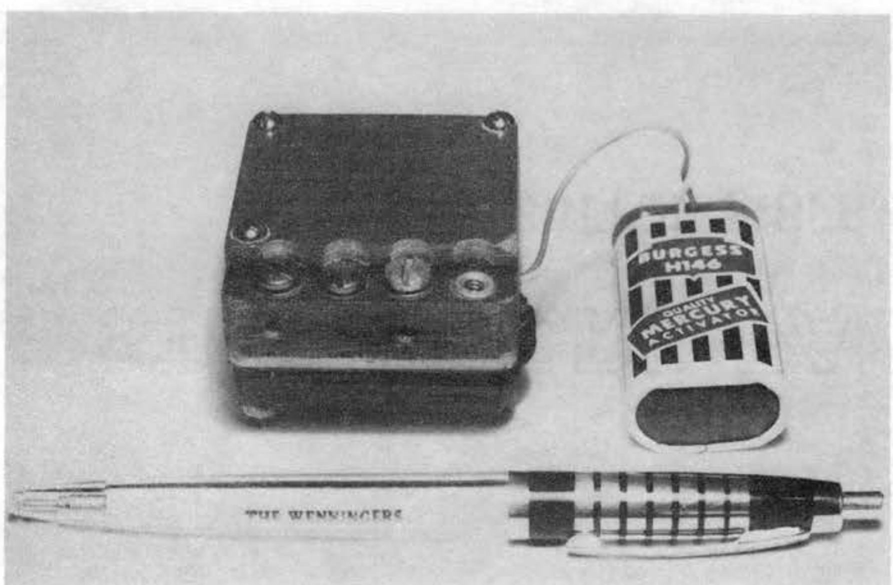


Fig. 35. Completed Animal Unit

CHAPTER V

SUMMARY AND CONCLUSIONS

In Chapter I the basic terminology and system specifications were outlined. Chapter II presented the basic system in block form and the fundamental principles of operation were explained. Chapter III presented circuit details of the master control unit, and Chapter IV included circuit details of the radio frequency transmitter and animal unit.

The complete system has been constructed and has performed satisfactorily in experiments. Figure 36 shows the completed master control unit and radio frequency transmitter. The master control unit employs a total of 650 electronic components including a total of 98 transistors, the majority of these components being mounted on 29 etched circuit plug-in cards. Figure 37 shows a typical plug-in card and Fig. 38 illustrates the method of construction. The transmitter, employing 8 tubes, is constructed around turret tube sockets and terminal strips. The animal unit, employing 46 electronic components, is constructed on two etched circuit boards and is contained within 3.3 cubic inches of space.

