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AMPLIFIER DESIGN FOR PROPORTIONAL IONIZATION CHAMBERS

(Ad Interim Report)

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Prepared By: W. H. Baker

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SUMMARY

This paper presents the requirements of a nuclear amplifier of short resolving time, designed to accept pulses of widely varying amplitudes. Data are given which show that a proportional ionization chamber loaded with a 1,000-ohm resistor develops pulses of 0.5 microsecond duration and several volts amplitude. Results indicate that seven basic requirements are imposed on the amplifier when counting soft beta and gamma radiation in the presence of alpha particles, without absorbers. It should, (1) have a fast recovery time, (2) have a relatively good low frequency response, (3) accept pulses of widely varying heights without developing spurious pulses, (4) have a limiting output stage, (5) preserve the inherently short rise time of the chamber, (6) minimize pulse integration, and (7) have sufficient gain to detect the weak pulses well below the chamber voltage at which continuous discharge takes place. The results obtained with an amplifier which meets these requirements is described.

A formula is derived which indicates that redesign of the proportional ionization chamber might eliminate the need for an amplifier. This may be possible if the radioactive particles are collimated parallel to the collecting electrode.

DEFINITIONS[1]

"Ionization - The act or the result of any process by which a neutral atom or molecule acquires a charge of either sign, or by which electrons are liberated.

"Radiation - Electromagnetic or corpuscular radiation.

"Ionizing Event - Any event in which ionization is produced, such as the passage of a charged particle through the counter.

"Primary Ionizing Event - The ionizing event which initiates the pulse.

"Pulse - A change in voltage of the central wire system of the counter. This change in voltage is usually abrupt and is a result of the collection of ions produced in the gas of the counter.

"The Characteristic Curve of a Counter - The curve of the counting rate plotted against voltage, all pulses counted being greater than a certain minimum size, determined by the sensitivity of the detecting circuit.

"Plateau - The more or less horizontal portion of the characteristic curve of a counter.

"Threshold Voltage for Geiger Counting Action - The lowest voltage at which all pulses produced in the counter by any ionizing event are of the same size, regardless of the size of the primary ionizing event.

"The Gas Amplification in a Counter - The number of additional ions produced by each electron that is produced in the primary ionizing event as it travels to the central wire.

"The Proportional Region - The part of the characteristic curve of the counter in which the pulse size is proportional to the number of ions formed in the initial ionizing event. In this region, amplification is constant for all pulses at any one voltage.

"The Region of Limited Proportionality - The part of the characteristic curve of the counter in which amplification depends on the number of ions produced in the initial ionizing event, and also on the voltage.

"The Geiger Region - The part of the characteristic curve of pulse size versus voltage in which the pulse size is independent of the number of ions produced in the initial ionizing event.

"Resolving Time - The minimum time interval between counts that can be detected. The word may refer to an electronic circuit, to a mechanical recording device, or to a counter."

Continuous Discharge - A rapid series of continuous pulses which occur in the ionization chamber because of a high field intensity.

Tau - The figure of merit used to describe the ability of a counting system or its separate units, to distinguish between successive pulses occurring close together. For this report, a two-sample method of determining Tau was used. Sample 1 (cc_1) is counted alone, then Sample 1 and Sample 2 (cc_2) are counted together. Then Sample 2 is counted alone. Tau is computed as follows:

$$\text{Tau} = \frac{cc_1 + cc_2 - cc_{1+2}}{(cc_{1+2})^2 - (cc_1)^2 - (cc_2)^2}$$

Coincidence Correction - The number of counts which must be added to the count of an unknown sample to obtain the true number of ionizing events. The relationship between Tau and coincidence correction is as follows:

$$\text{Tau} = \frac{\text{Ionizing Events} - \text{Recorded Counts}}{(\text{Recorded Counts})^2} = \frac{\text{Coincidence Correction}}{(\text{Recorded Count})^2}$$

INTRODUCTION

Counting soft beta particles and gamma-induced electrons in the sensitive volume of a proportional ionization chamber, when in the presence of alpha particles, poses some unique problems in design. It was necessary to design an amplifier to avoid overloading and double pulsing. The maintenance of a short resolving time also presents a problem. The solution of these problems are treated in this paper.

The proportional ionization chamber[2] is widely used for counting the disintegrations of radioactive materials. This chamber usually consists of a small center wire mounted concentrically within a circular or rectangular metal case. The Gas Flow Simpson Proportional Ionization Chamber used in our research allows the passage of a gas through it. This gas is used to prevent recombination of ions and to suppress the too rapid rise of gas amplification due to positive ion bombardment of the cathode. The chamber is constructed with a slide holder to permit insertion of a radioactive sample into the sensitive volume. When this sample is inserted in the chamber, its disintegration produces ionization of the gas. High voltage applied between the center wire and shell of the chamber, rapidly draws the electrons to the center wire while the positive ions drift toward the shell. When the chamber voltage is high enough, the electrons acquire sufficient velocity to knock other electrons from the gas, causing a multiplication of electrons collected. These electrons develop a negative pulse which is detectable with a suitable nuclear counting system. As the chamber voltage approaches the region where the pulse height is independent of the type of ionizing radiation (Geiger region), gas amplifications of 10^4 are readily obtainable.

Commercially available counting systems have proven satisfactory for use with proportional ionization chambers for non-critical work, i.e., the detection of one type of particle at a time. However, when we attempted to count beta particles in the presence of alpha radiation we did not succeed. Therefore, a project was initiated to determine the factors which limited the use of these scaling units. Our study was divided into three parts, as follows: (1) the coupling system between the ionization chamber and amplifier, (2) the amplifier, and (3) the trigger pair coupling between the amplifier and the scaling circuits. This report is concerned with the first two parts of this investigation.

Early research convinced us that Studies 1 and 2 could be grouped together into one problem. This involved the reduction of the pulse attenuation and integration, by achieving a maximum possible decrease of the shunt capacity across the ionization chamber. Capacitive reduction can be accomplished in one of two ways, (1) the use of a cathode-follower mounted at the ionization chamber, or (2) the design and construction of a miniature amplifier to be mounted at the chamber. In either case the amplifier is necessary and the problem then becomes one of amplifier design.

The results of research on the amplifier has led to seven basic conclusions regarding its design for use with a proportional ionization chamber. The amplifier should have the following characteristics:

1. A fast recovery time.
2. A relatively good low frequency response.

3. A dynamic range sufficient to accept pulses of widely varying heights without developing spurious pulses.

4. A limiting output stage.

5. Inherently the same short rise time of the chamber.

6. Minimum pulse integration.

7. Sufficient gain to detect weak pulses well below the chamber voltage at which continuous discharge begins.

This paper presents data and results which bear out the above conclusions. A theoretical analysis of the effect of the chamber load resistance on the chamber output voltage is also presented. This analysis shows that even though the chamber load resistance is small, the pulse voltage at the chamber terminals can be made to approach the generated voltage. This phenomenon occurs when the electron collection time is short compared with the time constant of the external network. Calculations and experimental results show that this voltage may exceed 20 volts. It is shown that the maximum chamber voltage recorded against load resistance for given circuit parameters, forms a straight line on semi-logarithmic paper. A tabulation has been made of the effect of chamber load resistance on pulse duration.

From observed data, it is speculated that pulses of short duration and sufficient amplitude to operate a trigger pair, could be developed in the ionization chamber.

An amplifier was developed which met the seven conditions outlined and has proven satisfactory for counting beta-gamma radiation in the presence of alpha particles. This amplifier is an experimental model and is not intended for use for routine operation.

BASIC PRINCIPLES

The end result desired in the analytical counting of radioactive materials is accuracy. Lewis[3] has shown that accuracy is a function of resolving time (the ability to distinguish between two successive pulses).

$$r = p - \left[pr \left(\frac{1}{q}\right) \right] \qquad (1)$$

Where:

r = Number of recorded pulses per second.

p = Mean rate of random pulses per second.

$\frac{1}{q}$ = Minimum resolving time of the system in seconds.

As the resolving time $\frac{1}{q}$ approaches zero the number of recorded pulses approaches the mean rate of random pulses. This equation can be expressed in terms of percentage error as follows:

$$\text{Per Cent Error} = \text{antilog} \left[\log r + \log \frac{1}{q} + 2 \right] \qquad (2)$$

For a given counting rate this shows that we should expect a 10-fold decrease in error if the resolving time is decreased 10-fold. It is obvious that a short resolving time is highly desirable for relatively fast counting rates.

One reason the proportional ionization chamber is used is because it is capable of producing strong pulses of short duration. The pulses are short because it is possible to obtain the maximum percentage of the ionization current by electron collection. Nicodemus[4] has worked out a formula whose solution gives the value of ionization current to be expected from a a cylindrical chamber.

$$\frac{I^-}{I^+ + I^-} = 1 - \frac{1}{2 \log b/a} \tag{3}$$

where:

I^- = Electron flow.

I^+ = Ion flow.

b = Inner radius of chamber.

a = Radius of collecting electrode and $b \gg a$.

