A PROPORTIONAL COUNTER SPECTROMETER

by

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TABLE OF CONTENTS

INTRODUCTION

The purpose of a proportional counter spectrometer is to detect and measure the energy and intensity of electromagnetic radiation and nuclear particles. The significant function is accomplished in the counter tube and the results, in the form of electrical pulses, are analyzed by electronic devices. The size of the pulse is proportional to the energy of the incident particle. A discriminator is used which can record the number of pulses of a certain size or which lie within a given interval.

The counter tubes are usually cylindrical with a wire along the axis of the cylinder. The cylinder is filled to a desired pressure with a gas or a mixture of gases and a high voltage is placed across the cylinder and the wire with the wire positive with respect to the shell. A window is provided in the shell to allow radiation to reach the interior of the tube.

When a voltage V is applied to the tube whose wire radius is A and whose inside radius is B, the field intensity E at any point inside the tube a distance R from the wire is given by the relation:

$$E = \frac{V}{R \ln B/A}$$

The field is greatest near the wire and for the smallest sizes of wires. Since high field intensities are desired, wires larger than five-mil are usually not used. The smallest usable wire size is determined by its fragility. The length of the tube is chosen to be long enough that no radiation causes ionization near the end of the tube where the field is distorted due to the end effect.

As the voltage across the counter is increased from zero, the counter passes through three regions. These are commonly known as the ionization chamber region, the proportional region and the Geiger region. In the first region, the electric field within the chamber does not accelerate the ions sufficiently to cause further ionization and the process stops with the initial ionizing event. In the second region, the ions have greater acceleration and as they move toward the anode, they acquire enough energy in one mean free path to create ionization by collision with another gas atom. All collisions hereafter will produce ionization and an avalanche is formed. This continues until the ionizing electrons reach the wire and are collected there. They will change the potential of the wire by an amount

$$dV = \frac{ANe}{C}$$

where N is the number of ion pairs formed by the initial event, A is the number of additional ion pairs formed plus the original ion, ie, the gas amplification, e is the charge of the ion and C is the distributed capacity of the counter. The pulse formed is much larger but is still proportional to the energy of the incident particle since the initial energy controls the number of ion pairs formed by the initial event. In the Geiger region, the entire field within the counter is of such intensity that all collisions cause ionization. As the negative ions, in the form of electrons, move toward the anode, the positive ions move toward the cathode at a much slower rate. These positive ions form a space charge which tends to reduce the field as seen by the electrons and the magnitude of the ionizing process is quenched. Therefore the height of the pulse is no longer proportional to the energy of the incident radiation but is controlled entirely by the positive space charge. A counter of this kind can be used only to count the number of particles producing ionization.

In the proportional region the field is of sufficient magnitude to cause ionization only near the anode. This gives a shorter distance to travel for the electrons than for the positive ions before being collected. This shorter distance combined with the greater mobility of the electrons makes the collection time, after initial ionization, of the electrons much less than that of the positive ions. The contribution of the positive ion sheath to the voltage change at the grid is negligible since the positive ion sheath is collected in much longer time than is the RC time of the coupling network and the charge leaks off as quickly as it is collected. If the entire pulse is to be considered, the RC time constant must be large as compared to the collection time of the electrons and the positive ions. In practice the contribution of the positive ions is not considered and hence the RC time constant is made large only compared to the collection time of the electrons. The dead time or recovery time of the proportional counter is much less than for the Geiger counter. This is attributed to the fact that in the Geiger region, the positive ion sheath renders the counter inoperative until it can be collected which is a time of about 100 to 200 micro-seconds as reported by Korff (16). He estimated that the time to collect the negative ions in a proportional counter is between one-tenth and ten micro-seconds. In the Geiger counter the discharge takes place over the entire volume of the counter and the large positive ion sheath renders the entire counter inoperative until the positive sheath can be collected. In the proportional region, the ionization takes place only over small regions in the tube and the rest of the tube is free to receive additional particles for counting. Therefore the recovery time in a counter is dependent upon such things as geometry of the counter, voltage, gas filling and the location in the chamber of the initial ionizing event. If the wire is made small, the chamber large, and the chamber voltage as small as possible and still have sufficient gas gain to obtain reproducable pulses, then the location of the initial ionization is essentially eliminated as a variable controlling the recovery time since these ideal conditions make the sensitive region a very small cylindrical volume about the wire and the electrons traveling the very short distance to the anode are collected in a very short time, hence the recovery time is very short.

The distance from the wire that the initial ionization occurs determines the number of mean free paths between the point of ionization and the wire thereby controlling the number of collisions and the amount of secondary ionization, i.e., the gas gain, which also determines the size of the pulse. If the ideal conditions are approached, then essentially all the initial ionization occurs at the same distance from the wire and this factor is eliminated as a function of the pulse height.

A uniform field is desired so that a constant gas amplification will be maintained. At the end of the chamber the inside diameter is much smaller for construction reasons and extremely large fields are present. Near the end of the chamber the field is non-uniform. To eliminate these effects, the window is put in the center of the chamber and the chamber is made long. This insures that the initial ionization will take place in the uniform field region near the center of the chamber.

For particles of energy greater than 150 kev., the initial ionization produces pulses of sufficient magnitude to be investigated without any gas gain. For such particles an ionization chamber can be used. A proportional counter is used for energies lower than this and relies upon gas gain to obtain pulses of necessary magnitude.

The necessary equipment for a proportional counter spectrometer is; (1) a stabilized high voltage power supply, (2) a linear high gain amplifier, (3) a discriminator, (4) an ionization chamber and (5) a pulse counting unit. The latter was available in satisfactory working order and will not be discussed.

