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A TRANSISTOR QUENCHING CIRCUIT FOR GEIGER COUNTER TUBES - SIMKO

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A TRANSISTOR QUENCHING CIRCUIT
FOR GEIGER COUNTER TUBES

By

Andrew M. Simko

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Physics

The University of New Mexico

1963

ANDREW M. SIMKO

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

W. J. Parish
DEAN

June, 1963
DATE

Thesis committee

Victor H. Regener
CHAIRMAN

C. P. Leavitt

Roy Thomas

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PREFACE

This thesis attempts to provide a solution to a basic problem inherent in the operation of Geiger-Mueller counting tubes, that is, reduction of the insensitive time, or "dead time", following the discharge. Many researchers, using various quenching gases for internal quenching and various vacuum tube circuits for external quenching, have succeeded in reducing the "dead time" significantly. Reduction of the insensitive time provides more efficient and accurate counting. The solutions presented in this thesis utilize transistor circuits instead of vacuum tube circuits for external quenching. In an extensive research of current literature no attempts to transistorize a quenching circuit could be found.

Acknowledgement is made of the many valuable suggestions and sincere interest of Dr. Victor H. Regener, Chairman of the Physics Department, University of New Mexico, who posed this problem.

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PREFACE

This thesis attempts to provide a solution to a basic problem involved in the operation of Geiger-Mueller counting tubes, that is, reduction of the insensitive time, or "dead time", following the discharge. Using resistors, using various quenching gases for internal quenching and vacuum tubes in the circuits for external quenching, are successful in reducing the dead time significantly. Reduction of the dead time [illegible] are efficient and accurate counting. The effort [illegible] presented in this thesis utilize transistor circuits instead of vacuum tube circuits for external quenching. In an extensive research of current literature [illegible] no transistorized quenching circuit could be found.

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INTRODUCTION

This thesis is concerned with the problem of quenching the discharge and reducing the insensitive time of a Geiger counter by means of a transistorized external quenching circuit. A solution of this problem would avoid the use of polyatomic quenching gases which shorten the useful life of Geiger counters, or the use of halogen quenching gases which are corrosive and which reduce the efficiency of Geiger counters. An external electronic quenching circuit which is transistorized would make, at the same time, both the Geiger counter and the quenching device compatible with existing transistorized amplifier circuitry.

As recent as September 1962, the best published attempt to reduce Geiger counter dead-time consisted of a fast response vacuum tube circuit.[1] This, being an unacceptable version of the solution, emphasized the originality and difficulty of attempting to electronically quench large Geiger counters with transistor circuits. Referring to a very early attempt by Simpson[2] to reduce dead-time by positive ion collection, Korff, in 1946, pointed out that:

> . . . circuits of this type will no doubt be simplified and become part of standard laboratory practice. The success of this experiment points the way to important new developments in counter technique and suggests many interesting and significant fields of study. An order of magnitude has already been gained and further progress seems probable.[3]

---

[1] J. H. L. Smuts, J. Sci. Inst. 39, 475 (1962).

[2] J. A. Simpson, Phys. Rev. 66, 39 (1944).

[3] S. A. Korff, Electron and Nuclear Counters (D. Van Nostrand Company, Inc., New York, 1955), p. 126.

INTRODUCTION

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> . . . circuits of this type will no doubt be simplified and become a part of standard laboratory equipment. The success of this experiment points the way to important new developments in counter technique that are particularly interesting and significant [illegible]. An important beginning has already been gained and further progress seems probable.

---

[1] J. E. L. Barke, J. Sci. Instr. 38, 377 (1961).

[2] J. A. Simpson, Phys. Rev. 66, 39 (1944).

[3] S. A. Korff, *Electron and Nuclear Counters* (D. Van Nostrand Company, Inc., New York, 1955), p. 120.

In order to completely present the problems associated with the functioning of an electronic quenching circuit for Geiger counters, it is necessary to relate briefly the basic aspects of radiation detection, the discharge mechanism, and multivibrator operation. In addition, an occasional reference to previous and current research efforts in external quenching methods is incorporated to indicate trends and progress in radiation counting.

In order to completely present the problems associated with the functioning of an electronic quenching circuit for Geiger counters, it is necessary to relate briefly the basic aspects of mechanism of counter discharge production, and methods of operation. In addition, a brief reference to previous and current research on each phase of operating method is incorporated to indicate trends and any need for further experimenting.

CHAPTER I

THE COUNTER MECHANISM

General

A Geiger counter is a coaxial arrangement of a cylindrical metal tube and a central wire insulated from the tube. This is essentially a capacitance which is charged with a high-voltage power supply. The tube is the cathode and the central wire is the anode. The sealed space inside the tube is the sensitive volume and is filled with gas to provide atoms and molecules to be ionized. The radial electric field which surrounds the wire is intense close to the wire. The field intensity at any point inside the sensitive volume can be easily calculated.

Ionization, Avalanche, and Discharge

Ionizing radiation passing through the gas-filled sensitive volume loses about 32 ev of energy per ion pair formed. The electric field collects the electrons on the anode and attracts the positive ions toward the cathode. If the operating potential is high enough, electrons formed from primary ionizations attain sufficient kinetic energy to cause additional, or secondary, ionizations near the central wire. In addition, both outer and inner shell orbital electrons of the gas atoms are raised into excited states and radiate photons of sufficient energy to create additional ion pairs. The process of ionization is amplified near the central wire, especially as the operating potential is raised to higher and higher levels. This amplification, or rapid increase in the total number of electrons produced, is the familiar Townsend avalanche. If α is the number of ion

CHAPTER I

THEORETICAL [illegible]

General

A Geiger counter is a coaxial arrangement of a cylindrical metal cathode and a central wire [illegible] which is charged with a high-voltage power supply. The [illegible] is the cathode and the central wire is the anode. The [illegible] is the sensitive volume and is filled with gas [illegible] may be ionized. The radial electric field [illegible] the wire [illegible] close to the wire. The field intensity at any point in the sensitive volume can be easily calculated.

Ionization [illegible] Multiplication

Ionizing radiation passing through the gas-filled sensitive volume [illegible] loses about 32 ev of energy per ion pair created. The electric field [illegible] lects the electrons on the anode and attracts the positive ions toward the cathode. If the operating potential is high enough, electrons released in primary ionizations attain sufficient kinetic energy to produce additional, or secondary, ionizations near the central wire. In addition [illegible] outer and inner shell orbital electrons of [illegible] into excited states and [illegible] photons of sufficient energy to create additional ion pairs. The process of ionization [illegible] as the operating potential is raised [illegible]. This amplification [illegible] is produced in the familiar Townsend avalanche [illegible]

pairs formed by an electron per centimeter of drift toward the anode, then

$$dN = \alpha N dx \quad \text{and}$$

$$N = N_o e^{\alpha x}$$ where N is the number

of electrons in the avalanche a distance x from the point of ionization where N_o initial electrons were formed.[4] The pulse formed plotted versus counter voltage in Figure 1. illustrates the specific regions of operation for basic counters. The Geiger-Mueller region is the operational mode having the highest counter voltage and precedes continuous discharge of the counter tube. Actually, the G-M region of operation represents complete discharge of the tube but is not continuous. This is because of the great number of ion pairs from the Townsend avalanche formed so close to the anode, normally within 5 mils, and because the electrons are collected so rapidly, normally within 10^{-11} seconds, that a dense sheath of the positive ions remaining decreases the field intensity near the anode and prevents further ion collection. For all practical purposes, the discharge is quenched and the G-M tube is insensitive to incoming radiation.

When the slowly moving positive ion sheath has reached a position, called the critical radius, the field strength has increased to where another avalanche will occur. The time period from quench to the next avalanche is the natural insensitive time, or dead-time. The counter will thus alternately discharge and recover even though successive avalanches will not be as large because of the reduced field and slow moving ion sheath.

Significant is the fact that the subsequent discharges may be caused by recombination photons, de-excitation photons, photoelectrons from the gas

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[4] *Ibid.*, p.56.

pairs formed by an electron in [illegible]

[illegible] and

[illegible]

of electrons in the avalanche [illegible]

N_0 initial electrons [illegible]

voltage. In Figure [illegible]

counters. The Geiger-Mueller region [illegible]

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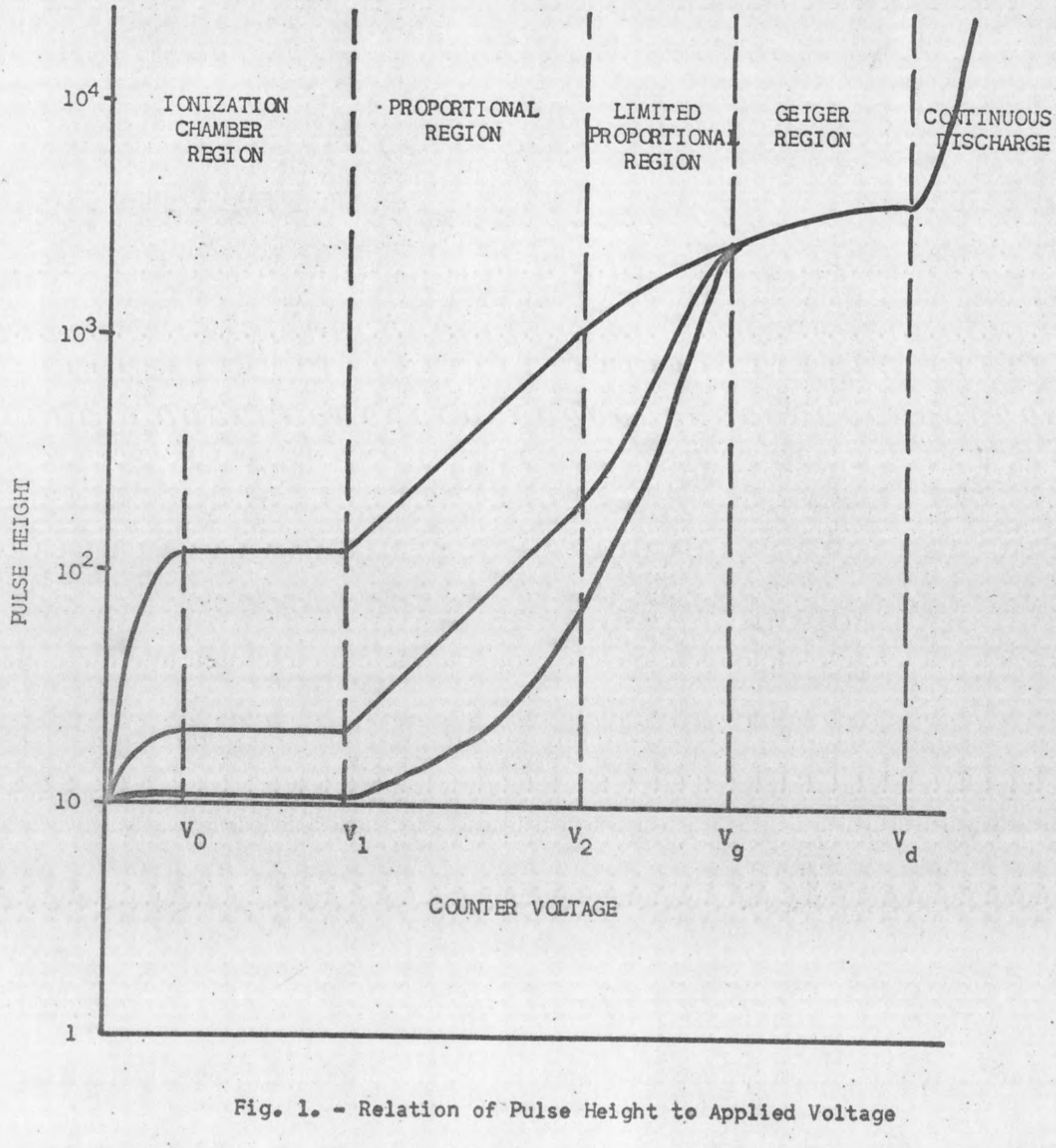

Fig. 1. - Relation of Pulse Height to Applied Voltage

and from the cathode, and by other secondary processes within the tube.

The initial discharge is characterized by the breakdown of the counter and the sudden collection of charge on the anode. This lowers the anode potential suddenly because of the load resistor. The recovery of the wire potential is actually a charging of the detector capacitance through the load resistor, and it is a function of the RC time constant of the fundamental circuit. Normally five RC time constants are allowed for passage of the positive ion sheath from the critical radius to neutralization at the cathode.[5] This time is called the recovery time of the circuit. Both dead-time and recovery time are on the order of 10^{-4} seconds in typical rare-gas, or non-self-quenched G-M counters. The collection of electrons, or flow of charge, appears across the load resistor as a pulse. Pulse size is not a concern in the G-M region because of the completeness of the discharge. All pulses are essentially the same voltage except for those formed during the recovery phase of the preceding pulse. If $V = Q/C$ and $V = Q/C$ since $Q = Ane$, then the pulse height may be expressed as $V = Ane/C$ where A is the amplification factor, n is the number of primary ionizations, e is the electronic charge in Coulombs, and C is the counter tube capacitance.

Reduction of the Dead-Time

During the time the counter is insensitive it is inefficient because ionizing radiation may be present but cannot be detected. Attempts to reduce the dead-time of Geiger counters have been undertaken by many researchers, among them Simpson (1944), Thamer and Voight (1956), and Smuts (1962). The experiments to reduce the dead-time primarily utilized counter tubes which contained a quenching gas of halogen or polyatomic gas in the sensitive vol-

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[5] Field Command, Armed Forces Special Weapons Project, Nucleonics Fundamentals, Pamphlet No. 2 (Sandia Base: AFSWP, 1952), p. II-17.

and from the cathode, and by other secondary [illegible].

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Reduction of the Dead-time

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[4] Field Command, Armed Forces Special Weapons Project, [illegible], Pamphlet No. 2 (Sandia Base, [illegible]), p. [illegible]

ume which would prevent retriggering of the discharge. It is significant to note that non-selfquenched counter tubes, that is, tubes containing only rare gases will produce an endless series of discharges at a rate of about 10^4 discharges per second once it is triggered unless the load resistance is very high. This series of discharges was previously referred to in the discussion of discharge and recovery, and it is the result of retriggering rather than incoming radiation. Quenching must be employed after each ionizing event to prevent retriggering. Since retriggering occurs in non-selfquenched counters, a load resistance as high as 10^8 ohms must be used to prevent this. To do so limits the resolving time of the counter to about 200 μs and when the recording circuitry is considered it may increase to about 250 μs. Using external electronic quenching on commercial halogen and organically quenched tubes, dead-times of 10 μs and less were recorded by Smuts[6] and others.[7] Such an approach to counting accuracy relies on confining the discharge to a small section of the anode, especially in long counters.[8]

The Geiger Counter Tube

The Geiger counter tube used with the quenching circuits of later chapters is made of aluminum alloy with welded end pieces and cylindrical cathode with a 5 mil tungsten wire anode. Counter data are as follows:

Counter cathode diameter:	8 inches
Counter anode length:	54 inches
Starting voltage:	approximately 1530 volts(quenched tube)
Anode beading:	9 sections

This counter tube, filled with commercially pure Argon gas, was to be quench-

[6] Smuts, loc. cit., p. 476.

[7] V. Caini and I.U. Olsson, Arkiv Fysik 22, 225-35 (1962).

[8] B. B. Trott, J. Sci. Inst. 37, 336 (1960).

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note that non-self-quenching counter tubes [illegible]

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ternal electronic quenching [illegible]

tubes, dead-time of [illegible]

an approach to [illegible]

small decision of the [illegible]

<u>The Geiger Counter Tube</u>

The Geiger counter [illegible]

tere is made of [illegible]

with a 5 mil tungsten wire [illegible]

Counter cathode [illegible]

Counter [illegible] length: [illegible]

Starting voltage: [illegible]

Anode [illegible]: [illegible]

This counter tube, [illegible]

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[6] Barday, loc. cit. [illegible]

[7] V. Cohen and [illegible]

[8] [illegible]

ed using the transistor circuit described in Chapter IV. The tube actually used in experimenting was filled with Argon and a polyatomic quenching gas. This tube performed very well providing trigger pulses up to 10 volts and having a lifetime of approximately 10^{10} counts when filled to a pressure of 10 cm. of the quenching mixture. For non-selfquenched operation, trial and error was used to determine a suitable operating potential and filling pressure. The tube was charged to operating potentials up to 2000 volts and filled to pressures up to 10 cm. of pure gas. When filled to 1.5 cm. pressure and operated at 675 volts, a slightly detectable pulse of .02 volts was recorded at the tube anode. This pulse was insufficient to trigger the transistor quenching circuit; hence, the quenched tube was used to provide the trigger.

ed using the transistor circuit discussed in Section IV. [illegible]
used in experiment number [illegible]
This tube contained [illegible]
having a lifetime of [illegible]
10 cm. of the quenching mixture [illegible]
error was used to [illegible]
ture. The tube was flushed [illegible]
ed to pressures up to 10 cm. of [illegible]
and operated at [illegible] volts, [illegible]
recorded at the tube anode. This pulse was [illegible]
transistor quenching circuit [illegible]
the trigger.

CHAPTER II

EXPERIMENTAL VACUUM TUBE CIRCUITS

Quenching of Geiger-Mueller detectors with external circuits has been the subject of much research. The Neher-Pickering[9] and Neher-Harper[10] circuits (Figures 2. and 3.) were among the early external quenching circuits used with counter tubes. The multivibrator circuit of Getting (Figure 4.) was one of the earliest attempts to use switching to accomplish quenching.[11] In 1944, J.A. Simpson attempting to reduce the natural dead-time of Geiger counters utilized a more complex circuit (Figure 5.) and by reversing the anode voltage and collecting the positive ion sheath as well, succeeded in reducing the insensitive time to 20 μs.[12] The circuit developed by Kalab (Figure 6.), while sensitive to a .3 millivolt pulse, provides a rectangular quenching pulse with an amplitude of up to 2000 volts. This circuit has a direct coupling of the quenching pulse to the counter tube to ensure that the change in voltage across the counter is independent of the counting rate.[13] The shortest time interval applicable to Kalab's apparatus, which utilized a univibrator, was 60 μs.

In 1960, Trott, using a flexible monostable multivibrator (Figure 7.), attempted to measure the dead-time reduction in a halogen-quenched X-ray

---

[9] H.V. Neher and W.H. Pickering, Phys. Rev. 53, 316 (1938).

[10] H.V. Neher and W.W. Harper, Phys. Rev. 49, 940 (1936).

[11] I.A. Getting, Phys. Rev. 53, 103 (1938).

[12] J.A. Simpson, loc. cit., p. 45.

[13] B. Kalab, J. Sci. Inst. 38, 253 (1961).

CHAPTER II

[illegible]

Quenching of Geiger-Mueller detectors with external circuits has been the subject of much research. The Neher-Pickering and Neher-Harper circuits (Figures 4 and 5) were among the [illegible] used with counting [illegible] [illegible] quenching circuit (Figure 6) was one of the earliest [illegible]. In 1944, J.A. Simpson attempting to reduce the interval [illegible] of Geiger counters utilized a more complex circuit (Figure [illegible]) and by reversing the anode voltage and collecting the [illegible] succeeded in reducing the insensitive time to 20 µs.[12] The [illegible] developed by [illegible] (Figure 6.), while permitting [illegible] quenching pulse with an amplitude of [illegible]. [illegible] a direct coupling of the quenching pulse to the [illegible] the change in voltage across the [illegible] is [illegible]. The shortest time interval measurable [illegible] which utilized a multivibrator, was 30 µs.

In 1950, [illegible], using a flexible [illegible] (Figure 7), attempted to measure the [illegible]

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[9] H.V. Neher and H.R. Pickering, Phys. Rev. 53, [illegible] ([illegible]).

[10] H.V. Neher and W.W. Harper, Phys. Rev. 49, [illegible] ([illegible]).

[11] I.A. Getting, Phys. Rev. 53, [illegible] ([illegible]).

