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A RADIO FREQUENCY VOLTAGE SUPPLY

by

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A RADIO-FREQUENCY VOLTAGE SUPPLY

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This thesis is approved as a creditable independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Approved by . . . .

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CHAPTER I

INTRODUCTION

The operation of Geiger-Mueller tubes requires D.C. voltages ranging up to two kilo-volts and currents of the order of a few hundred micro-amperes. There are two types of voltage supplies which can be used for furnishing these high D.C. voltages.

In the conventional high-voltage supply, the output voltage is obtained by rectifying and filtering the high A.C. voltage obtained from an iron core step-up transformer operating from the sixty cycle power line. Problems encountered in obtaining good insulation make it difficult to construct a small sixty cycle transformer for high voltages. Practical transformers therefore are cumbersome and heavy and are capable of furnishing currents much larger than those usually required.

A high-voltage supply in which the input power is generated by a vacuum tube oscillator operating at a relatively high frequency has proved to be a practical source of D.C. voltages, providing the current requirements are not too high. This sort of supply, known as a radio-frequency supply, has the following advantages:

(1) it is compact, requiring only two tubes; (2) the use of high frequency permits a lower transformer induction and thereby simplifies transformer construction; (3) the filter circuit is very simple and requires parts which are small and inexpensive; (4) low energy storage in the small filter capacitors reduces the danger of a lethal shock; (5) the output voltage is conveniently varied by varying the screen voltage of the oscillator tube; (6) the overall cost is substantially lower than that of sixty cycle supplies.

An account of the theory and design of radio-frequency high-voltage supplies for use in television receivers and similar applications has been covered in the literature and elsewhere.[1,2] Since this laboratory had had no previous experience with this type of supply, it seemed desirable to undertake the development of a model capable of furnishing up to two kilo-volts for use in connection with Geiger-Mueller tube operation. This was done, and this thesis is concerned with the resulting supply and its operating characteristics.

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[1] O. H. Shade, "R.F. Operated H.V. Supplies for Cathode-Ray Tubes," Proceedings of the Institute of Radio Engineers, April 1943, p. 158.

[2] W. C. Elmore and M. Sands, Electronics, 1st ed., p. 384.

CHAPTER II

THE RADIO-FREQUENCY SUPPLY

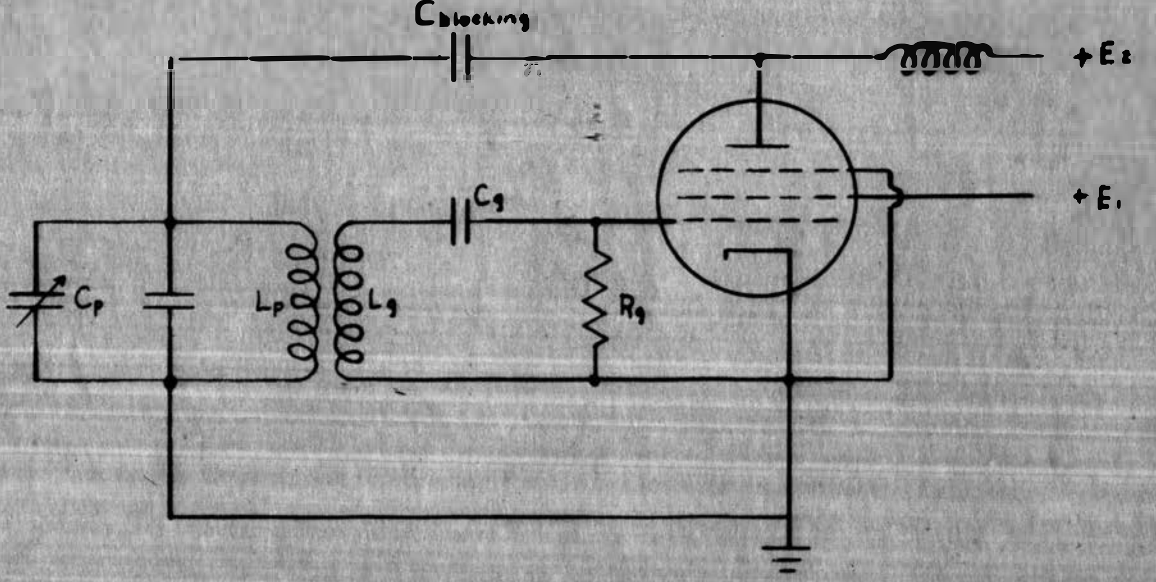
The Oscillator

The oscillator circuit employed in the radio-frequency voltage supply is indicated in Figure I. The plate of the 6SJ7 oscillator tube is connected directly across the tank circuit while the grid is inductively coupled to it in opposite phase. The tank circuit is composed of the primary winding of the transformer, a fixed mica condenser, and a variable air capacitor all of which are connected in parallel. Energy is stored in this resonant circuit and losses are replenished by the pulsating plate current. A coil loosely coupled to this tank circuit provides the voltage to drive the grid in the required manner. A radio-frequency choke allows the D.C. plate voltage to reach the plate of the oscillator while preventing the radio-frequency from reaching the D.C. plate voltage source. The blocking condenser blocks off the D.C. plate voltage from the tank circuit while by-passing radio-frequency components of the plate current.

The oscillator makes use of the conventional automatic amplitude control known as the grid leak and condenser combination. This combination gives a grid bias which is proportional to the amplitude of oscillation. When the circuit is first turned on, the amplitude is very low. Thus the bias is low, making the plate current and hence the amplification large. Any small transient voltage or thermal agitation at the frequency of the resonant circuit can start the building up of oscillations. As the amplitude increases, the bias increases, and the amplification is reduced until an equilibrium condition is reached. Since the grid resistor R_g is of fairly high value (20,000 ohms) the condenser C_g charges nearly to the peak voltage across the grid coil. The grid bias therefore is almost equal to the peak grid swing. This means that the grid is driven past cutoff for most of the cycle causing the plate current to flow in short pulses as with a class C amplifier. This nonsinusoidal plate current may cause the plate voltage to be slightly nonsinusoidal; however, the fact that the plate circuit is tuned tends to keep the plate voltage sinusoidal. Figure II shows an oscillogram picture of the alternating plate voltage.

Coil Design

The all around performance of a radio-frequency voltage supply hinges on the design of the transformer coil. The physical size of the coil should be as large as space permits, since a large coil, as compared to a