As with most prototype electronic systems, certain changes

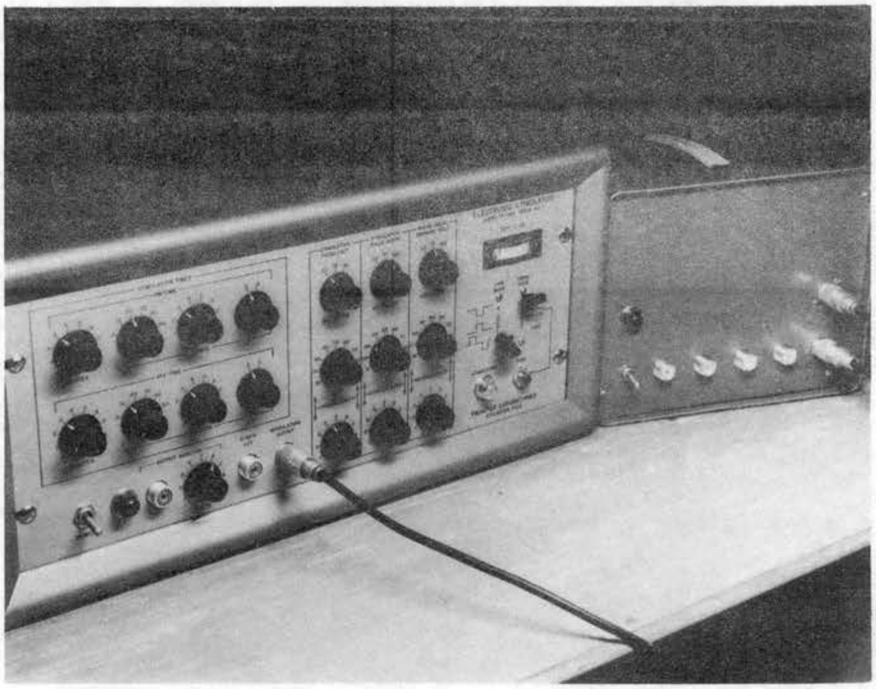


Fig. 36. Master Control Unit and Radio Frequency Transmitter

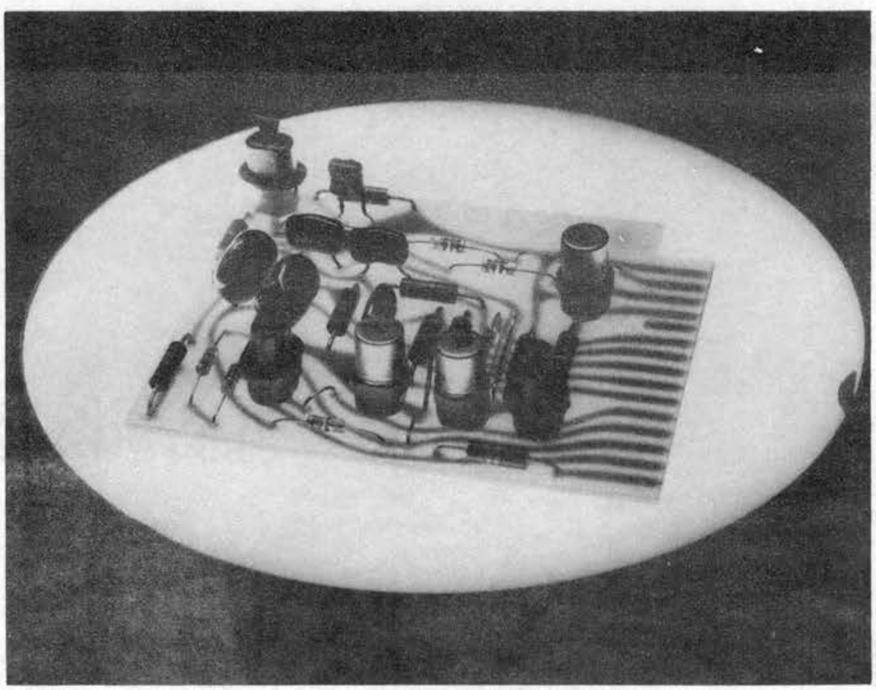


Fig. 37. Typical Plug-in Card

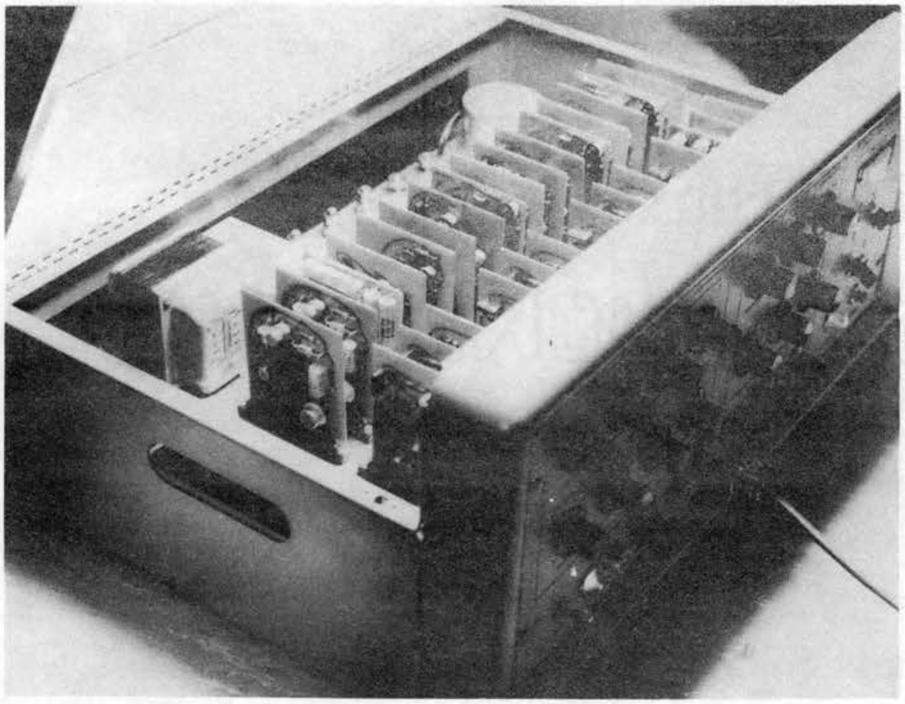


Fig. 38. View of Stimulator Showing Assembly

could be made that would improve the over-all operation of the system.

A major area for further development in this system lies in the transmitter and receiver antenna. With the present system, each type of cage requires a unique antenna and considerable experimentation is required to achieve satisfactory results. The primary sources of difficulty are 1) the animal unit's antenna is severely limited in size, and 2) the dimensions of the cage are comparable to the wavelength of the transmitted signal, resulting in unusual signal strengths throughout the cage. A theoretical analysis of the electric and magnetic field components in close proximity of the antenna could pinpoint the major improvements necessary for a more desirable antenna system.