[12] J.A. Simpson, loc. cit., p. [illegible]

[13] [illegible], J. Sci. Instr. [illegible] ([illegible]).

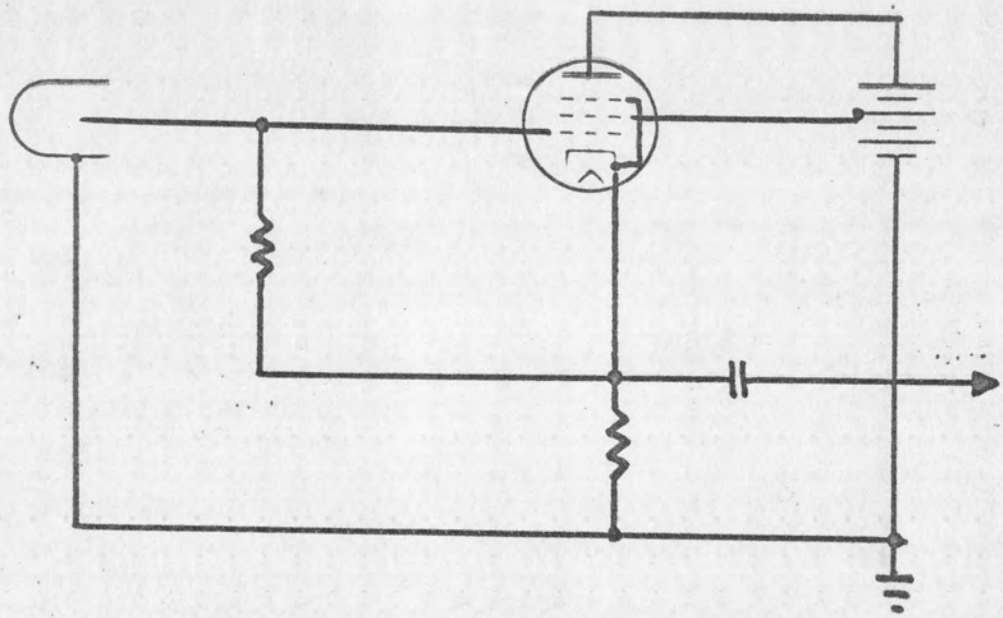


Fig. 2. - Neher-Pickering Quenching Circuit

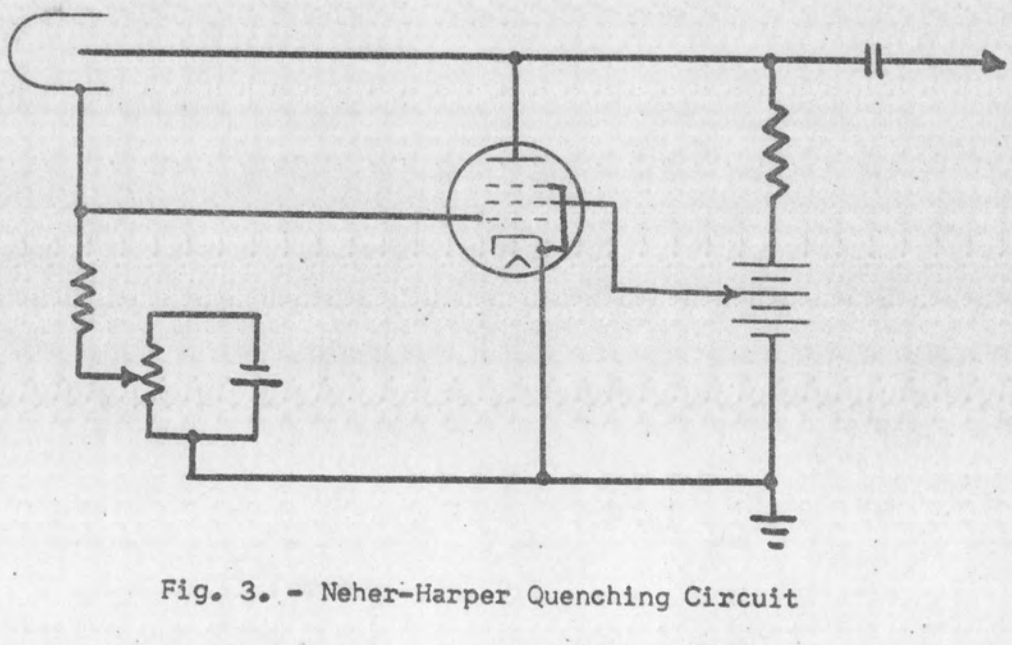


Fig. 3. - Neher-Harper Quenching Circuit

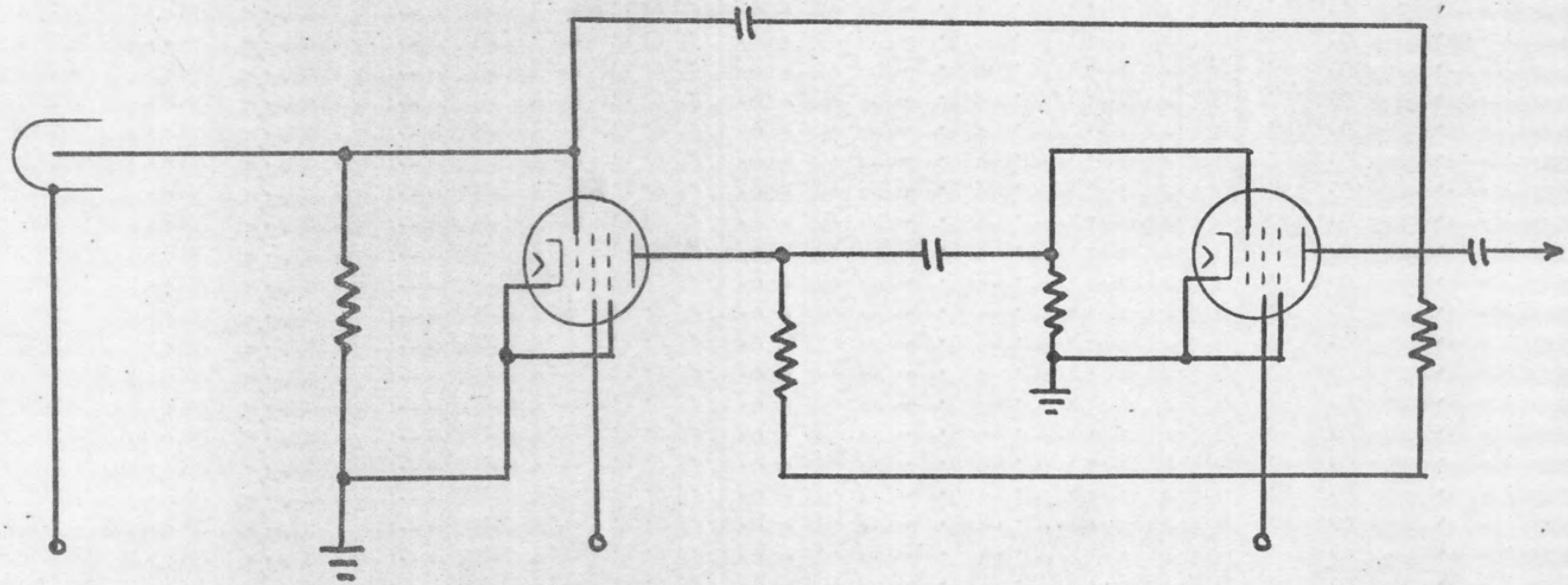


Fig. 4. - Getting Multivibrator Quenching Circuit

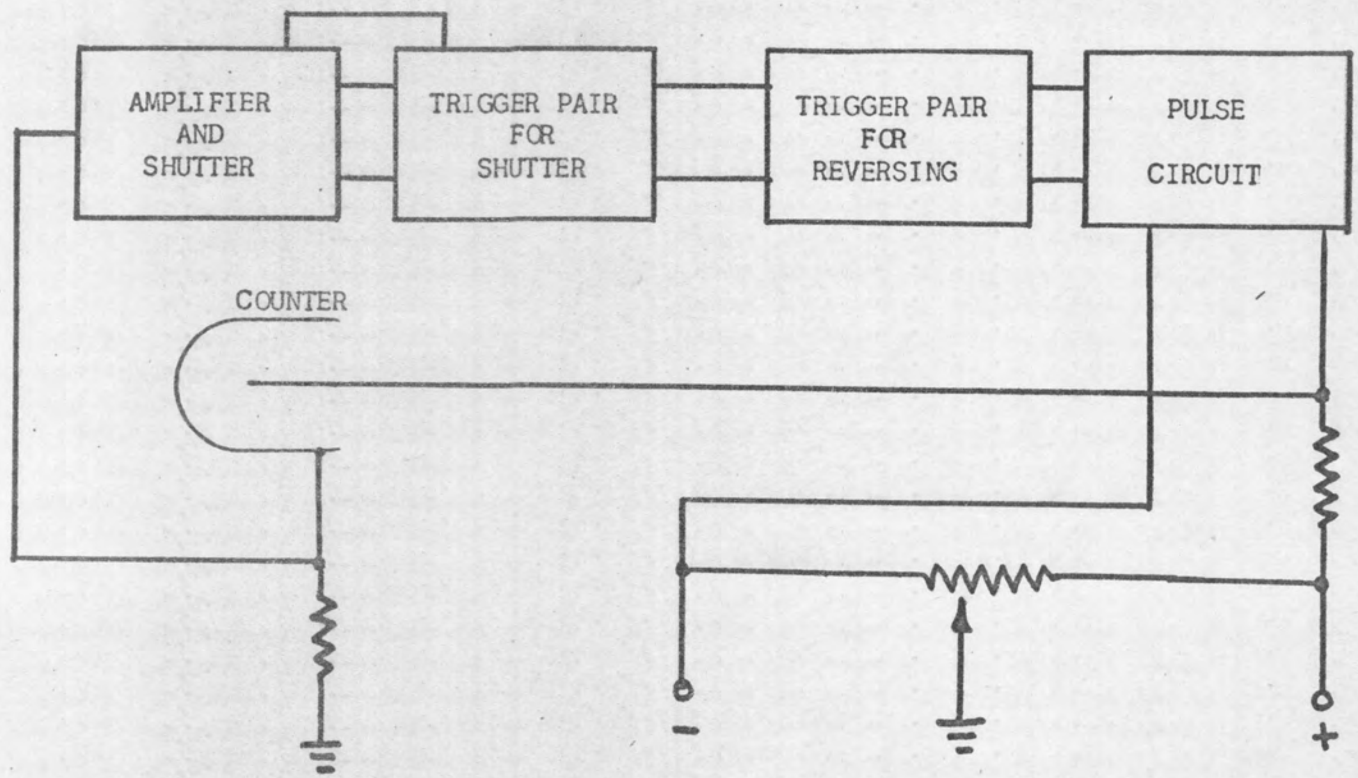


Fig. 5. - Block Diagram of Simpson's Potential-Reversing Circuit

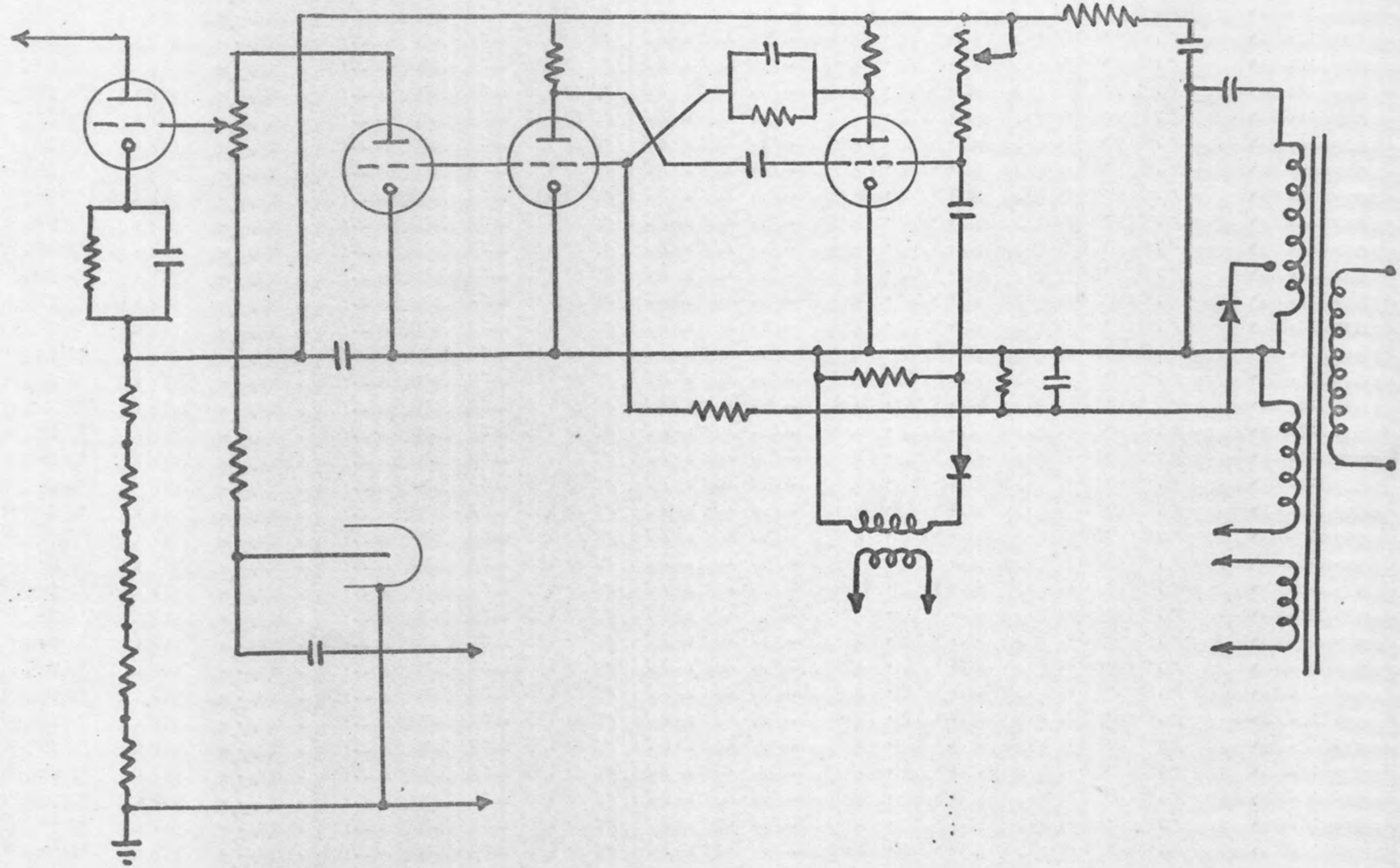
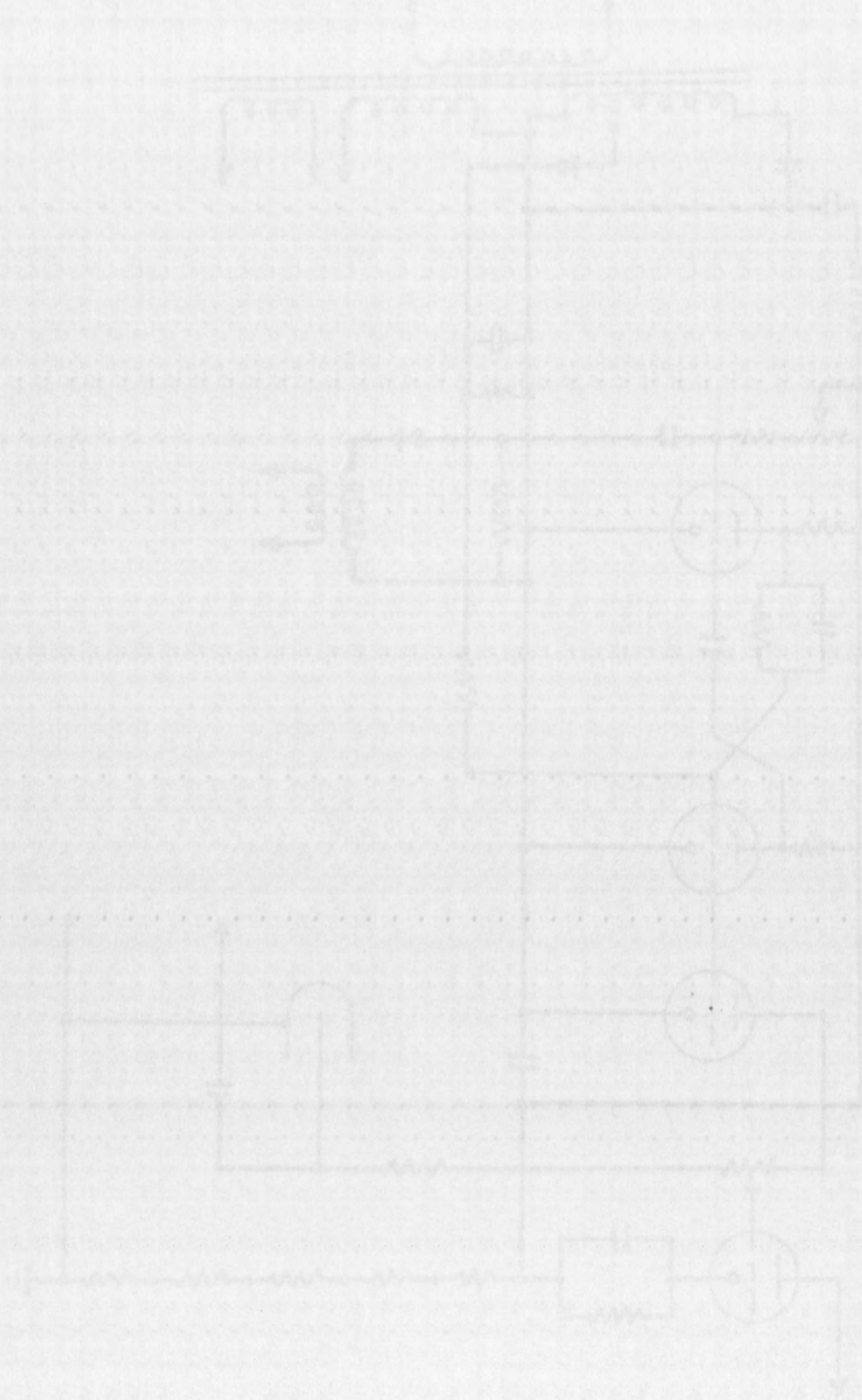