OSCILLATOR CIRCUIT

FIGURE 1

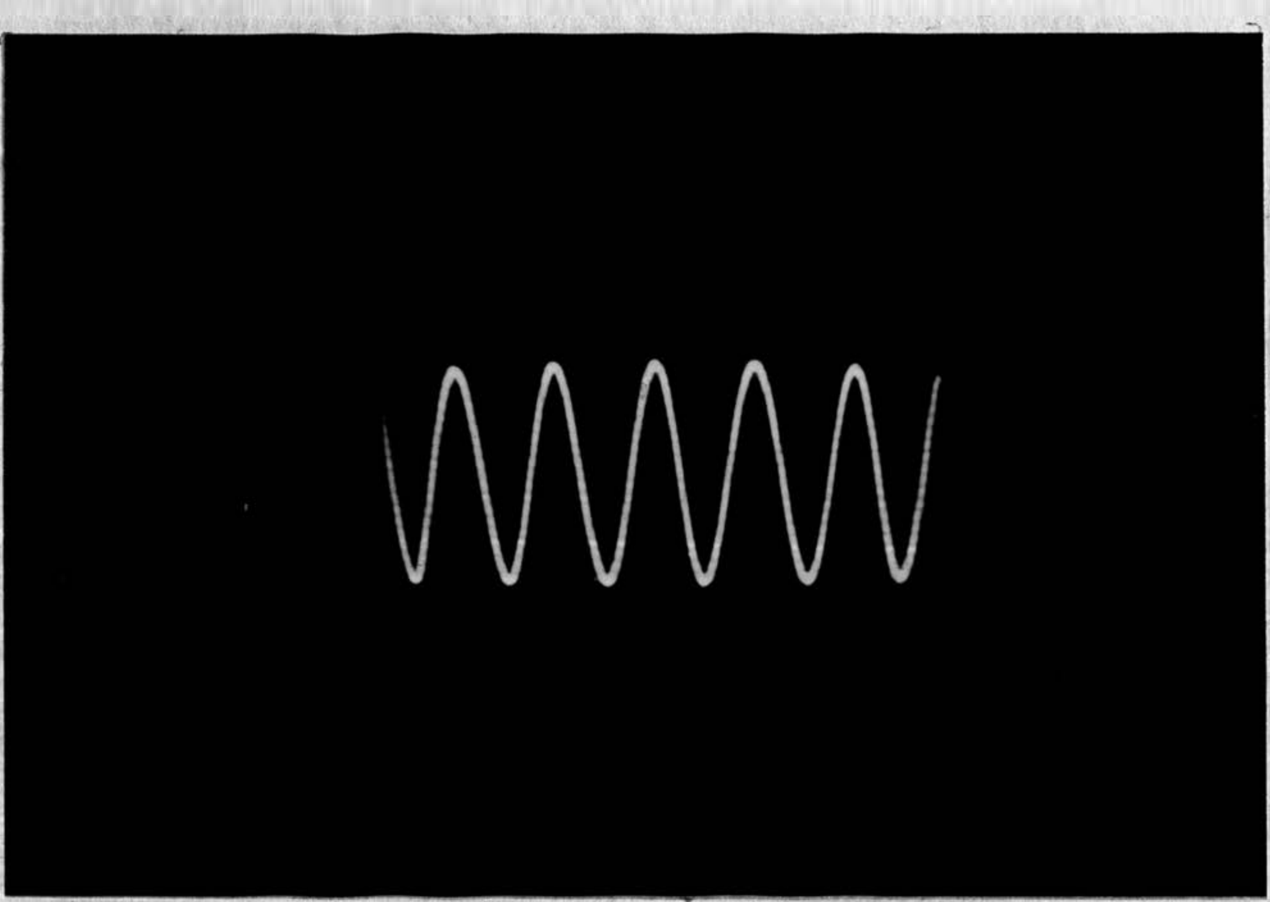


Figure II. Oscillogram Picture of A.C. Tank Voltage small coil, has a higher Q, requires fewer turns to obtain a given inductance, and permits the use of larger wire diameter. It is especially desirable to use litz wire in the construction of air cored coils for resonant circuits where the frequency does not exceed one thousand kilocycles per second. Litz wire consists of several strands of small insulated wire which are thoroughly interwoven and connected in parallel at their ends. At frequencies higher than one thousand kilocycles per second, the benefits of litz wire tend to decrease because of capacitance between the strands. High frequency operation requires small strand diameter so as to increase the overall surface area of the wire and thus reduce skin effect.

The optimum frequency for the resonant circuit of a radio-frequency voltage supply is apparently determined by problems encountered in transformer construction. At low frequencies, the limiting factor is the problem of insulation; at high frequencies, the coil resistance due to eddy currents and skin effect becomes predominant.

The transformer is essentially two coupled resonant circuits, both of which must resonate at the same frequency to give minimum load on the oscillator. The secondary high-voltage winding is tuned by the distributed capacitance of the winding, capacitance of the rectifier tube, and stray wiring capacitance; hence, it has a natural resonant frequency. At this frequency, the self capacitance and the coil inductance are in parallel resonance. The tank circuit is tuned to this natural resonant frequency of the secondary winding by adjusting the variable air capacitor.

For this supply, it was decided to follow a transformer design suggested by W. C. Elmore.[3] This design was apparently arrived at primarily by the cut and try method and may not represent an optimum design. The cylindrical coil form shown in Figure III was turned from a solid one inch rod of polystyrene, this material being chosen for its low loss qualities. The various sections of the transformer were universal wound using litz wire, a universal winding being one in which the wire in adjacent layers touches only at points where the wires cross. This mode of winding not only reduces the capacitance shunting the secondary coil but also makes the various sections self supporting. The secondary coil was divided into three banks in order to reduce the potential difference between layers. Each layer contained approximately ten turns. The banks were placed relatively close together so that the potential gradient between banks should be the same as that inside

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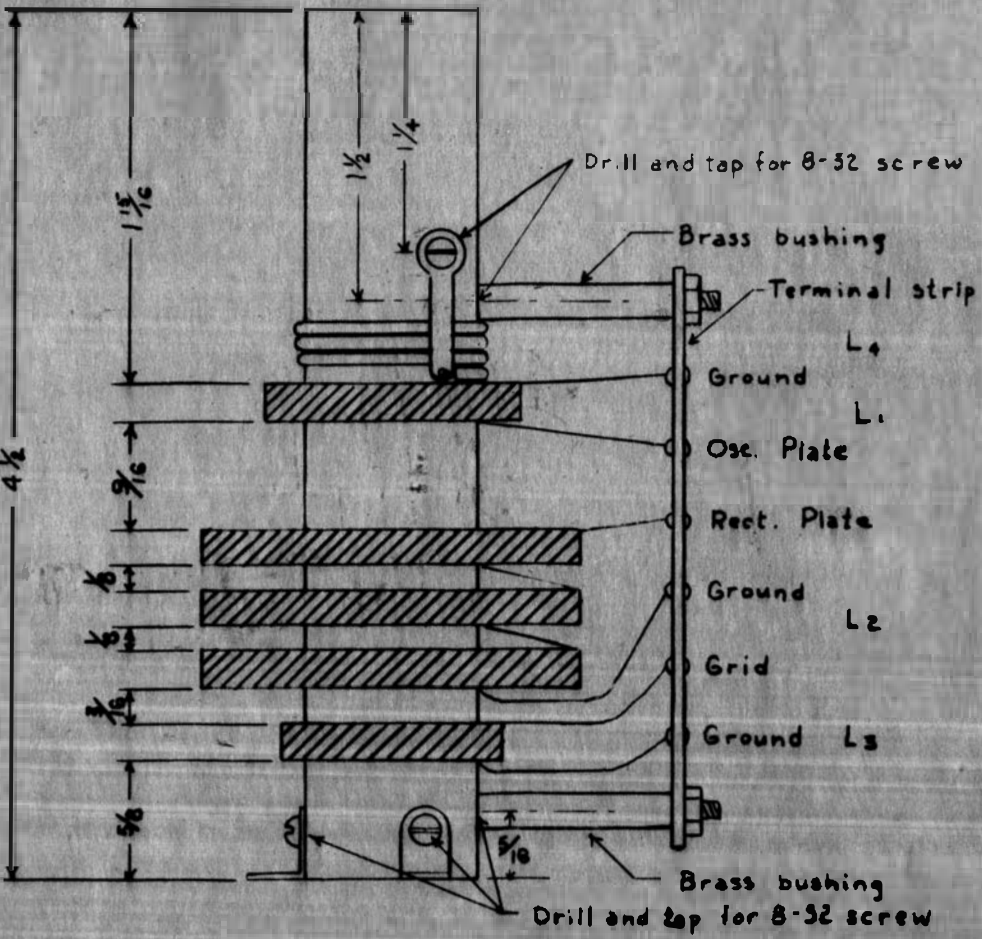
[3] Ibid., p. 385.

the windings. Polystyrene in solution was applied to the wire as it was fed into the coil winder. When dry, the hard coating formed by the polystyrene served to protect the fine wire, make the banks more rigid, and reduce losses due to absorption of moisture.