The Simpson proportional chamber which has been used in a number of our experiments will collect approximately the following percentage of the total ionization current developed in the chamber:

b = 0.626 inches.

a = 0.001 inches.

$$\frac{I^-}{I^+ + I^-} = 1 - \frac{1}{2 \log \frac{0.626}{0.001}}$$

$$\frac{I^-}{I^+ + I^-} = 1 - 0.179 = 0.821$$

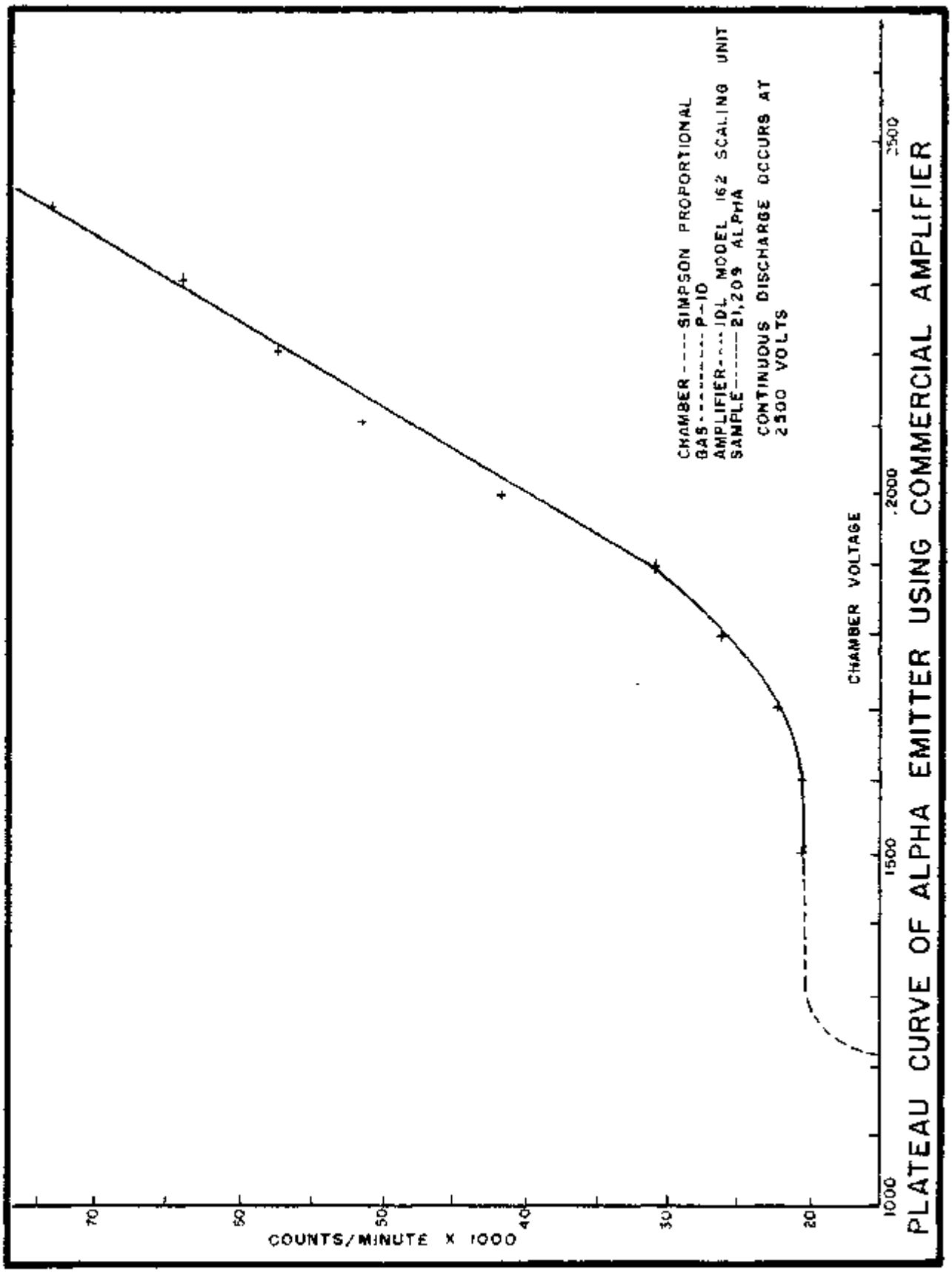
$$\frac{I^-}{I^+ + I^-} = 82.1 \text{ per cent of total current.}$$

This example shows the most of the energy of the pulse voltage is derived from the collection of electrons. This is desirable as it allows us to obtain pulses of short duration.

AMPLIFIER PROBLEMS

One very good way of testing the amplifier of a nuclear counting system for proper operation is to obtain data for drawing a plateau curve. When the amplifier and counting system are in good operating condition an alpha sample of monomolecular thickness (no absorption) should produce a horizontal plateau. If this plateau has zero slope, a change in chamber voltage due to poor power supply regulation will have little effect on the accuracy of counting. If a sample registers within ±1 per cent of its true count for each chamber voltage setting along the plateau 90 per cent of the time, its slope is considered zero, when a precision of 99 per cent is acceptable. For routine counting the chamber voltage is adjusted to the center of the plateau to count unknown samples. A graph of a plateau curve is shown in Figure 1. The data for this curve were obtained using a gas flow Simpson proportional ionization chamber, P10 gas (90 per cent argon and 10 per cent methane), and a commercial scaling unit. This is a typical curve. Even though the data were taken with a pure alpha sample in the chamber, the counting rate continued to rise above the plateau, through the point where continuous discharge begins. This made it impossible to obtain a beta plateau when a beta sample was placed in the chamber alongside the alpha sample.

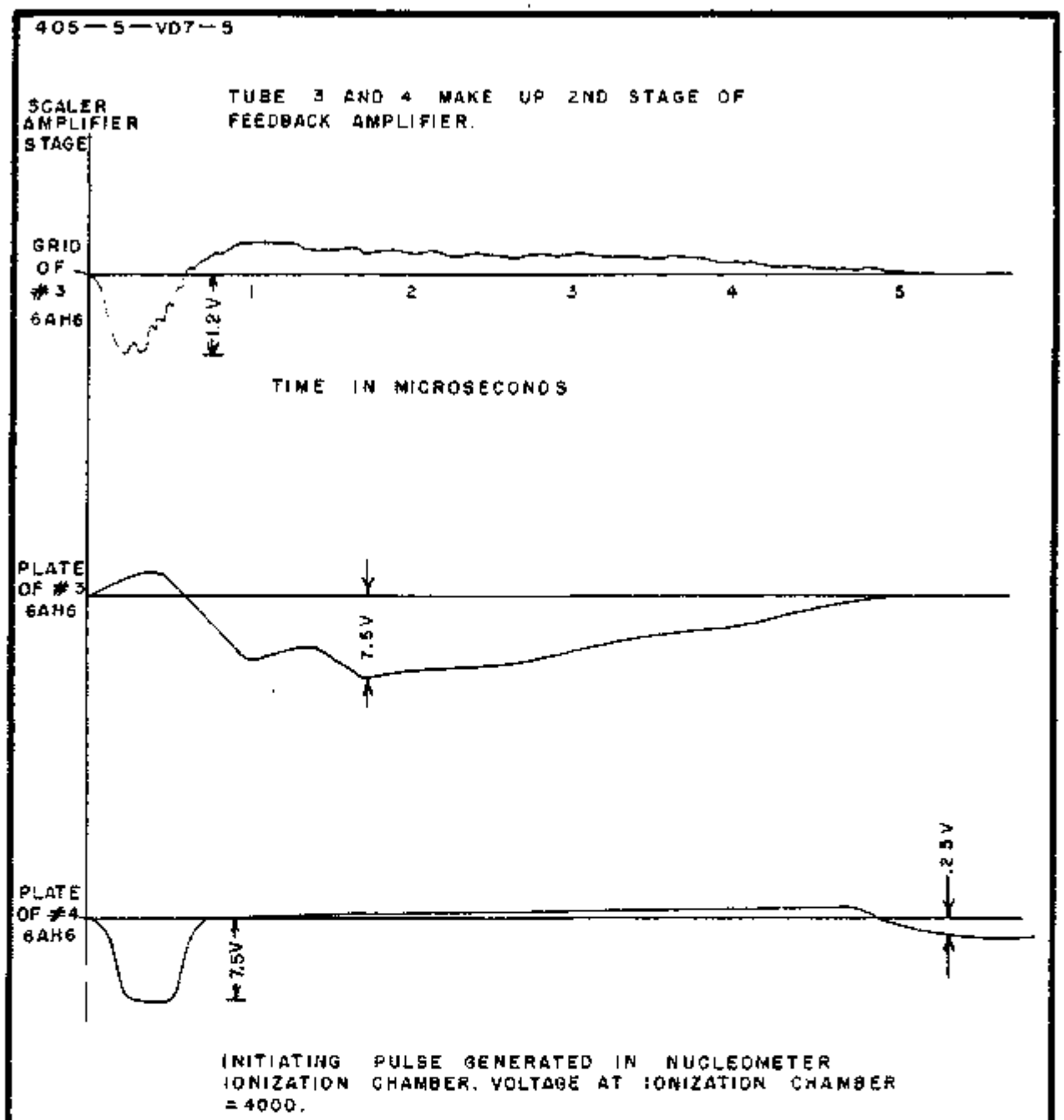
Experimentation showed that this rise in counting rate was caused by spurious pulses which developed in the amplifier. These pulses were caused by overloading of the amplifier, poor recovery time of the amplifier, and poor low-frequency response. The effect of a modified commercial



PLATEAU CURVE OF ALPHA EMITTER USING COMMERCIAL AMPLIFIER

amplifier on strong pulses from the ionization chamber is shown in Figure 2. (The modification consisted of increasing the mid-frequency gain from 0.6 to 4 megacycles. The low-frequency response of the amplifier was unchanged and began to drop at 0.1 megacycle.) It is to be noted that a phase reversal exists in the 3rd and 4th tube of the chain-of-two inverse feed back amplifier and that its output contains a spurious pulse which occurs approximately four microseconds after the main pulse. The effective phase reversal in these tube circuits is caused by non-linear amplification of the very strong pulses with their overshoot which occur when alpha particles are present in an ionization chamber whose gas amplification is very large. The amplitude of the spurious pulse is sufficient to trip the trigger pair, thereby causing a count to be registered. A spurious pulse is caused by an overshoot of the main pulse when the recovery time and low-frequency response of the amplifier are poor. The theory of overshoots has been thoroughly covered by Valley and Wallman.[5]

The main problem now becomes one of limiting the overshoot regardless of the input voltage. Since the maximum sensitivity of our trigger pair is approximately 100 millivolts and the gain of the amplifier is approximately 300, the overshoot was limited to 0.33 millivolts. This limitation may be achieved by designing an amplifier with a fast recovery time and a relatively low frequency characteristic. The amount of overshoot that can be tolerated is inversely proportional to the gain of the amplifier.



