AN ACCOUNT

OF THE WORK DONE DURING THE YEAR IN

SETTING UP A COUNTER CIRCUIT

A Dissertation presented in canditature for the degree of Master of Science of the University of London.

By

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INTRODUCTION

When an ionizing particle or radiation enters the sensitive volume of a counter an avalanche of electrons is formed by the process known as ionization by collisions. In general a counter is operated with the central wire positive with respect to the cylinder, and consequently the electrons are collected by the wire. A negative voltage pulse is thus developed on the wire, the size of which depends upon the capacitance of the wire system and the magnitude of the collected charge. The duration and form of the pulse will depend upon the characteristics of the particular counter used and upon the time constant of the receiving system. In general each ionizing particle produces a voltage pulse, and it is the function of the associated electrical circuits to record these pulses and thus count the number of particles entering the sensitive volume of counter.

The size of the voltage pulse varies with the counter and the type of particle being detected, but the pulses can be increased to the necessary size to actuate scaling and recording devices by means of an amplifier. For counters operating in the Geiger region the pulse size is independent of the type of ionizing agent being detected, providing the voltage across the counter is kept constant. As the counter voltage is increased the pulse size varies over a considerable range until the voltage is reached at which the counter goes into continuous discharge. In consequence, for use in conjunction with different counters, working at various operating potentials, an amplifier with variable gain is necessary. The amplifier can then be set to give a suitable output pulse to the following circuits independently of the size of the input pulse.

For slow counting rates the counter and amplifier can be used directly in conjunction with a suitable mechanical recorder. Many counters have recovery times as short as 10^{-4} seconds and correspondingly high counting rates. Amplifiers can be designed with RC time constants as short as 10^{-5} seconds or less, so that the results are not affected by the amplifying stage. On the other hand mechanical recorders have comparatively long time constants and if used directly would seriously decrease the possible counting rate. This is avoided by the use of electrical scaling circuits which pass on only a certain proportion of the pulses to the recording circuit. In this case the recovery time and counting rate of the whole system is governed

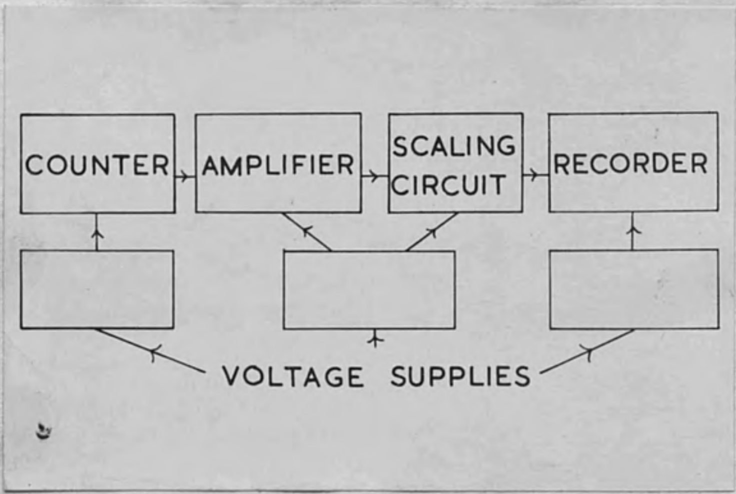

COUNTER
AMPLIFIER
SCALING CIRCUIT
RECORDER
VOLTAGE SUPPLIES

Diagram I

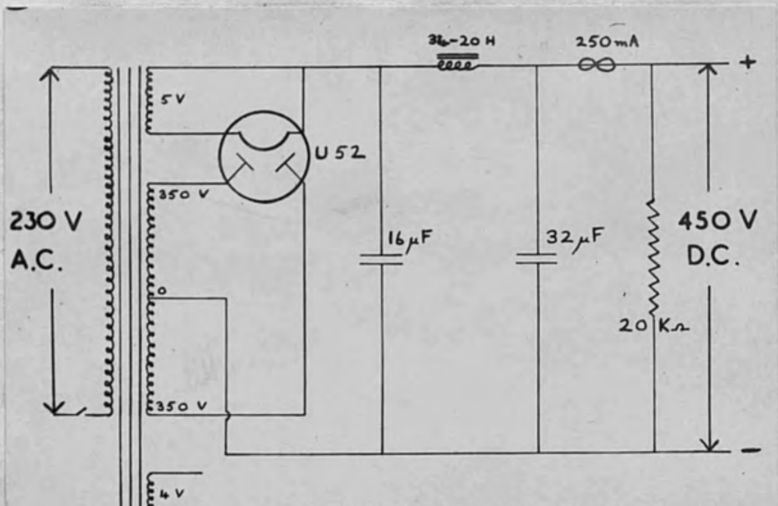
entirely by the characteristics of the counter itself.