Since a radio-frequency supply of this type operates at high voltages, due regard should be paid to corona which starts at about 1,250 volts. Any point at this high a potential can ionize the surrounding air and produce a corona effect which results in power loss. When soldering the high potential ends of the transformer windings to the terminal strip, care was taken so that no sharp ends of the fine wire were left protruding.

Rectifier Circuit

The rectifier tube used is the type 8016 half wave vacuum rectifier, which was developed by R.C.A. especially for use in radio-frequency voltage supplies. The 8016 tube has a directly heated cathode which requires only one quarter watt of power and thus permits the use of radio-frequency in heating the filament. A few turns of wire coupled with the oscillator transformer provides a unique means of obtaining the necessary filament voltage. Sufficient insulation for the high potential difference between the filament winding and the <u>secondary</u> winding of the transformer is obtained by spacing the two windings



Coil Form: Polystyrene tubing 7/8 inch outside diameter.

L_1 is 170 turns of 10-41 Litz.

L_2 is 700 turns per bank of 3-41 Litz.

L_3 is 150 turns of 3-41 Litz.

L_1, L_2, L_3 are universal wound -- Width of each pie is 5/16 inch.

Cam throw of winder is 3/16 inch.

Gear ratio is $\frac{\text{cam revolutions}}{\text{form revolutions}} = \frac{42}{44}$.

L_4 is 3¼ turns of no. 18 stranded wire wound as close to L_1 as possible. The terminals of L_4 are 8-32 screws with lugs fastened directly to the coil form.

FIGURE III. TRANSFORMER COIL

a moderate distance apart. The filament voltage required for the 8016 tube is 1.25 volts. The following procedure was used to obtain this voltage from the transformer: The filament was first connected to a D.C. supply of 1.25 volts and its color temperature checked visually by observing the incandescent filament in a small mirror placed beneath the tube. The filament was then connected to a few turns of number eighteen stranded wire wound around the upper part of the coil form and the number of turns adjusted until the color temperature of the filament matched that produced by the 1.25 D.C. voltage supply. When adjusting the radio-frequency filament voltage in this manner, great care was taken so that the filament temperature was not allowed to reach a temperature higher than that caused by operation at a D.C. voltage of 1.5 volts. Higher temperatures are certain to cause the filament to be permanently impaired.[4] Extreme caution was taken to prevent coming in contact with the filament voltage of the rectifier tube, since this point in the circuit is at highest D.C. potential with respect to the chassis.

Filter Circuit

Smoothing the rectified A.C. voltage is accomplished by use of a condenser input filter in which

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[4] R.C.A. Receiving Tube Manual, Technical Series RC 15, p. 62.

the usual series inductance has been replaced by a series resistance. This arrangement is widely used in tuned radio-frequency amplifiers and has the advantage that a resistance is much less expensive than an inductance capable of producing corresponding results. Its disadvantage is that a voltage drop occurs in the resistance and thus limits this type of filter to cases where the current requirements are small enough to permit such a voltage drop.

Since the frequency is high, the value of the shunting condensers can be made quite small. The smallness of the filter capacitors is one of the many attractive features of a radio-frequency voltage supply. From the relation

$$X_c = \frac{1}{2\pi fC}$$

it is seen that a capacitance of 0.003 μf at 160 kilocycles per second has a reactance of 331 ohms. A capacitance of 8 μf would be required to give the same reactance at 60 cycles per second. It is seen that a very efficient filter circuit for a radio-frequency supply can be constructed from small and inexpensive parts.

Construction

Figure IV shows the wiring diagram followed in the construction of the radio-frequency voltage supply.[5] A somewhat unusual type of construction was used, since it was desired to have a completely shielded unit with short leads. The tube sockets were mounted on spacers five eighths of an inch high so that all connections could be made above the chassis. The front and back panels were bolted to the chassis, and a metal shield cover with ventilating louvres was made to fit over the top thereby shielding all sides. Shielding was necessary to prevent possible interference with radio and television equipment. At least one coil radius was allowed between the transformer and the metal shield box in order to prevent the absorption of power. An octal tube socket was mounted at the center of the back panel to facilitate making external connections. The dimensions of the shield box are five and one half inches by five inches by six inches.

A micro-ammeter with full scale deflection of 150 micro-amperes was mounted in the top of the shield cover and used as the output voltage meter. This was connected in series with a thirteen and one third megohm resistance to give a full scale deflection of 2,000 volts. The leads used to connect the meter were made long enough to permit the removal of the cover.

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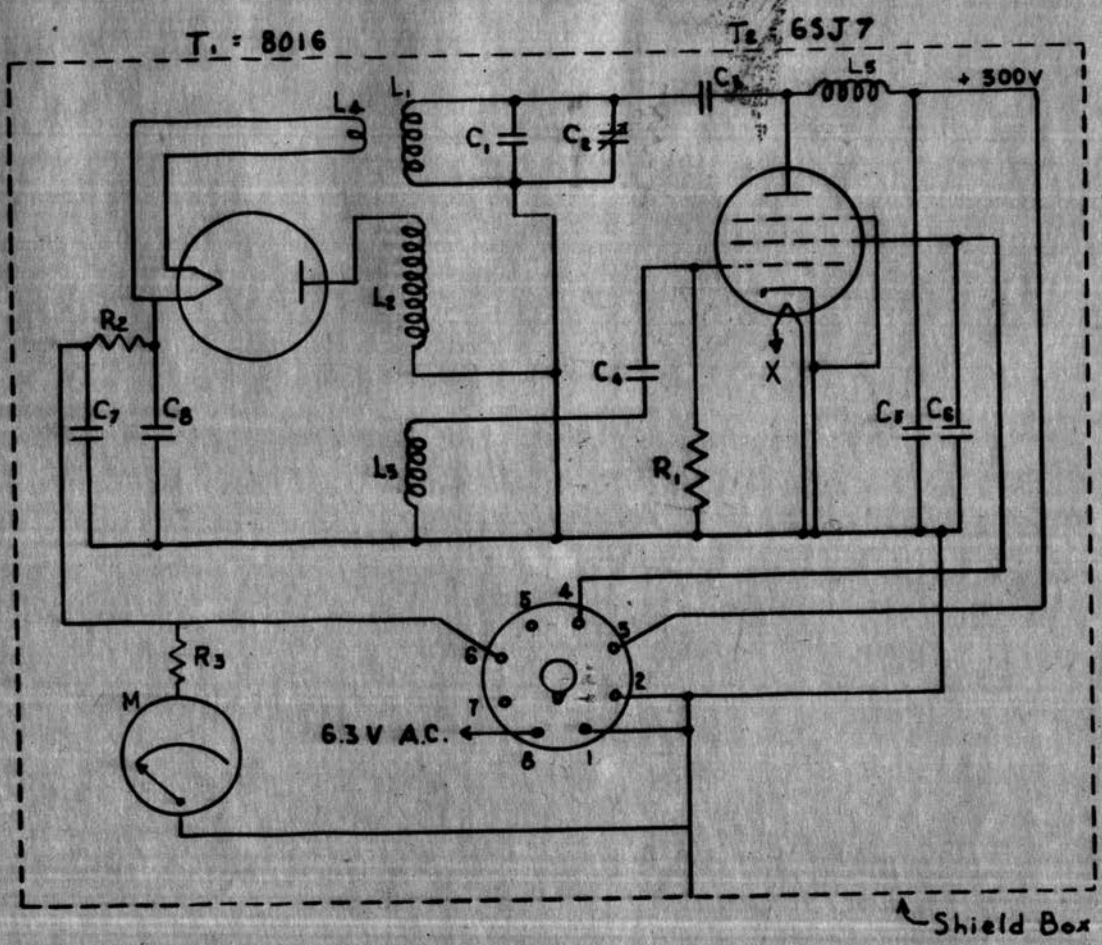
[5] Elmore and Sands, op. cit., p. 387.