PULSE SKETCH SHOWING PHASE REVERSAL AND OVERSHOOT OCCURING IN SCALER AMPLIFIER.

PROPORTIONAL IONIZATION CHAMBER OUTPUT PULSE

Next to the problem of overshoots was the problem of amplifier overloading. As a prelude to this problem the maximum input voltage to be expected was computed and verified by experiment.

$$V = \frac{Q}{C} \tag{4}$$

where:

V = Volts.

Q = Charge in coulombs (charge of electron = 1.59×10^{-19} coulombs).

C = Capacity in farads.

A value of 23×10^{-12} farads was used for C as this was the capacity of our experimental setup which included a Nucleometer ionization chamber (two inches in diameter), circuit wiring, and oscilloscope input. The method of connection is shown in Figure 3.

For the purpose of computation, we assumed that the primary alpha ionizing event forms an average of 4×10^4 ion pairs (Pu^{239}) in one centimeter of travel.

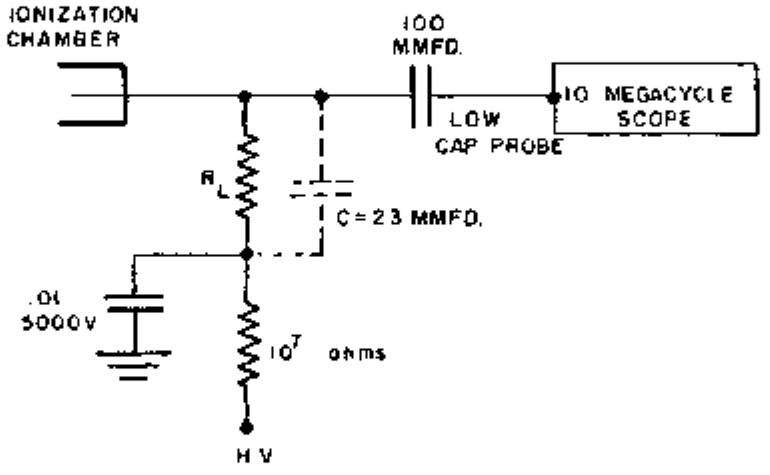
Therefore,

$$Q = (1.59 \times 10^{-19}) \times (4 \times 10^4) = 6.36 \times 10^{-15} \text{ coulombs}$$

$$V = \frac{6.36 \times 10^{-15}}{23 \times 10^{-12}} = 0.276 \times 10^{-3} = 0.276 \text{ millivolts}$$

Assuming a gas amplification of 10^4,

$$V = 0.276 \times 10^{-3} \times 10^4 = 2.76 \text{ volts/cm.}$$



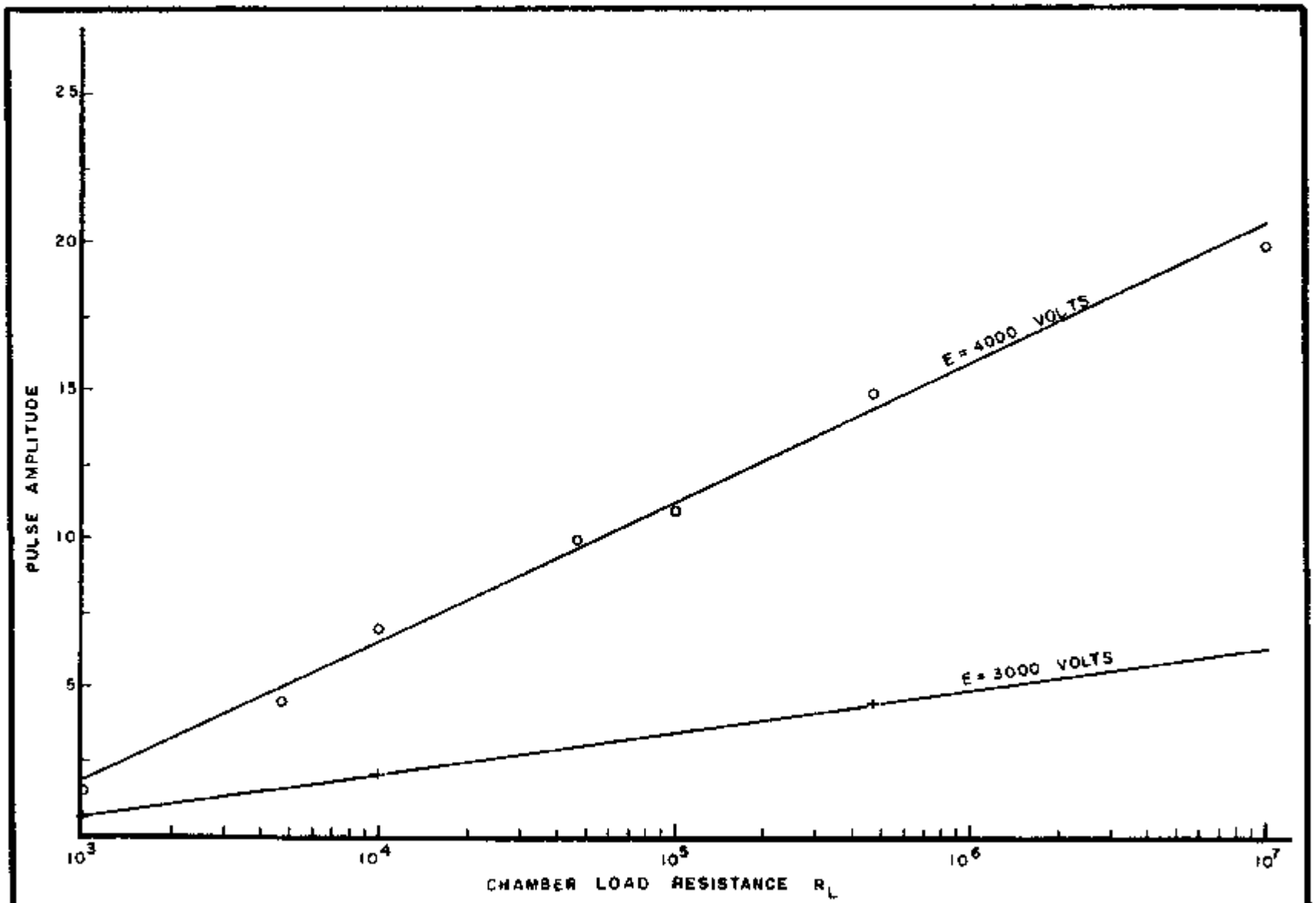
CIRCUIT FOR MEASURING PULSE AMPLITUDE

Assuming an alpha sample with a maximum range of approximately 3.68 centimeters (Pu^{239}),

$$V\ (\text{total}) = 2.76 \times 3.68 = 10.2 \text{ volts.}$$

To check our calculations the maximum pulse output of the ionization chamber, just under the voltage of continuous discharge, was measured with a Model 511AD Tektronix oscilloscope (10-megacycle bandwidth). The pulse voltage obtained across 10^7 ohms was 20 volts which is of the same order of magnitude as the calculated value. Since $V = Q/C$ a reduction of C from 23 to 12 micro-microfarads (capacity of circuit wiring and ionization chamber) should raise V from 20 to approximately 40 volts across 10^7 ohms. From these data it can be seen that large pulses may be expected from an ionization chamber if the gas amplification is high, the capacity low, and if the ionizing event is initiated by an alpha particle. This pulse of 20 volts amplitude was obtained across 10^7 ohms which in conjunction with the circuit capacity produced a pulse 400 microseconds long. Since this pulse was too long, we checked the effect of the load resistance, R_L, on the pulse height and duration. The results are shown in Table I. Pulse height versus load resistance is plotted as a straight line on semi-logarithmic graph paper in Figure 4.

Since the change in output voltage versus load resistance, R_L, is a logarithmic function, the maximum voltage dropped from 20 to 1.5 volts as the resistance was decreased from 10 megohms to 1,000 ohms. The pulse duration when using this load resistance of 1,000 ohms was 0.3 microsecond. This duration was caused by the short time constant of the external circuit of the ionization chamber.