The pulses from the last stage of the scaling circuit pass on to the recording circuit. It is the function of this circuit to use these pulses to operate some mechanical recorder. The pulses are not usually able to influence the counter directly, and so a hard valve or thyratron is used in conjunction with a telephone or Cenco counter.

It will be seen from the above discussion that the electrical circuits needed for use in association with a Geiger counter are as follows:-

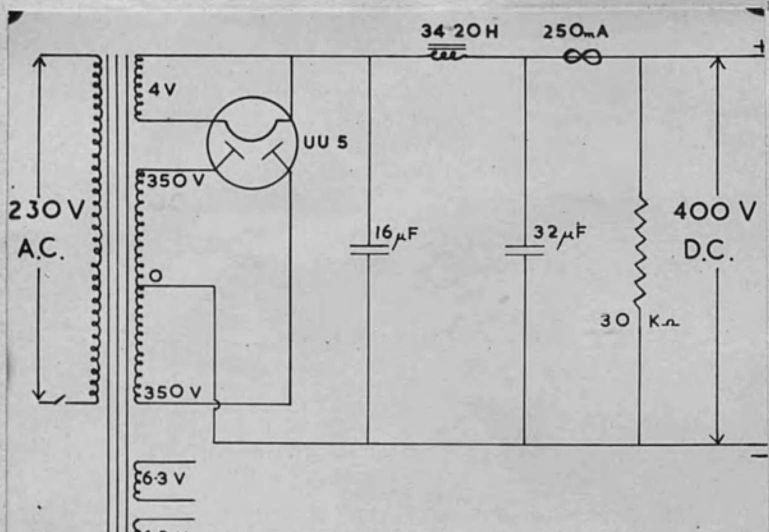
1. Voltage supply circuits for amplifier, scaling and recording circuits.
2. Pulse amplifier.
3. Scaling circuit.
4. Recording circuit.
5. Stabilised high voltage supply for Geiger counter.

The arrangement of these circuits will be such as is shown in block form in diagram I.



AMPLIFIER H.T. SUPPLY

Diagram II



SCALING CIRCUIT H.T. SUPPLY

Diagram III

VOLTAGE SUPPLY CIRCUITS

Before the amplifier and scaling circuits can be built and tested the circuits for the production of the necessary anode and screen-grid voltages must be constructed. The simplest method is to use the 230 volt alternating mains supply. This voltage is first stepped-up by a transformer and then rectified with a diode valve. The resulting ripple in the direct current voltage produced is smoothed with a filter consisting of a combination of two condensers and a choke.

The actual circuits that were constructed are shown in diagrammatic form in diagrams II and III. The voltages required were 450 volts for the amplifier and 350-400 volts for the scaling circuit. There were a number of rectifying valves that would have been suitable for the purpose, and those used were determined mainly by considerations of the availability of both the valves and the accompanying components. Transformers were obtainable which gave the correct heater and anode voltages for the UU 5 and U 52 valves, and the transformer in the voltage supply for the amplifier also had two 6.3 volt secondary windings, which were used to provide the heater voltages for the valves in the amplifier and scaling circuits.