PULSE GENERATOR

To test the high gain linear pulse amplifier, it was desired to have a negative pulse source of stable amplitude and short rise time. The model 100 pulse generator as described by Elmore and Sands (12) was selected. In this model, positive pulses of short rise time are obtained from the cathode of a thyratron, acting as a relaxation oscillator, and coupled to the grid of T2 (Plate I) and through a .5 micro-second delay line to the grid of T3. T2 is a cathode follower providing positive pulses for external triggering of an oscilloscope. The pulse to T3 is delayed so that the test pulse will occur .5 micro-second after the trigger pulse. T3 is normally cut off and the delayed positive pulses are of sufficient amplitude to make the tube conduct. The fast negative pulses at the plate are coupled through the diode T4 to place a negative charge on C3. This cuts off T5 which is normally conducting. C3 must discharge through R5 and the time that T5 is cut off is controlled by R5 and C3. The diode T4 is biased so that only the steepest part of the positive pulse will be coupled to T5. This insures that T5 will be cut off very quickly and hence a very fast positive pulse occurs at the plate. This method of cutting off the current through a tube and taking the pulse from a plate resistor has the advantages that plate voltages before and after the step are very definite and that pulses free from minor oscillations are obtained if no transient effects are encountered at the time the current is cut off. A pentode is used as the pulse generator with the output taken from the plate where by the screen grid prevents capacitive coupling from the grid to the plate and overshoots at the end of the step rise are eliminated. The output is controlled in part by the rheostat R7 in the cathode circuit of T5 which varies the bias of the tube and thereby varies the lower dc level of the positive pulse generated at the plate and in part by R8 which varies the value of the plate load resistance.

The upper dc level of the pulse is the positive regulated high voltage level which is connected to ground. The desired output is a negative pulse so a feedback loop of three tubes, employing negative current feedback, having a resultant gain of minus one is used. The input to the minus one amplifier is controlled by a 250 ohm Allen-Bradley linear carbon potentiometer, R8, used as a rheostat. It is not possible to employ a precision wire wound potentiometer on account of the large parasitic inductance it possesses. In the output a step attenuator of 150 ohms constant output impedance is used. The output range of the pulse generator is from 4 micro-volt to one volt using the 100:1 and the 10:1 external attenuators (plate I).

The unit was already constructed but was not functioning properly. The output, as viewed by a model 514D Tektronix oscilloscope, appeared to have two discrepancies. Operation appeared to be intermittent and motor-boating prevailed. Several checks localized the intermittent trouble to the relaxation oscillator. Replacement of the 884 thyratron eliminated the trouble but no defect of the old tube could be found by checking it in a tube tester. The motor-boating was localized to the minus one amplifier. Various decoupling networks were tried, shielding was applied, rearrangement of component parts was tried, and even separate power supplies for each stage of the minus one amplifier was tried, but only one of the decoupling networks was found to eliminate the trouble. C4 and R6 was added to the minus one amplifier as indicated in Plate I. The output was now stable as observed with the scope. After two months of continual operation, it was noticed that the frequency "jumped" from one value to another. The period of oscillation for such a circuit is nearly $R(C1+C2)$ where R is the sum of the plate resistors. Replacement of C1 eliminated the trouble. A frequency stability check using a Hewlett-Packard Audio Oscillator and an oscilloscope and the Lissajous pattern method revealed the following data:

Table 1. Frequency stability of the pulse generator.

Period of elapsed time	Frequency (cps)
Initial reading	97.6
2 hours	97.6
3 hours	99.3
5 hours	96.4
8 hours	98.0

This shows a frequency variation of 1.2 per cent over a period of eight hours.

To calibrate the pulse generator as described in Elmore and Sands (12), the angular position of the dial on the potentiometer and the value of the plate current are varied until the dc voltage between the point P and the ground supply bus agrees with the reading of the dial. The resistance shunting the meter is then adjusted to make the meter read full scale. It was intended that for any future use of the generator, the only calibration adjustment necessary is to adjust the meter-set, R7, until the meter reads full scale. In this calibration it was assumed that the inversion amplifier had a gain of minus one so that the output of the pulse generator had the same magnitude as that at the plate of T5 but of opposite polarity. This no longer was true since insertion of the de-coupling network to eliminate the motor-boating decreased the gain of the minus one amplifier to minus .747 by increasing the feedback fraction. This made it necessary to have the output of T5 1.34 times the desired generator output. The probable error in reading the meter was about 2 percent. The step attenuator resistances as measured with an impedance bridge showed a variation of 8 percent for the .01 step, 3 percent for the .02 step, 1.2 percent for the .05 step, .6 percent for the .1 step and .2 percent for the .2 step. If the inversion amplifier were to be a minus one amplifier, it would have been necessary that the cathode feedback resistance be the same as the sum of the plate resistances in V8. As this no longer was the condition, the variation of the cathode resistance was not considered important. The precision with which the Allen-Bradley potentiometer could be calibrated was about 2 percent. The variations in the step attenuator resistances would have made it necessary to have the Allen-Bradley potentiometer calibrated for each step. This was not done, but was calibrated for the unity step.

Since the magnitude of the output pulse is determined by the conducting level of the plate of T5 and since this tube is normally conducting and is cut off by the fast negative pulse at its grid, the stability of the magnitude of the output pulse was checked by checking the stability of the conducting level of the plate of T5. To keep T5 conducting, it was necessary to remove the negative pulse which cuts it off by removing T3. A Leeds and Northorp type K1 potentiometer and a Leeds and Northrop model 2420A galvanometer was used to determine the IR drop from point P to the ground supply bus. The following data was taken with the meter-set and the Allen-Bradley potentiometer kept constant.

Table 2. Stability of the pulse height of the pulse generator.

Elapsed time	IR drop(volts)	Percentage variation
Initial reading	1.19580	0.000
1 day	1.19973	0.328
2 days	1.20379	0.666
3 days	1.20238	0.663
4 days	1.20718	0.943
5 days	1.21106	1.260

After several months of operation, the pulse output was observed visually to have an amplitude variation of about 10 percent which varied at a rate of about two times per minute. Replacement of V3 was found to eliminate the trouble.