C_1 = 0.001 μf
C_2 = 140 μμf single gang variable condenser
C_3 = 0.002 μf
C_4 = 0.002 μf
C_5 = 0.05 μf
C_6 = 0.05 μf
C_7 = 0.005 μf 2.5 KV
C_8 = 0.005 μf 2.5 KV
L_1 = 170 turns of 10-41 Litz
L_2 = 2100 turns of 3-41 Litz
L_3 = 150 turns of 3-41 Litz
L_4 = 3¼ turns of no. 18 stranded wire
L_5 = 5 MH R-F Choke
R_1 = 20 Kilohm, 1 watt
R_2 = 100 Kilohm, 1 watt
R_3 = 13⅓ Megohm
M = Microammeter, 150 microamperes full scale

FIGURE IV. CIRCUIT DIAGRAM FOR RADIO FREQUENCY VOLTAGE SUPPLY

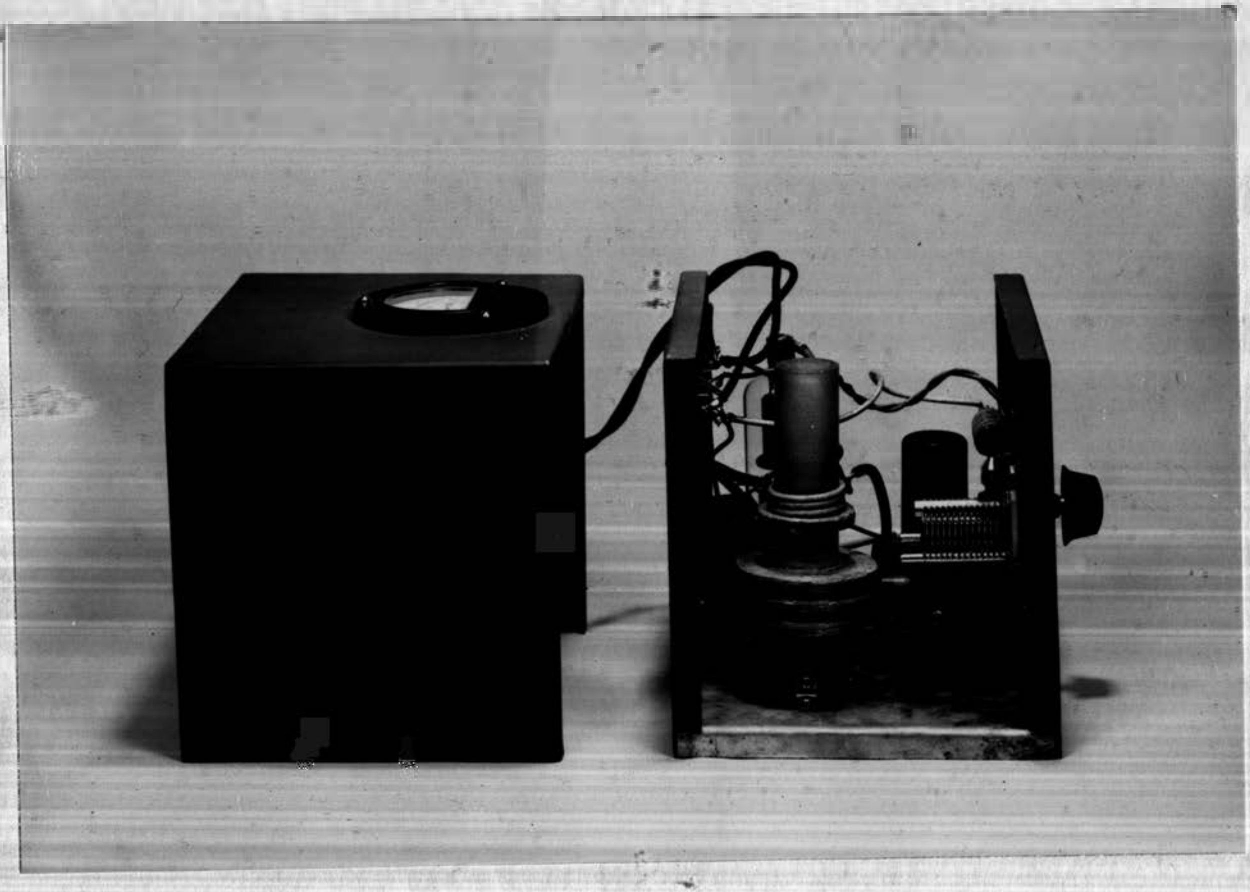


Figure V. Radio-Frequency Voltage Supply With Cover Removed.