The condensers were of the electrolytic type

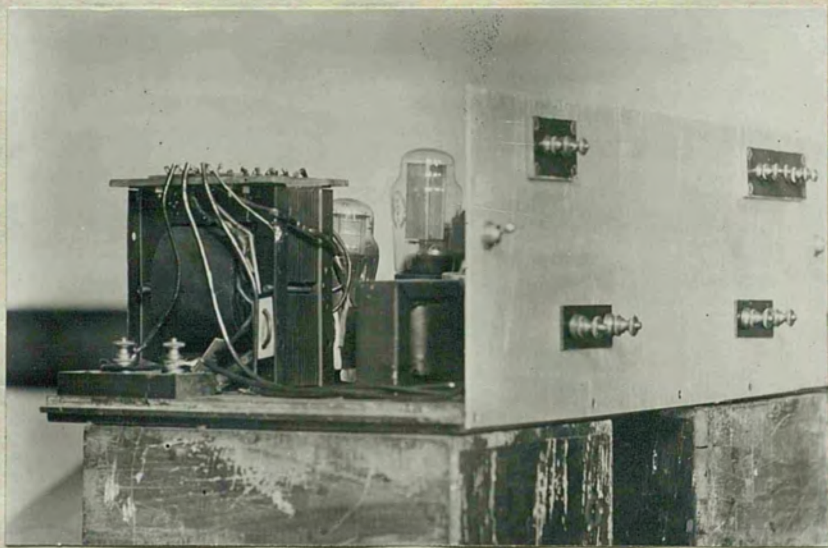


Diagram IV

which were perhaps not ideal for the purpose, but have the advantage of large capacitance in proportion to their size. Although the necessary values of the capacitances for good smoothing were large, single condensers were used in each case and not a number of smaller ones in parallel. When a number of condensers are used the direct current voltage stress divides between them in proportion to their leakage resistances and so may cause undue strain on one of them.

The 'bleeder' resistances that are connected across the output are most essential as they allow the condensers to discharge to earth as soon as the mains are switched off.

The two voltage supplies were built up on the same wooden base-board with an aluminium front to hold the switches and terminals. (See diagram IV).

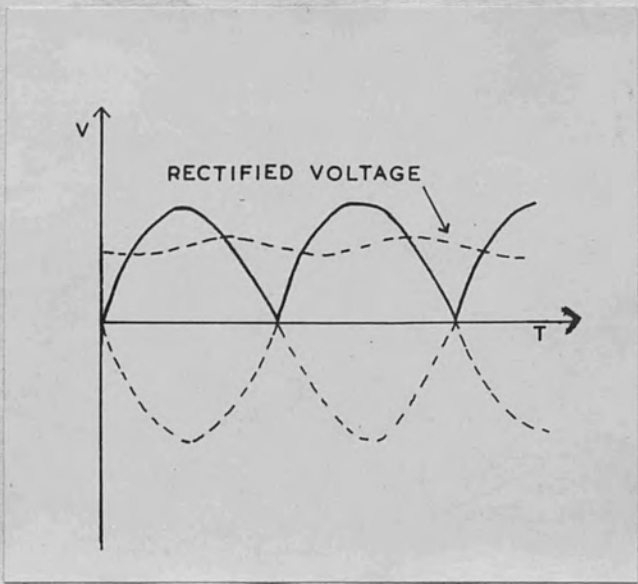


Diagram V

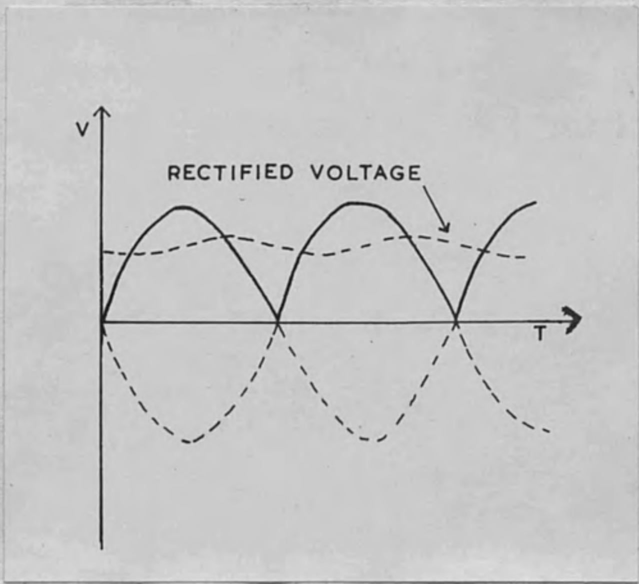
Action of the Circuit

The two anodes of the double-diode are connected to opposite ends of the centre-tapped secondary of the transformer. Thus the alternating voltages applied to the anodes are in anti-phase, so that when one is at a positive potential the other is negative. This means that the anode current flows throughout both half-cycles of the alternating voltage.