Fig. 6. - Kalab's Quenching Circuit



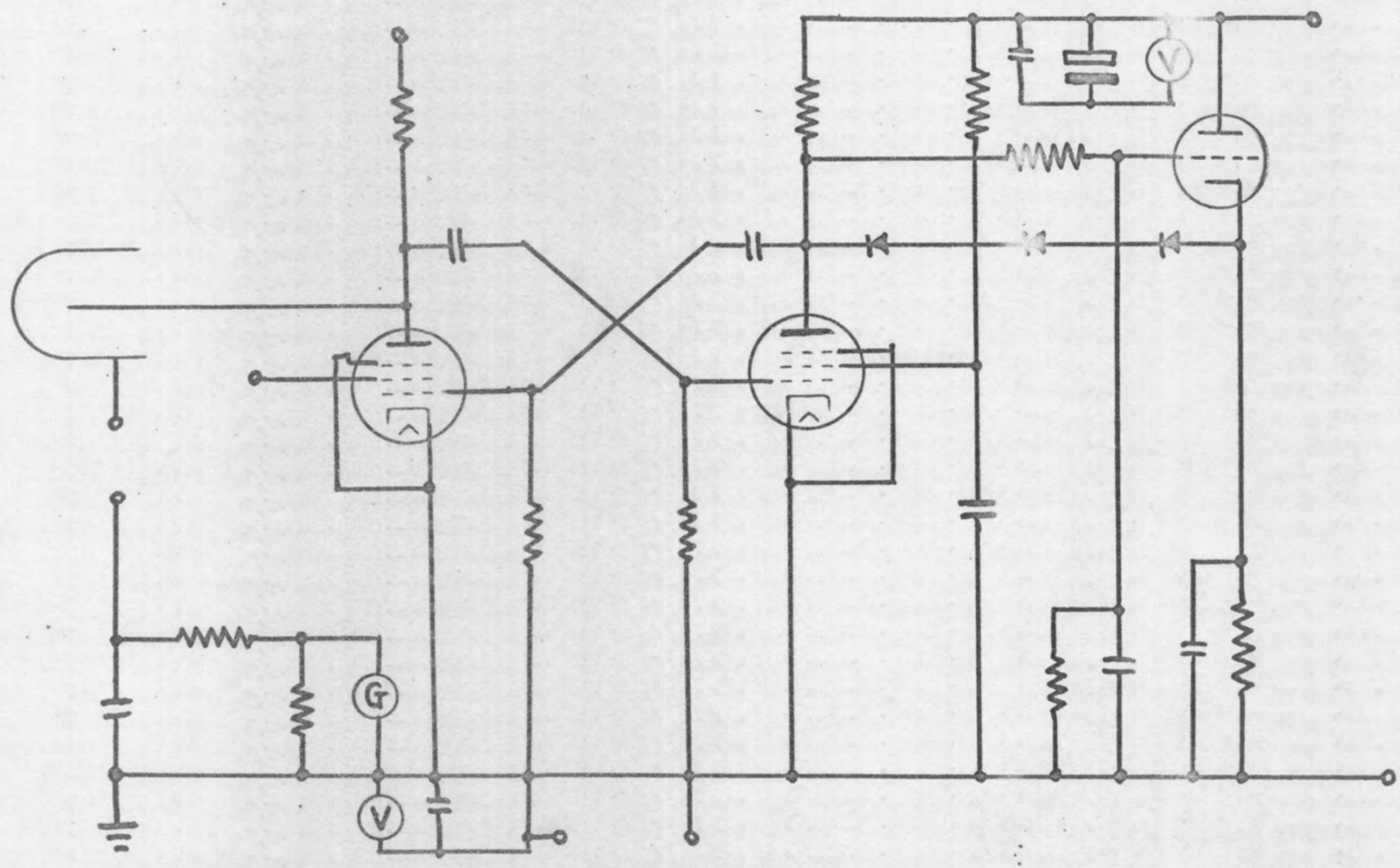


Fig. 7. - Trott's Multivibrator Quenching Circuit

counter.[14] He pointed out the impracticability of ion collection by Simpson's method of reducing the anode voltage several hundred volts below the cathode potential. Trott also indicated the wide use of the principle of localizing the discharge in long cosmic ray counters by providing a fast voltage drop of 300 volts to the anode so that most of the length of the tube became active again within a few microseconds. Other researchers using these methods in conjunction with halogen or organically quenched counters (usually alcohol) obtained dead-times on the order of 30 - 40 μs.[15] Smuts improved Geiger counter dead-time reduction by devising a simple three-vacuum-tube fast quenching circuit (Figure 8.). Smuts also employed a direct coupled monostable multivibrator and achieved dead-times in the range of 10 μs for both halogen and organically quenched counters. As indicated earlier, this circuit had a limited region of useful operation determined by the negative bias on one vacuum tube and the quench voltage.[16] The method of operation of Smuts' circuit is basically similar to the method of operation of the final circuit presented in Chapter IV.

In 1948, Thamer and Voigt developed a quenching circuit to be used with Geiger tubes in counting high-intensity beta and gamma radiation.[17] The method of quenching was to quickly reverse the polarity of the G-M tube after it received the pulse. Using self-quenched tubes with 10% ethyl alcohol vapor and 90% argon, the dead-time was found to be approximately 20 μs with a 12 μs quenching pulse. This circuit used seven vacuum tubes.

---

[14] Trott, loc. cit.

[15] P.J.A. McKeown and A.R. Ubbelohde, J. Sci. Inst. 31, 321 (1954).

[16] Smuts, loc. cit.

[17] U.S., Atomic Energy Commission, Multivibrator Quenching of Geiger-Mueller Tubes, by B.J. Thamer and A.F. Voigt (Oak Ridge, 1948), p.2.

counter.[14] He pointed out [illegible] son's method of reducing the anode [illegible] cathode potential. [illegible] localizing the discharge in [illegible] voltage drop of 300 volts [illegible] tube became active again within a [illegible] these methods in combination with (a) [illegible] (usually alcohol) [illegible] improved Geiger counter dead time [illegible] vacuum-tube fast quenching circuits [illegible] rect coupled [illegible] of 10 μs for both [illegible] earlier, this circuit had [illegible] by the negative bias on the vacuum tube [illegible].[16] [illegible] od of operation of [illegible] operation of the final circuit [illegible] Chapter IV.

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[14] Trost, loc. cit.

[15] P. J. A. McKeown and [illegible] (19[illegible]).

[16] [illegible], loc. cit.

[17] U.S. Atomic Energy Commission, [illegible] Mueller Tubes, by D.H. [illegible]

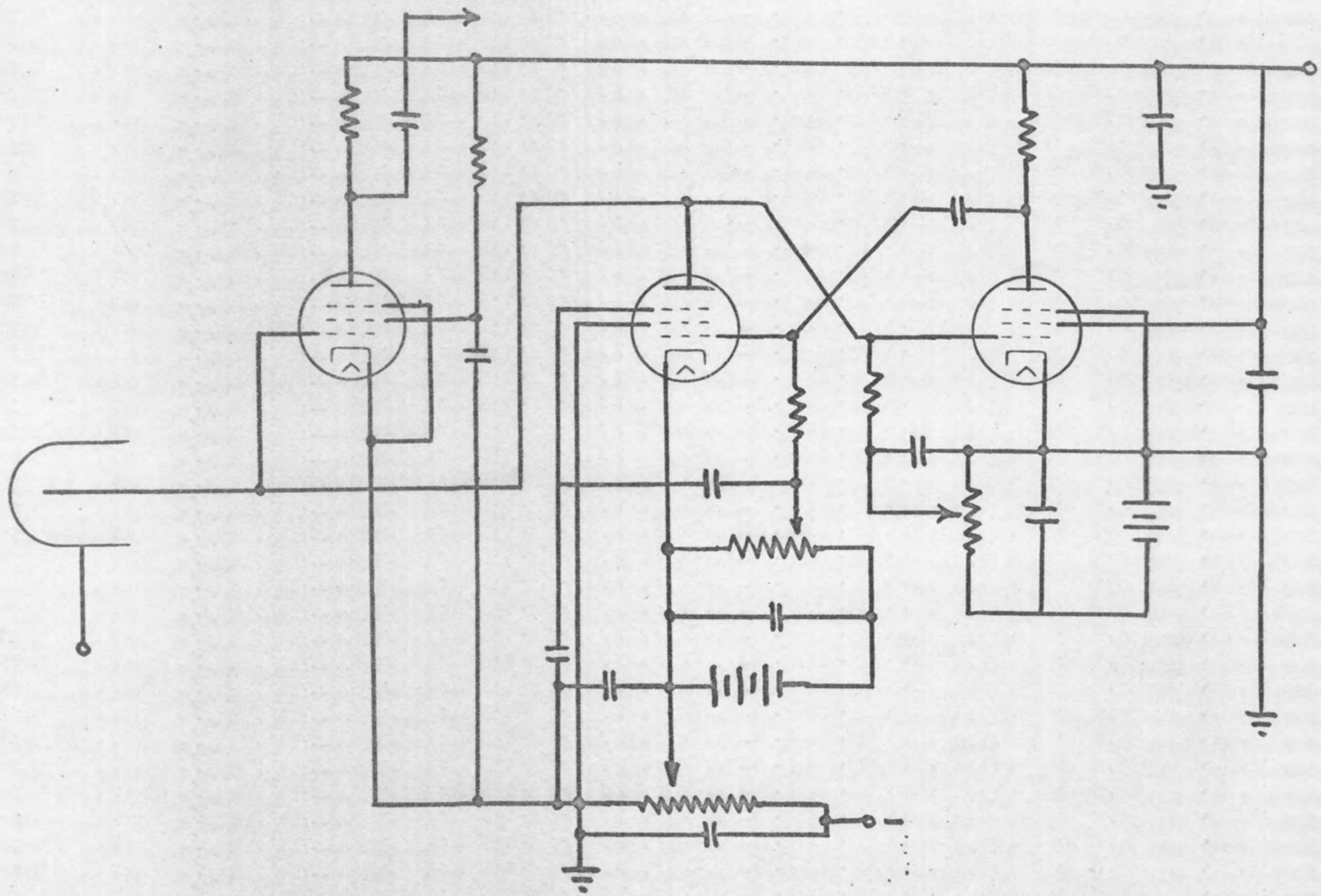
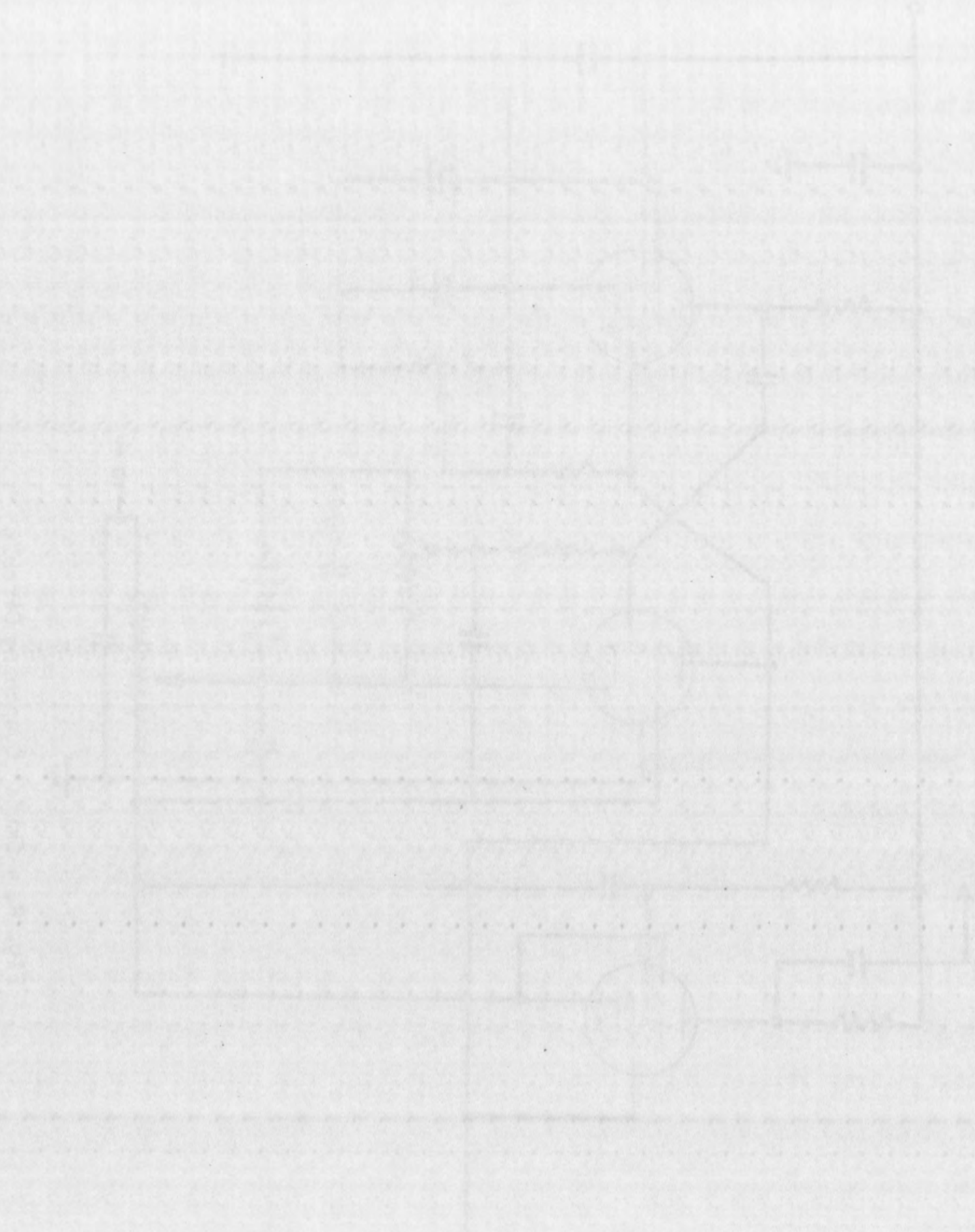


Fig. 8, - Smuts' Quenching Circuit



CHAPTER III

EXPERIMENTAL TRANSISTOR CIRCUITS

While vacuum tube quenching circuits generally regulated the voltage pulsed to the counter tube using triggered quench tubes or similar components, the use of a transistor circuit to quench the courter was considered. The transistor circuit would have to detect, shape, and amplify the counter pulse into a quench pulse. The use of a thyratron tube triggered by a transistor circuit was rejected because of the slow response time of the thyratrons. It was decided that a fast pulse transformer, such as the Microtran M8050 or the Thorardson TR-36, pulsed by a transistor could provide a quench pulse.

Initially the counter voltage was to be dropped below the Geiger threshhold for approximately 200 μs. This would provide an insensitive time comparable to a halogen or organically quenched counter tube. This approach paralleled localizing the discharge by lowering the anode voltage but would not result in faster operation since the longer pulse prevented retriggering. Circuits were bread-boarded, using both one and two transistors, that produced output pulses of the desired voltage and width. Later, the attempt was made to completely reverse the anode potential to collect not only the avalanche electrons but also the positive ions. The initial circuits were designed and tested using only bench equipment, i.e., power supply, pulse generator, and oscilloscope. Impedance matching of the early circuits to the counter tube was not attempted but later circuits were integrated into the counter tube circuitry. For the initial circuits no data were taken since all the inputs and outputs were artificial and in no way considered equivalent to the actual counter tube.

CHAPTER III

[illegible]

While vacuum tube quenching circuits [illegible] pulses to the counter tube were [illegible] the use of a transistor circuit [illegible] transistor circuits would have [illegible] into a quench pulse. The use of a [illegible] circuit was rejected because of [illegible] It was decided that a [illegible] the Thordarson TR 35, [illegible]

Initially the counter [illegible] threshold for approximately 200 [illegible] time comparable to a [illegible] approach permitted localizing [illegible] would not result in [illegible] gering. Circuits were [illegible] produced output pulses of the desired [illegible] was made to completely prevent the [illegible] avalanche electrons but also the [illegible] signed and tested using only [illegible] stop, and oscilloscope. [illegible] or tube was not attempted [illegible] tube circuitry. For the initial [illegible] puts and outputs were artificial [illegible] actual counter tube.

One-Transistor Circuits

Two circuits using a single transistor were tested. The initial circuit (Figure 9.) was only bench tested but produced an output pulse to the oscilloscope of 200 volts amplitude and 200μs width. If this circuit had been coupled to the counter tube it would not have lowered the anode voltage much below the Geiger threshhold. Pulse input variation was from -200 mv to -10 mv and up to 2 Kc frequency. Above this frequency the circuit indicated an increase in the d.c. operating level. This condition was later found to be characteristic of this type circuit coupling.

A later one-transistor circuit (Figure 10.) was incorporated into the counter tube input and output circuitry. This circuit was patterned after the basic circuit of Schwartz.[18] With the variable resistor, the circuit operation could be changed to suit the requirements of a triggered blocking oscillator. The large output from this type circuit in d.c. to d.c. converters is due to the free running condition and when triggered, the loading tends to reduce the output considerably. Nevertheless, this circuit failed to provide a solution because it would either free run with an output of large amplitude or would not trigger at all.

Two-Transistor Circuits

The monostable multivibrator was the basic experimental two-transistor circuit used. The wide use of multivibrators in vacuum tube quenching circuits by many previous researchers indicated it to be the most likely circuit for transistorization. The functioning of a multivibrator as a quenching circuit is described in the last section of this chapter. Many two-transistor circuits were bread-boarded and tested. The design of two-transistor monostable

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[18] S. Schwartz (ed.), Selected Semiconductor Circuits Handbook (John Wiley and Sons, Inc., New York, 1960), p. 6-21.

[illegible] Circuit

The [illegible] using a single [illegible] (Figure 5.) was only [illegible] scope of 300 volts amplitude [illegible] plied to the counter tube [illegible] low the Geiger threshold. [illegible] and up to [illegible] frequency [illegible] crease in [illegible] characteristic of this type [illegible]

A [illegible] (Figure [illegible]) was [illegible] counter tube input and output circuits. [illegible] the basic circuit of Schmitt.[10] [illegible] operation could be [illegible] oscillator. The large output [illegible] and is due to the [illegible] to reduce the output considerably [illegible] vide a solution because it would [illegible] plitude or would not trigger at all.

Pre-Pulse [illegible]

The [illegible] circuit [illegible] The [illegible] by many previous [illegible] transistorization. The [illegible] is described in the last section of [illegible] cuits were breadboarded and tested. [illegible]

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[10] [illegible] (ed.), [illegible], Wiley and Sons, Inc., New York, [illegible]

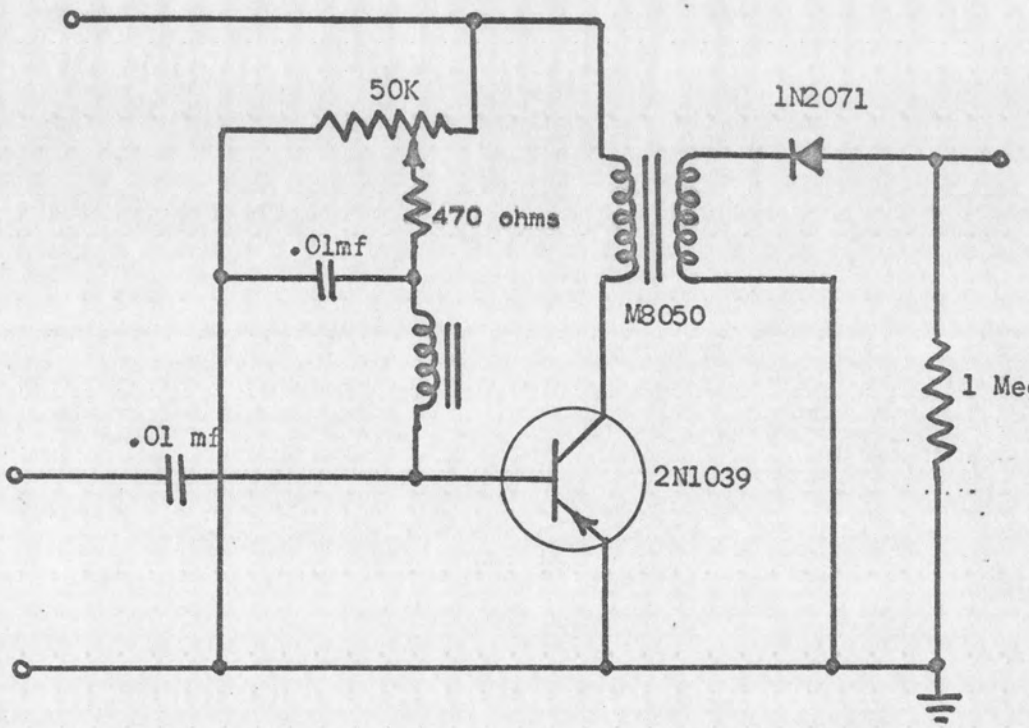

Fig. 9. - One-Transistor Circuit A

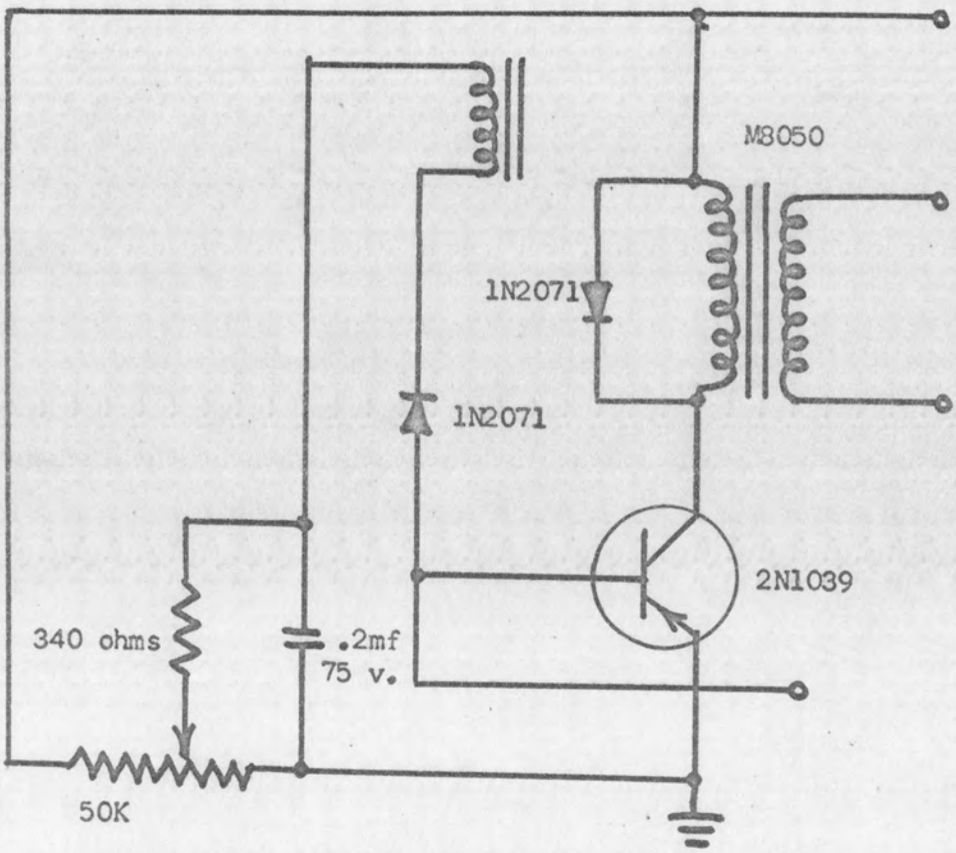

Fig. 10. - One-Transistor Circuit B

multivibrators is well-known and is described in many publications.[19,20,21]

Initially, without the counter tube and related circuitry, complications were introduced which could not be avoided using the pulse generator as an input and the oscilloscope in the output. As nearly as possible the output of the pulse generator was modified with various impedances to appear to the multivibrator input as a Geiger tube, but no appreciable difference in the circuit operation was noted.