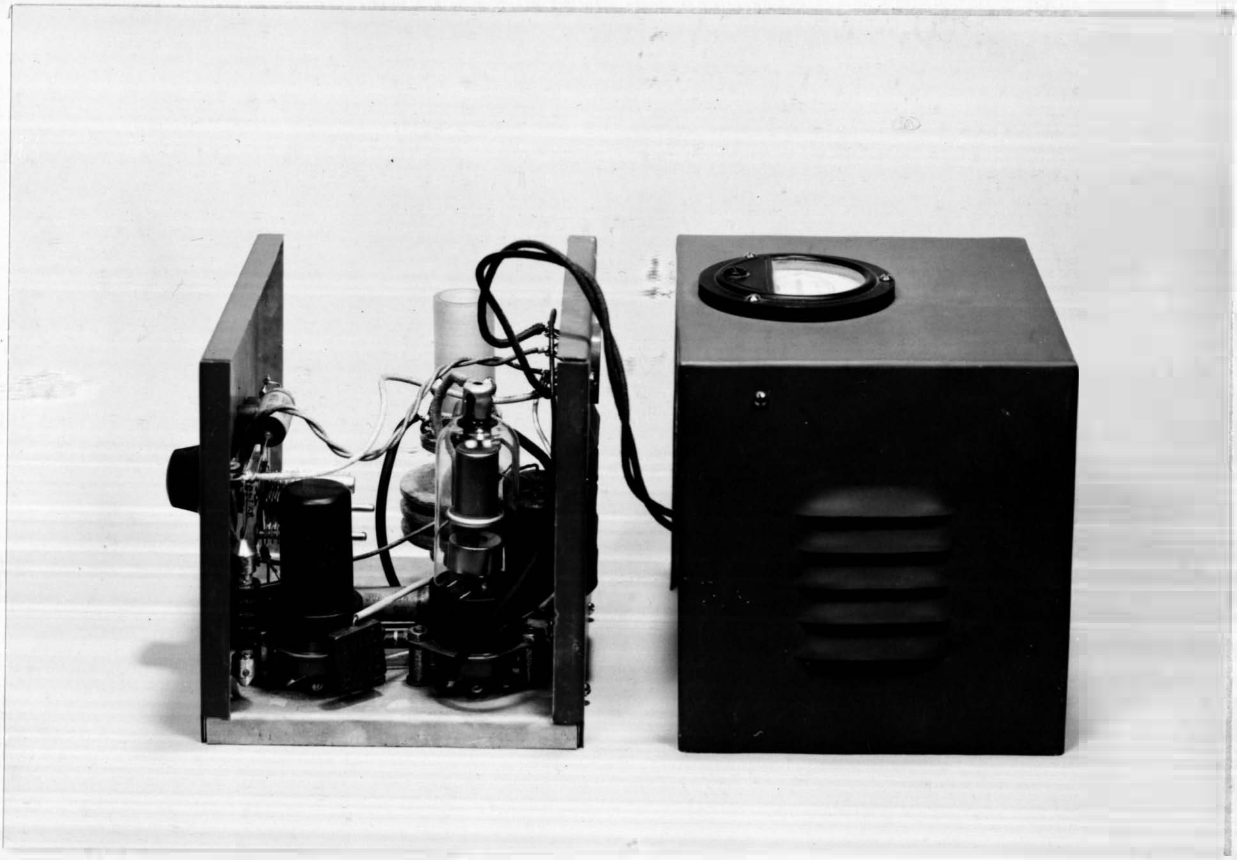


Figure VI. Radio-Frequency Voltage Supply With Cover Removed.

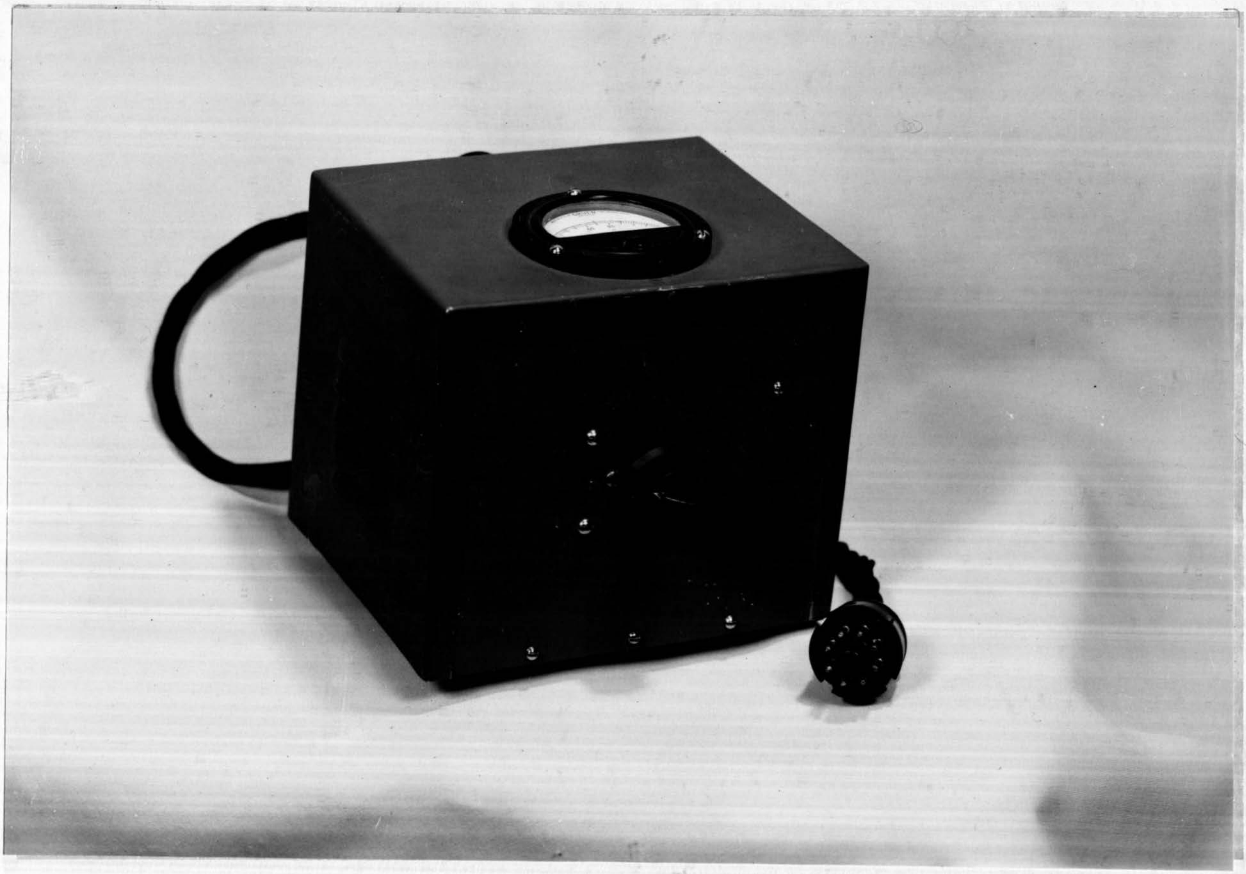


Figure VII. Radio-Frequency Voltage Supply.

CHAPTER III

OPERATING CHARACTERISTICS AND PERFORMANCE

Figure VIII shows a plot of output voltage versus screen voltage. It is seen that the output voltage is almost directly proportional to the screen voltage. Data for this curve was obtained by holding the plate voltage constant at 300 volts and varying the screen voltage.

Figure IX shows how the output voltage varies with load at various screen voltages. Again the plate voltage was held constant at 300 volts. The data for these curves was obtained by connecting the output of the radio-frequency supply through a micro-ammeter and onto the plate of a type VT 255 transmitter tube. As the filament voltage of the transmitter tube was increased, so the load was increased. The load could thus be varied in infinitesimal steps. It was found that the voltage supply could furnish up to approximately 200 micro-amperes at normal operating conditions.

An attempt was made to measure the ripple voltage at various load currents by picking off a small portion of the output voltage and placing it across the horizontal plates of an oscilloscope. A comparison of the amplitude of the ripple voltage could then be made with the amplitude of a known A.C. voltage and its value thus ascertained. The ripple voltage was found to be entirely negligible even at high load currents.

The frequency of the resonant circuit of the voltage supply was found to be 153.5 kilocycles per second with the tuning condenser set at maximum and 158.5 with the tuning condenser set at minimum. The following procedure was used to determine these frequencies: A few turns of wire were wrapped loosely around the transformer coil and the ends connected to the horizontal plates of an oscilloscope. A radio-frequency signal generator was connected to the vertical plates of the oscilloscope and its frequency adjusted until a round Lissajou figure appeared on the screen of the oscilloscope. When the round figure appeared, the frequency of the resonant circuit and the frequency of the signal generator were identical.