The pulse shape is indicated in Fig. 1.

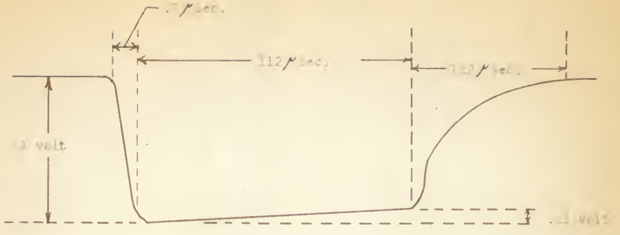


Fig. [illegible]. Pulse generator output.

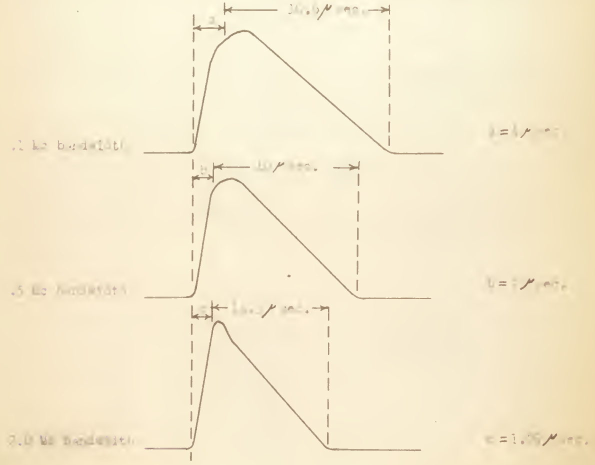
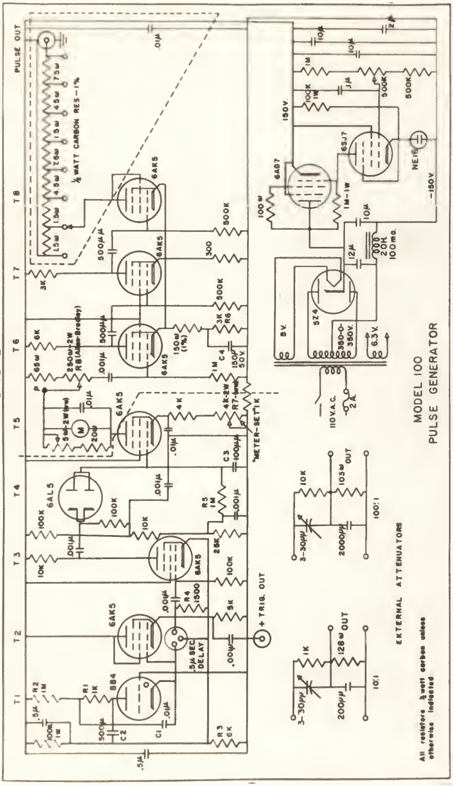


Fig. [illegible]. Amplifier output pulse.

EXPLANATION OF PLATE I

Schematic diagram of the pulse generator and external attenuators.

PLATE I


PULSE OUT
½ WATT CARBON RES-1%
T1
T2
T3
T4
T5
T6
T7
T8
884
6AK5
6AL5
6AK5
6AK5
6AK5
6AK5
6AK5
.5μ SEC DELAY
+ TRIG. OUT
"METER-SET" 1K
250ω-2W R8 (Allen-Bradley)
6AB7
6SJ7
5Z4
NE16
150V.
-150V.
20H 100ma.
6.3V.
5V.
350-0-350V.
110 V.A.C.
2A
EXTERNAL ATTENUATORS
10:1
100:1
OUT
MODEL 100
PULSE GENERATOR
All resistors ½ watt carbon unless otherwise indicated

HIGH VOLTAGE POWER SUPPLY

The high voltage supply to be used was a regulated positive 5 kilo-volt R.F. power supply as described by Adams (1). When a positive supply is used as the source of high voltage for the central wire of the counter tube, any ripple in the power supply output is coupled to the grid of the pre-amplifier input and is seen in the amplifier output. For this reason it was desired to convert the supply for a negative output. To do this the plate and cathode connections of V9 (Plate II) were interchanged. It was also necessary to change the output of the first difference amplifier from the plate of V1B to the plate of V1A so that the output would regulate in the proper manner. It was not necessary to change the polarity of the filter condensers as they were not electrolytic. The grid of V1B had to vary about a value of +105 volts and still be used for the negative input to the difference amplifier. To accomplish this the high voltage bleeder network was ungrounded and returned to positive 300 volts regulated through R33, R34, and R35 which gave appropriate biasing. The positive 300 volts was obtained from two VR150 tubes V11 and V12. The meter M1 was connected in series to indicate the bleeder current. R35 was selected to be 30,000 ohms to provide an IR drop of proper magnitude to be measured by a potentiometer to check the stability of the power supply. It is to be emphasized that R35 be inserted in the bleeder network so as to be as close to ground potential as possible to prevent insulation leakage of current to chassis and potentiometer. A stability check of the power supply by measuring the IR drop across R35 using a Leeds and Northrop type K1 potentiometer and a Leeds and Northrop model 2420A galvanometer showed a variation of 10.75 percent over a period of 6 hours. A check revealed that the screen voltage of the R. F. oscillator tube was 400 volts. The bias of V1B was changed so that the regulation point of the screen voltage would be 310 volts as prescribed. The 30,000 ohm resistor R35 which was originally carbon was replaced with a wire wound resistor so that any variation measured would not be due to its change in value. By touching the control shaft of the potentiometer in the grid circuit of V1B, the point of regulation of the screen grid voltage of the R. F. oscillator could be changed so the potentiometer was removed and fixed resistors inserted in its place. With these corrections, a stability check showed a variation of .32 percent over 5 hours. Since the underside of the chassis became very warm, the solid aluminum bottom was replaced with ½ inch screen mesh in an attempt to ventilate it. A stability check now showed a variation of .52 percent over a period of 4 hours. The solid aluminum bottom was chosen in place of the screen mesh. A stability check now indicated the following data:

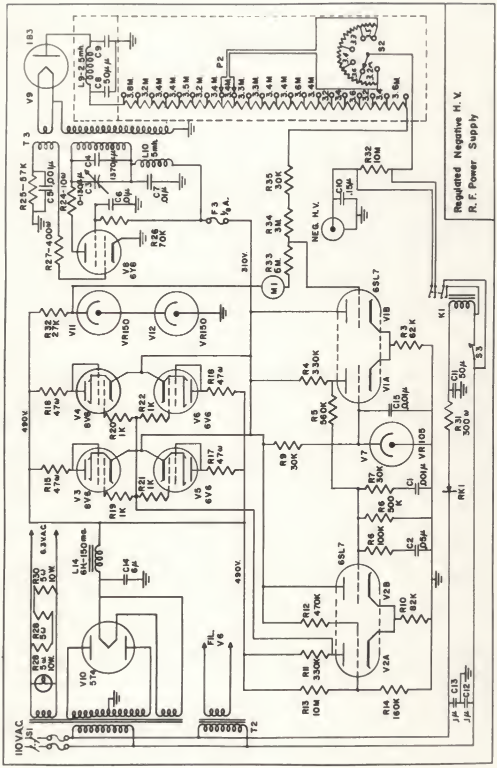
Table 3. Stability of the R. F. power supply.

Elapsed period of time	Emf across R35(volts)	Percentage variation
Initial reading	1.13418	0.000
1 day	1.13550	0.116
2 days	1.13710	0.258
3 days	1.13316	0.347
4 days	1.13598	0.282
5 days	1.12770	0.827

EXPLANATION OF PLATE II

Schematic diagram of the high voltage power supply.

PLATE II



AMPLIFIER AND PREAMPLIFIER

The amplifier to be used with a proportional counter should be linear, stable, have a high gain and a high signal to noise ratio. It is usually impractical to have the complete amplifier near the radiation source so a preamplifier with a connecting cable is used. The amplifier and preamplifier chosen is a general purpose linear amplifier model A1 as described by Jordan and Bell (13). In this model the voltage at the grid of the input tube is the time integral of the signal current. The signal is then amplified in the preamplifier until it is larger than the noise of the preamplifier and then differentiated in the preamplifier before being applied to the main amplifier. The main amplifier consists of two feedback loops and a cathode follower and employs negative current feedback. For a feedback loop such as this, the resultant gain is given by the expression

$$Kr = \frac{K}{1-KB}$$

where K is the nominal gain of the amplifier without feedback and B is the feedback fraction. A three position bandwidth selector is provided which varies the frequency and amplitude response by controlling the feedback coupling in the first loop. The nominal gain was made large so that KB is much greater than unity and the resultant gain is directly proportional to the reciprocal of the feedback fraction. Under these conditions, small signals are amplified in the same ratio as large signals and variations in tube quality have very little effect on the resultant amplification. Thus the amplifier is stable and linear. The calculated resultant gain of each stage is 100 for the wideband position. An output pulse height of 100 volts can be obtained.

The preamplifier integrator circuit consists of the capacity of the ionization chamber plus distributed capacity and a grid resistor. There is a decaying of the signal voltage as the condenser discharges through this resistor. Upon differentiation of this negative pulse an overshoot is produced. Even though this overshoot is small compared to the signal size which produced it, it becomes large when the amplifier gain is increased to investigate smaller signals in the presence of larger ones. This causes grid current to be drawn at the grid of V5 (Plate IV) thereby blocking the amplifier for a period of time following this. Thus there were long time intervals in which all signals were either greatly altered in magnitude or were absent entirely. For these reasons the amplifier was modified as suggested by Magee, Bell, and Jordan (18).

In the preamplifier the following modifications were made:

1. The cathode bypass condenser of V2 (Plate III) was removed because the short time constant produced additional overshoots.

2. The bias of V3 was increased by increasing the voltage at the cathode of V3 so that larger negative signals could be tolerated without overload. This was done by making R3 larger.

3. A germanium diode was inserted at the grid of V4 to limit the maximum signal height. This is adjusted by the voltage divider network R1 and R2 in the grid of V4 so that maximum amplifier output was obtained with the gain of the amplifier at a minimum. This utilized full coverage of the amplifier range without limitation.

4. The variable differentiator input in the main amplifier was removed and a fixed differentiator C3 and R2 at the grid of V4 was inserted. Although no bandswitch is provided, the coupling condenser C3 should be 33 micro-microfarad for the 2.0 Mc bandwidth, 330 micro-microfarad for the .5 Mc bandwidth, and .0033 microfarad for the .1 Mc bandwidth.

5. Resistors R4 and R5 were inserted in the screen circuits of V3 and V4 to suppress parasitics.

6. Larger coupling condensers C1 and C2 were inserted.

EXPLANATION OF PLATE III

Schematic diagram of the model A1-A preamplifier.

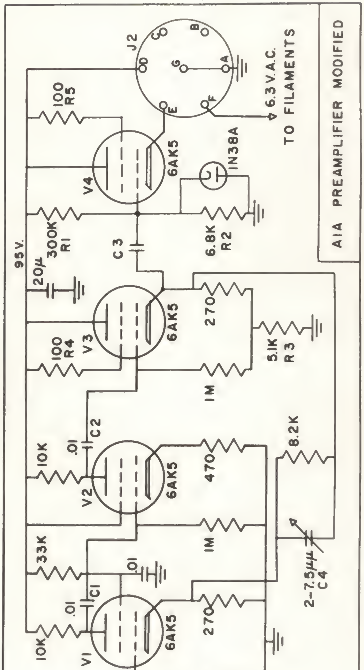


PLATE III
INPUT
J1
V1
6AK5
10K
.01
C1
33K
.01
270
100M
1M
V2
6AK5
10K
.01
C2
470
8.2K
2-7.5μμ
C4
V3
6AK5
100
R4
270
5.1K
R3
1M
95V.
20μ
300K
R1
C3
V4
6AK5
100
R5
6.8K
R2
1N38A
J2
6.3 V.A.C.
TO FILAMENTS
A1A PREAMPLIFIER MODIFIED

The only other corrections necessary in the preamplifier were to replace J1 with a standard Amphenol connector so that coaxial cables could be connected directly to the preamplifier to prevent 60 cycle pickup and to try several 6AK5 tubes for V1 to find one with the least amount of noise.