More than seventy circuits and circuit variations were built and tested using the above publications as well as other design references,[22,23] however, only three representative circuits will be described in this section. These circuits (Figures 11.,12., and 13.) were designed, assembled, and tested without using the counter tube circuitry. Several of the early circuits were prepared to lower the anode voltage by only several hundred volts to take advantage of the beaded anode in localizing the discharge. The circuit in Figure 11. would be suitable for this purpose if adapted to the counter tube circuitry, however, no advantage in counting speed is gained over selfquenching tubes because of the 200 μs pulse width. In his analysis of dead-time reduction, Trott[24] indicated that dead times of 30 μs acquired by other researchers , namely A.L. Hodson, were shown to be due to localization of the

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[19] M.V. Joyce and K.K. Clarke, Transistor Circuit Analysis (Addison-Wesley Publishing Co.,Inc., Reading, Mass., 1961), p. 358.

[20] R.F. Shea (ed.), Transistor Circuit Engineering (John Wiley and Sons, Inc.,New York, 1957), p.347.

[21] R.B. Hurley, Transistor Logic Circuits (John Wiley and Sons, Inc., New York, 1961), p.323.

[22] G.L. Jackson, "Transistor Bias Circuit Design," Electronics World, November 1961, p.42.

[23] H.R. Lowry and Others, General Electric Transistor Manual ,Fifth Edition, General Electric Company, Liverpool, New York, 1960. p.123.

[24] Trott, loc. cit.

multivibrator is well known and [illegible]

Initially, without the [illegible] were [illegible] which could not [illegible] and the [illegible] in the [illegible] the pulse generator was modified [illegible] multivibrator input on a [illegible] circuit operation was [illegible].

More than seventy circuits [illegible] using the above [illegible] as well as [illegible][22,23] [illegible] only three representative circuits [illegible] circuits (Figures 11, 12, and 13) [illegible] out using the [illegible] proved to lower the [illegible] tage of the [illegible] and 11 would be [illegible] circuitry, however, no [illegible] the [illegible] reduction, Trott[24] indicated that [illegible] operators, namely A.L. [illegible]

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[19] M.V. Joyce and K.K. Clarke, Transistor Circuit Analysis (Addison-Wesley Publishing Co., Inc., Reading, [illegible]

[20] R.F. Shea (ed.) Transistor Circuit Engineering ([illegible] Inc., New York, 1957), p. [illegible]

[21] R.B. Hurley, Transistor Logic Circuits ([illegible] New York, 1961), p. 343

[22] C.L. [illegible], Transistor High Circuit Design, [illegible] November 1961, p. 42.

[23] R.F. Lowry and [illegible] General Electric [illegible] Edition, General Electric [illegible]

[24] Trott, loc. cit.

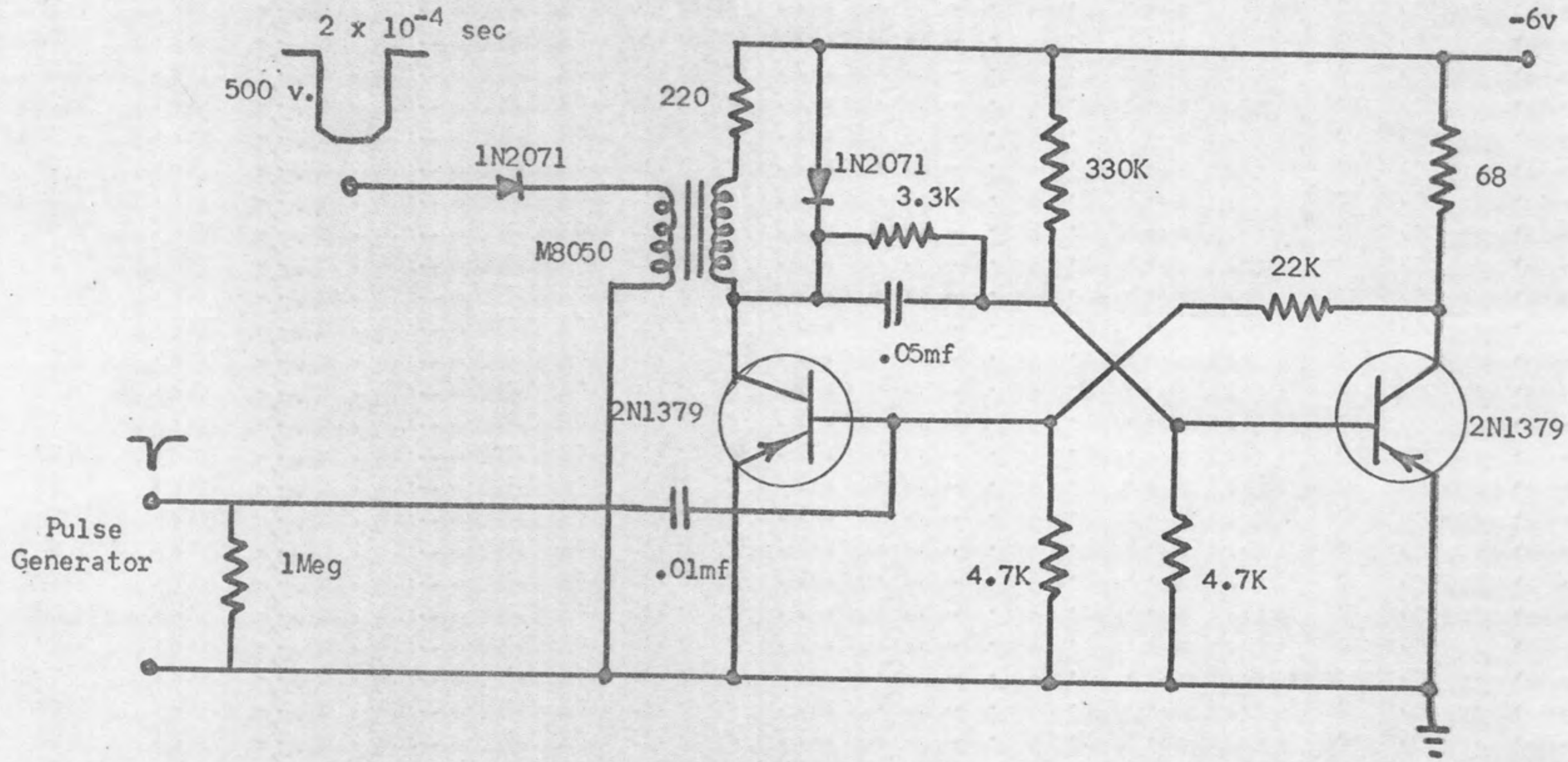

Fig. 11. - Two-Transistor Circuit A

discharge to a small fraction of the full length of the tube in long cosmic ray counters. The distinct difference in the expected dead-time reduction in different types of counters was stated as follows:

> Thus, two versions of the system arose:
> (a) in short Geiger counters, the ion collection principle was employed. Simpson reduced the anode voltage to several hundred volts below the cathode potential, hoping to collect all the positive ions,. . . .
> (b) in long cosmic-ray counters, a small voltage drop (e.g. 300 volts) was used to localize the discharge, so that most of the length of the tube became active as soon as the voltage pulse ceased (after a few microseconds). This principle has been used widely.
> All of the above work was done with counters using an organic quenching gas (usually alcohol).[25]

The early potential-reversing circuits (Figures 12. and 13.) generated pulse amplitudes up to 1500 volts but the calculated circuit time constants could not be realized. The circuit factors responsible for the slow response time of 200 μs were assumed to be "ringing" in the collector circuit, stray capacitance from bread-board leads, leakage currents, and other factors. Circuit "C", Figure 13., produced an 1100 volt pulse with 75% recovery time within 50 μs but the primary "ringing" extended complete recovery to 110 μs. The fast fall and rise times of this pulse would have made this a suitable circuit with elimination of the "tail."

Since the transistorized quenching circuit is to be used with counters having monatomic or diatomic gases, the expectations of Trott did not apply. First, the monatomic gas would lower the operating potential such that localization of the discharge is not necessary since a circuit could effectively reverse the anode voltage completely. Second, glass beads on the center wire already accomplished partial localization. Third, to provide infinite lifetime, the experimental counter used no quench gas while Trott's expectations were based on quenched tubes.

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[25] Ibid.

discharge to a small fraction of the [illegible]

ray counter. The distinct [illegible]

different types of [illegible]

These [illegible] were:

(a) In [illegible] counter [illegible]
plowed. [illegible]
low the cathode potential [illegible]
(b) In [illegible]
[illegible]
of the tube [illegible]
few microseconds) [illegible]

All of the above [illegible]
quenching gas (usually alcohol).

The early potential pre-amplifier [illegible] (Figures 1_ and 1_) [illegible]

pulse amplitudes [illegible] and [illegible]

could not be [illegible]

time of 200 μs [illegible]

capacitance [illegible]

unit "C". Figure [illegible]

in 50 μs but the [illegible]

tent tail and rise [illegible]

with elimination of the [illegible]

Since the [illegible]

having [illegible]

First, the [illegible]

tration of the discharge [illegible]

reverse the [illegible]

already [illegible]

time, the [illegible]

wave [illegible] quenched [illegible]

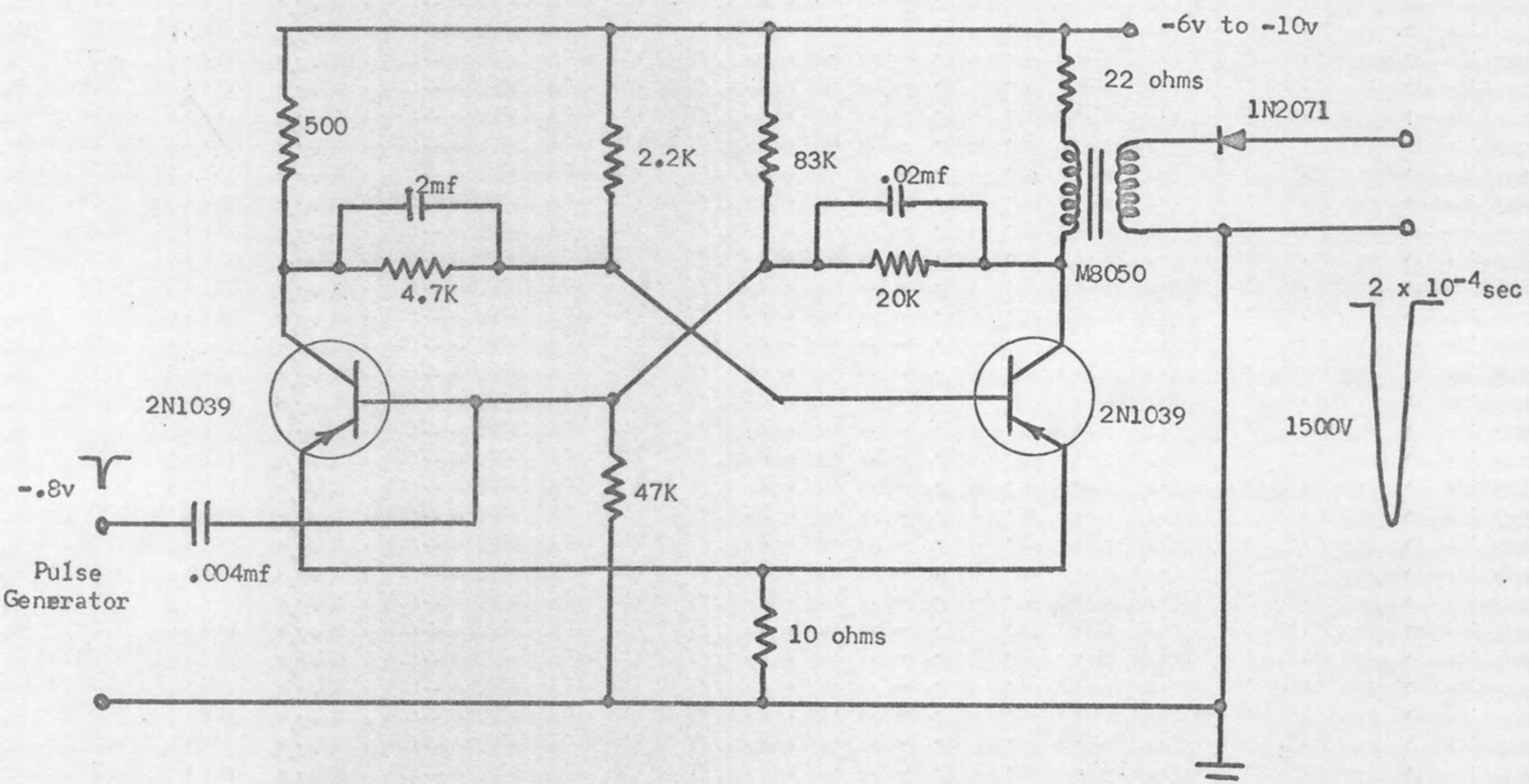

Fig. 12. - Two-Transistor Circuit B

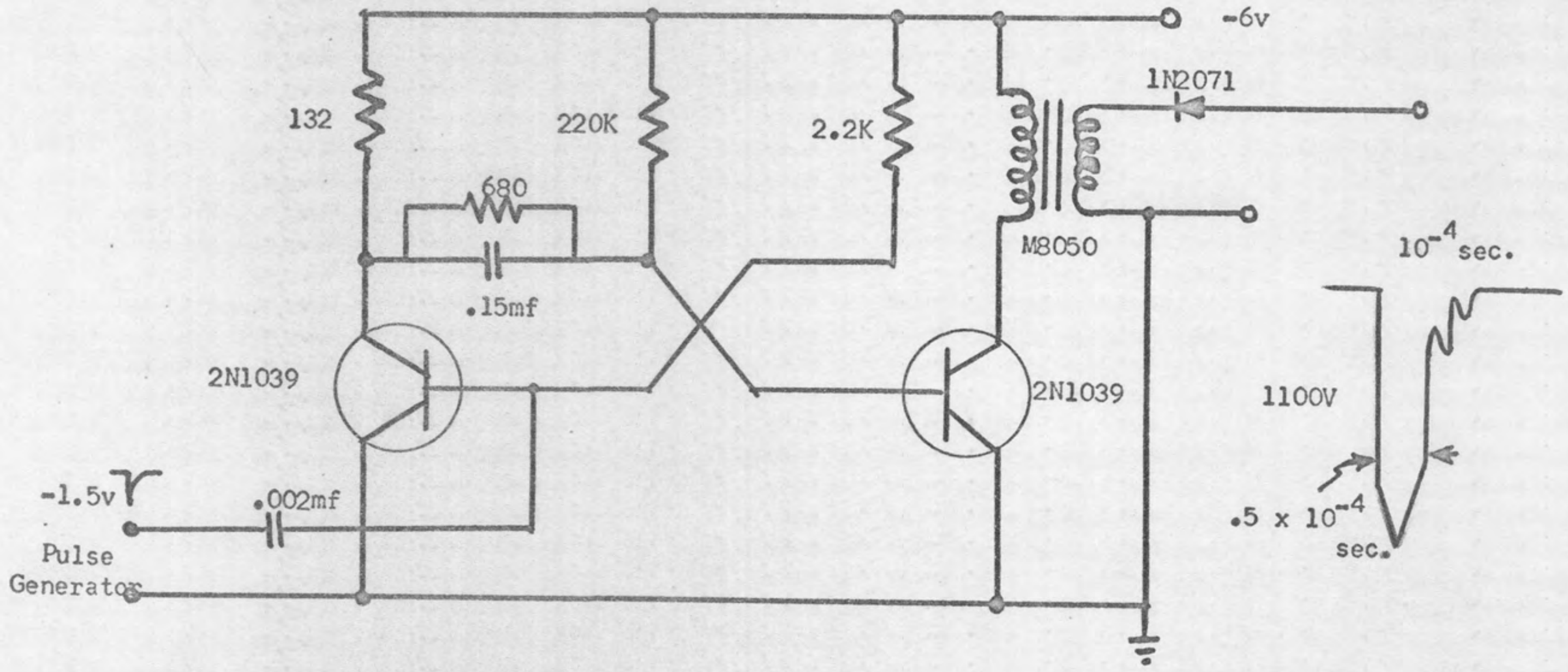

Fig. 13. - Two-Transistor Circuit C

The vacuum tube circuit developed by Trott was a monostable multivibrator which produced a quenching pulse of 3 - 6 μs with effective dead time of 130 μs and pulse amplitude of 300 volts.

Other Circuits

Several other circuits were breadboarded and incorporated into the actual cosmic ray counter circuitry. These were two and three-transistor circuits which approached the minimum requirements but could not completely provide the potential reversal. These circuits are shown in Figures 14. and 15. Techniques of biasing and circuit design were adapted from another design reference[26] because of circuit similarity and ease of calculations. The first attempt to place the transformer primary in the collector of the "off" transistor is shown in Figure 14. This approach reduced current requirements and after proper biasing provided a moderately stable triggered circuit. The major disadvantage was the large pulse width of 200 μs caused primarily by the recharging of the 470 μμf capacitor through the primary windings. With the other primary windings connected to the circuit, the pulse increased to nearly 500 volts with a corresponding increase in pulse width. This approach should be investigated further because of the rapid fall of the quenching pulse. A first attempt to use an emitter follower as the input transistor is shown in Figure 15. The output of this circuit when not connected to the counter tube is a good 650 - 700 volt, 75 μs pulse, but when connected to the tube provided only a 75 volt quench pulse. The 2.2 megohm resistors, the 6 volt bias battery and the diode circuit prevented excessive voltages from reaching the emitter-follower. The diode ceases to conduct after the negative pulse is received. These circuits were important in the development of the final circuits described in Chapter IV.