EFFECT OF R_L ON THE AMPLITUDE OF IONIZATION CHAMBER PULSES

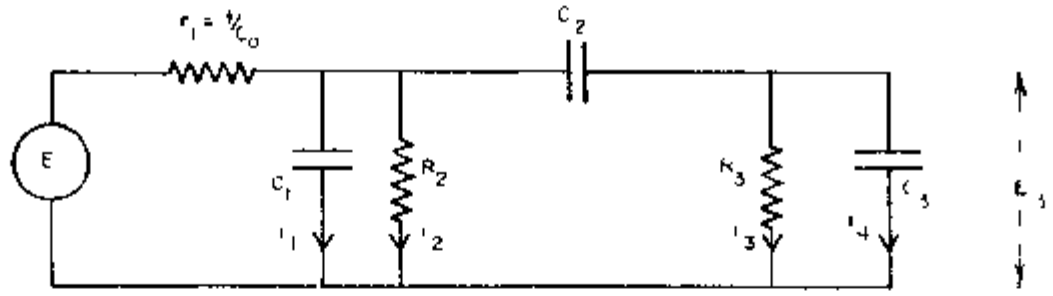
Table I

THE DEPENDENCE OF PULSE HEIGHT AND PULSE DURATION ON THE IONIZATION CHAMBER LOAD RESISTANCE

Ionization Chamber Voltage (Volts)	Ionization Chamber Load Resistance (Ohms)	Pulse Duration at Base (Microseconds)	Maximum Pulse Amplitude (Volts)
4,000	1,000	0.3	1.5
4,000	4,700	0.6	4.5
4,000	10,000	1.0	7.0
4,000	47,000	4.0	10.0
4,000	100,000	6.0	11.0
4,000	470,000	50.0	15.0
4,000	10,000,000	400	20.0
3,000	1,000	0.3	0.6
3,000	10,000	0.6	2.0
3,000	470,000	30.0	4.5

Since the output voltage of the ionization chamber was not a simple function of load resistance, we decided to derive an equation which would show the relationship between the generated voltage and the various circuit parameters across the chamber. The equivalent circuit of the ionization chamber and its network is shown in Figure 5. From this circuit the following equation was derived:

$$E_3 = \frac{Kt\sum^{-\frac{\beta}{2a}t} \sin\sqrt{\frac{\gamma}{a} - \frac{\beta^2}{4a^2}}}{a\sqrt{\frac{\gamma}{x} - \frac{\beta^2}{4x^2}}} \qquad (5)$$



EQUIVALENT CIRCUIT OF IONIZATION CHAMBER AND EXTERNAL NETWORK

where:

$K = ER_2R_3C_2$

$\alpha = (C_2C_3 + C_1C_2 + C_1C_3)\, r_1R_2R_3$

$\beta = r_1R_3(C_2 + C_3) + r_1R_2(C_1 + C_2) + R_2R_3(C_2 + C_3)$

$\gamma = r_1 + R_2$

E = Equivalent generated voltage

$r_1 = dt/C_o$

$C_o = \dfrac{C_1C_2 + C_1C_3 + C_2C_3}{C_2 + C_3}$

E_3 = Output voltage of network

Example of $E_3 = \int(t)$

The following values were substituted in the equation for the determination of E_3 and t:

$E = 13$ volts

$C_o = 12.6 \times 10^{-12}$ farads

$C_1 = 4.6 \times 10^{-12}$ farads

$C_2 = 10^{-10}$ farads

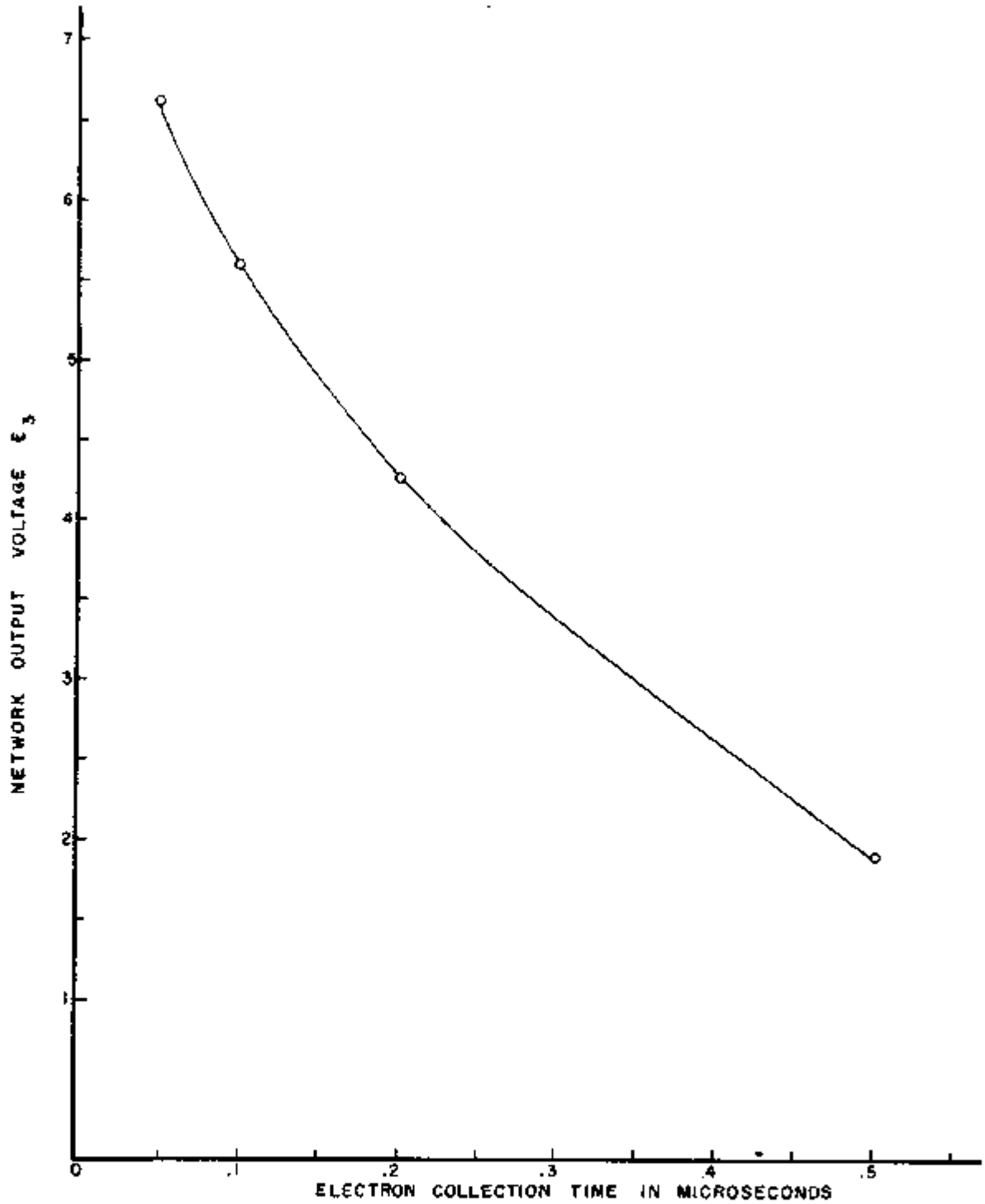
$C_3 = 8 \times 10^{-12}$ farads

$r_1 = t/C_o$

$R_2 = 10^7$

$R_3 = 10^4$

A graph of network output voltage, E_3, versus electron collection time, t, was plotted as shown in Figure 6. A study of this graph indicates that E_3 approaches the generated voltage as the electron collection time approaches



ELECTRON COLLECTION TIME WITHIN ION CHAMBER VERSUS NETWORK OUTPUT VOLTAGE (GENERATED VOLTAGE = 13)

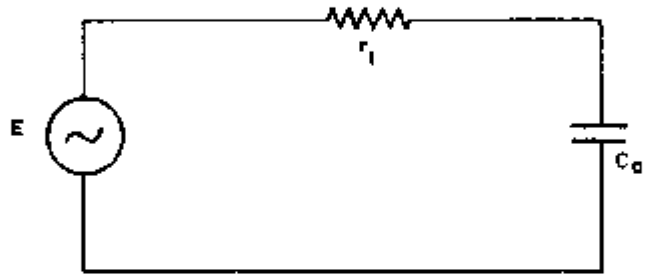
zero. This study helps to explain the reason the voltage E_3 changed from 20 to 1.5 volts, a factor of approximately 13, while the load resistance changed from 10^7 to 10^3 ohms, a factor of 10,000. In the above analysis, r_1 is a variable resistance which is a function of time Δt. The method of computing r_1 is described below.

In the circuit of Figure 7, r_1 represents the equivalent resistance of an ionization chamber as the charge is collected. When the collection time is zero, the current, q/t, is infinitely large, the equivalent resistance is zero, and the full voltage is developed across C instantaneously. When the collection time is finite, a retarding element is assumed to be present, and the voltage across C does not reach a maximum until some finite time after zero.

$$r_1 = \frac{e}{i} = \frac{q/C}{q/t} = \frac{1/C}{1/t} = \frac{1}{C}\,t$$

where r_1 is the equivalent resistance of the ionization chamber for the increment of Δt considered, e is the instantaneous voltage across the capacity C, and i is the instantaneous current which produces the voltage e. In other words this analysis says that the maximum voltage is built up in an ionization chamber when the instantaneous charges are collected faster than they can leak off.