The first condenser is charged up to a voltage slightly less than the peak value of the alternating voltage and then discharges into the inductance as the voltage falls. The condenser does not discharge fast enough to allow the voltage to fall to zero before the next positive pulse arrives. As a result the ripple is considerably reduced as shown by the dotted curve in diagram V.

The choke continues the smoothing process as it tends to resist any change in the current flowing through it. The final condenser tends to short-circuit the remaining ripple to earth and thus develops an almost steady direct voltage across its terminals. Both condensers have to be able to withstand the maximum direct current voltage delivered by the rectifier.

The action of the filter circuit was tested with a cathode ray oscillograph. The amplifier gain switch of the oscillograph was placed in the position for single-



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The action of the filter circuit was tested with a cathode ray oscillograph. The amplifier gain switch of the oscillograph was placed in the position for single-stage amplification and the output of the voltage supply was connected directly across the earth and input terminals. With this arrangement the alternating component of the output is applied to the Y-plates of the oscillograph giving a vertical displacement of the spot. The direct current component is blocked by the isolating condenser in series with the input terminal of the oscillograph. The gain of the amplifier was then increased step by step until the trace attained measurable proportions. The scale of the oscillograph was then calibrated using the 4.3 volt secondary winding of the transformer in the voltage supply for the scaling circuit. From these results the percentage ripple could be calculated.

a) Voltage Supply for Amplifier

Height of trace for 4.3 volt A.C. = 7 cm.

Height of trace for ripple voltage = 0.1 cm.

$$\therefore \text{ Peak ripple voltage} = \frac{4.3 \times \sqrt{2} \times 0.1}{7} \text{ volt}$$

D.C. output of supply = 450 volt

$$\text{Percentage ripple} = \frac{\text{Peak ripple voltage}}{\text{D.C. output voltage}} \times 100\%$$

$$= \frac{4.3 \times \sqrt{2} \times 0.1 \times 100}{450 \times 7}\ \%$$

$$\simeq 0.02\%$$

b) Voltage supply for Scaling Circuit

Height of trace for 4.3 volt A.C. = 7 cm.

Height of trace for ripple voltage = .15 cm.

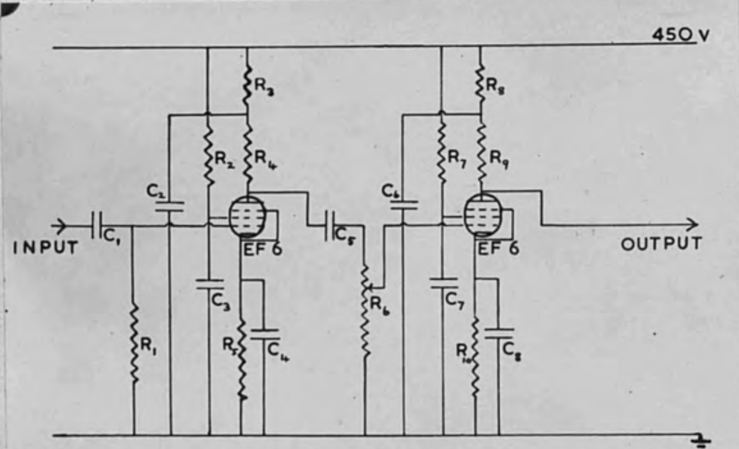
D.C. output of supply = 400 volt.

$$\text{Percentage ripple} = \frac{4.3 \times \sqrt{2} \times 0.15 \times 100}{400}\ \%$$

$$\simeq 0.033\%$$

These results show that the smoothing was very good, the percentage ripple being less than 0.05% in each case. Both circuits have now been used for some months and they have produced the required voltages without any trouble.