Further development could certainly be justified in reducing the size of the animal unit. In the present units, standard available components were necessitated for economic reasons. Unquestionably, use of new microtransistors and components would significantly reduce the size of the animal units. Use of more expensive components in the master control unit would, in some cases, permit circuit simplifications and would reduce the rise time of the output pulses to less than the present value of one microsecond.

The stimulation system described in these pages is not, by any means, the ultimate in stimulation systems. However, it is felt that the system does represent a major improvement over stimulation systems of the past. It is hoped that the system will justify its existence by providing researchers with a versatile instrument that will facilitate their investigations.

A SELECTED BIBLIOGRAPHY

1. Greer, Monte A., M.D., and Grant C. Riggle, "Apparatus for Chronic Stimulation of the Brain of the Rat by Radio Frequency Transmission", pp 151 - 155, Journal Electroencephalography and Clinical Neurophysiology, 1957, Vol. 9, Feb. 1957.

2. Gengerelli, J. A. and V. Kallejian, "Remote Stimulation of the Brain in the Intact Animal", J. Psychology, 1950, 29:263-269.

3. Verzeano, M. and J. D. French, "Transistor Circuits in Remote Stimulation", EEG Clin. Neurophysiology, 1953, 5:613-615.

4. Nastuk, W. L., and J. T. Alexander, "A Rectangular-Wave Stimulator for the Research and Student Laboratory", Journal of Applied Physiology, Vol. 14, No.4, July, 1959.

5. Chaffee, E. L., and R. V. Light, "A Method for Remote Control of Electrical Stimulation of the Nervous System", Yale J. Biol. Med., 1952, 24: 351-358.

6. Lafferty, J. M. and J. G. Farrel, "A Technique for Chronic Remote Nerve Stimulation", Science, 1949, 110:140-141.

7. Smith, George W., and Roger C. Wood, Principles of Analogue Computation, McGraw-Hill Book Co., Inc., 1959, pp 6-7.

APPENDIX A

ANALYSIS OF ERROR IN VARIABLE FREQUENCY OSCILLATOR

With reference to Fig. 16, Chapter III, we may use the following equivalent circuit for purposes of analyses.

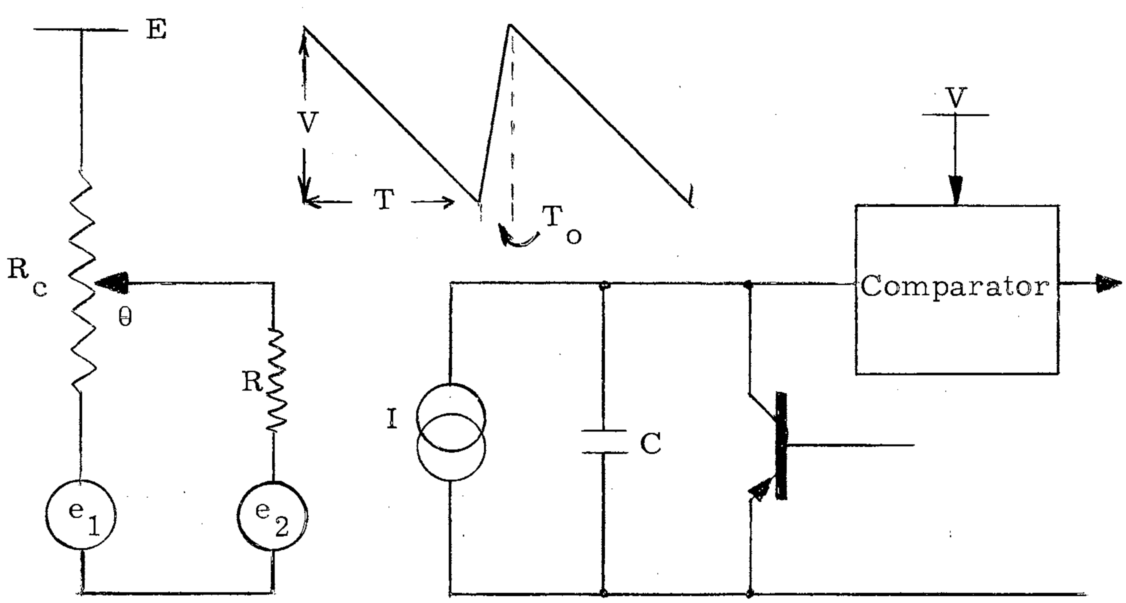


Fig. 39. Equivalent Circuit

In Figure 39

θ = setting of potentiometer arm with respect to full scale $0.1 \leq \theta \leq 1$

R = R_{181} of Fig. 16

e_1 = voltage drop across $D_{26} + D_{27} + D_{28} + R_{182}$ of Fig. 16

e_2 = sum of V_{be} drops for TR_{40} and TR_{41} of Fig. 16

I = current in timing condenser

C = capacity of timing condenser

V = reference voltage or peak amplitude of sawtooth voltage across C

T = charging time of timing capacitor C

T_o = discharge time of timing capacitor C .