The main amplifier was modified as follows:

1. A direct connection was made at the main amplifier input in place of the variable differentiator input.

2. Three sets of germanium diodes were installed to clip the under- and overshoots.

3. A coupling network C1, R3, and R4 was installed to give the germanium diodes a coupling condenser upon which to act.

4. Resistors were added to the screen circuits of V6 and V7 to suppress parasitics.

5. A .6mh. choke L2 was added in series with the filament lead supplying filament current to the preamplifier.

The germanium diodes are not sensitive to signals smaller than $\frac{1}{2}$ volt so an arrangement referred to as an amplified diode was used to overcome this. For such a circuit the diode was connected from the grid of one stage to the succeeding grid of the next stage. If the amplification of the stage was A, then the diode saw a signal (A+1) times the input signal. By choosing the polarity of the diode properly the undershoot or overshoot was clipped. The signal across the back resistance of the diode was also (A+1) times as large and effectively the back resistance of the diode was reduced by this amount thereby causing a reduction in the nominal gain of the loop. This reduction in nominal gain caused the product KB to be comparable to unity and the resultant gain of the loop was neither linear nor stable. To compensate for this the authors suggested the following:

1. Use regenerative feedback within the loop by inserting a 3.3megohm resistor from the grid of V3 to the grid of V1.

2. Reduce the gain of the loop by reducing the feedback resistance.

The first of these was tried and found that oscillations prevailed and the amplifier blocked for any value of resistance which produced noticable increase in nominal gain. The second method was not tried.

The amplifier and preamplifier were previously constructed and the modifications suggested by the authors were already made. However, the overall amplifier was not stable, was not linear, the gain was too low, and oscillations prevailed. It was found that repositioning of components in the first loop and shielding the feedback network and S1 from the rest of the amplifier eliminated the oscillations. Further investigations showed the gain of the second loop to be very nearly 100 and the gain of the first loop to be reduced considerably. It was found that bypassing the cathode of V3 with a 150 microfarad 50 volt condenser increased the nominal gain of the first loop noticeably. It was also found that C1 was 100 micro-microfarad instead of .001 microfarad as called for. These corrections greatly increased the gain of the amplifier and it was linear as nearly as could be determined visually with the scope. For an amplifier output range from 15 to 100 volts, a more accurate linearity check was made by comparing the gain of the amplifier for small pulses to the gain of the amplifier for large pulses. The input pulse size was measured with the calibrated dial of the pulse generator and the output pulse size was measured with the pulse height selector. This method showed no variation in gain of the amplifier but it must be subject to the probable error of the calibrated dial.

A visual check with the scope indicated that the amplifier gain was not stable over a period of time. The amplifier was turned on its side and a large fan was used to cool the underside of the chassis. A stability check showed the variation to be 3.72 percent over a period of one day. A stability check with the germanium diodes removed from the first loop only showed a variation of .318 percent over a period of 3 days. This indicated that the back resistance of the germanium diodes was changing with temperature and was causing the gain to vary. This has been reported before in articles dealing with semiconductors such as that by Morton (20). Installation of a small blower fan on the underside of the chassis was tried as a method of keeping the germanium diodes at the same temperature but this resulted in a variation of 5 percent over a period of 6 hours. Removal of the germanium diodes and insertion of 6AL5 minature tube diodes V12 and V13 was tried. A 60 cycle pickup was present now and was traced to the first diode V12 in the first loop. A dc filament supply for this tube eliminated the pickup. This was inconvenient so elimination of the pickup was tried. It was found that if a shielded filament lead was used and if the half of the diode that has its pin connections as far removed from the filament pins as possible is also used, the pickup could be eliminated. This resulted in using diode pin connections 1 and 7, grounding pin 3 and using pin 4 as the filament connection. Figure 3 shows the stability of the amplifier graphically and the numerical results are listed in Table 4. The variations listed in the third column are subject to the variations of the pulse generator also as the data was taken by allowing the amplifier and pulse generator to run continuously without alteration. The variations due to the pulse generator are taken from Table 2 and are listed in the fourth column.

Table 4. Stability of the amplifier.

Elapsed Time	Pulse Height (volts)	Total Percentage variation	Pulse Generator variation (%)
Initial reading	55.80	0.000	0.000
1 day	54.75	1.88	0.328
3 days	54.25	2.78	0.663
4 days	54.00	3.23	0.943

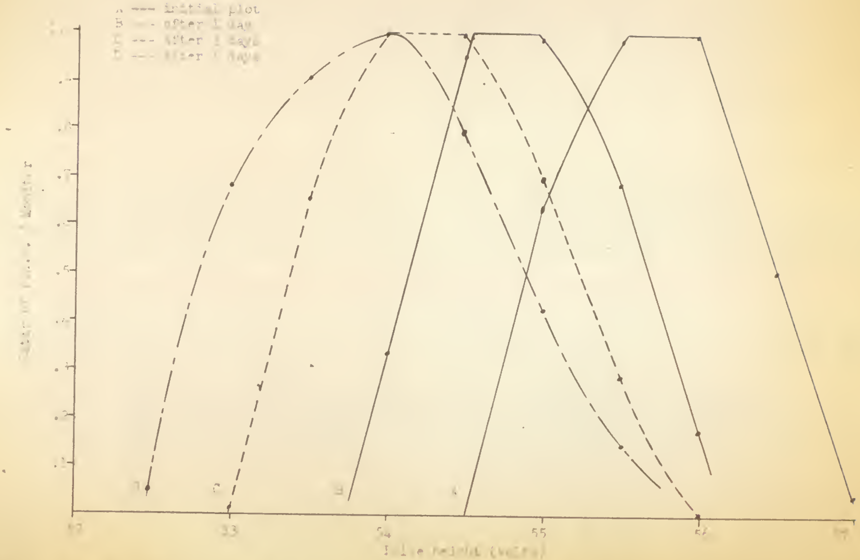


Fig. 6. Stability of pulse height selector and amplifier. [illegible]

It was believed that the back resistance of the germanium diodes in the second loop also changed but was less realized because of their position at the end of the amplifier.