It was found that the voltage supply operated most efficiently when the tuning condenser was set nearly at minimum. Apparently, the frequency of the resonant circuit is approximately 158.5 kilocycles per second.

The performance of the voltage supply, when operating as a source of D.C. plate voltage for a Geiger-Mueller tube, was checked by connecting it to the discriminator and driver circuits shown in Figure X[6] in conjunction

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[6] Ibid., pp. 223, 214.

with a Tracerlab TGC-2 self quenching Geiger-Mueller tube and a Central Scientific impulse counter.

A plateau curve for the Geiger-Mueller tube was obtained in the following manner: A small capsule of radium, which was enclosed in a lead shield to shield off the alpha and beta particles, was placed near the mica screen of the Geiger-Mueller tube and the counts per five minutes recorded at various anode voltages ranging approximately from 1,300 volts to 1,600 volts. A plot of counts per five minutes versus anode voltages is shown in Figure XI. Such a curve is called the plateau curve for this particular Geiger-Mueller tube. The flat portion of the curve extends approximately from 1,425 volts to 1,525 volts. This is the region in which the tube should be operated.

The counting rate should vary inversely as the square of the distance between the radio-active sample and the screen of the Geiger-Mueller tube, providing the radio-active sample is small enough to be considered a point source. Figure XII shows that the points plotted from actual measurements follow very closely the inverse square curve. It was found that for distances less than about 70 centimeters, the inverse square relation was not closely followed. The reason for this was probably due to the fact that the radio-active sample was not truly a point source.

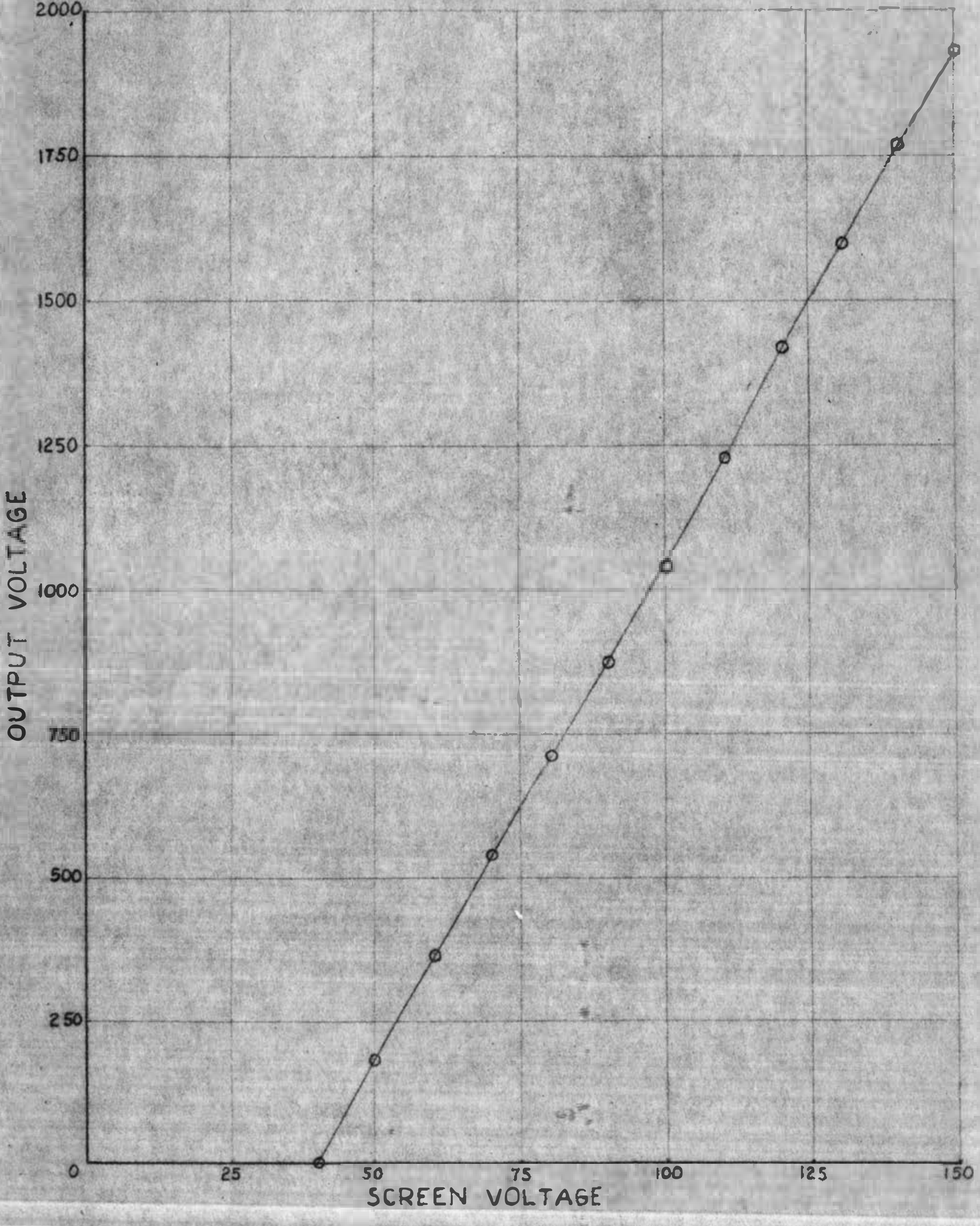

FIGURE VIII. OUTPUT VOLTAGE VERSUS SCREEN VOLTAGE. PLATE VOLTAGE = 300 VOLTS.