From Fig. 39 we have

$$I = \frac{\theta (E - e_1) + e_1 - e_2}{R} \quad . \tag{1}$$

Now

$$T = \frac{CV}{I} \quad , \text{ and by substitution}$$

$$T = \frac{CVR}{\theta (E - e_1) + e_1 - e_2} \quad . \tag{2}$$

The frequency f is inversely proportional to the total period $T + T_o$ or

$$f = \frac{1}{T + T_o} \quad . \tag{3}$$

Substitution of (2) in (3) yields

$$f = \frac{1}{\frac{CVR}{\theta (E - e_1) + e_1 - e_2} + T_o}$$

or

$$f = \frac{\theta (E - e_1) + (e_1 - e_2)}{CVR + T_o \left[\theta (E - e_1) + (e_1 - e_2)\right]} \tag{4}$$

In equation (4) we have assumed that TR_{41} is a perfect constant current generator and, for the present, we have assumed that the emitter follower TR_{40} completely isolates the divider R_c so that the voltage at the divider arm is a linear function of θ.

Now, it is necessary that the frequency varies over a ten to one range as θ varies from $\theta = 0.1$ to $\theta = 1$. That is, if the frequency is f_1 when $\theta = 0.1$, the frequency must be $10 f_1$ when $\theta = 1$. Thus

$$10 \left[\frac{.1 (E - e_1) + (e_1 - e_2)}{CVR + T_o \left[.1 (E - e_1) + (e_1 - e_2)\right]} \right] = \left[\frac{(E - e_1) + (e_1 - e_2)}{CVR + T_o \left[(E - e_1) + (e_1 - e_2)\right]} \right] . \tag{5}$$

With some manipulation (5) may be written as

$$(.2\, T_o)\, e_1^2 - (9\zeta + 8.3\, T_o E - 7.9\, T_o\, e_2)\, e_1 + \left[(9\zeta + 10.1\, T_o E)\, e_2 - .9\, T_o E^2 - 9\, T_o e_2^2\right] = 0 \tag{6}$$

where $\zeta = CVR$. Solution of (6) for e_1 will determine the adjustment of R_{182} necessary to permit the frequency to vary over a ten to one range.

For the purpose of illustration, let us examine the error of the circuit in the frequency range of 1 cps to 10 cps . In this case we have

$$
\begin{aligned}
T_o &\doteq 3 \times 10^{-4} \text{ seconds} \\
\zeta &\doteq \text{CVR} \doteq 1 \\
E &= 10 \text{ volts} \\
e_2 &\doteq 0.6 \text{ volts} \quad .
\end{aligned}
\qquad (7)
$$

Solution of (6) for e_1 under the above conditions gives

$$e_1 \doteq 0.597 \text{ volts} \quad . \qquad (8)$$

Figure 40 is a plot of the error versus frequency when (7) and (8) are substituted into (4).

If we consider the effect of the loading on R_c by R_{181} and TR_{40} we have[1]

$$\theta = \frac{a}{1 + a\,(1-a)\,R_c/R_L} \qquad (9)$$

where

θ = actual fraction of full scale of potentiometer arm

a = dial reading of fraction of full scale of potentiometer arm

$R_L \doteq (\beta \text{ of } TR_{40}) \times R_{181}$.

Taking $R_c/R_L = 0.005$ and substituting (9), (8) and (7) into (4) gives the composite error (Fig. 41).

It is interesting to note that the effect of potentiometer loading may reduce the total error.