The authors of the modification also suggested the addition of a .25mh. choke in the plate circuit of V5 to improve the amplifier linearity for large pulses on the wideband position. This was tried and oscillations resulted. It was believed that the authors had intended that the output be taken from the plate side of the choke instead of from the side they indicated. This was also tried and no effect could be noticed.

Other data concerning the performance of the amplifier is listed below in Table 5. The calibrated dial of the pulse generator was used to measure the input pulse size and the pulse height selector was used to measure the output pulse size. The scope was used to observe the noise level of the amplifier.

Table 5. Gain and noise level of the amplifier.

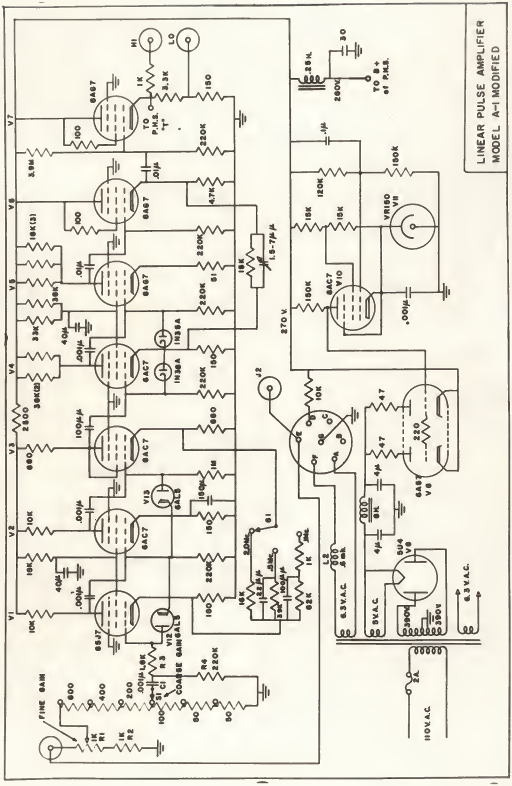
Bandwidth	Gain	Noise level (micro-volt)
2.0 Mc	8.34×10^4	20
0.5 Mc	1.13×10^5	18.5
0.1 Mc	1.10×10^5	18.5

Figure 2 shows the output pulse for the bandwidths.

EXPLANATION OF PLATE IV

Schematic diagram of the linear pulse amplifier model A1, modified.

PLATE IV



PULSE HEIGHT SELECTOR

The data of a proportional counter is plotted as energy versus intensity. The amplitude of the output pulse is proportional to the energy of the incident radiation and the number of pulses per unit time is indicative of the intensity. These relationships were obtained from the amplifier output by a pulse height selector. A record of the number of pulses per unit time having a given amplitude will be indicative of the intensity of the energy corresponding to this pulse height. If this is repeated for all possible pulse heights, the desired plot will evolve. Actually, discrete pulse heights were not selected but a range of pulse heights known as the channel width was used. This range could be varied from 0 to 100 volts which was the range of the amplifier output.

The positive output of the amplifier was fed to tubes V1 and V4 of the pulse height selector (Plate V) which were normally cut off. Their bias was varied by R1, R3, R8, and R11. R3 was a General Radio type 314 wire wound linear potentiometer. The dial of R3 was calibrated from 0 to 200. The dial was positioned on the shaft of R3 by setting the movable arm to the ground position for a dial reading of 200. The dial was calibrated by adjusting R1 until the potential on the arm of the potentiometer was at 100 volts for a dial setting of zero. The screwdriver adjustment R6 determined the channel width. With the pulse generator as a source, a 50 volt output pulse from the amplifier, zero channel width, and the dial set to 100, R8 and R11 were adjusted until V1 and V2, respectively, just began to conduct. This was observed by connecting the scope to the plates of V2 and V5, respectively. When V1 conducted, a positive pulse of large amplitude was fed to the grid of V3A which caused it to conduct heavily and placed a large positive charge on C2. This biased V3B so that any pulse from V7 did not cause it to conduct. When V4 conducted, the positive output from

V5 was delayed and differentiated before being applied to the grid of V3B. As the rise time of the amplifier output pulse was not zero, V4 began conducting before V1. To insure that no output pulse appeared if coincidence occurs, i.e., V1 and V4 both conduct, the delay was introduced so that the bias was applied to V3B before the signal from the delay. The time constant of R18 and C2 was made large enough that the bias remained until after the delayed pulse had arrived at the grid of V3B. Thus an output from the pulse height selector was observed only when a signal appeared at the grid of V3B without the bias, i.e., when V4 was triggered and V1 was not. The difference in triggering points of these two tubes was controlled by the channel width potentiometer R6. R9 was adjusted just below the point that an output was observed from the pulse height selector when coincidence occured and V5 was removed. This adjustment assured that the reduced differentiated pulse from the delay would have maximum amplitude.

The unit was already constructed on the main amplifier chassis but was not stable. It could be made to function properly but could not be relied upon to continue in this manner. Two discrepancies were noticed. When curves of counts per unit time versus dial setting was plotted over a period of time, the width of the distribution and the peak of the distribution was observed to change. It was possible that a variation in amplifier gain was causing the position of the peak to change. It was found that the voltage at the arm of the potentiometer R3 was varying over a period of time whereas the supply voltage did not. This indicated that the resistors in the voltage divider network were changing in value. A check revealed that R1 was a carbon potentiometer and that R2 was a deposited carbon resistor. Deposited carbon resistors are precision in value but do not have an exceptionally low temperature coefficient. Replacement with wire wound resistors eliminated the variation.