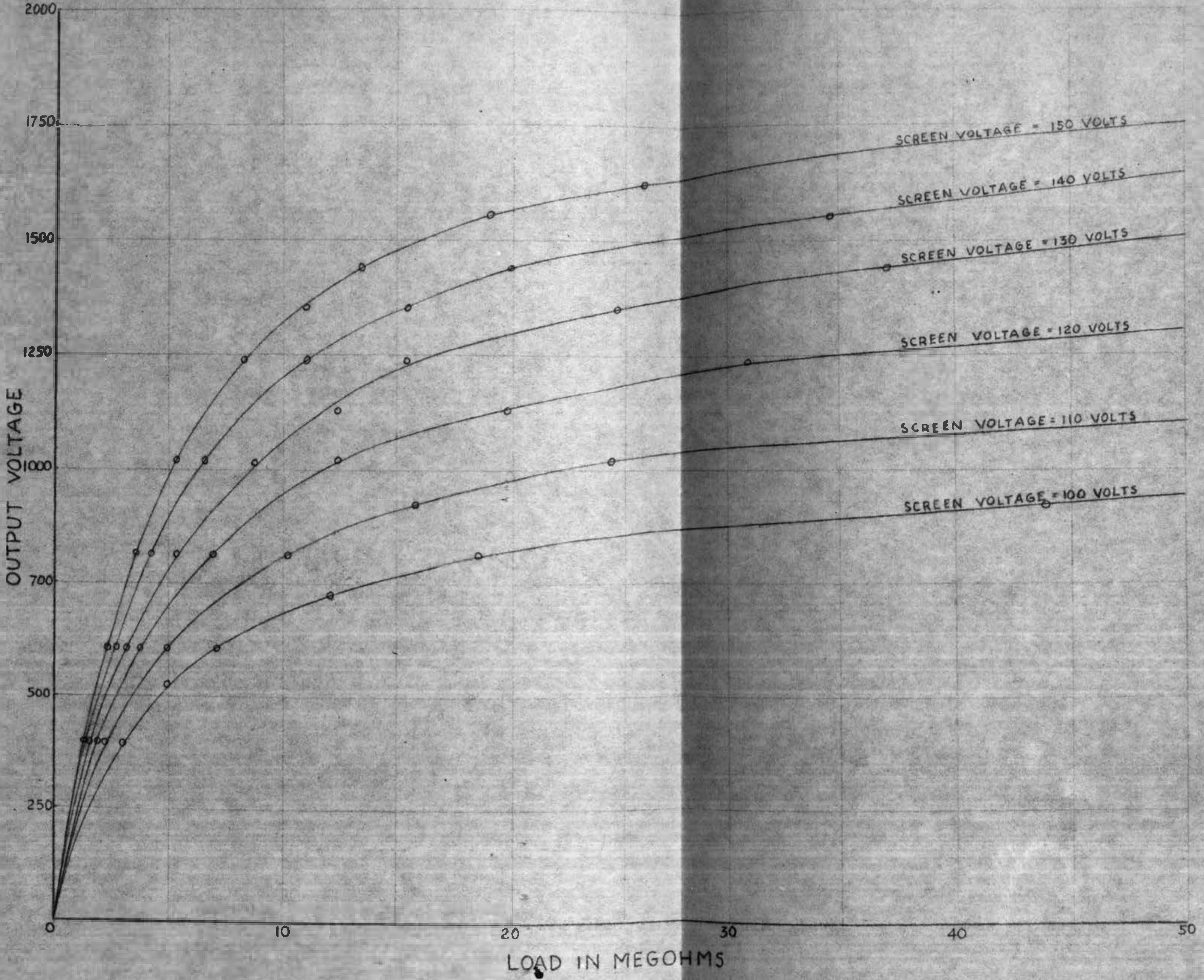

FIGURE IX. OUTPUT VOLTAGE VERSUS LOAD WITH PLATE VOLTAGE = 300 VOLTS.