No attempt was made to verify Figs. 40 and 41 experimentally due

---

(1) Reference No. 7

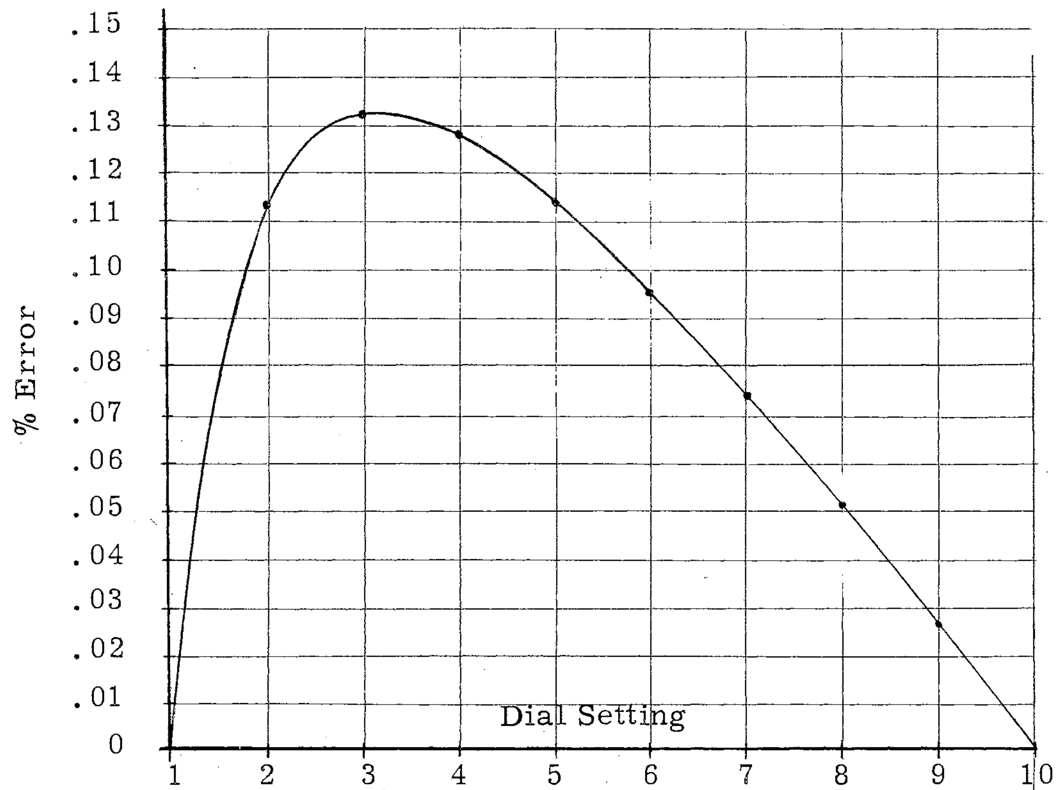


Fig. 40. Error vs. Frequency

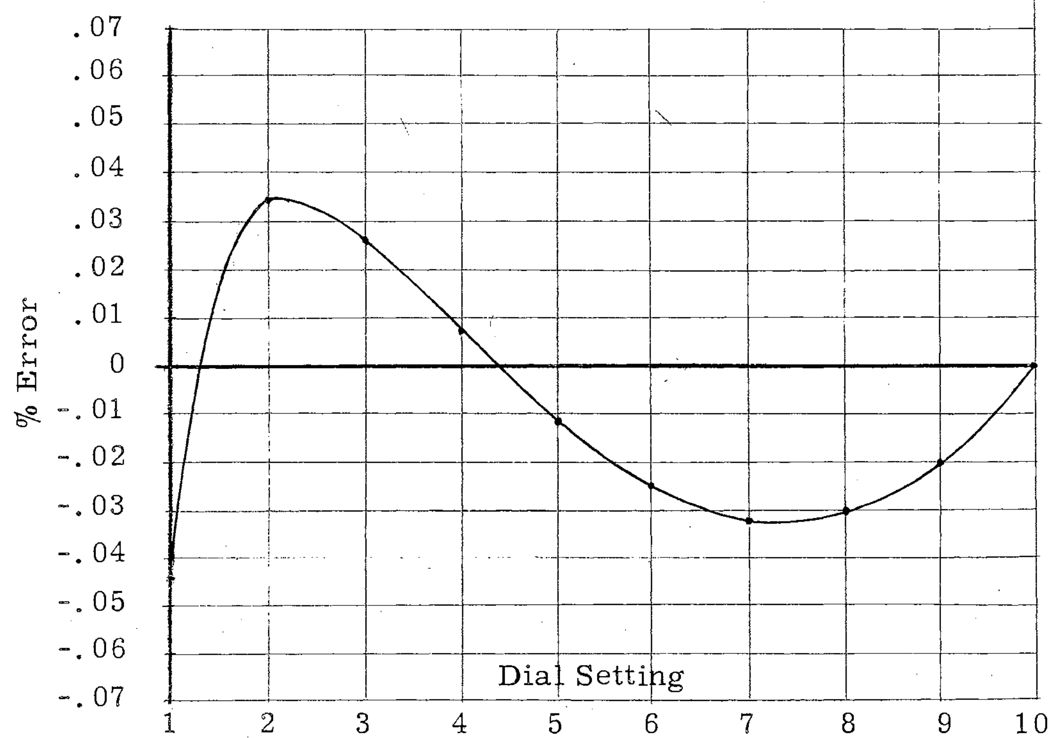


Fig. 41. Error vs. Frequency with Potentiometer Loading Considered

to lack of instruments of sufficient accuracy. The accuracy of the circuit is, of course, a function of temperature and the curves in Figs. 40 and 41 would be valid only at one specific temperature. However, the circuit is accurate to better than 1% over the range of normal operating temperatures.