The voltage supply for the recording circuit could not be constructed owing to lack of time. Its design would have been similar to those just described but adapted for use with the particular valve chosen for the recording circuit.



C_1 = 10 $\mu\mu$F , C_2 = C_6 = 8 μF , C_3 = C_7 = ·05 μF , C_4 = C_8 = 50 μF , C_5 = ·0001 μF
R_1 = R_4 = R_9 = 100 KΩ , R_2 = R_7 = ·5 MΩ , R_3 = R_8 = 5 KΩ , R_5 = R_{10} = 680 Ω , R_6 = 100 KΩ

AMPLIFIER

Diagram VI

PULSE AMPLIFIER

The amplifier is of the resistance-capacity coupled type with two stages connected by condensers and resistors of suitable values. (See diagram VI). The characteristics of the amplifier are governed by the magnitudes of these coupling components and by the properties of the valves. It is essential that the amplifier should be constructed so that it is shielded from external electro-magnetic disturbances. Also filter circuits must be used to prevent fluctuations in the anode voltage supply from affecting the amplifier.

The amplifier must be designed to produce sufficient amplification to render the pulses capable of actuating the recording device without undue distortion.

In order to prevent pick-up of disturbances from outside sources it is necessary to have the amplifier peaked to respond only to the frequency range of the pulses. The amplifier will then have good resolution for the voltage pulses from the counter, but will be insensitive to disturbances from the surrounding 50-cycle mains.

The amplifier can be designed to have a recovery time less than that of the Geiger counter. The highest counting rate will then be governed by the characteristics of the counter itself. The recovery time of the counter will depend upon the capacitance of the wire system, which includes the coupling condenser and the first amplifying valve. In order that this recovery time should be as small as possible the first valve is chosen to have the minimum grid-cathode capacitance. For this reason the Mullard EF 36 was chosen as the amplifying valve as in this case the internal capacity is only about 5 $\mu\mu$F. Thus with a resistance of 10^5 ohms the recovery time of the counter will be of the order of 10^{-5} seconds.

The values given to the anode resistors, R_4 and R_9, and the screen-grid resistors, R_2 and R_7, are governed by the required anode and screen-grid voltages. The approximate anode and screen currents are known so that the resistors can be chosen to give the required IR drop below the voltage of the anode supply.

Self-biasing was used; the negative grid voltages being obtained from the IR drop in the cathod resistors R_5 and R_{10}. The total space current, which is the sum of the anode and screen currents, flows through these resistors. This gives the cathode a positive potential with respect to the common earth level and thus causes the grid to become negative with respect to the cathode. This method of grid-biasing eliminates the grid-bias batteries. The grid voltage is arranged to have a value such that the working point of the valve is approximately in the centre of the linear part of the mutual characteristic.

This prevents distortion of the pulse shape on amplification. For the EF 36 the necessary grid voltage is approximately -1.8 volt. The bias resistors are by-passed by condensers, C_4 and C_8, so that the amplified current flowing in the anode circuit will have no effect on the cathode voltage. If these condensers are large enough they will short-circuit to ground any alternating current developed in the cathode circuit.

The filter circuits, R_3 and C_2, and R_8 and C_6, were used in order to prevent disturbances reaching the amplifier from the anode voltage supply. If any variations occur in this voltage they are by-passed to earth through the filter condensers and are not amplified and passed on to the next stage. These filter circuits also prevent pick-up of high frequency oscillations from outside sources.

Leakage currents between the stages are prevented by the use of mica condensers for all coupling purposes. If leakage occurs the condenser will allow a direct current to flow through the grid-leak resistance (R_6) to earth and thus give the grid of the second valve a positive bias.

The gain of the amplifier was designed to be variable by the use of a potentiometer (R_6) in the coupling stage. The gain for the first stage is given by the approximate formula:-

$$\text{Gain} = \mu = \frac{g_m R_4}{1 + \frac{R_4}{R_6} + \frac{R_4}{R_a}}$$

where g_m = mutual conductance of valve

R_a = anode resistance of valve.