The pulse height from the network will approach the voltage generated in the ionization chamber when the electron collection time is relatively short. Therefore, it may be possible to develop sufficient voltage to operate a trigger pair by collimating the particles so that their path is parallel to the center wire of the chamber. Collimating the particles might be done



EQUIVALENT CIRCUIT OF IONIZATION CHAMBER

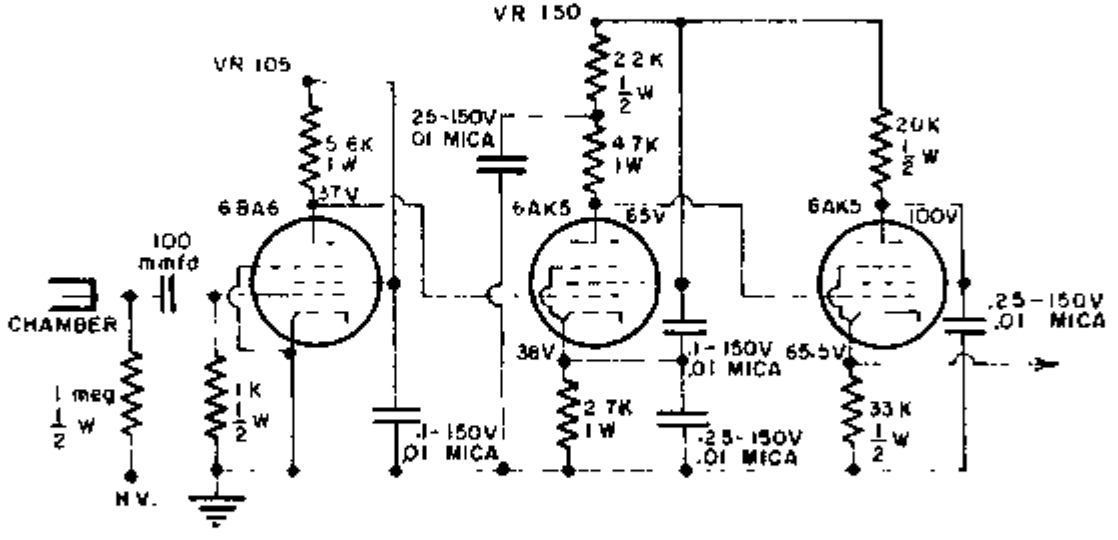
magnetically or electrostatically. However, because of the large fields that would be required to collimate alpha particles in these ways, collimation by geometric means would probably prove most satisfactory for strong alpha samples.

Since the maximum voltage expected from the ionization chamber loaded with 1,000 ohms of resistance was 1.5 to 3.0 volts depending on the shunt capacitance, our next step was the determination of the minimum pulse to be expected. By varying the "Sync" voltage control of the test oscilloscope we found that the spread of alpha pulses was at least 50 to 1. Based on a three-volt maximum pulse the minimum should be approximately 30 millivolts which allows a safety factor of 2 to 1. The literature indicated that a Pu^{239} alpha of 5.16 million electron volts developed a total ion pair formation of 1.47 x 10^5 in 3.68 centimeters[6] representing an average of 40,000 ion pairs per centimeter. In contrast to this a medium velocity beta particle forms 100 ion pairs[7] per centimeter. This represents a spread of 400 to 1 when the chamber is operated in the proportional region. For design purposes a somewhat smaller spread can be figured since advantage may be taken of the tendency toward pulse equalization which occurs in the limited proportional region of the ionization chamber, where beta particles may be readily counted. Because of pulse equalization less gain is needed to bring the pulse height to 0.25 volts, the sensitivity of our trigger pair. As shown later our amplifier with a gain of 300 worked satisfactorily. This does not mean that this gain is the ultimate but it is sufficient to illustrate the points we are emphasizing in this paper.

DESIGN OF THE AMPLIFIER

With the accumulated data on hand it became apparent that the design of a useful amplifier should incorporate the following features: (1) a fast recovery time, (2) a relatively good low frequency response, (3) the ability to accept pulses of widely varying heights without developing spurious pulses, (4) have a limiting output stage, (5) the ability to preserve the inherently short rise time of the chamber, (6) minimum pulse integration, and (7) have sufficient gain to detect weak pulses well below the chamber voltage at which continuous discharge begins.

The experimental amplifier designed to accomplish this is shown in Figure 8. For an amplifier in a counting system it has several unique features: (1) a low input resistance of 1,000 ohms, (2) a remote cutoff input pentode, (3) direct coupling, and (4) a voltage output limiter. The 1,000-ohm resistor allows a pulse of short rise time and short duration, the remote cutoff pentode accepts pulses of widely varying heights, direct coupling allows a fast recovery time, eliminates parts, and allows the second tube to be operated near zero bias for maximum mutual conductance, while voltage limiting prevents overloading of the trigger pair coupling circuit. A cathode-follower output stage allows the amplifier to be mounted at the ionization chamber, thereby keeping the pulse integration and attenuation to a minimum. The dimensions of the amplifier are 4 1/4 x 3 x 2 inches. Two views of it are shown in Figures 9 and 10.



MODEL II AMPLIFIER

FIGURE 9

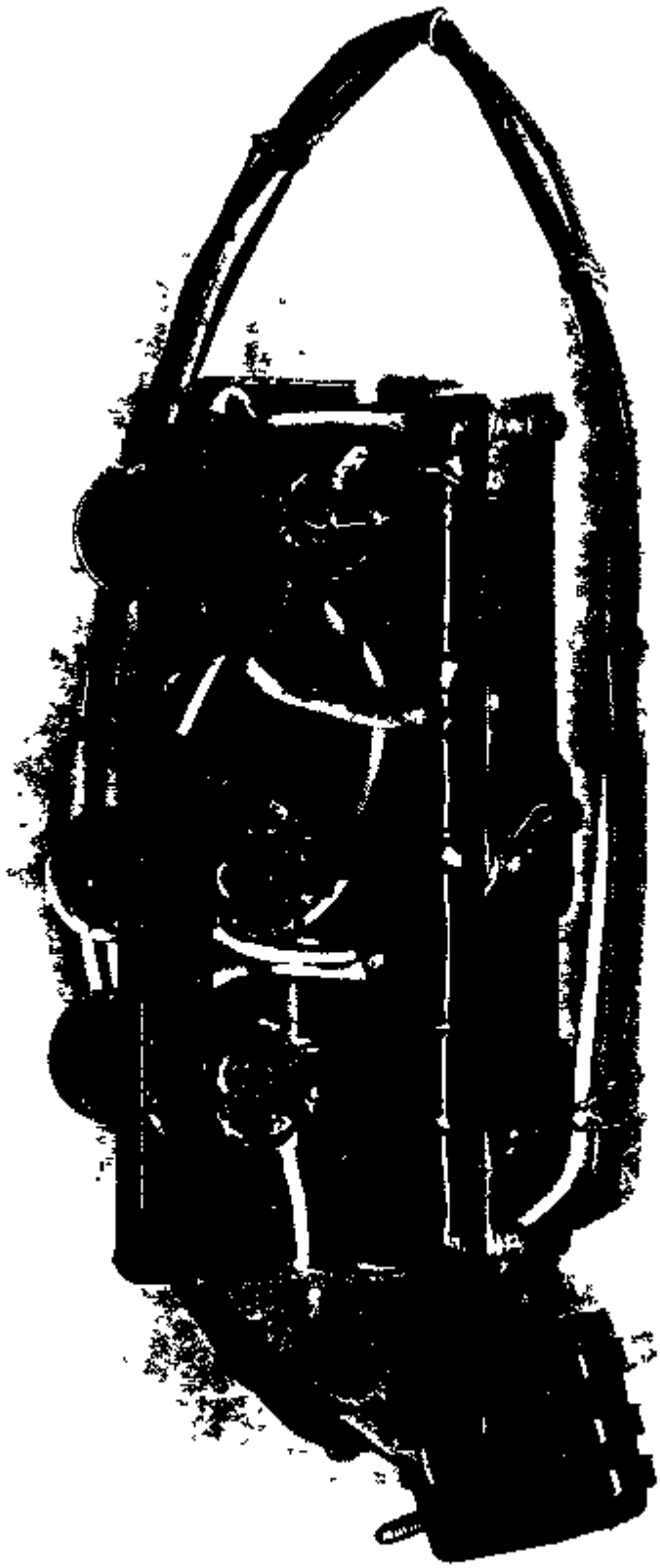
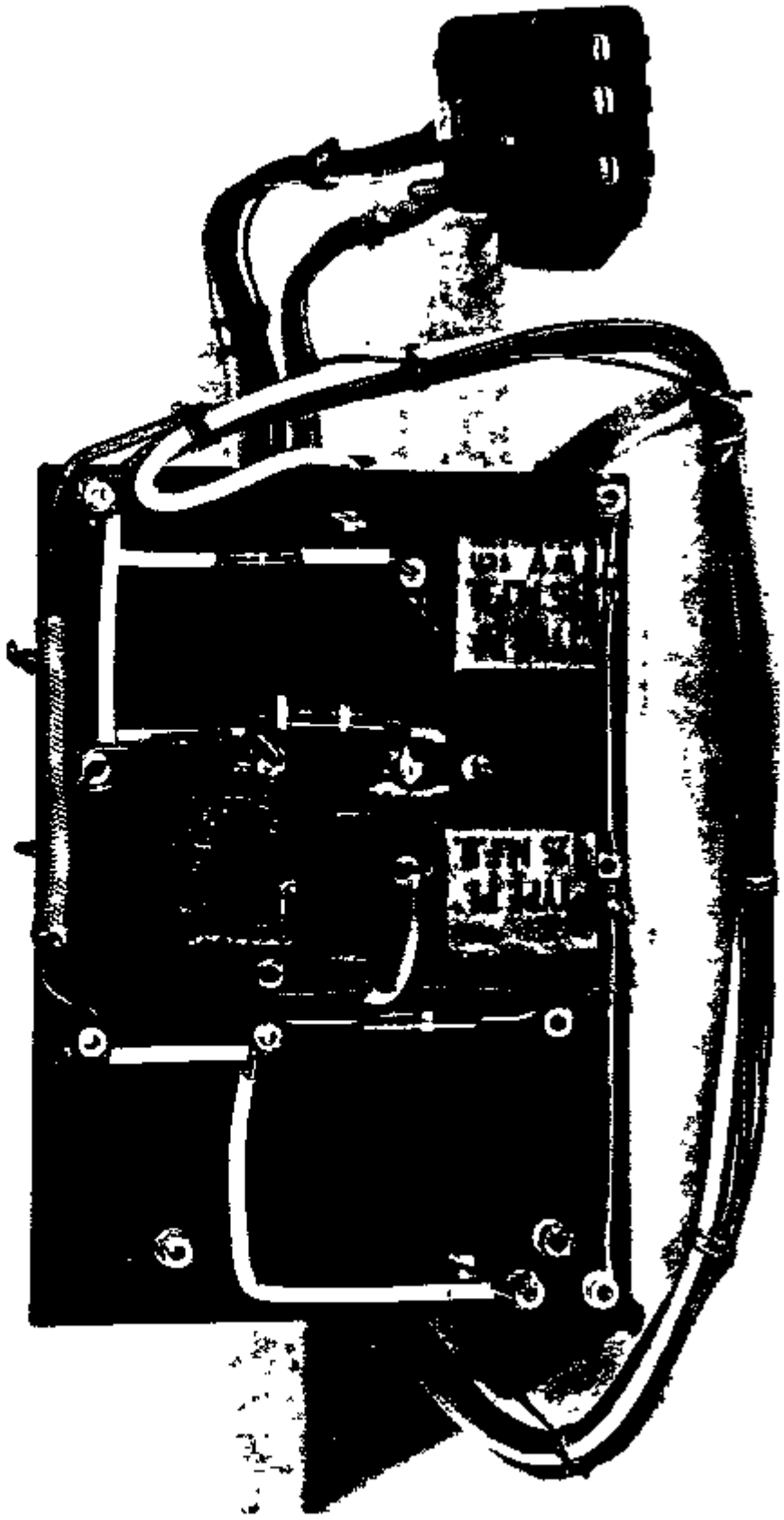