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[26] J. Millman and H. Taub, Pulse and Digital Circuits (McGraw-Hill Book Co., Inc., New York, 1956), p. 600.

The vacuum tube thyratron [illegible] within produced a quenching pulse [illegible] with a rise time of [illegible] μs and pulse amplitude of 150 volts.

Other Circuits

Several other circuits were [illegible] to quench the avalanche counter [illegible]. These were [illegible] which approached the [illegible] potential reversal. These circuits [illegible] diagram of [illegible] because of circuit [illegible] attempt to place the transformer [illegible] shown in Figure 14. [illegible] after proper [illegible]. The major disadvantage was the large pulse width of [illegible] reconnecting of the [illegible] other primary [illegible] 500 volts with a [illegible] be investigated further because [illegible] First attempt to use [illegible] Figure 15. The output of this circuit [illegible] is a good 650 - 700 volt, [illegible] μs pulse [illegible] only a 75 volt quench pulse. The [illegible] and the diode clamp [illegible] follower. The diode [illegible] These circuits were important in the development [illegible] described in Chapter IV.

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[26] J. Millman and H. Taub, Pulse and Digital Circuits (McGraw-Hill Book Co., Inc., New York, 1956), [illegible].

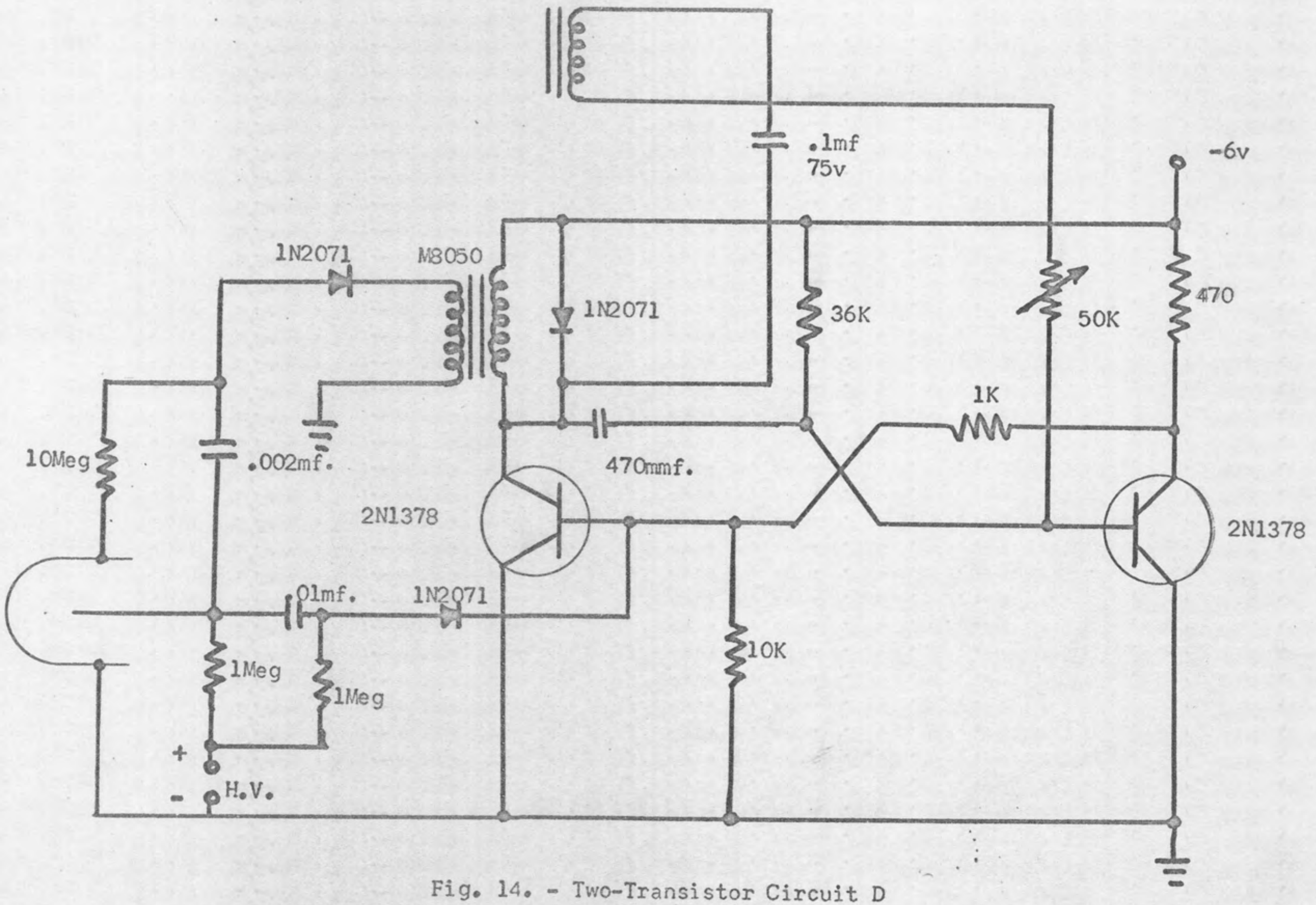

Fig. 14. - Two-Transistor Circuit D

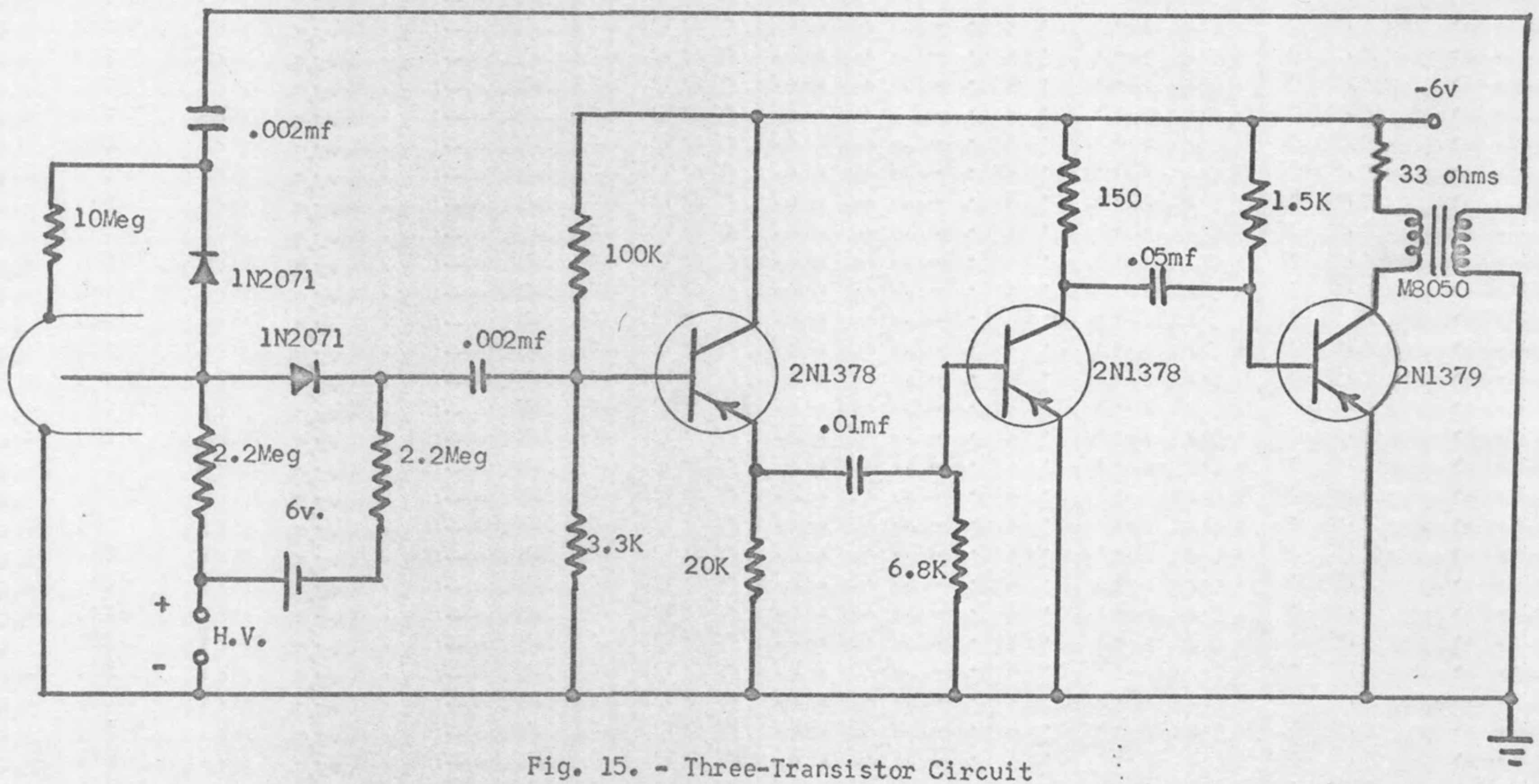

Fig. 15. - Three-Transistor Circuit

Multivibrators

Multivibrators are generally characterized by three basic types according to their mode of operation, i.e., astable or free-running, bistable or on-off triggered, and monostable or on-triggered only. The control required for operation of a quenching circuit is best found in the monostable mode of operation. Either negative or positive output pulses, rectangular and uniform in size are available at the collectors. In addition, use of an emitter re-sistor provides a uniform low impedance output useful for triggering a counting circuit.

A basic monostable multivibrator (Figure 16) operates with one of the transistors in the cut-off region and the other transistor in the saturation region. When the circuit is untriggered, i.e., in the quiescent condition, it is in a stable region of operation. Triggering with an external pulse moves the operating point from one stable region to another stable region where it remains for a time determined by the circuit, then returns to the original stable region. This mode of operation is referred to as "flip-flip", since triggering flips the circuit and after a design time, flips back to its original state.[27]

In the circuit of Figure 16., transistor Q1 is in cut-off and Q2 is in saturation. Q2 is forward biased by battery Vcc. Because Q2 is in saturation the collector voltage is essentially zero. Q1 is reverse biased by battery Vbb and Q1 collector is effectively at voltage Vcc. Capacitor C1 is charged to voltage Vcc through RL1 and the base-emitter junction of Q2. The collector of Q1 becomes more positive and decreases the forward bias on Q2. This causes the base current and collector current of Q2 to decrease and increases the negative potential of the base of Q1 through R2. This regeneration drives

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[27] U.S., Department of the Army, Basic Theory and Application of Transistors, Technical Manual TM 11-690, 1959, p.200.

[illegible] Multivibrators

Multivibrators are [illegible] classified [illegible] accord-
ing to their mode of operation, i.e., astable or free-running, bistable or
on-off triggered, and monostable [illegible]
for operation of a [illegible] circuit [illegible]
operation. Either [illegible] and [illegible]
in size are available for the [illegible]
circuit provides a [illegible]
ing circuits.

A basic monostable multivibrator (Figure [illegible]) [illegible] of two
transistors in the [illegible] region [illegible]
region. When the circuit is [illegible]
it is in a stable region of operation. Triggering with an external pulse
moves the operating point from one stable region to [illegible] region
where it remains for a time determined by [illegible] and then returns to the
original stable region. [illegible]
[illegible] triggering [illegible]
original state.[27]

In the circuit of Figure [illegible], transistor [illegible]
saturation. Q2 is forward biased by [illegible]
the collector voltage is [illegible]
Vcb and Q1 collector [illegible] voltage [illegible]
to voltage Vcc through R1, [illegible]
of Q1 becomes more positive [illegible]
the base current and collector current of Q2 [illegible]
negative potential of the base of Q1 [illegible]

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[27] E. B. [illegible] Technical [illegible]

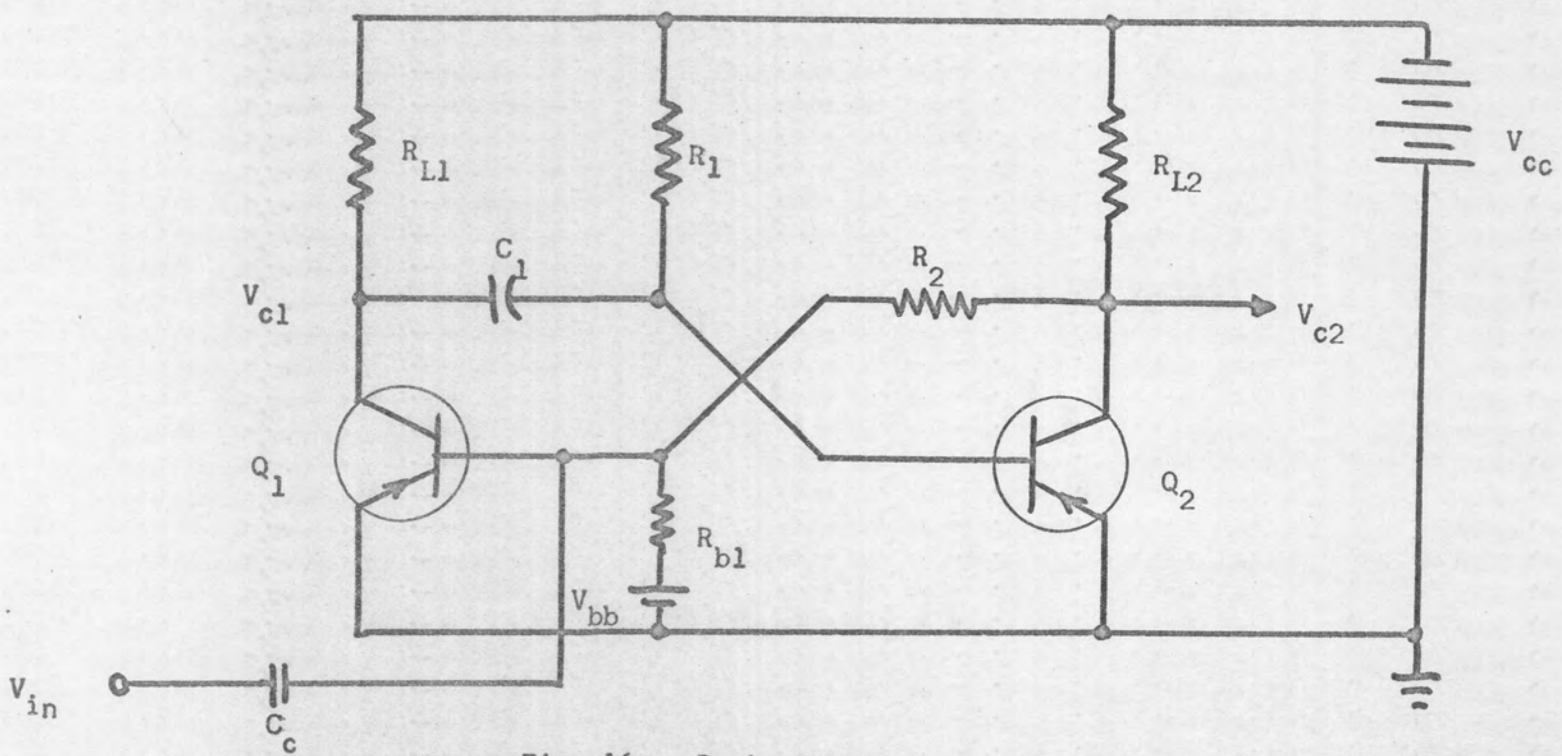
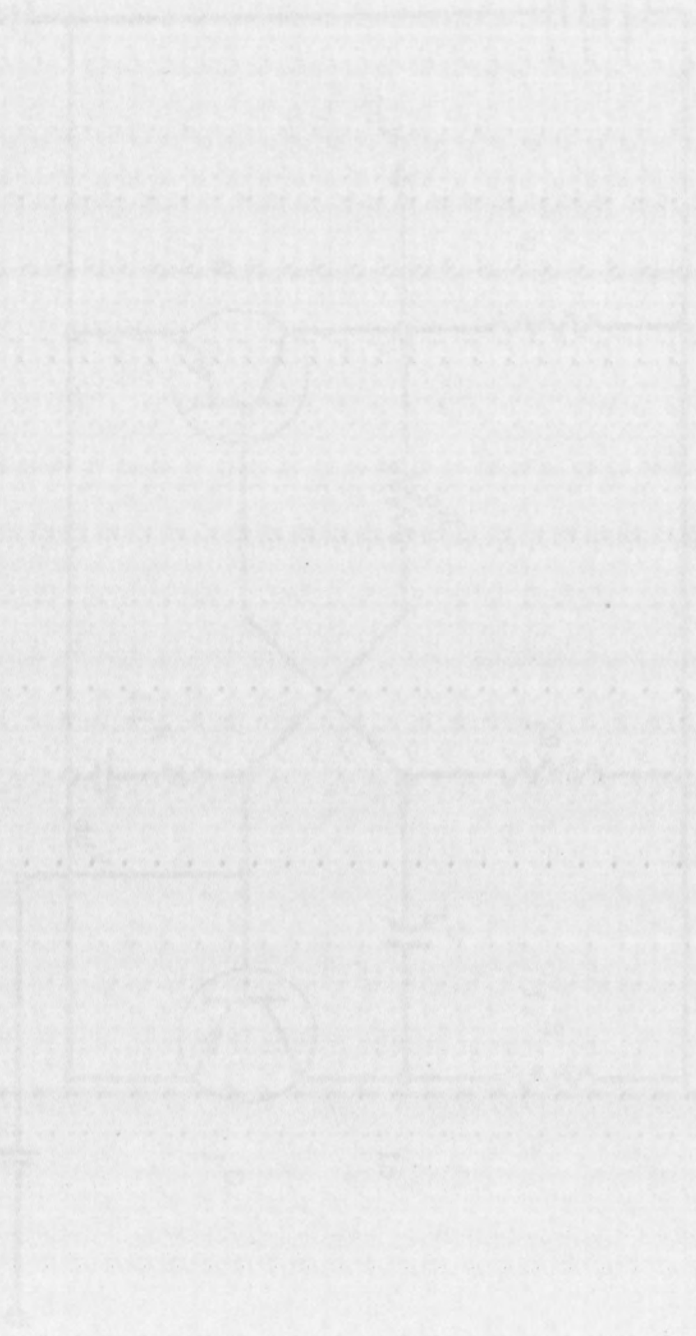


Fig. 16. - Basic Multivibrator Circuit



transistor Q1 into saturation and transistor Q2 into cut-off. The wave forms (Figure 17.) graphically show these rapid changes. Capacitor C1 discharges through the low resistance of Q1 and R1 and makes the base of Q2 less positive. This condition results in Q2 again conducting. The collector of Q2 increases positively and this drives Q1 into cut-off. Q2 is in saturation and Q1 is in cut-off as in the original condition. This condition is maintained until another pulse triggers the circuit.

In order for the circuit to provide the desired output pulse width, the RC time constant, or discharge time of C1 through R1, is important. Not only will the time constant determine the resolving time for the circuit, but together with the insensitive time of the counter tube will also determine the efficiency of counting.

At high counting rates, even when the events are purely random in nature, there will be many occurrences when the time interval between two successive pulses or events will be less than the tube recovery time or insensitive time. This loss of counts at high rate is expressed in an equation used by Simpson[28] in 1944:

$N_a = N_t/(1 + N_t\alpha)$, where

N_a = observed counting rate,

N_t = true counting rate, and

α = insensitive time

Thus, the circuit resolving time and the tube recovery time, both functions of the RC time constant, are significant to efficient counting.

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[28] Simpson, loc. cit., p.39.

transistor Q1 into saturation and [illegible] (Figure 17.) practically [illegible] through the low resistance of [illegible] This condition remains [illegible] positively and this drives Q1 into cut-off [illegible] cut-off as in the original condition. [illegible] other pulse triggers the circuit.