Further inspection revealed that no wire wound resistors were employed in any of the trigger circuits. Replacement of R4, R5, R7, R8, R10, R11, R12, R13, and R14 with wire wound resistors followed and the stability of the unit can be seen in Fig. 3 by noting the width and shape of the distribution curves taken over a period of 4 days. The front edge of the curve is determined by the conducting point of V4 and the back side of the curve is determined by the conducting point of V1. If these two edges remain the same distance apart then the channel width is stable. The only other variation that could occur is for the peak point to change. For this to occur the potential at the arm of R3 must change and this does not occur as previously reported.

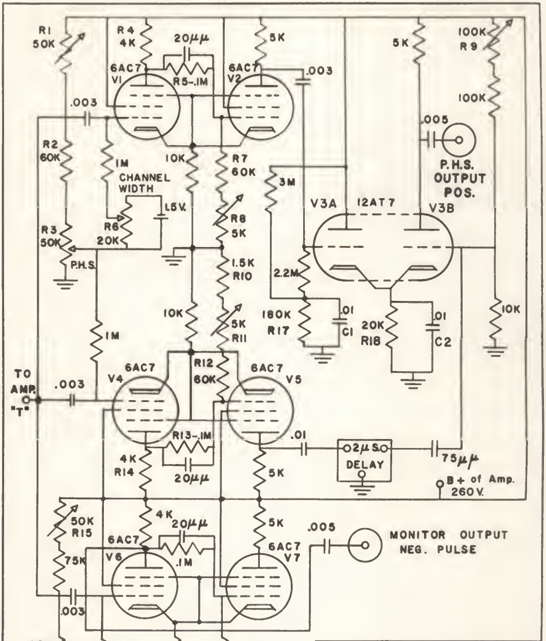
The sensitivity of the adjustment of the large variable resistors in the grid circuits of V2 and V5 was too great and replacement of them with large fixed resistors and small variable resistors proved very helpful.

The monitor was used to count the total number of pulses that came through the amplifier. Its output was negative to operate the counting units available. One advantage of the monitor output over the amplifier output for counting purposes was that its bias could be adjusted above the noise of the amplifier and thus count only actual pulses.

EXPLANATION OF PLATE V

Schematic diagram of the pulse height selector and monitor.

PLATE V



PULSE HEIGHT SELECTOR
and MONITOR

THE COUNTER TUBE

Two cylindrical tubes were available for tests. One had an inside diameter of 4 inches and was 16.5 inches long. The other had an inside diameter of 3 inches and was 13 inches long. Both had 3 mil tungsten wires and a 1 mil circular aluminum window ½ inch in diameter. Other construction details are described by Adams (1).

Two radioactive sources were available. One was an Fe^{55} K-capture isotope which emits 5.86 and 2.7 kev Manganese X-rays. The other was a Radium D source which has 9.5 and 13.5 kev Bi X-rays and a 46.4 kev gamma ray.

Two peaks were expected to be seen in the plot of pulse size versus counts per unit time when the Fe^{55} source was used. However, no peaks were ever found.

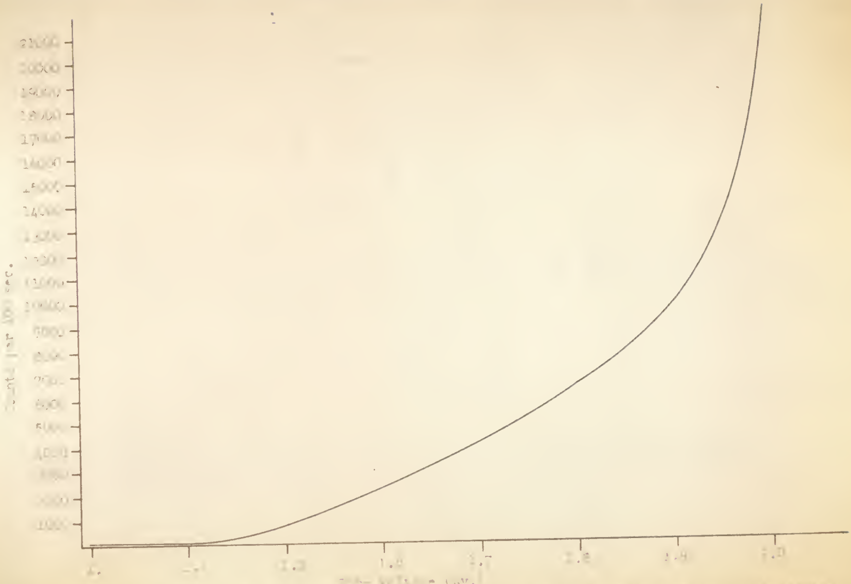
The large and small tubes were tried with their initial unknown gas fillings. The amplifier gain was adjusted so that the largest pulses due to the source were being investigated. The following table indicates the conditions that were tried.

Table 6. Combinations tried for initial gas fillings of the counter tubes.

Tube used	Source	Chamber voltage	Amplifier gain
Small	Radium D	1880	1.30×10^3
Small	Radium D	1880	1.04×10^4
Small	Fe^{55}	1750	1.04×10^4
Small	Fe^{55}	1725	2.08×10^4
Small	Fe^{55}	1690	2.08×10^4
Large	Fe^{55}	1690	1.04×10^4

Amplifier gains were varied to investigate the entire energy range. Removal of the source removed the pulses (except for those due to cosmic radiation which produce extremely large pulses) and therefore indicated that spurious pulses due to corona discharge were not present.