FIGURE 10

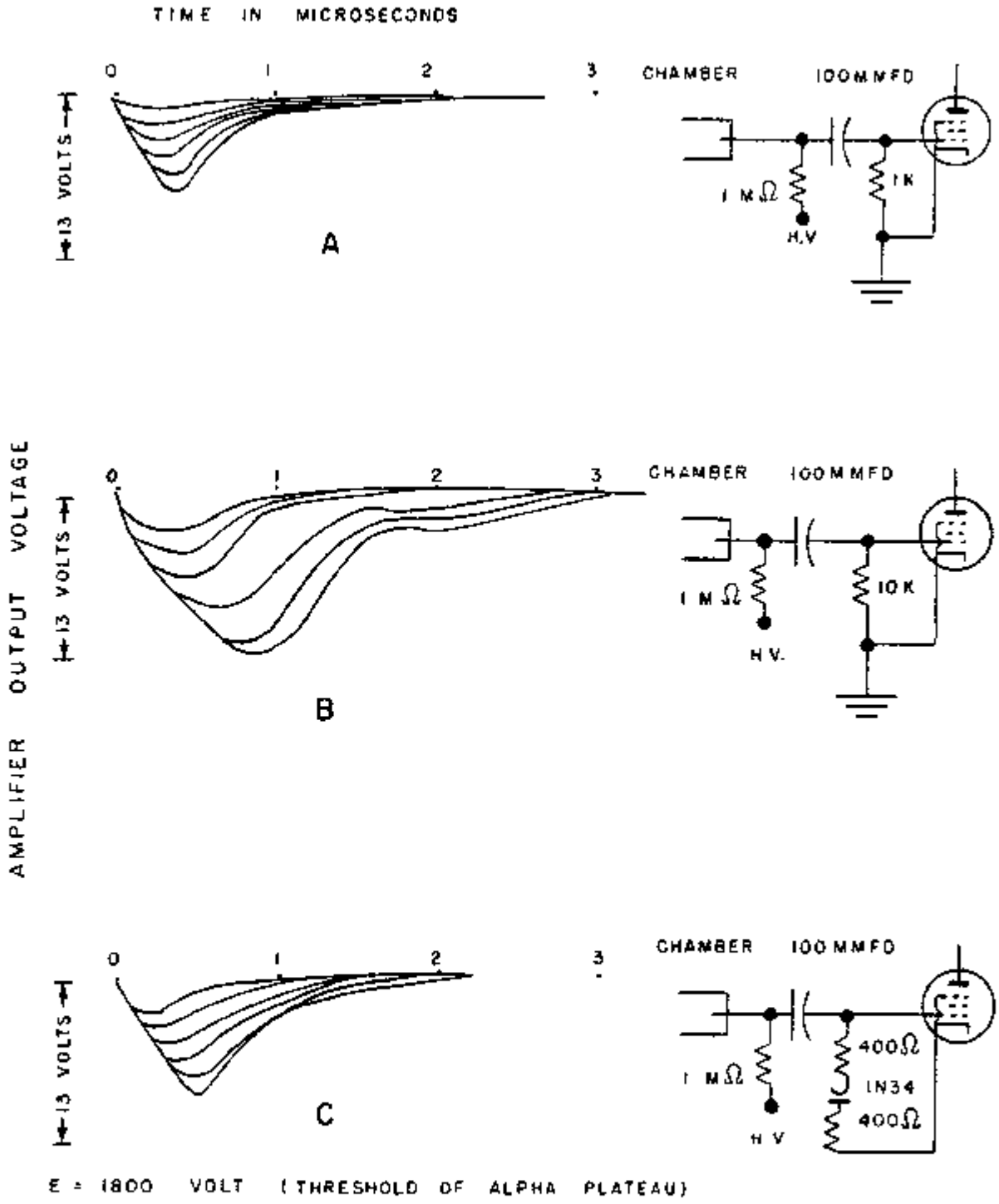


The output of the amplifier is limited to 7.5 volts when pulsed with 5 volts from a pulse generator. However, 4 volts was the maximum output obtained when the amplifier was pulsed with the maximum signal from a Simpson proportional counter.

RESULTS OBTAINED WITH NEW AMPLIFIER

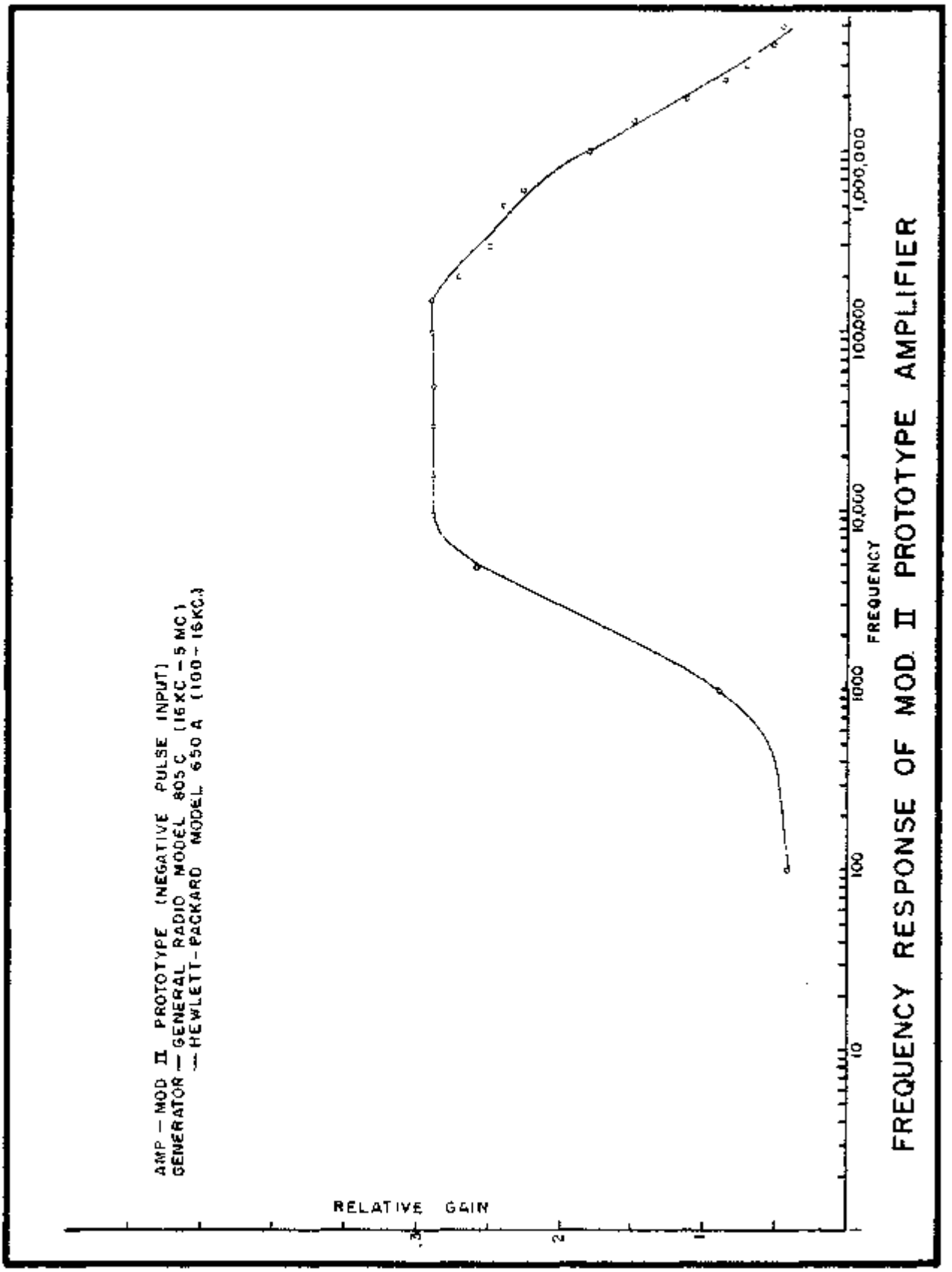
The effect of the 1,000-ohm input resistor on the pulse shape is shown in Figure 11A. Figures 11B and 11C show the effect of other resistors on the pulse shape. The frequency response of the amplifier is shown in Figure 12. Figure 13 shows a graph of counts per minute versus chamber voltage obtained with a plutonium sample when using the experimental amplifier. (Pu^{239} is an alpha-gamma emitter with some internal-conversion electrons.[8]) There are two distinct plateaus, one an alpha plateau and the other an alpha plus gamma plus internal-conversion electron plateau. It seems logical to assume that no detectable amount of spurious counts are developed when an alpha and alpha plus gamma plateau is obtainable, otherwise the counting rate would continue to rise instead of leveling off. The effect of spurious counts are illustrated in Figure 1.