In order for the circuit to provide the [illegible] RC time constant, or discharge time [illegible] will the time constant determine the resolving time of the circuit [illegible] gether with the insensitive time [illegible] efficiency of counting.

At high counting rates [illegible] there will be many occurrences that the time interval between two successive pulses or events will be less than the [illegible] This loss of counts at high rates [illegible][28] in 1944:

$$N_o = N_t/(1 + N_t\tau) \text{ where}$$

N_o = observed counting rate

N_t = true counting rate, and

τ = insensitive time

Thus, the circuit resolving time and the [illegible] tions of the RC time constant are significant [illegible]

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[28] Glasstone, [illegible]

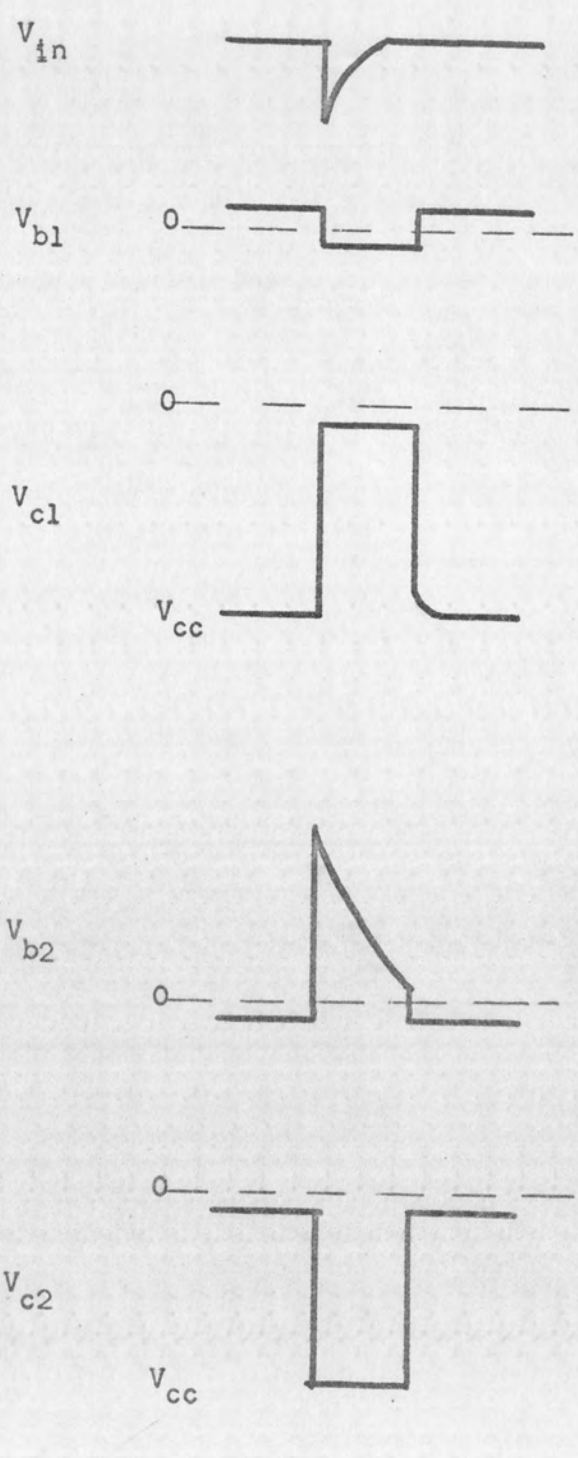

Fig. 17. - Multivibrator Waveforms

CHAPTER IV

THE FINAL CIRCUIT

Design

The lack of published data on transistor quenching circuits required a basic design approach. The requirements of the circuit were generally established as follows:

Input trigger minimum:	-.5 volts
Supply voltage:	- 6 volts
Output pulse:	600 - 800 volts
Output pulse width:	50 µs
Transistors:	2N1378, 2N1379, 2N1038, 2N1039 or similar.

The single-shot multivibrator of Hurley[29] was selected for simplicity. After some modification, this circuit (Figure 18.) proved to be adequate. Though other circuits were tested, the results failed to satisfy one or more of the requirements.

Within the design parameters, all circuits tested were designed using basic formulae of Shea[30], Joyce[31], Jackson[32], and others. The origin of the design requirements should be mentioned. In order to collect both electrons and positive ions after the counter tube discharge, at least 200 volts of opposite operating polarity on the anode was necessary. This potential reversal collects all of the positive ions in less than 20 µs. While others

[29] Hurley, loc. cit.

[30] Shea, loc. cit.

[31] Joyce and Clark, loc. cit.

[32] Jackson, loc. cit.

[illegible]

[illegible]

The lack of [illegible] basic design [illegible]
listed as follows:

[illegible]

Single pulse [illegible]

Anode pulses [illegible]

Output [illegible]

Resolution [illegible]

The single-shot multivibrator [illegible] and modification, this circuit (Figure [illegible]) was found to [illegible] other circuits were tested, the [illegible] requirements.

Within the [illegible] basic circuit [illegible] design requirements should be [illegible] and positive [illegible] opposite operating [illegible] and calculate all of the [illegible]

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[29] Hunter, [illegible]

[30] [illegible]

[31] [illegible]

[32] Jacobs, [illegible]

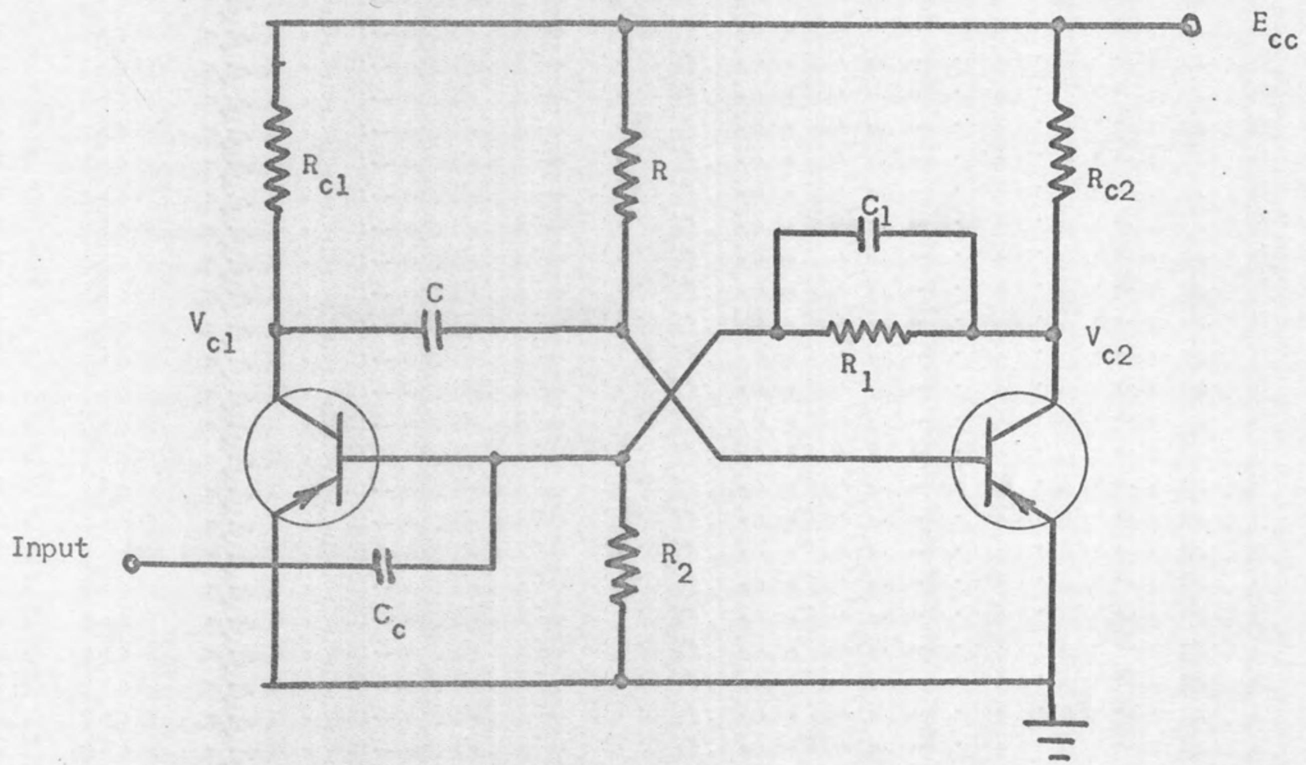
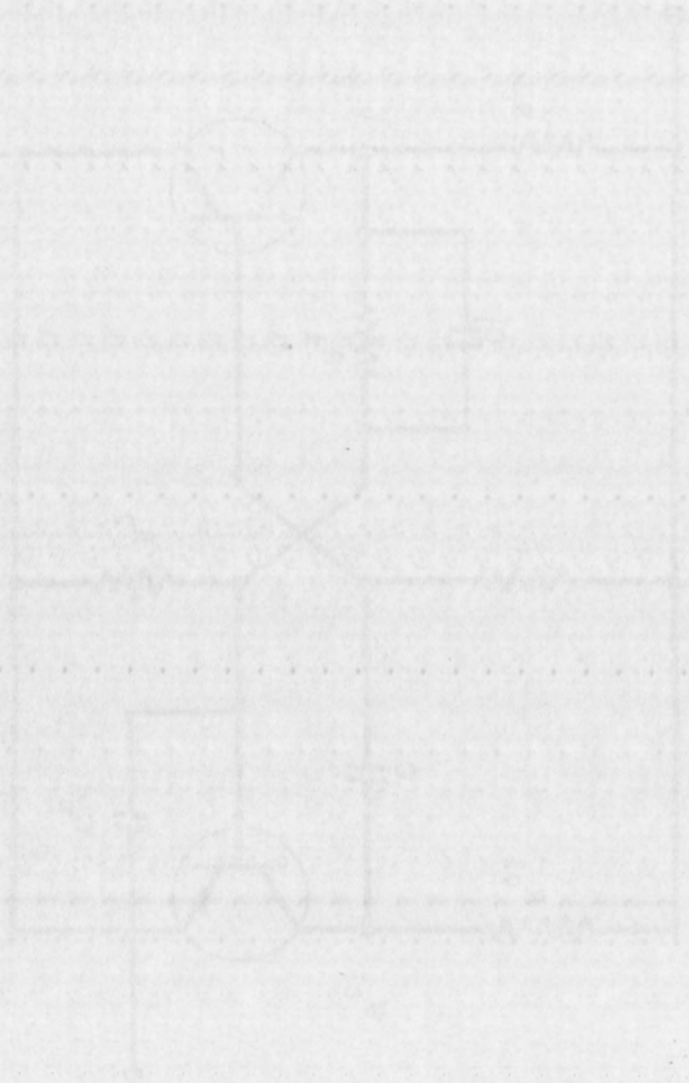


Fig. 18. - Basic Design Circuit



achieved faster collection times for more rapid counters, it was not felt this was necessary or could be achieved with the large counter tube used in this experiment.

The quench pulse of 600 - 800 volts was selected since it is possible[33] using pure argon to achieve G-M tube operating voltages from 300 to 600 volts.

While a trigger pulse of -.5 volts was desired and available from self-quenched tubes, it was not likely that a pure argon tube would produce a -.5 volt output pulse, since the amplification factor for argon is quite low compared to quenching mixtures, and a large load resistance is required to produce a detectable pulse. The best output from an argon counter tube was .02 volt. In this instance the load resistance was varied from 10^8 to 10^{10} ohms with no detectable change because of the low input impedance of the circuit. This pulse size was insufficient to trigger the circuit. The 25-foot length of coaxial cable, approximately 30 μμf per foot, coupling the counter tube to the circuit which attenuated the pulse was shortened to 6 inches for the quenched tube.

The primary of the M8050 transformer in the collector circuit caused many transient and unstable conditions in the circuit operation. In addition, impedance matching across the transformer showed that the output impedance was 2500 times the primary impedance since the turns ratio of the M8050 was 12 to 600.

Using Hurley's procedures, R_{c2} was made small enough to provide stabilization against Q_2 collector loads. Including d.c. resistance of the primary, R_{c2} approximated 40 ohms resistance. The ratio $R_1 / (R1 + R_2)$ was selected to provide reverse bias on base Q_1. Later, it developed that this bias could be provided from the counter tube supply. R_1 and R_2 were chosen small for

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[33]Korff, <u>loc. cit.</u>, p. 115.

achieved [illegible]. It [illegible]
was necessary [illegible] with the [illegible]
experiment.

The quench pulse [illegible] using pure argon to [illegible]

While a [illegible] pulse of [illegible] volts was [illegible] quenched tubes, it [illegible] likely that a pure argon tube would [illegible] volt output pulse, since the [illegible] factor [illegible] pared to quenching mixtures, and a [illegible] is required to produce a detectable pulse. [illegible] volts. In this instance the [illegible] with no detectable change [illegible]. This pulse size [illegible]. The [illegible] of coaxial cable, approximately [illegible] per foot, [illegible] to the circuit which [illegible] quenched tube.

The primary of the [illegible] many turns and [illegible]. In addition, impedance matching [illegible] impedance was 2500 times the primary [illegible] ratio [illegible] was 12 to 600.

Using [illegible] R_{eg} [illegible] lation against [illegible] collector [illegible] R_{eg} approximated 40 ohm [illegible]. The ratio [illegible] to provide reverse [illegible] be provided from the [illegible] tube supply [illegible] earlier.

[33] [illegible]

for bleeder current biasing but not too large to lower the voltage level during the collector swing on Q_2. Capacitor C_1 was chosen small, approximately 470 μμf, but was later increased. Resistor R was replaced by a variable resistor to experimentally determine the proper degree of saturation of Q_2. Capacitor C was approximated for the desired pulse width, and R_{c1} was made small to stabilize the circuit against the loads of the Q_2 collector.[34]

Preliminary Circuits

The first successful circuit to be bread-boarded and connected to the counter-tube circuitry deviated slightly from that calculated. This circuit is shown in Figure 19. The battery supply in the input circuit was found to be necessary in biasing the input diode to protect the input transistor. The battery was later eliminated, though the input circuit still provided a high impedance path for the quenching pulse.

While this circuit did provide a quenching pulse of 450-500 volts to the counter anode for 60 μs, it had low input sensitivity, high current drain and used an additional battery supply. Nevertheless, the approach was successful and its use suggested corrections in the circuits to follow.

The next successful circuit (Figure 20.) was developed by rebiasing the previous circuit. It had all the disadvantages of this circuit, however, it produced a cleaner quenching pulse of 600 volts for 50 μs. An additional battery was used to bias the transistors into a complete cut-off and saturation.

The Final Circuit

The final approach incorporated much of the previous circuitry, yet it utilized two basic design improvements. The final circuit (Figure 21.) used two different transistors, i.e., the 2N1379 as the "off" transistor and the

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[34] Hurley, loc. cit.

the [illegible] current [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] ing the condenser using on [illegible]. [illegible] the [illegible] [illegible] [illegible] 470 μμf, but [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] to experimentally determine the [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] that C was [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] to stabilize the circuit [illegible] [illegible] the [illegible] [illegible] the [illegible].

[illegible] [illegible] [illegible] [illegible]

The first [illegible] [illegible] [illegible] [illegible] [illegible] and connected to the conventional circuit [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] is shown in Figure [illegible]. [illegible] [illegible] [illegible] in the [illegible] [illegible] was found to be necessary in [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]. The battery was later [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] impedance path for the [illegible] pulse.

While this circuit did provide a [illegible] [illegible] [illegible] [illegible] [illegible] the counter [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] and used in [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] and [illegible] [illegible] [illegible] [illegible] in the circuit [illegible] [illegible] [illegible].

The next [illegible] circuit (Figure [illegible]) [illegible] [illegible] [illegible] [illegible] previous circuit. It had all the [illegible] [illegible] [illegible] [illegible] [illegible] produced a cleaner [illegible] pulse [illegible] [illegible] [illegible] [illegible] [illegible] battery was used [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] tion.

The Final Circuit

The final [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] utilized [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] (Figure [illegible]) [illegible] two different [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

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[24] [illegible] [illegible]