For a pentode $R_a \gg R_4, R_6$

$$\therefore \mu = \frac{g_m R_4}{1 + \frac{R_4}{R_6}}$$

For EF 36; $g_m = 1.8$ mA/Volt

$R_4 = 100K\Omega$

$R_6 = 100K\Omega$

$$\therefore \mu = \frac{1.8 \times 100}{1 + 1} = 90$$

$\therefore$ as R_6 is varied from 0 to 10^5 ohms, the gain of the first stage varies from 0 to 90. The second stage produces further voltage amplification.

Action of the Amplifier

A valve is able to function as a voltage amplifier because a small change in grid voltage can be made to correspond to a considerable change in anode current. If a large load resistance (R_4) is placed in the anode circuit a voltage will be developed across it when the anode current flows. This voltage will be greater than the input voltage. Thus each valve produces voltage amplification, and if the voltage change in the anode circuit of one valve is applied to the grid of the next valve further

Diagram VII

amplification can be produced.

The direct-current voltage drop across the load resistance is prevented from reaching the grid of the next valve by means of a coupling condenser (C_5). This blocks the direct voltage whilst allowing the alternating signal to pass. After producing further amplification the second valve passes the pulses on to the first stage of the scaling circuit.

The amplifier was built up on a rectangular chassis (See diagram VII). Care was taken to make the whole system rigid by keeping all connecting wires as short as possible.

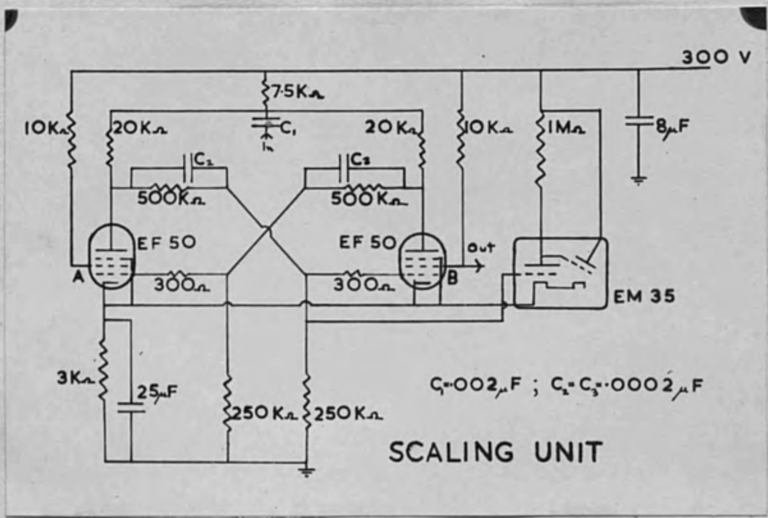

300 V
7·5KΩ
C₁
10KΩ
20KΩ
20KΩ
10KΩ
1MΩ
8μF
C₂
C₃
500KΩ
500KΩ
EF 50
EF 50
out
A
B
300Ω
300Ω
EM 35
3KΩ
25μF
250KΩ
250KΩ
C₁=·002μF ; C₂=C₃=·0002μF
SCALING UNIT

Diagram IX

SCALING CIRCUIT

In order to scale down the pulses to a rate which can be followed by a mechanical recorder it is necessary to use circuits which pass on only one pulse for every two applied to them. A number of the circuits can be used in series so that the actual number of pulses passed on to the recording circuit is considerably reduced. The use of scaling circuits will also decrease the errors due to double counts. Two closely spaced pulses would be registered as one by a mechanical recorder but are registered as two by the scaling circuits which have short recovery times.

One unit of the scaling circuit is shown in diagram ~~VIII~~ IX. The values of the circuit constants are arranged so that one pentode is conducting and the other is not. When the anode voltage supply is switched on one anode is sure to reach the minimum voltage for conduction through the valve slightly before the other one. A current will begin to flow through this valve (let it be B) and so a current will flow through the resistance linking the anode of B to the first or control grid of valve A. Thus a negative potential is applied to the control grid of A and the valve will remain non-conducting even when the anode voltage rises to its maximum value. The valves are now in a stable state. If a negative pulse is applied to the system through the coupling condenser, the circuit swings over.