APPENDIX B

SIMPLIFIED DESIGN OF BASIC FLIP FLOP

One of the fundamental building blocks used in the stimulation system is the flip flop, or some ramification thereof. A person desiring to design a basic flip flop can find a myriad of information in the literature. He may find charts, graphs, nomographs, truth tables, matrices, non-linear differential equations, statistics, and so on, all devoted to optimum design of basic flip flops. In many cases, the person does not care if his design is optimum or not. He simply wants a reliable circuit that will perform satisfactorily in a given system.

It is the purpose of this Appendix to present a basic thought process that may be used to design transistor flip flops. This method is by no means original, and it is assumed that many experienced engineers often use a similar technique. However, it is hoped that the space allotted to this Appendix will be justified by aiding the person who is unfamiliar with transistor flip flops and who wants a fast basic design procedure that is not necessarily optimum, but entirely reliable.

Consider the basic flip flop of Fig. 42. The value of the collector resistor is first chosen on the basis of, (1) maximum dissipation rating of transistors, (2) type of load to be driven by the flip flop, and (3) the steady state current that is desired. Suppose that TR_2 is saturated, so that the supply voltage V_1 is impressed across R_2. Thus a current of almost V_1/R_2 is flowing in the collector of TR_2. Suppose the transistors have a minimum H_{fe} of 50 over the range of anticipated operating temperatures. If we assume a H_{fe} of say, 4 in our design, then certainly any long-term changes in the characteristics of the transistors and components will have little effect on the operation of the flip flop. Thus, if $H_{fe} = 4$, then we must have a current in the base of TR_2 equal to one-fifth of the current flowing in the collector. This base current and the current flowing in R_6 are supplied from V_1 via R_1 and R_3.

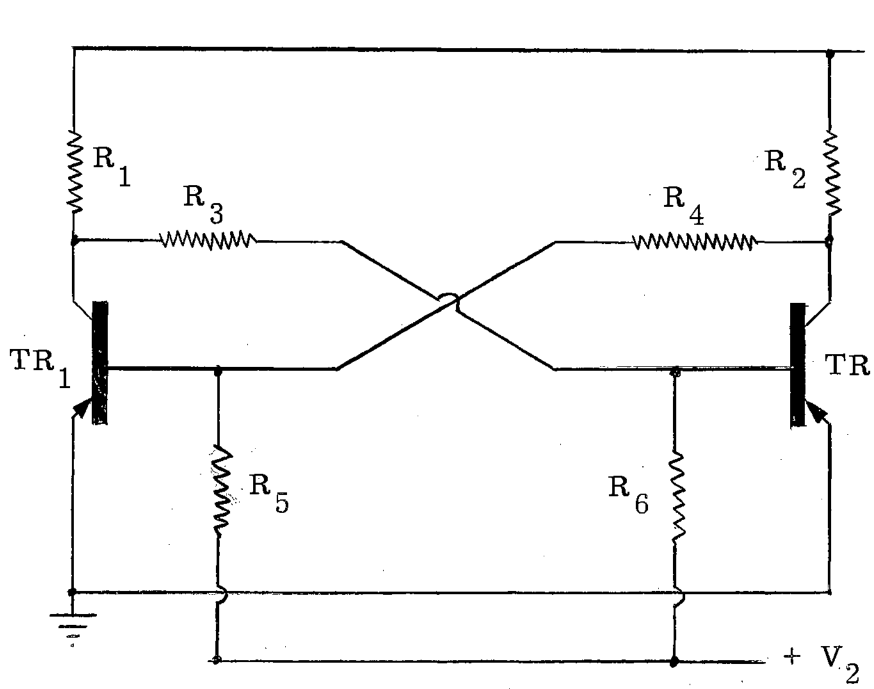


Fig. 42. Basic Flip Flop

As a first approximation for R_3, assume that the current in R_6 is small compared to the base current in TR_2. Since $R_1 = R_2$, R_3

can be calculated immediately. Thus, neglecting V_{be},

$$R_3 = R_4 \doteq R_2 \; H_{fe} \qquad (1)$$

or, in our case,

$$R_3 \doteq 4 \, R_2 \quad .$$

Now, suppose we want TR_1 to be held off by a base voltage of $+1$ volt. Since TR_2 is saturated we have

$$\text{Holdoff voltage} = V_h = \frac{V_2 R_5}{R_4 + R_5}$$

or, solving for R_5

$$R_5 = \frac{V_h R_4}{V_2 - V_h} \quad . \qquad (2)$$

Now, we need to be sure that the off transistor will not turn on at high temperatures. Suppose the maximum anticipated I_{cbo} of the off transistor is $I_{cbo\ max}$. The base of TR_1 looks into an impedance of R_4 and R_5 in parallel, so that I_{cbo} will decrease the base hold-off voltage by

$$\Delta V_h = I_{cbo\ max} \left[\frac{R_4 R_5}{R_4 + R_5} \right] \quad . \qquad (3)$$

If this change exceeds the hold-off voltage by V_{be}, the transistor will turn on. Thus, after calculating all of the resistor values, we may check the design and determine $I_{cbo\ max}$. If the calculated $I_{cbo\ max}$ is less than the actual $I_{cbo\ max}$, then the design must be revised, e.g., the parallel resistance of R_4 and R_5 must be decreased or the hold-off voltage must be increased. In most cases, assuming a low value for H_{fe} (such as 5) and keeping the collector resistor small, will cause R_4 to be small and hence the parallel resistance of R_4 and R_5 will be small enough to keep the change of V_h below the minimum.