Plateau curves (fig.4) of counts per unit time versus tube voltage were made for the long chamber with its initial gas filling in order to operate the tube


21000
20000
16000
10000
9000
8000
6000
5000
4000
1000

well within the proportional region. It was found that anything less than 1750 volts would be satisfactory for the initial gas filling.

The large tube was refilled with ethyl alcohol and tank argon. Table 7 shows the combinations tried.

Table 7. Combinations tried for ethyl alcohol and argon fillings.

Tube	Source	Gas pressure Alcohol	(cm Hg.) Argon	Tube voltage (volts)
Large	Fe^{55}	3.0	58	1500
Large	Fe^{55}	3.4	15	1500
Large	Ra D	3.4	15	1500

Reference to other articles on the subject shows that the gas filling usually used was 15 cm of methane plus 60 cm of argon. Pure methane was not available so a filter system of concentrated sodium hydroxide and concentrated sulfuric acid was set up to filter line methane. Again various combinations, listed in Table 8 were tried.

Table 8. Combinations tried for methane and argon fillings.

Tube	Source	Gas pressure (cm Hg.) Methane	Argon	Tube voltage (volts)
Large	Fe^{55}	15.0	60	2400
Small	Fe^{55}	13.5	60	2175
Small	Fe^{55}	13.5	60	2620
Small	Ra D	13.5	60	2260

The large chamber was disassembled and loose aluminum filings were found over the interior of the tube. A previous worker, Adams (1), reported wrapping the glass insulators of the chamber with aluminum foil to reduce collection of static charges on it. Apparently the gases reacted with the aluminum. This had been reported before by Korff (15). The glass insulators were coated with aquadag as suggested by Curran, et al (3) to reduce static accumulation, the counter was cleaned with pure alcohol, and new wire was installed in the chamber. Accuracy of the centering of the wire was not determined. The tube was filled to 15 cm of methane and 58.2 cm of argon and operated at 2410 volts. Trials were made with the Fe^{55} source and also with Molybdemum target X-ray tube operated just above the K shell ionizing potential but no peaks were found.

Figure 5 is a plot of counts per 50 seconds through the pulse height selector versus the pulse height for the Fe^{55} source. The channel width was 1.5 volt, the tube voltage was 1500 volts, the medium bandwidth was used, and the tube was filled to 3 cm of ethyl alcohol plus 58 cm of argon. The shapes of these curves are typical of those produced for all the preceeding data. The variation in the position of the curves is significant of the stability of the entire equipment and shows the reliability with which they could be reproduced over a period of 2 days.

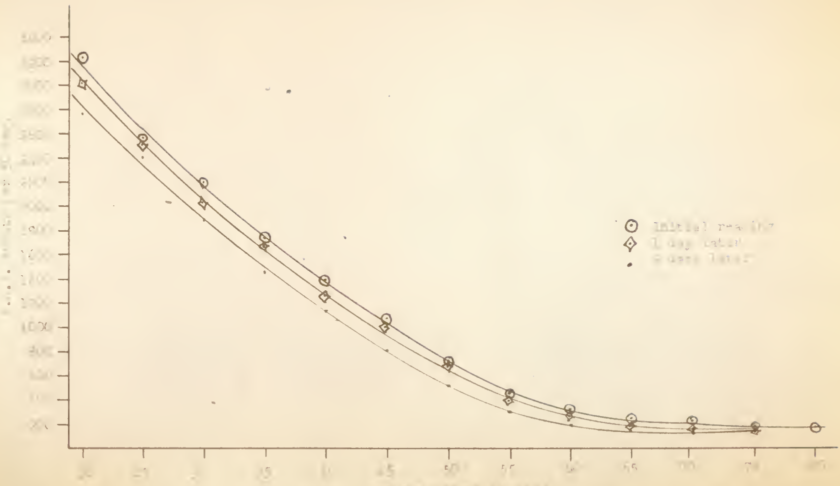


Fig. 7: Intensity vs. energy [illegible] channel width [illegible] volts, tube voltage [illegible] volts, Sodium iodide [illegible]

SUMMARY

A pulse generator for use in testing the amplifier and pulse height selector has been made stable. The performance of the amplifier has been greatly increased. The power supply has been converted for negative output. Stability of the pulse height selector has been increased. The stability of each unit has been determined.

No positive information using the proportional tube has been obtained but many tests were performed and many troubles eliminated which reduce the possibilities of trouble in securing the desired information.

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A PROPORTIONAL COUNTER SPECTROMETER

by

EUGENE B. COX

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AN ABSTRACT OF A THESIS

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The purpose of this project was to obtain a proportional counter spectrometer which could be used to investigate low energy radiation and nuclear particles. This involved a counter tube in which the radiation or particle was detected, a high voltage power supply to operate the counter tube, a high gain linear amplifier to amplify the signals produced in the counter tube, a pulse height selector to convert the amplifier output into usable data and a pulse generator to test and calibrate the amplifier and pulse height selector.

The equipment was previously constructed and the high voltage power supply and pulse height selector functioned but not satisfactorily. The pulse generator and the amplifier were not functioning. The first step was to correct and calibrate the pulse generator so that a pulse source was available to test the amplifier and pulse height selector. After the pulse generator was made to function, tests were made to locate the troubles of the amplifier and to improve the performance of the pulse height selector. The high voltage power supply was converted for negative output. An X-ray tube and two radioactive isotopes were used as sources for investigation. The tube was filled with several ratios of pressures of ethyl alcohol and argon and methane and argon. The amplifier gain was varied over a large region in order to investigate the entire energy range. Plateau curves were made in order to operate the counter tube well within the proportional region. The results of the counter appeared to be a continuous distribution of intensity versus energy instead of the discrete levels that should be expected and have been obtained by others in this field.

Although no significant data was obtained with the radioactive sources, many tests were performed and many troubles were eliminated thereby reducing the possible factors which prevent the desired result. The stability of each unit was determined so that the source or sources of trouble remaining may be localized to individual components.