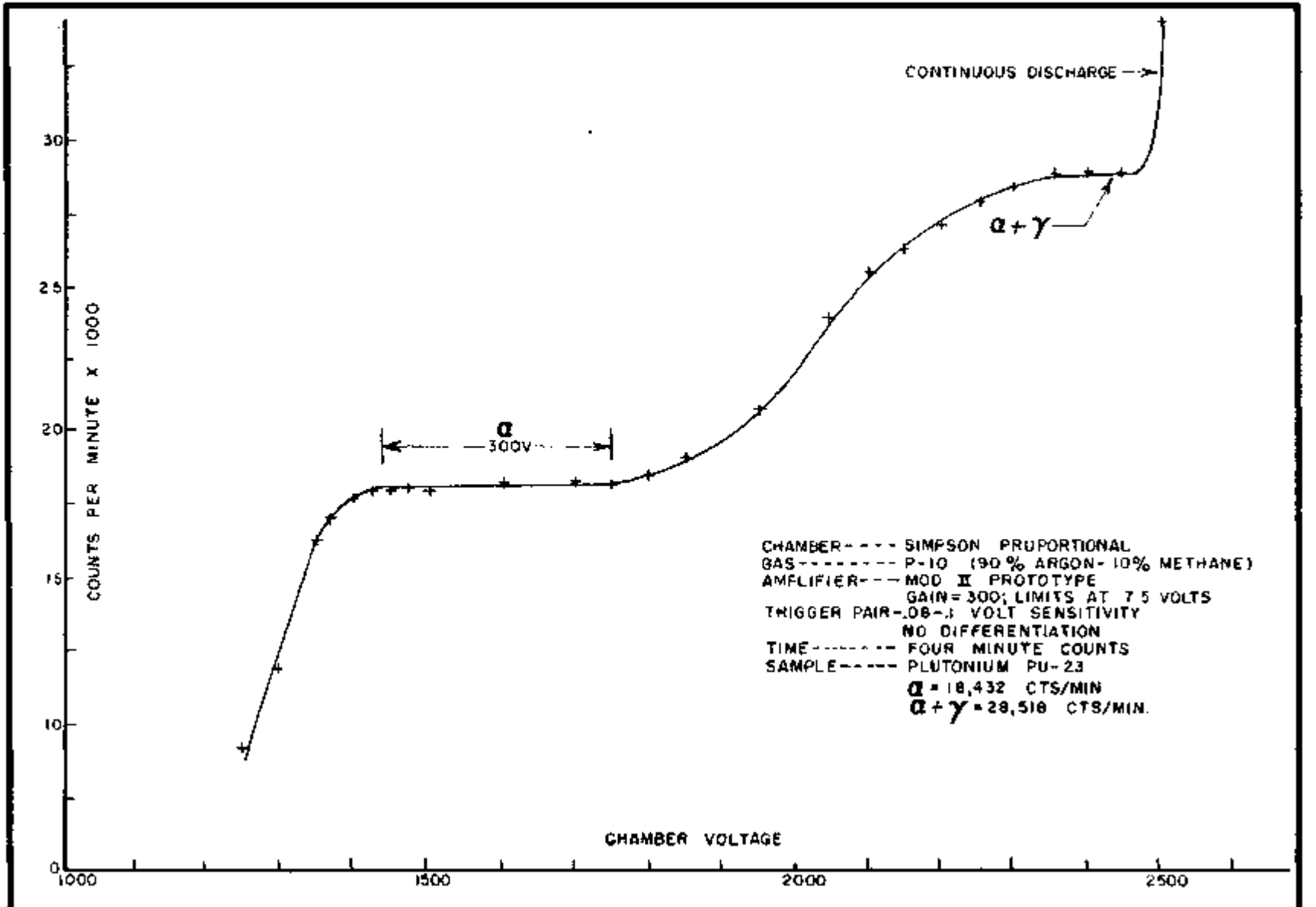
To further test our amplifier a pure alpha emitter was placed in the ionization chamber and a graph drawn from the data obtained. The results are shown in Figure 14. This curve should be compared with that of Figure 1 to judge the effectiveness of the experimental amplifier. This plateau has been increased from 300 to 1,000 volts in length and is level up to the voltage where continuous discharge begins.



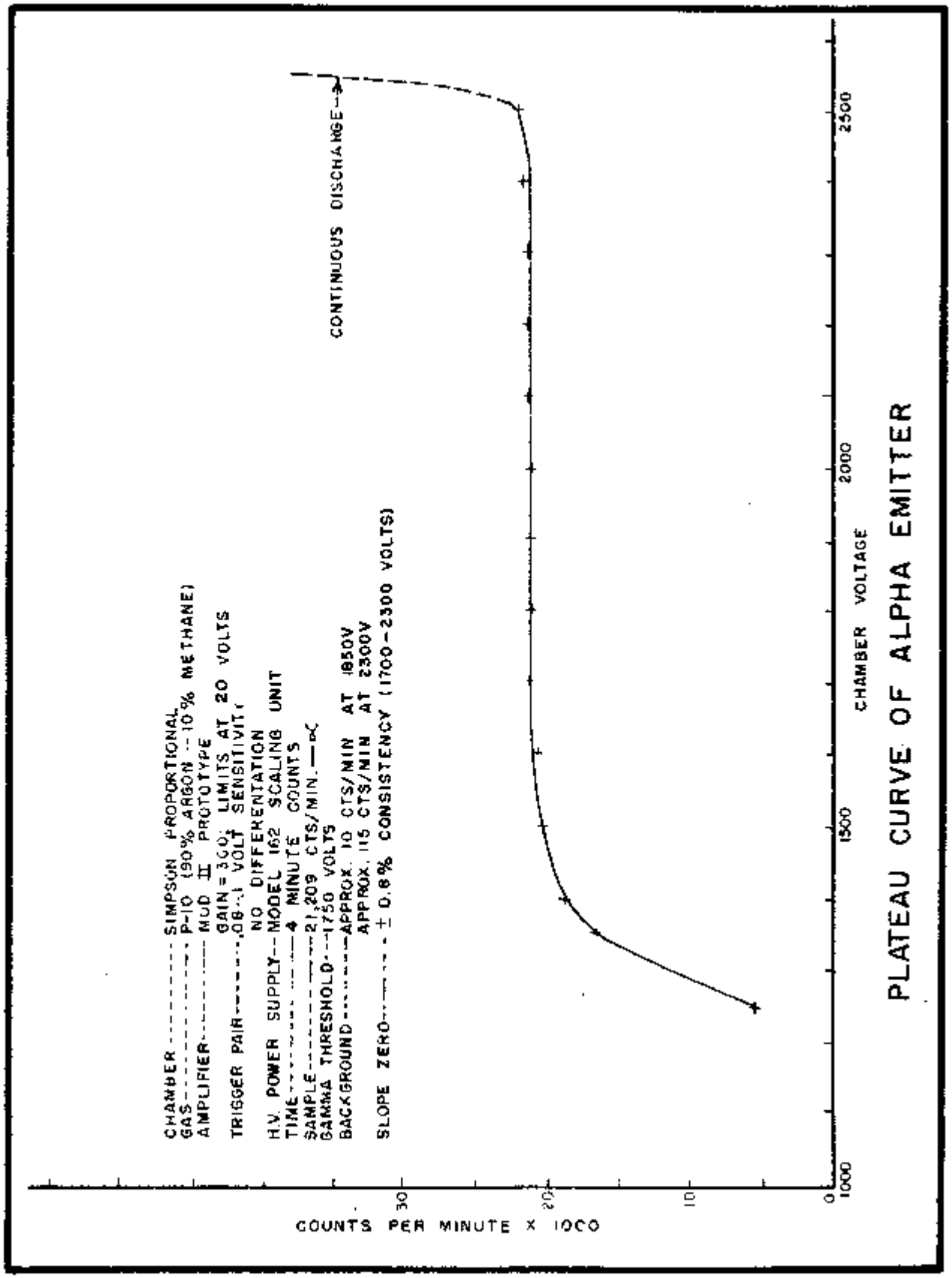
E = 1800 VOLT (THRESHOLD OF ALPHA PLATEAU)