Typical Design Example.

Let

$V_1 = -15$ volts	actual minimum
$V_2 = +2$ volts	$H_{fe} = 50$
$R_1 = R_2 = 6.8$ K	$V_{be} = .3$ volts

Transistor Type $\equiv$ 2N1381

Now, the current in the saturated transistor is $\frac{15 \text{ volts}}{6.8 \times 10^3} \doteq$ 2.2×10^{-3} amp = 2.2 mills = I_c .

Assuming a H_{fe} of 4 we have from (1)

$$R_3 = R_4 = 6.8 \times 10^3 \times 4$$

or

$$R_3 = R_4 \doteq 27 \text{ K ohms}$$

and from (2), letting $V_h = .6$ volts,

$$R_5 = R_6 = \frac{.6 \times 27 \times 10^3}{2 - .6}$$

$$R_5 = R_6 \doteq 12 \text{ K ohms}$$

Solving (3) for $I_{cbo\ max}$

$$I_{cbo\ max} = \frac{(V_{be} + V_h)(R_4 + R_5)}{R_4 R_5} \tag{4}$$

$$I_{cbo\ max} = \frac{(.3 + .6)(27 + 12) \times 10^3}{6.8 \times 12 \times 10^6}$$

$$I_{cbo}\ max = .108 \times 10^{-3}\ \text{amp}$$

$$I_{cbo\ max} = 108\ \mu a$$

This is certainly more than would be anticipated from a 2N1381 transistor so the design is safe.

It may be desirable to calculate the actual minimum value of H_{fe} that the transistor could have for the above circuit to operate. Since we have made several simplifying assumptions, we should expect the actual value of H_{fe} min to be higher than the value H_{fe} min = 4 that was assumed. Since V_{be} = .3 volts, when TR_2 is on, 2 + .3 volts will be impressed across R_6. Thus the current in R_6 will be $\frac{2.3 \text{ volts}}{12 \times 10^3}$ = 192 μa . The total current flowing in R_1 and R_3 will be

$$\frac{V_1 - V_{be}}{R_1 + R_3} = \frac{14.7}{(6.8 + 27) \times 10^3} = 435\ \mu a \quad .$$

Hence the current flowing in the base of TR_2 is (435 - 192) μa = 243 μa . Since the collector current must be 2.2 ma for the transistor to remain saturated, we have for the minimum value of H_{fe}

$$H_{fe} \quad \min = \frac{2.2\ ma}{.243 ma}$$

or

$$H_{fe} \quad \min \doteq 9$$

This is, of course, considerably less than the actual value of 50, so the circuit will be quite stable and reliable. This simplified procedure was used extensively in the initial design of the stimulation system and resulted in a considerable saving of time. As the system design was refined, some modifications were made in component values determined by the simplified procedure, although the initial design was, in all cases, reliable and the circuits performed satisfactorily.