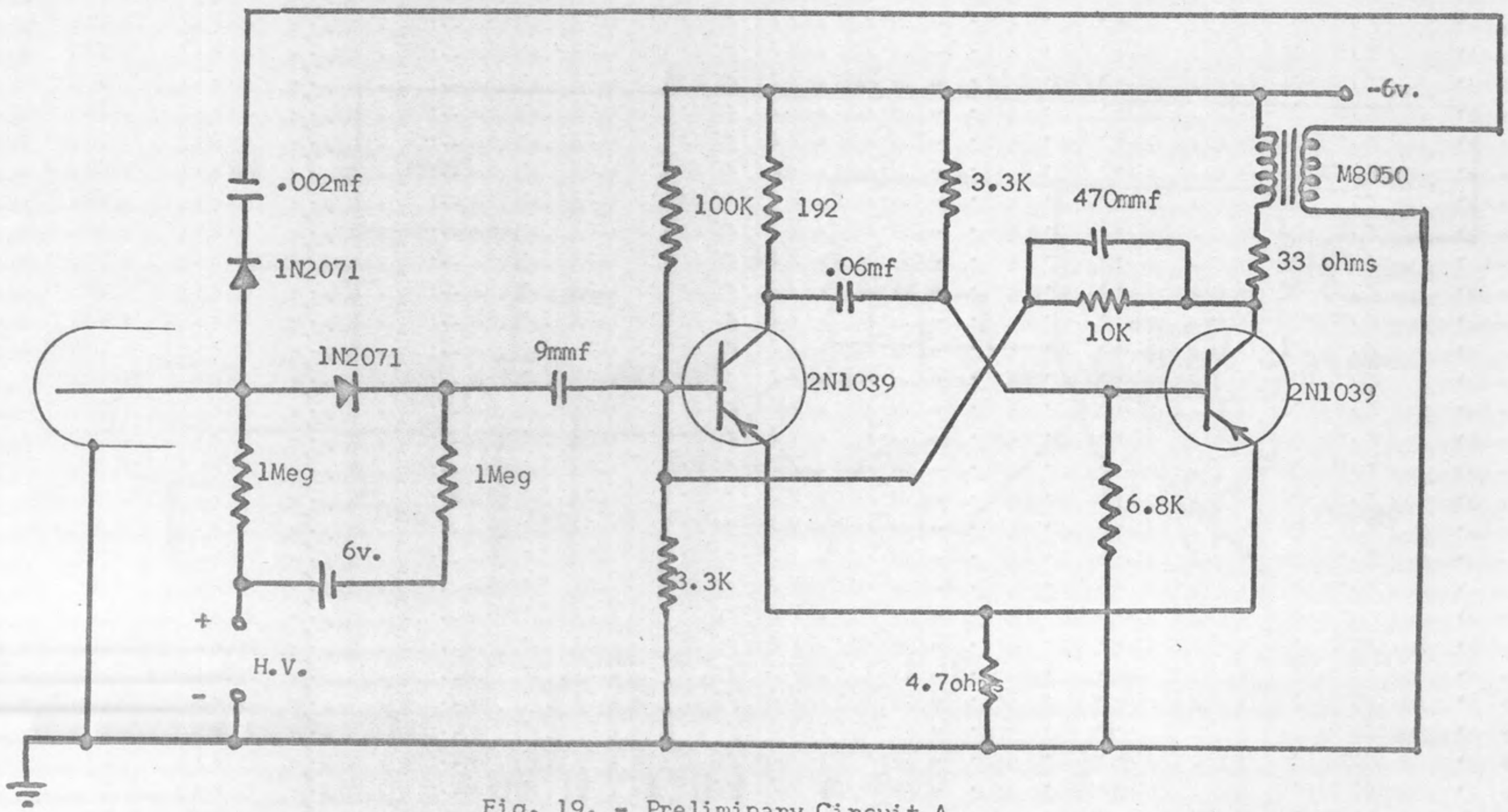

Fig. 19. - Preliminary Circuit A

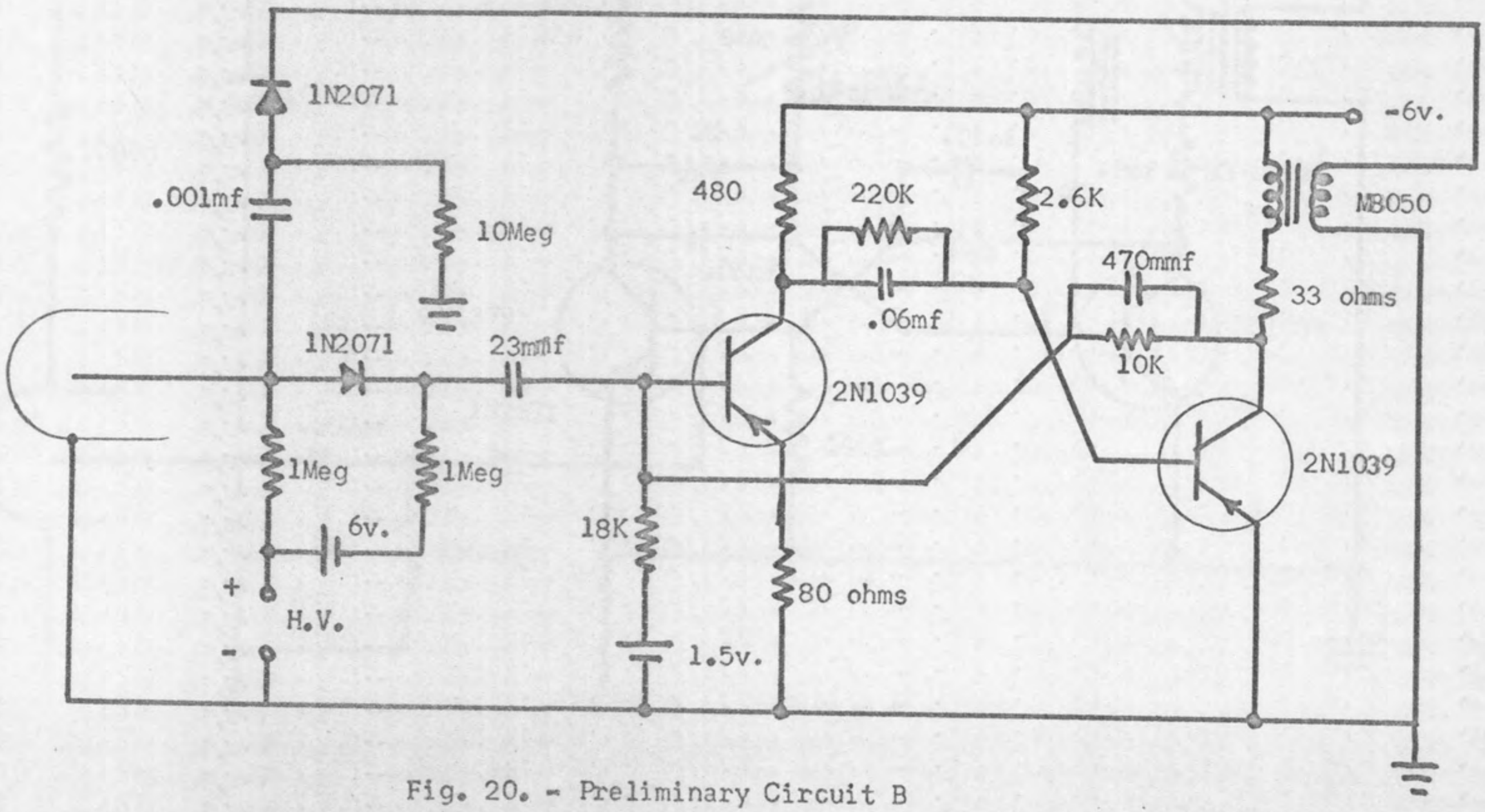

Fig. 20. - Preliminary Circuit B

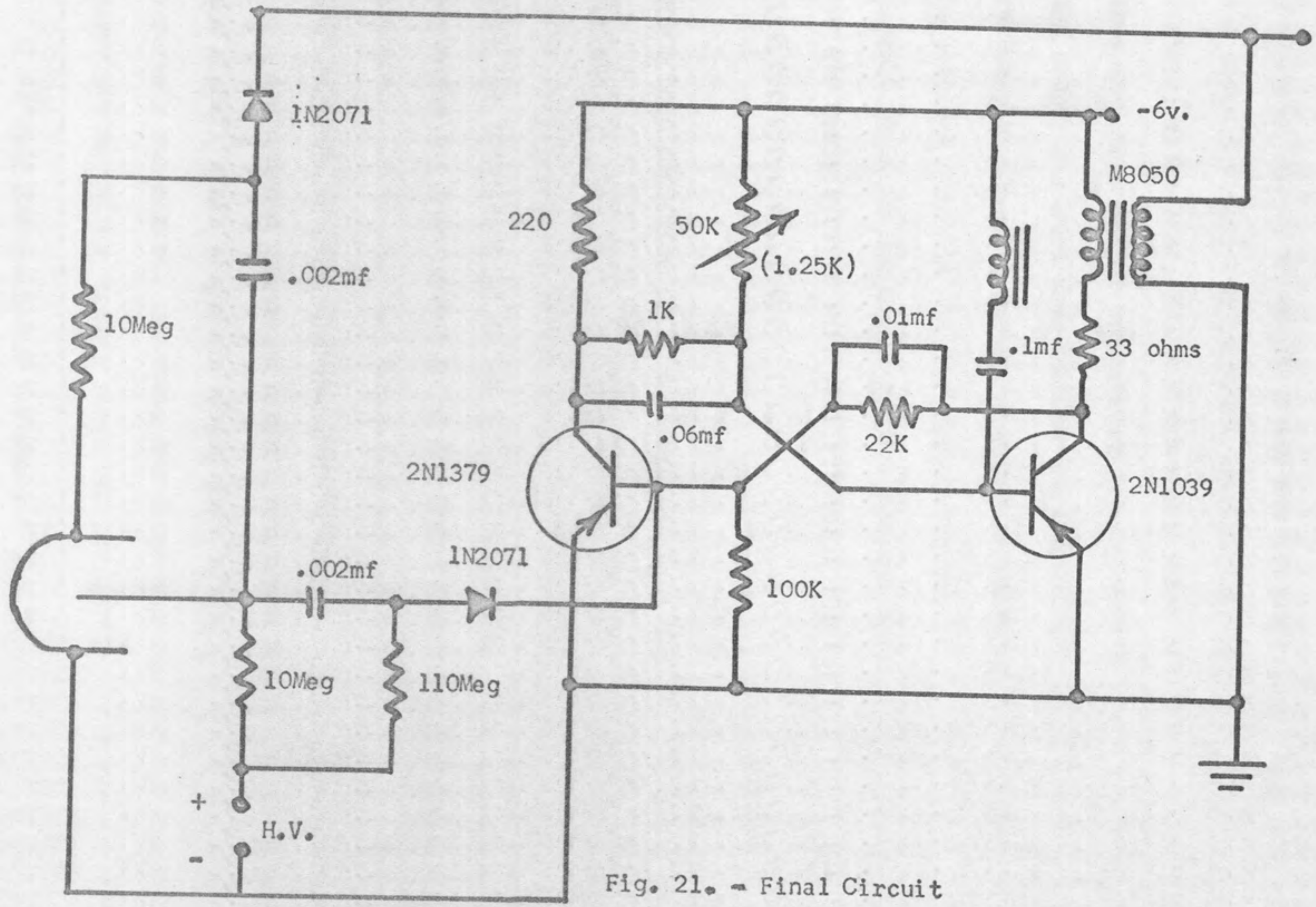

Fig. 21. - Final Circuit

2N1039 as the "on" transistor. In addition, the voltage divider and diode input maintained a good impedance match while increasing the sensitivity. Previously the other set of transformer primary windings was not used. With the circuit biased for increased sensitivity, monostable operation produced a sharp, spike-like, 300 volt quenching pulse of less than 40 μs duration. When the other set of transformer primary windings were coupled to the circuit the output was more than doubled and shaped into a fairly clean, somewhat rectangular 620 volt amplitude quenching pulse of 65 μs duration. (Figure 22.) In previous circuits the "on" transistor was in saturation, however, in this circuit it is in the active region. Maximum collector swing does not develop but the transistor is more easily driven. The base current can be calculated from the circuit values:

$$i_{b2} = v_{b2}/R_{b2} = -.25/1.25 \times 10^3 = .2 \text{ ma}$$

For a test condition of $I_c = -1$ amp and $i_b = -100$ ma , the maximum value of $V_{CE}(sat)$ is -.25 volt.[35] While the V_{CE} for the circuit is -.2 volt, the other conditions far exceed the circuit characteristics. It is not unlikely that the transistor is in the active region very close to saturation. Experimentally, this proved to be the case since slight variation of the resistance R drove the "on" transistor into saturation and the multivibrator into astable, or free-running, operation.

Approximate values of circuit components were calculated from Hurley[36] and Joyce.[37] Final component values were determined experimentally rather than precisely calculated. However, the close correlation between computed and experimental values in many cases was not surprising because of the simplicity

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[35] "1962 Semiconductor Reference," Electrical Design News, June, 1962.

[36] Hurley, loc. cit.

[37] Joyce, loc. cit.

2N 329 as the "on" transistor. [illegible] input maintained a good [illegible] Fortunately the other set of [illegible] the circuit [illegible] a charge, [illegible] When the other set of input [illegible] the output [illegible] rectangular 320 volt [illegible] (Figure [illegible].) In previous circuits the "on" transistor [illegible] circuit it is in the active region [illegible] and the transistor is [illegible] from the circuit values:

[illegible]

For a test condition of I_C = [illegible] the [illegible] V_{CE}(sat) is -.2 volts. [illegible] other conditions for [illegible] that the transistor is [illegible] pertinently, this [illegible] resistance R [illegible] "on" [illegible] into saturation [illegible]

Approximate values of [illegible] and Joyce.[3] [illegible] precisely calculated. [illegible] experimental values [illegible]

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[2] 1962 [illegible] Reference. [illegible]

[3] Hurley, [illegible]

[4] Joyce, [illegible]

of the circuit. Since mode IV operation was initially desired, that is, Q_2 saturated and Q_1 cut-off, then for this condition

$$\beta R_{C2} > R \quad \text{and} \quad V_{b1} < V_e$$

and the desired back bias on Q_1 could be approximated from the previous circuit:

$$E_{off} \leq \frac{R_1 (E_{cc} - I_{co} R_2)}{R_1 + R_2}$$

Since β max = 60 for 2N1039 and β max = 300 for 2N1379, and R_{c2} had been experimentally determined from previous circuits as approximately 40 ohms, the resistance R was calculated as

$$R < \beta R_{c2} = 60 \times 40 = 2400 \text{ ohms, and}$$

$$R_2 > \frac{\beta R_1 R_2}{\beta R_{c1} - R_1} > 500{,}000 \text{ ohms}$$

Actually R_2, because of the positive bias from the input circuit, was reduced to 100K ohms. R_{c1} had been arbitrarily selected as approximately twice R_{c2}, a procedure indicated by Joyce[38] for expedient mode IV operation. R_{c1} was then experimentally increased to 220 ohms, since Q_1 was not the same transistor as Q_2. The timing circuit consisting of R and C was calculated from T = .693 RC. Assuming the base voltage of Q_2 passes through zero with reasonable slope, we have

$$0 = E_{cc}\, e^{-\frac{T}{RC}} - E_{cc} \left(1 - e^{-\frac{T}{RC}}\right)$$

$$e^{\frac{T}{RC}} = 2, \quad \text{or} \quad T = RC \ln 2 = RC(.693)$$

Since $R < 2.4$K ohms and $T_{desired} = 50\ \mu s$, then

$$50 \times 10^{-6} = .693\,(2.4 \times 10^3)\, C\ , \text{ or}$$

$$C \leq 30 \times 10^{-9} \text{ farads or } 30\ K\ \mu\mu f.$$

Experimentally R was determined to be approximately 1.25 K ohms. This pro-

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[38] Ibid.

of the circuit. Since mode IV operation [illegible] that [illegible] is saturated and Q_1 [illegible] then for this condition

$$\beta\, I_{CB} > [illegible] \quad V_s \quad < \quad V_s$$

and the design [illegible] R_L [illegible] circuit:

$$[illegible] < R_{eff}$$

Since β max = 60 [illegible] experimentally [illegible] the resistance R was calculated as:

$$R < \beta\, R_L [illegible]$$

$$R_E > [illegible]$$

Actually R_1, because of [illegible] circuits, was reduced to 100K ohms. R_E [illegible] twice R_E [illegible]

R_E was then experimentally [illegible] transistor as Q_1. The [illegible] from T = .693 RC. Assuming the [illegible] reasonable slope, we have

$$0 = R_E [illegible] (1 - e^{[illegible]})$$

$$e^{[illegible]} = [illegible]$$

Since R < 2.4K ohms [illegible]

$$[illegible] \times 10^{[illegible]} = .693 ([illegible] \times 10^{3})\, C$$

$$C = 39 \times 10^{[illegible]}$$

Experimentally it was determined [illegible]

Ibid.[39]

vided a new time constant when the experimental value of C was increased to $60\ K\ \mu\mu f$, or $T = .693 \times 1.25 \times 10^{3} \times 60 \times 10^{-9} = 52\ \mu s$.

Because C charges through R_{c1}, four $R_{c1}C$ time constants must be allowed between the end of the pulse and the next trigger, or

$$4\ R_{c1}C = 4 \times 220 \times 60 \times 10^{-9} = 53\ \mu s.$$

This, referring to Figure 22., is exactly the recovery time of the quenching pulse at the collector.

Other than voltage divider problems and simple circuit relations, as indicated above, no extensive calculations were carried out for circuit elements or the trigger input. The greatest difficulty was encountered in maintaining a stable operating circuit in or to experiment with the components after simple calculations were made.

The input trigger was a continual problem. Because the argon tube would have an extremely small output, the exact level for triggering was unknown. For the self-quenched tube trigger magnitude was no problem, but in matching the impedances the loss of sensitivity was directly affected by the increase in output quenching and stability in biasing the circuit. As Schwartz described the situation, . . . "transistor switching circuitry has been in a fluid state . . ."[39] and "unfortunately, triggering is usually considered after the basic design is complete and often becomes the most unreliable section of the circuitry."[40]

Final Circuit Functioning and Characteristics

As outlined in Chapter III, this circuit functions as a monostable multivibrator. A negative trigger applied to the base of Q_1 turns this transistor "on". The positive going voltage at the collector coupled to

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[39] Schwartz, loc. cit., p. 6-7.

[40] Ibid., p. 6-17.

vided a new time constant when the critical value [illegible]

20 K and [illegible] or [illegible] = .005 x [illegible]

Because C charges through R_L [illegible] C [illegible]

tween the end of the pulse and the next triggering [illegible]

$$t = R_L C \ldots$$

This, referring to Figure [illegible] the recovery time [illegible] quenching

pulse at the collector.

Other than voltage divider problems [illegible] circuit [illegible] are

indicated above, [illegible] elements of the trigger input. [illegible] maintaining a stable operating [illegible] units after simple calculations were made.

The input trigger [illegible] would have an extremely small [illegible] unknown. For the self quenched [illegible] in matching the impedance [illegible] the increase in [illegible] Schmitt described the situation [illegible] been in a fluid state [illegible] considered after the basic [illegible] reliable section of the circuitry.

Final Circuit [illegible]

As outlined in Chapter I, [illegible] multivibrator. A negative trigger [illegible] transistor [illegible]. The [illegible] voltage [illegible] collector [illegible]

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[39] Schmitt, loc. cit., p. [illegible]

[40] Ibid., p. [illegible]

the base of Q_2 turns this transistor "off". The negative-going voltage at the collector induces currents in the transformer secondary and produces an output voltage which is coupled back to the input circuit. The positive-going voltage at the base of Q_2 is coupled through the second set of primary windings and induces currents in the secondary of the transformer in phase with and added to the first output. Regenerative coupling drives the base of Q_1 more negative and more rapidly into saturation. Upon discharge of the timing capacitor through R and the emitter of Q_1, the base voltage of Q_2 drops to saturation level and Q_1 returns to its original state.

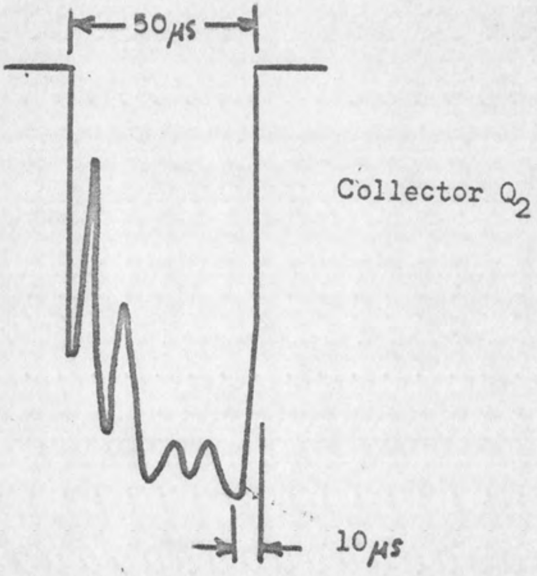
The input diode is reverse biased providing a path through the voltage divider bias network to keep Q_1 cut-off. The diode will thus conduct negative-going pulses equal and slightly larger than the reverse bias voltage. This voltage, .45 volt, establishes the sensitivity input level. When artificially triggered using a pulse generator at the base of Q_1, the minimum trigger level was found to be -.3 volt. No attempt was made to reach this sensitivity level because any pulse output from the self-quenched tube would exceed this level, and any output from the pure argon counter tube would have to be amplified in order to trigger the circuit. Nevertheless, the diode conducts for all pulses of -.45 volt and perhaps slightly larger amplitude but larger negative pulses from the feedback loop to the counter anode will drive the diode into a forward bias condition and it will cease to conduct. This protects the base input to Q_1

Other characteristics of the circuit are graphically shown in Figures 22., 23., 24., and 25.; Figure 22. is a drawing of the oscilloscope patterns for the collector waveform of Q_2 and the quenching pulse at the counter anode. Other circuit waveforms resemble those of the standard multivibrator in Figure 17. A shunt diode across the collector load of Q_2 will eliminate the "ringing" in the collector circuit but the output voltage drops to 200 volts.

the base of Q_2 turns this transistor [illegible] large value collector induces current in the [illegible] put voltage which is [illegible] voltage at the base of Q_2 [illegible] time and induced current in the [illegible] and added to the [illegible] more negative and [illegible] capacitor through R and the [illegible] saturation level and Q_2 [illegible]

The input [illegible] divider [illegible] tive-going pulses equal [illegible] This voltage. [illegible] sufficiently triggered [illegible] base of Q_2 [illegible] less trigger level [illegible] this sensitivity level [illegible] would exceed this level, [illegible] would have to be applied in order to [illegible] the diode conducts [illegible] magnitude but larger negative [illegible] anode will drive the [illegible] to conduct. This prevents the [illegible]

Other [illegible] 22, 23, 24, and 25 [illegible] for the collector [illegible] Other circuit waveforms [illegible] Figure 17. A small [illegible] "ringing" in the collector [illegible]



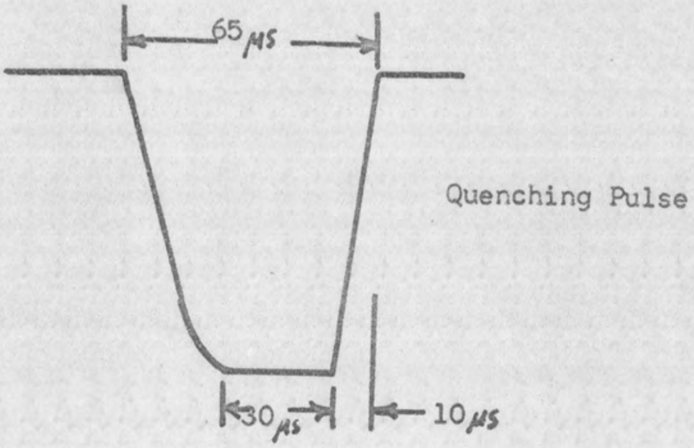


Fig. 22. - Circuit Waveforms

Since this ringing is not intense enough to damage the transistor and does assist the output, no corrective measures were necessary. Attempts were made to decrease the effect of this oscillation on the pulse width, since there is a detectable delay in the fall time of the output pulse due to this non-linear effect.