The pulse is applied to the anodes and grids of the two valves. The small momentary drop in anode voltage will be insufficient to cause B to become non-conducting and the increased negative bias on the control grid of A will result in its remaining non-conducting. On the other hand the negative pulse applied to the grid of B will be sufficient to prevent the flow of current so that the valve ceases to conduct. As a result the anode voltage of B rises by an amount equal to the IR drop in the anode resistor. Thus a positive voltage pulse is produced and this is applied to the grid of A. In consequence A will become conducting and will apply a negative potential to the control grid of B. In this way B will be rendered permanently non-conducting until another pulse arrives. The circuit will thus swing from one stable state to the other as the negative voltage pulses arrive.

A positive voltage pulse would have no effect on the circuit as it would momentarily increase the grid-bias on the two valves, but would be insufficient to render A conducting. The circuit constants can be chosen so that the system is sensitive to negative voltage pulses of the order of 30 volts, whilst being insensitive to positive pulses.

As the pulses arrive the voltage of the anode of

B is continually rising and falling. A similar change takes place in the screen-grid voltage. As B becomes non-conducting the voltage rises to the value of the anode voltage supply, and as B becomes conducting it falls. Thus every time B becomes conducting a negative voltage pulse is produced. This will only occur once for every two negative pulses entering the scaling circuit. Thus the circuit reduces the number of pulses by one half.

The output pulse from B can either be sent straight into the recording circuit, or, if it is necessary to scale the number of pulses down still further, it can be sent into another scaling unit. This circuit will operate in exactly the same way and the two scaling circuits in series will send on one negative pulse for every four entering the system. It is essential that the circuits should be insensitive to positive pulses; otherwise the second circuit would operate when B becomes non-conducting and produces a positive pulse. Any number of scaling units can be arranged in series until the required proportion of the input pulses is sent on to the recorder. If n scaling units are used the resulting reading of the recorder must be multiplied by the factor 2^n. In the present case five scaling units were constructed thus producing a 'scale of thirty-two.'

In general the number of pulses will not be an integral multiple of 2^n and so it is necessary to have some means of indicating the exact number of pulses that have entered the scaling circuit. For this purpose a 'magic eye' valve is included in each scaling unit. These valves give a visual indication of the application of a single negative pulse to the unit.

The 'magic eye' valve, which is shown in diagrammatic form in the circuit diagram ~~VIII~~ IX, consists of two valves in the same envelope. One is a triode with high amplification, and the other is a diode. The anode of the diode is in the form of a fluorescent target, part of which is shielded by a blade-like electrode that is connected to the anode of the triode. The target is connected directly to the anode voltage supply and the anode is connected to the supply through a high resistance. When the grid is at zero potential the anode and control electrode are at a lower potential than the target owing to the IR drop in the anode resistor. Electrons from the cathode strike all parts of the cathode except those shielded by the control electrode. Thus on viewing the valve from above a dark sector is seen in the bright fluorescent circle caused by the impact of the electrons. If a negative voltage pulse is applied to the grid of the triode the anode current falls and the anode voltage rises. The shielding effect of the control electrode is thus reduced and the sector of darkness will decrease. If the applied pulse is large enough, the whole sector will light up and the 'eye' is said to close. For the valves used a voltage of 10 volts is easily sufficient to make them shut.