VITA

Freddie W. Wenninger

Candidate for the Degree of

Master of Science

Thesis: AN ELECTRONIC STIMULATOR FOR MEDICAL RESEARCH

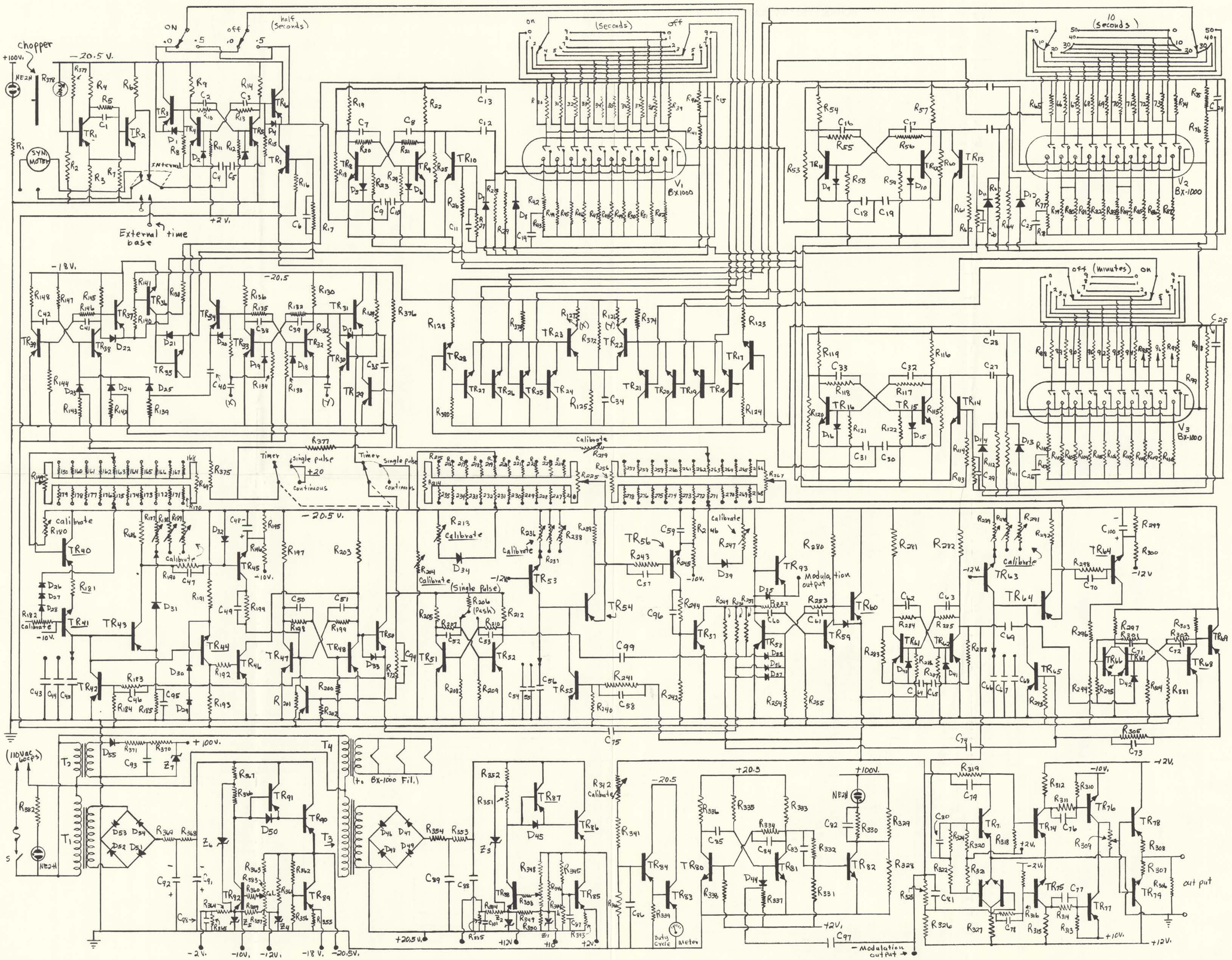
Major Field: Engineering

Biographical:

Personal Data: Born on February 6, 1939 in Alva, Oklahoma, the son of Fred W. and Opal G. Wenninger.

Education: Attended primary and secondary schools in Alva, Oklahoma and graduated from Alva High School in May, 1956; completed requirements for the Degree of Bachelor of Science in Arts and Sciences at Oklahoma State University in May, 1959; completed requirements for the Master of Science degree in May, 1962.

Professional Experience: Employed part-time by the Physics Department, Oklahoma State University, September, 1958 to January 1959 as lab instructor; employed part-time by the Research Foundation of Oklahoma State University from January, 1959 to May, 1959; employed as a physicist during the summer of 1959 by the National Aeronautics and Space Administration, Washington, D. C.; employed by Labko Scientific, Stillwater, Oklahoma, as physicist from September, 1959 to September, 1960, the responsibilities including design and development of a transistorized calibration unit for a photomultiplier micrometeor detector that was orbited in Explorer XIII; in September, 1960, jointly formed a partnership under the name Frontier Laboratories for the development of the stimulation system presented in this thesis; employed from September, 1960 to January, 1961 by the Math Department of Oklahoma State University as an instructor; employed from January, 1962 to May, 1962 as an instructor in the Physics Department of Oklahoma State University.


chopper
+100V.
NE2H
-20.5 V.
SYN. MOTOR
Interval
External time base
+2 V.
ON
off
half (Seconds)
(Seconds)
10 (Seconds)
V1 BX1000
V2 BX-1000
V3 BX-1000
off (minutes) on
-18V.
-20.5
Timer
single pulse
continuous
+20
Calibrate
-20.5 V.
Calibrate
(Single Pulse)
(Push)
Modulation output
-12V
-10V.
(110Vac 60cps)
+100V.
(to BX-1000 Fil.)
-2V.
-10V.
-12V.
-18 V.
-20.5V.
+20.5V.
+12V
+10
+12V.
Duty Cycle
Meter
+20.5
+100V.
-Modulation output
out put
+12V.
+10V.
-10V.