Since the circuit was triggered randomly by cosmic radiation entering the self-quenched tube, no qualitative data could be taken. However, when artificially pulsed with a laboratory constructed pulse generator, the data in Figures 23. and 24. were taken. The pulse generator characteristics were:

Maximum frequency:	7.6 kilocycles
Minimum frequency:	28 cycles per second (or pps)
Maximum amplitude:	11 volts
Pulse width:	25 μs or 3.2 μs

In conjunction with this equipment, a Hewlett-Packard Dual Trace Model 150A oscilloscope was used to detect waveforms and voltage levels. For the high voltage to the counter tube, a Smith-Florence high voltage power supply was used. Both regulated and fixed d.c. supply voltage sources were used.

All data were taken with the circuit triggered by the 25 μs pulse from the pulse generator. The frequency and pulse height were varied throughout the range of the generator. It was noted that for output frequencies over 3 kilocycles, the d.c. level of the counter anode increased positively up to several hundred volts. The quenching pulse was reduced in amplitude proportionately at the higher frequencies, i.e. up to several hundred volts, but only about 100 volt amplitude reduction in the final circuit. This effect, an increase in potential of the counter wire as the counting rate increases, is attributed to the capacitive coupling of the Geiger counter

Since this ringing is not [illegible] to [illegible]
ending the output, no [illegible] a [illegible]. [illegible]
to decrease the [illegible] of [illegible] oscillation [illegible]
is a detectable delay in the fall time [illegible]
linear effect.

Since the circuit was [illegible]
the self-quenched mode, no [illegible]. However, [illegible]
automatically [illegible] with a [illegible]
in Figures 23 and 24 were [illegible]

Maximum frequency [illegible]

Minimum frequency [illegible]

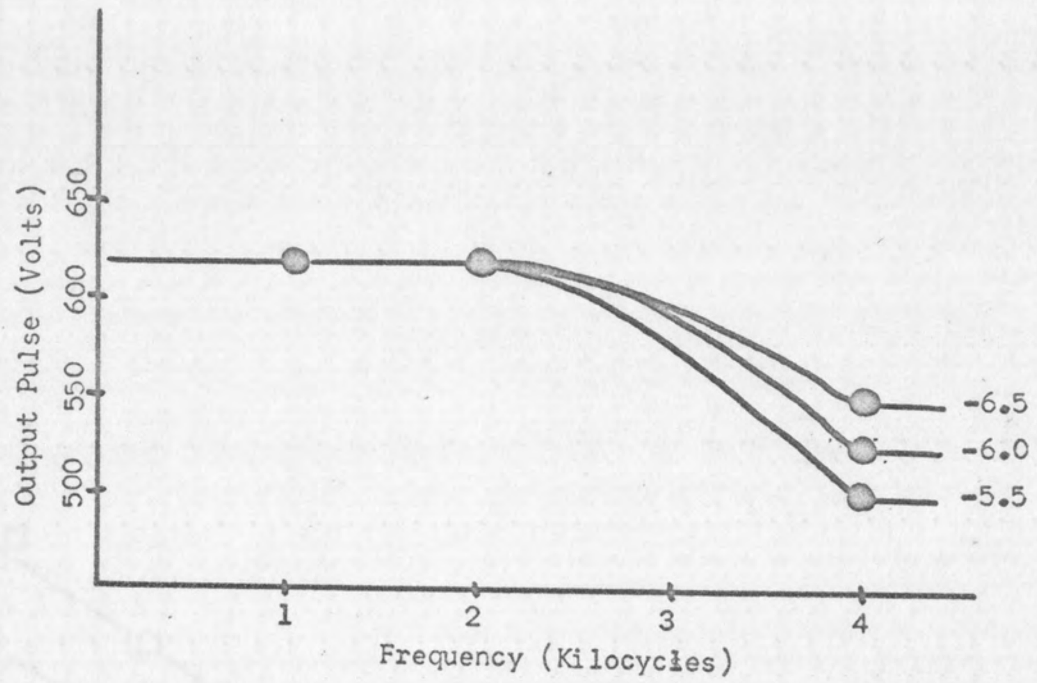
Maximum amplitude [illegible]

Pulse width [illegible]

In conjunction with [illegible]
oscilloscope was used [illegible]
voltage to the [illegible]
used. Both regulated and [illegible]

All data were taken with the circuit [illegible] Figure 25 [illegible]
the pulse generator [illegible]
the range of the generator. [illegible]
3 kilocycles, the [illegible]
to several hundred volts. The [illegible]
proportionately at the [illegible] several hundred volts,
but only about 200 volts [illegible]. This
effect, an increase in [illegible]
increases, is attributed to the [illegible]

Output vs Frequency



Trigger vs Frequency

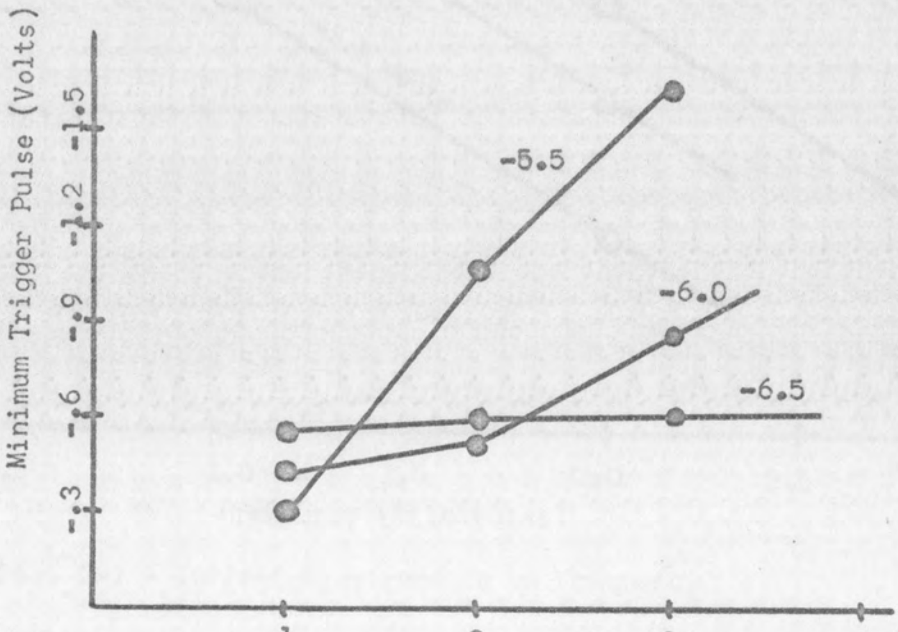


Figure 23.

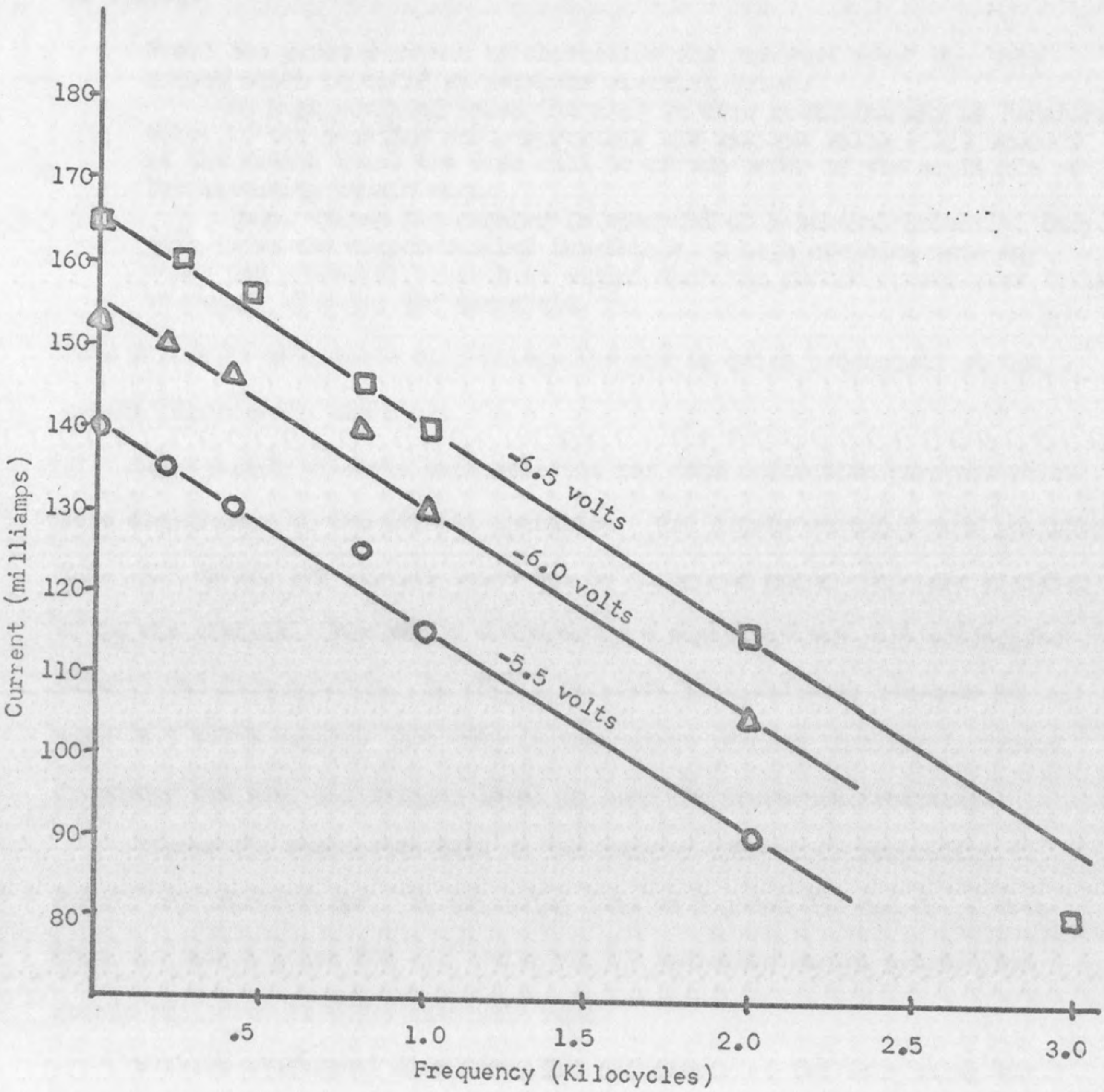


Fig. 24. - Current Requirements vs Frequency

to the quenching circuit preamplifier by Maier-Leibnitz.[41] A method of correcting the observed count for this effect is given by Wyard[42] and both the effect and application of correction factors are commented on by Gordon. He states:

> Wyard has given a method of correcting the observed count for this effect which is valid at moderate counting rates.
>
> At high counting rates the rise in wire potential may be considerable; if the counting rate approaches the maximum value (1/T where T is the quench time) the rise will be of the order of the amplitude of the quenching square wave.
>
> Thus, unless the counter is operated at a nominal potential only, just above the Geiger-Mueller threshhold, a high counting rate may raise the potential to such an extent that the quench square wave fails to reduce it below the threshold.[43]

This effect is noticeable at 3 kilocycles and is quite pronounced on the graphs (Figures 23. and 24.).

Three supply voltages were selected for data collection purposes which were significant to the circuit operation. For supply voltages more positive than -5.5 volts, the circuit could not be triggered unless the base resistor of Q_2 was changed. For supply voltages more negative than -6.5 volts, the circuit was free-running. It should be noted that the best response is with -6.5 volts supply. Not only is the output reduced less for increased frequency but also the trigger level is less for increased frequency.

Figure 25. represents data on the counter tube anode responding to cosmic ray interactions. In comparing data on Figures 23. and 25. , note that the output pulse for -5.5 volts supply indicates random pulses from cosmic radiation at a 2.5 kilocycle rate.

Without additional circuitry, the efficiency of the tube using the

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[41] H. Maier-Leibnitz, Rev. Sci. Instr. 19, 500 (1948).

[42] S.J. Wyard, J. Sci. Instr. 30, 389 (1953).

[43] R.L. Gordon, J. Sci. Instr. 31, 306 (1954).

to the quenching circuit [illegible] [41] A second [illegible] correcting the observed counts for this effect is given by [illegible] [42] the effect and [illegible] of [illegible] counter [illegible] by [illegible] He states:

> [illegible] has [illegible] method of correcting the counting rate for this effect which [illegible] [illegible].
> At high counting rates the [illegible] [illegible] of the [illegible] [illegible] (where [illegible] is the quench [illegible] of the [illegible] quenching pulse).
> Thus, [illegible] just above the [illegible] [illegible] the [illegible] to reduce it below [illegible].

This effect is noticeable at [illegible] [illegible] the graphs (Figures 23 and 24).

Three supply voltages were used [illegible] were significant to the [illegible]. For [illegible] than -4.5 volts, the [illegible] of V_g was changed. [illegible] circuit was [illegible]. It [illegible] with -6.5 volts [illegible] frequency but [illegible].

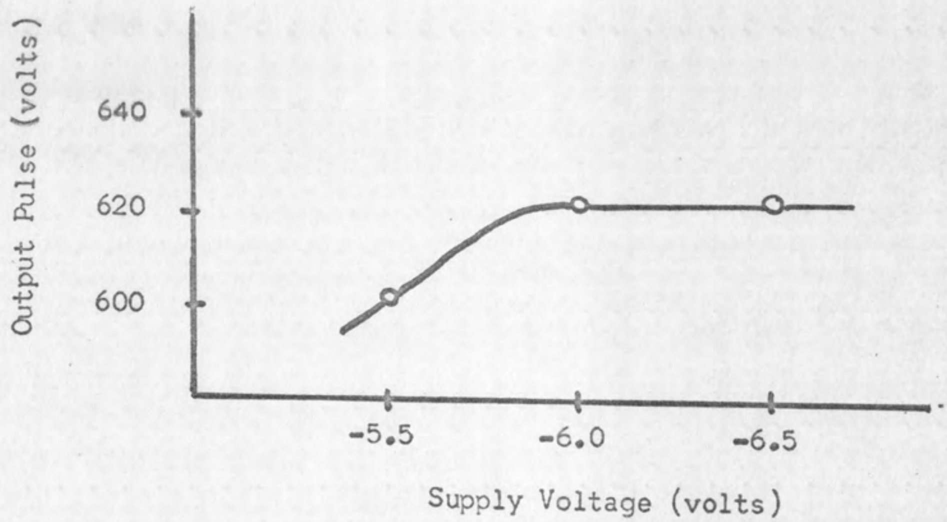
Figure 25: [illegible] sodium ray intensities. [illegible] that the [illegible] [illegible] cosmic radiation [illegible].

Without additional circuits [illegible]

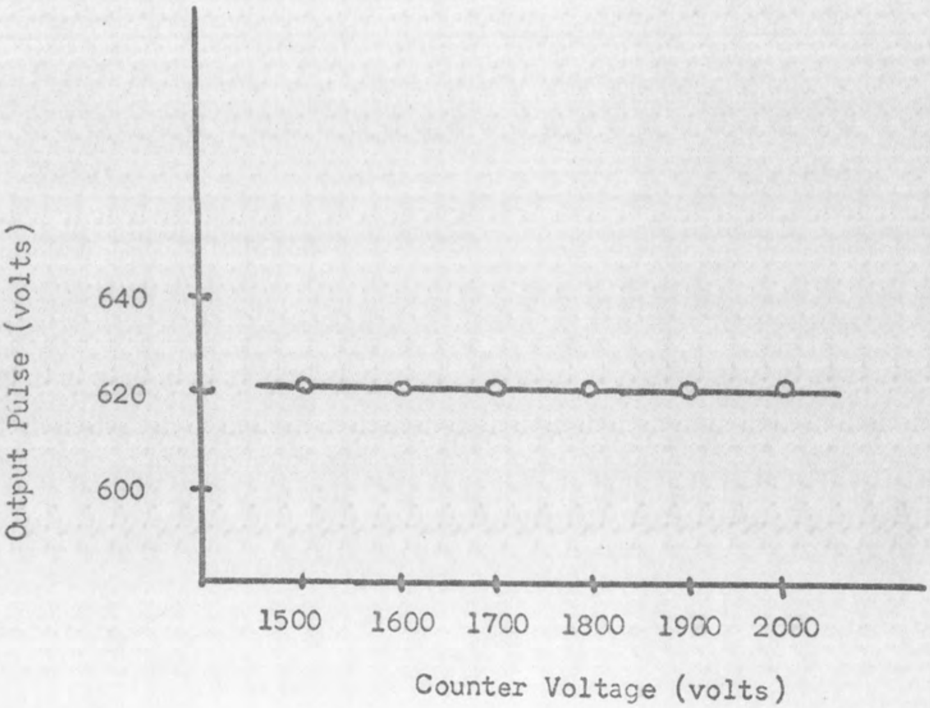
[41] R. [illegible] (19[illegible]).

[42] S.F. [illegible] (19[illegible]).

[43] H.L. [illegible] (19[illegible]).



Output Pulse vs Supply Voltage



Output Pulse vs. Counter Voltage

Figure 25.

quenching circuit could not be determined. This would require many counter tubes. Since tube output leads were shortened from 25 feet to 6 inches for these measurements, it was not considered desirable to modify other tubes because the data would be difficult to attain under the circumstances.

CHAPTER V

CONCLUSIONS

The result of this work has been to produce a workable transistorized quenching circuit within the requirements of the problem. The pertinent features of this work have been the lack of published research on transistorized quenching circuits, the matching of transistor circuitry to the impedance of the Geiger tube, and the difficulty of attaining pulse widths for this type circuit less than 50 µs.

A comparison of the circuit results and the requirements indicates the degree of successful operation of the circuit:

Function	Requirement	Result
Minimum trigger	-.5 volt	-.45 volt
Supply voltage	- 6 volts	- 6.5 volts
Quench pulse	600 to 800 volts	620 volts
Transistors	Minimum number	2
Current	Minimum	Stable: 165 ma Operating: 80 ma
Quench recovery	50 µs	65 µs

The major disadvantage of this circuit is the high current requirement. This could not be avoided using PNP transistors triggered by a negative pulse. The major advantage is that it meets the minimum requirements for a workable transistorized quenching circuit. While this circuit was intended to completely reverse anode potential and collect the positive ion sheath as well, if it is used with self-quenched counter tubes, it will extend the lifetime of the tubes considerably. It is thus concluded that this is a workable solution for transistorized Geiger counter quenching.

CHAPTER V

CONCLUSIONS

The result of this work has been to produce a [illegible] quenching circuit within the requirements [illegible] features of this work have been the [illegible] ized quenching circuits, the [illegible] ence of the Geiger tube, and [illegible] this type circuit less than [illegible]

A comparison of the circuit [illegible] the degree of successful operation of the [illegible]

Function	Requirement	Result
Minimum trigger	[illegible]	[illegible]
Supply voltage	[illegible] volts	[illegible]
Quench pulse	[illegible] volts	[illegible]
Transistors	[illegible]	[illegible]
Current	[illegible]	[illegible]
Quench recovery	[illegible]	[illegible]

The major disadvantage of the circuit [illegible] This could not be avoided [illegible] pulse. The major advantage [illegible] for a workable transistorized [illegible] intended to completely [illegible] should as well, if it is used [illegible] extend the lifetime of the [illegible] this is a workable [illegible]

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