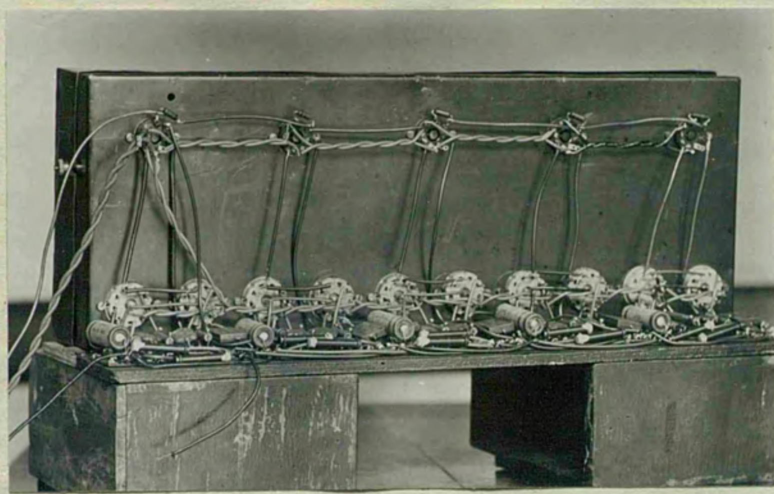


Diagram VIII

The grid of the magic eye is connected to the grid of the pentode B. Whenever a negative pulse is applied to the grid of B and it becomes non-conducting, the eye closes. When B becomes conducting the eye will 'open' and a negative pulse is sent into the next scaling unit. This will cause the second eye to close and indicate two counts. The eye in the third unit will close after four pulses have entered the circuit and so on. If the numbers 1, 2, 4, 8, 16 are given to the eyes in the five units, an addition of the numbers corresponding to the circuits in which the eyes are closed will give the number of counts to be added to those indicated by the recording circuit.

A single scaling unit was first built up on a wooden base in order to test the action of the circuit. Several minor adjustments were made until the circuit was working smoothly. The circuit was tested with negative voltage pulses produced by a high tension battery and a tapping key. It was found that few of the components have critical valves, but for smooth working it is necessary that the 300 ohm and 250K ohm resistors should be accurate pairs. The circuit is then well-balanced and swings quickly over from one stable state to the other on the introduction of a negative pulse.

A series of scaling units were then built up as shown in diagram ~~IX.~~ VIII In designing the complete circuit it was essential to have as compact an arrangement of the components as possible. This prevented the dimensions of the unit becoming too great and also allowed the magic eyes to be placed fairly close together. This is essential for ease of reading and accuracy of the results when the state of all the valves has to be noted quickly. The components were arranged so that the connecting wires should be as short as possible. This helps to prevent instability and disturbances from outside sources. The eyes were provided with a metal cover so that they were in darkness and could be read with ease in daylight.

The units were built up one at a time and each stage was tested by itself and in conjunction with the previous stages before the next stage was commenced. There was some trouble on coupling the units together when one stage did not pass on a large enough pulse to the next stage. This was overcome either by interchanging the valves or by slight alteration of the relevant components.

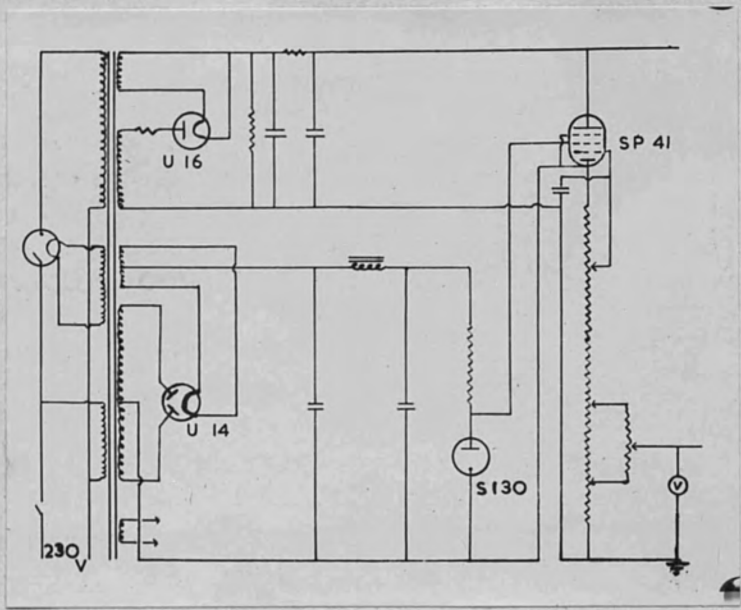


Diagram X

RECORDING CIRCUIT AND HIGH VOLTAGE SUPPLY

Owing to the great difficulties experienced in obtaining the necessary components it was not possible to build either the recording circuit or the high voltage supply for the counter. Diagram X gives an indication of the type of circuit that would have been constructed to produce the high voltage had time permitted. This voltage must be steady and variable over a considerable range.

The type of recording circuit used would depend upon the mechanical recorder selected.