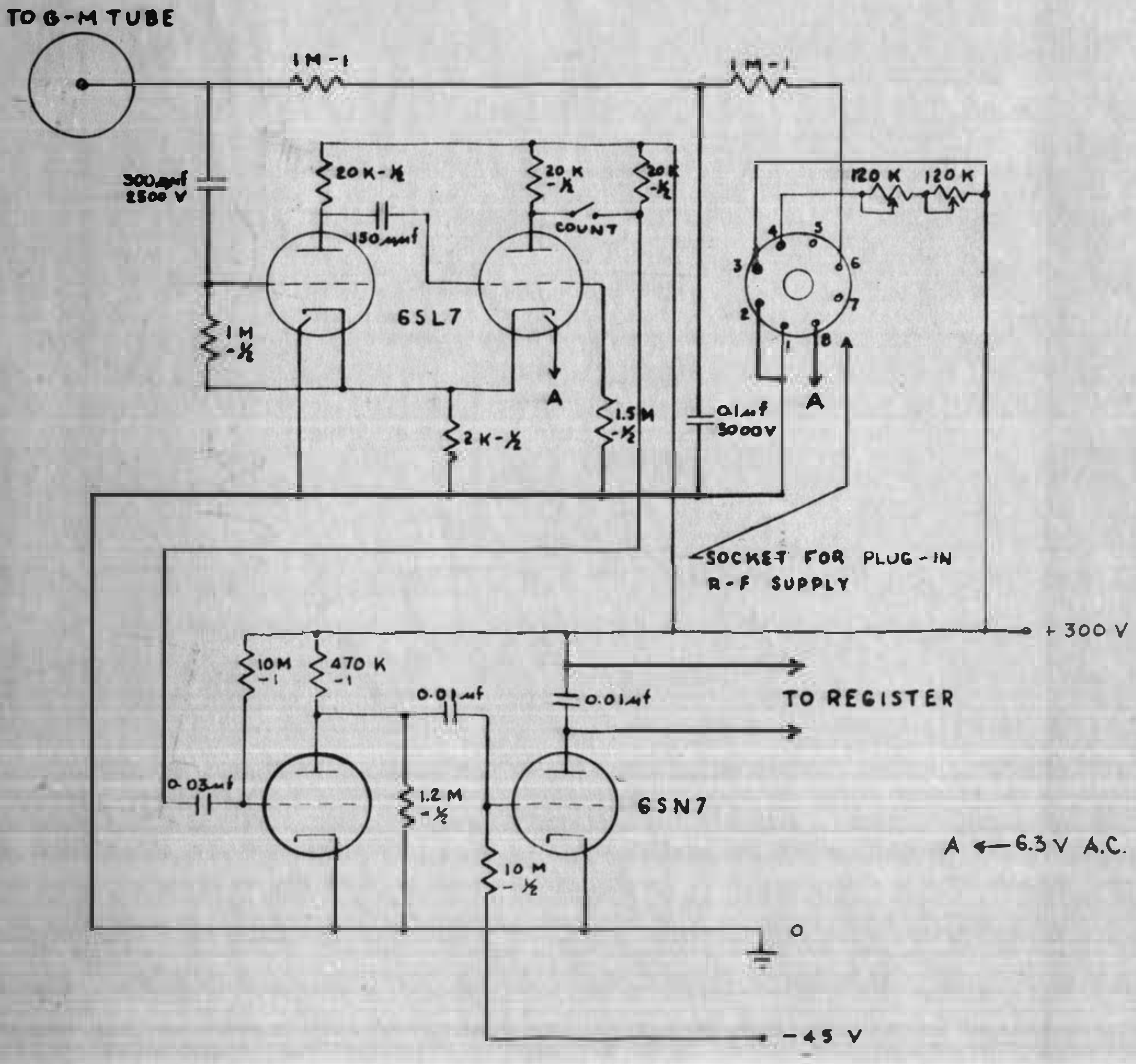

FIGURE X. DISCRIMINATOR AND DRIVER CIRCUITS

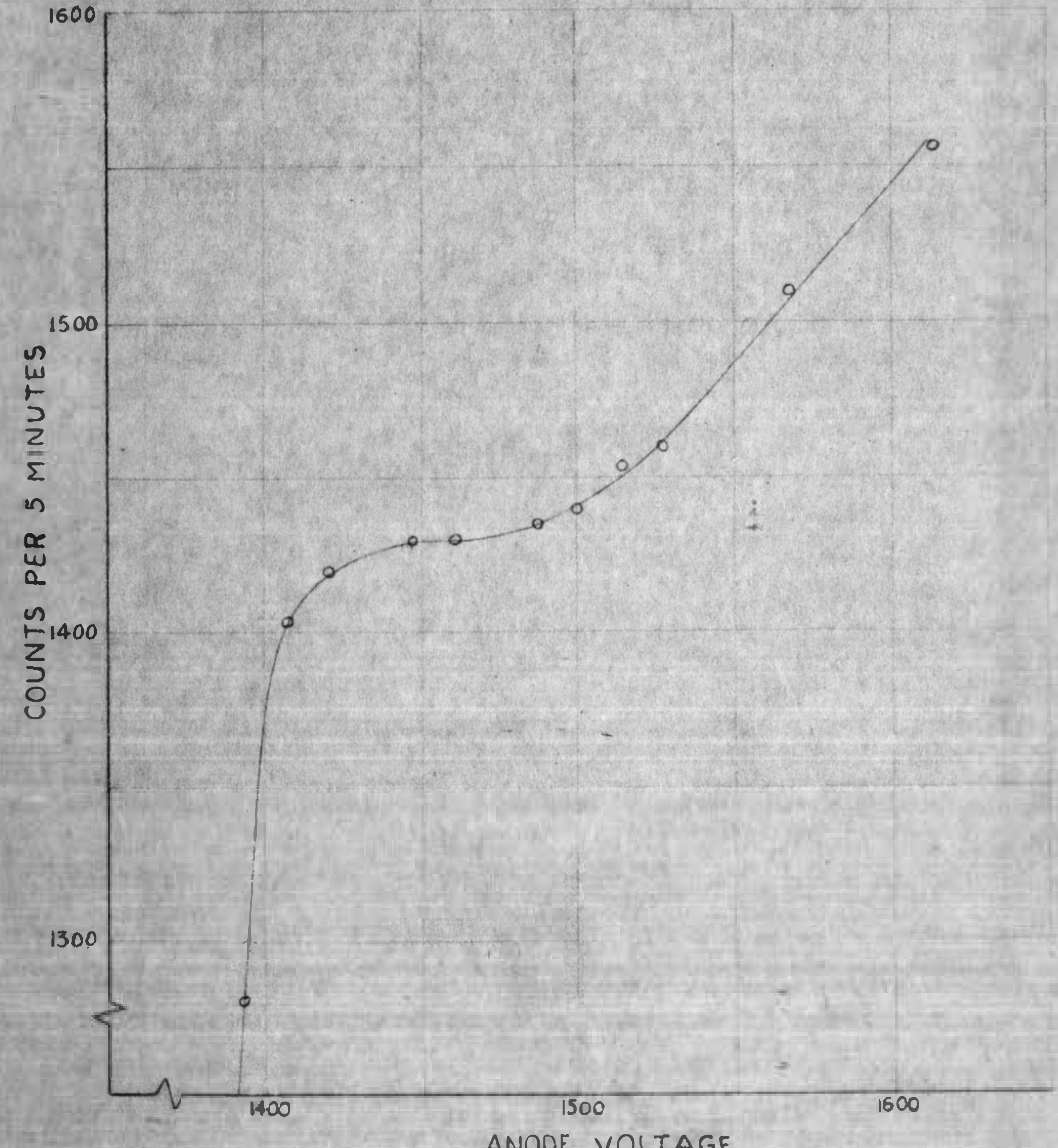

FIGURE XI. PLATEAU CURVE FOR GEIGER-MUELLER TUBE.

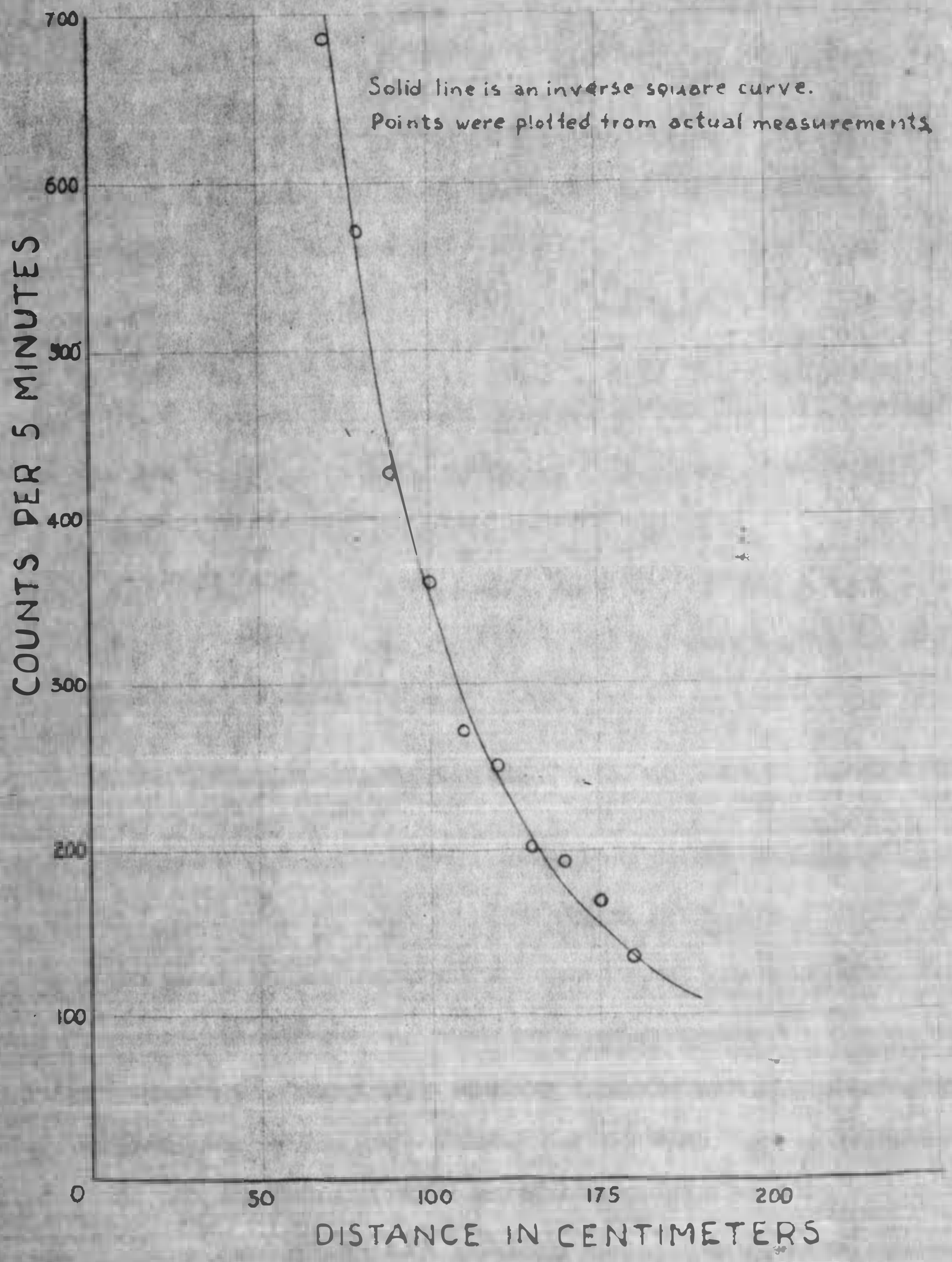

FIGURE XII. COUNTS PER 5 MINUTES VERSUS DISTANCE.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Summary

1. A source of high D.C. voltage that has proved very satisfactory for many low current applications is a radio-frequency supply based on a specially constructed step-up transformer which is energized by a radio-frequency oscillator.
2. Rectification is accomplished by a type 8016 half wave rectifier tube which was designed to permit radio-frequency heating of the cathode.
3. Filtering is accomplished by a condenser input series resistance type of filter commonly employed in tuned radio-frequency amplifiers.

Conclusions

1. Further investigation is necessary in determining optimum design and construction of radio-frequency step-up transformers for use in radio-frequency voltage supplies.
2. The condenser input series resistance filter circuit provides excellent filtering at the high frequency at which the voltage supply operates.
3. The radio-frequency voltage supply discussed in this

paper performs satisfactorily as a source of D.C. anode voltage for Geiger-Mueller tube operation.

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