PULSE SHAPE OUTPUT OF MODEL 2 AMPLIFIER WITH VARIOUS INPUT RESISTANCES


AMP — MOD II PROTOTYPE (NEGATIVE PULSE INPUT)
GENERATOR — GENERAL RADIO MODEL 805 C (16 KC – 5 MC)
— HEWLETT-PACKARD MODEL 650 A (100 – 16 KC.)
RELATIVE GAIN
FREQUENCY
10
100
1000
10,000
100,000
1,000,000
FREQUENCY RESPONSE OF MOD. II PROTOTYPE AMPLIFIER



PLATEAU OBTAINED WITH ALPHA-GAMMA EMITTER & MODEL II AMPLIFIER


CHAMBER ---------- SIMPSON PROPORTIONAL
GAS ---------- P-10 (90% ARGON - 10% METHANE)
AMPLIFIER ---------- MOD II PROTOTYPE
GAIN = 300; LIMITS AT 20 VOLTS
TRIGGER PAIR ---------- .08-.1 VOLT SENSITIVITY
NO DIFFERENTIATION
H.V. POWER SUPPLY -- MODEL 162 SCALING UNIT
TIME ---------- 4 MINUTE COUNTS
SAMPLE ---------- 21,209 CTS/MIN. — α
GAMMA THRESHOLD ---- 1750 VOLTS
BACKGROUND ---------- APPROX. 10 CTS/MIN AT 1850V
APPROX. 115 CTS/MIN AT 2300V
SLOPE ZERO ---------- ± 0.8% CONSISTENCY (1700-2300 VOLTS)
CONTINUOUS DISCHARGE
COUNTS PER MINUTE X 1000
0
10
20
30
1000
1500
2000
2500
CHAMBER VOLTAGE
PLATEAU CURVE OF ALPHA EMITTER

We were unable to obtain accurate data on the resolving time of this amplifier as no equipment was available which had a trigger pair with a resolving time short enough to allow an accurate check of Tau. A check of Tau using a standard scaling circuit and the experimental amplifier was made and was found to be 6.39×10^{-8} which is comparable to that obtained with the Simpson proportional counting system now in use. A comparison of the pulses of Figure 15A and 15B would indicate that a shorter resolving time should be possible with the experimental amplifier when used with a scaler whose resolving time is short enough to allow an accurate test.

APPENDIX

To derive Equation 5, four equations were set up as follows (refer to Figure 5):

$$E = (i_1 + i_2 + i_3 + i_4)\, r_1 + \frac{1}{C_1} \int i_1\, dt$$

$$0 = i_2 R_2 - \frac{1}{C_1} \int i_1\, dt$$

$$0 = -R_2 i_2 + \frac{1}{C_2} \int (i_3 + i_4)\, dt + i_3 R_3$$

$$0 = -i_3 R_3 + \frac{1}{C_3} \int i_4\, dt$$

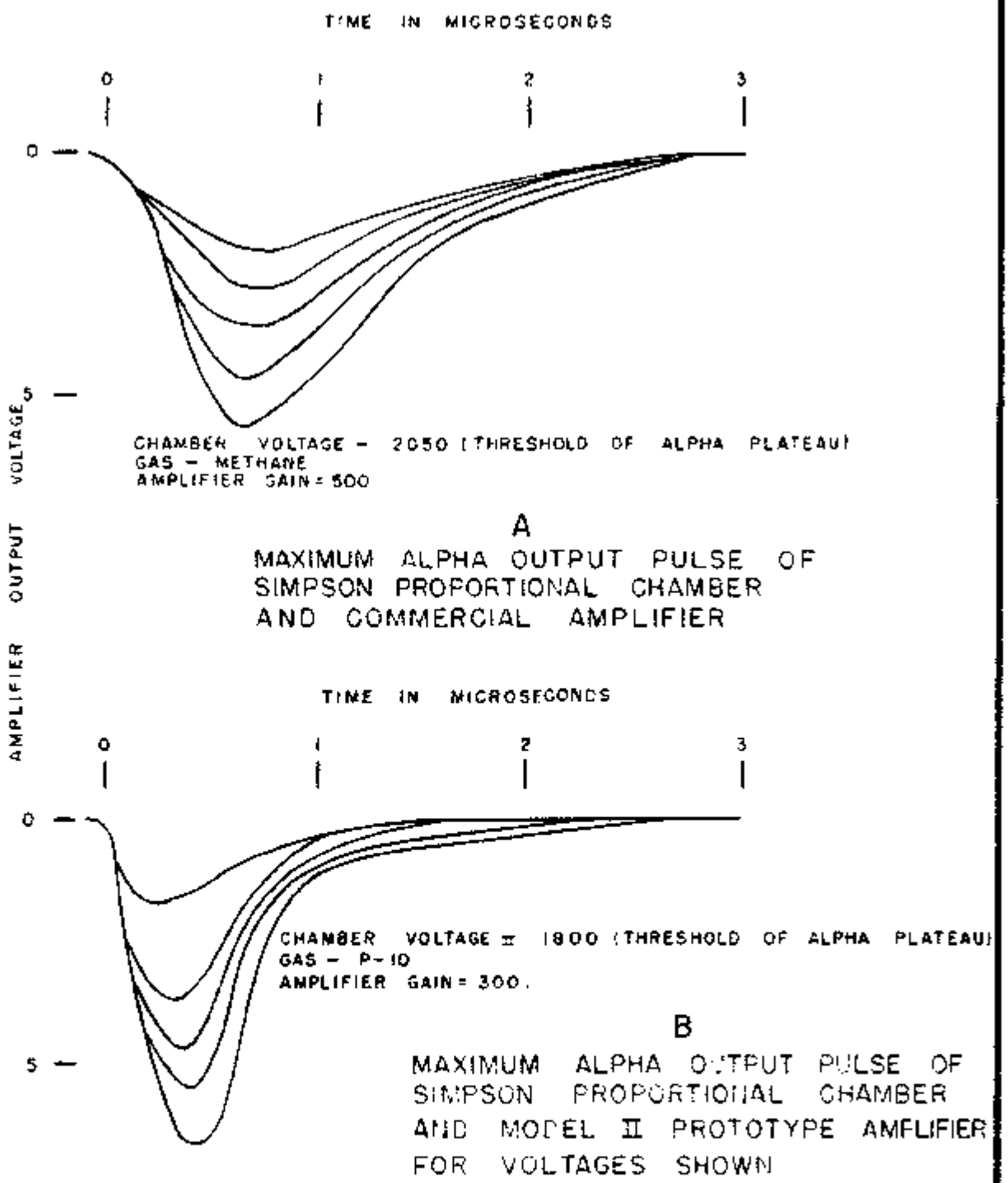
From the use of the La Place Transform[9]

$$\int_0^{\infty} e^{-st}\, F(t)\, dt = f(s)$$

the following equations were obtained:

$$E/s = \left[1/C_1 s + r_1 \right] I_1 + r_1 I_2 + r_1 I_3 + r_1 I_4$$

$$0 = \left[-1/C_1 s \right] I_1 + R_2 I_2 + 0 + 0$$



COMPARISON OF OUTPUT PULSE OBTAINED WITH COMMERCIAL AMPLIFIER AND MODEL II WIDE DYNAMIC RANGE LIMITING AMPLIFIER

$$0 = 0 - R_2 I_2 + \left[1/C_2 s + R_3\right] I_3 + \left[1/C_2 s\right] I_4$$

$$0 = 0 + 0 - R_3 I_3 + \left[1/C_2 s\right] I_4$$

Using determinants I_3 is found to be:

$$I_3 = \frac{E\, R_2 C_2}{\alpha s^2 + \beta s + \gamma}$$

when

$$\alpha = (C_2C_3 + C_1C_2 + C_1C_3)\, r_1R_2R_3$$

$$\beta = r_1R_3\,(C_2 + C_3) + r_1R_2\,(C_1 + C_2) + R_2R_3\,(C_2 + C_3)$$

$$\gamma = r_1 + R_2$$

Referring to table of Transform pairs[10]

$$i_3 = \frac{E\, R_2C_2 \Sigma^{-\frac{\beta}{2\alpha} t} \sin \sqrt{\frac{\gamma}{\alpha} - \frac{\beta^2}{4\alpha^2}}\; t}{\alpha \sqrt{\frac{\gamma}{\alpha} - \frac{\beta^2}{4\alpha^2}}}$$

$$E_3 = i_3R_3 = \frac{E\, R_2R_3C_2 \quad -\frac{\beta}{2\alpha} t \sin \sqrt{\frac{\gamma}{\alpha} - \frac{\beta^2}{4\alpha^2}}\; t}{\alpha \sqrt{\frac{\gamma}{\alpha} - \frac{\beta^2}{4\alpha^2}}}$$

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The author gratefully acknowledges the La Place solution leading to Equation 5 performed by Adrian Rogers of Mound Laboratory and the many helpful suggestions and encouragement tendered by Josef Heyd and Phillip Ohmart also of Mound Laboratory.

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