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Title ENLARGING RADIATION SURVEY READ-OUTS FOR LARGE AUDIENCE VIEWING

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A method is presented for enlarging read-outs from a Victoreen Model 575 Radocon, an ionization chamber type of radiation survey instrument. The read-out enlargement is accomplished by taking the signal across the Radocon indicating meter, amplifying it, and using the amplified signal to drive a projection meter. The face and back of the projection meter are made of transparent Lucite so that the meter may be placed in a standard lantern slide projector, and an enlarged image of the meter scale and index pointer projected on a screen or wall.

A field-effect transistor used as a source-follower provides the amplifier with an input impedance of over 100 megohms so that the current flowing through the Radocon indicating meter is not reduced when the amplifier input is connected in parallel with it.

An emitter-coupled differential amplifier takes its input from the source of the field-effect transistor; its output drives the

projection meter. The differential amplifier provides the gain necessary to accurately drive the projection meter. Through the property of common-mode rejection, the drift in output due to variations in temperature is reduced.

In operation, the input of the amplifier is connected in parallel with the Radocon indicating meter. The polarity is arranged so that the voltage on the gate of the field-effect transistor goes from zero to plus 0.1 volt as the Radocon indicating meter goes from zero to full scale. The amplified signal appears as a voltage difference between the collectors of the two transistors in the differential amplifier. The projection meter, placed between the collectors, provides the final read-out.

This method of read-out enlargement makes it possible to accurately display radiation measurements to a large audience. The read-out enlarger, used with the Radocon Model 575, can be used in a large classroom to demonstrate various physical laws which involve changes in radiation intensity. The same method may also be used to enlarge read-outs from other types of instruments. An accurate enlargement may be obtained without altering the circuit of the instrument or affecting its read-out.

# ENLARGING RADIATION SURVEY READ-OUTS FOR LARGE AUDIENCE VIEWING

by

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TABLE OF CONTENTS

## LIST OF FIGURES

# ENLARGING RADIATION SURVEY READ-OUTS FOR LARGE AUDIENCE VIEWING

## INTRODUCTION

The Victoreen Model 575 Radocon is a radiation survey instrument which could be a more valuable radiological demonstration aid, if its read-out could be made clearly visible to a large audience.

The Radocon's read-out appears on a small indicating meter which cannot be accurately read from more than six feet away. The problem is to accurately enlarge the read-out to a size which can be easily read by every viewer in an auditorium. It is desired that the enlarged read-out be accomplished without altering the circuit of the Radocon or the read-out appearing on the indicating meter.

# THE MODEL 575 RADOCON

## General Description

The Radocon is an instrument which measures the intensity of X or gamma radiation in roentgens per unit time from any appropriate radiation source, such as an X-ray installation (5, p. 1). The Radocon consists of an indicating control unit and sensitive ion chamber probe (Figure 1). The two units are connected by 45 feet of low-noise cable. The sensitivity of the instrument can be varied over a wide range by interchanging probes. The probes are similar in operation, but differ in chamber volume, wall material, and wall construction--hence, in sensitivity.

## Operation

The radiation sensitive volume is a thimble-type ion chamber located at one end of the probe. The probe shank contains an electrometer tube which amplifies the small current generated in the ion chamber and feeds it through the cable to the control unit. The control unit houses an electronic amplifier and indicating meter. The output voltage of the amplifier is directly proportional to the radiation intensity at the ion chamber and is presented on the indicating meter which is calibrated in roentgens per minute.


Figure 1. The Model 575 Radocon.

## Indicating Meter

The Radocon's indicating meter has a 100 microampere, 1000 ohm movement; and, therefore, reads full-scale when the voltage across its terminals is 100 millivolts.

## Read-out Enlargement

The read-out enlargement is accomplished by amplifying the signal across the Radocon indicating meter, and using the amplified signal to drive a projection meter. The face and back of the projection meter (Figure 2) are made of transparent Lucite so that the meter may be placed in a standard lantern slide projector, and an enlarged image of the meter scale and index pointer projected on a screen or lecture room wall.


Figure 2. Projection meter.

# THE SOLID STATE DC AMPLIFIER

## Requirements

In order to achieve its purpose, the amplifier must meet several requirements.

### Input Impedance

The resistance of the Radocon indicating meter is 1000 ohms. If the amplifier input impedance were also 1000 ohms, the current required from the Radocon would be doubled the moment the input of the amplifier was connected across the indicating meter. This loading of the indicating meter would cause a decrease in its reading and make inaccurate any signal which appeared across its terminals.

If, however, the input impedance of the amplifier were one megohm, the loading would be decreased by a factor of one thousand. This amount of loading does not make a noticeable change in the reading of the indicating meter, and the input signal to the amplifier remains accurate to 0.1 percent. The first requirement of the amplifier, therefore, is that its input impedance must be high enough to prevent noticeable loading of the Radocon indicating meter when the amplifier input is connected in parallel with it. An input impedance of one megohm or more is preferred.

## Gain

The current needed to drive the Radocon indicating meter to full scale is 100 microamperes; the current needed to drive the projection meter to full scale is one milliampere, or ten times as much current. Thus, the current gain of the amplifier must be exactly ten if the two meters are to register identical readings at all times.

The voltage required to drive the Radocon indicating meter to full scale is 100 millivolts; the same voltage also drives the projection meter to full scale. The voltage gain of the amplifier must, therefore, be exactly one if the meters are to read identically.

## Power Supply

Any variation in the power supply voltage changes the bias conditions of the transistors in the amplifier, which, in turn, produces a corresponding variation in the output of the amplifier. If a battery is to be used as a power source, some method must be devised to eliminate the drift in amplifier output due to the gradual drop in voltage as the battery is used.

## Temperature Stability

It is well known that the current gain ($h_{FE}$) of a transistor, as well as other DC parameters, varies with temperature (2, p. 95-96). These variations produce a corresponding change in the bias conditions of the transistor and the output of the device is changed. This change in output with temperature (temperature drift) is undesirable and must be eliminated before accurate readings can be obtained from the projection meter.

## Circuit Design

The amplifier design follows directly from the requirements listed in the preceding sections. For purposes of discussion, the amplifier may be thought of as three distinct units: a source-follower, a differential amplifier, and a constant voltage source.

### The Source-Follower

The required high input impedance is accomplished by using a field-effect transistor in a source-follower input stage. The input is placed on the gate of the field-effect transistor which is a reverse-biased junction. Hence, there is an input impedance of over 100 megohms.

Figure 3 shows schematically the cross-section of a p-channel field-effect transistor. The two n-type regions which are tied together form the gate. The gate voltage controls the resistance of the current path (channel) through p-type material between two

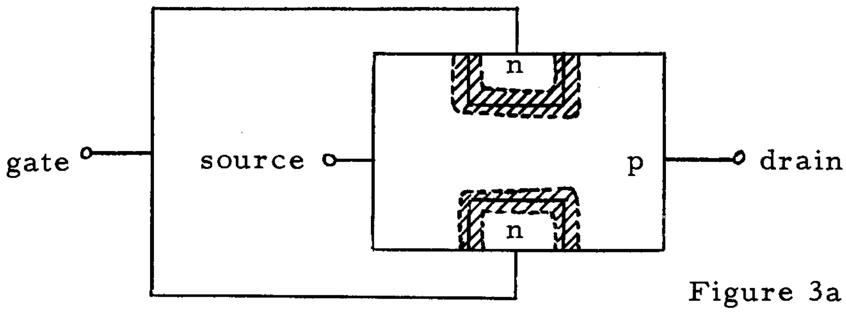


Figure 3a

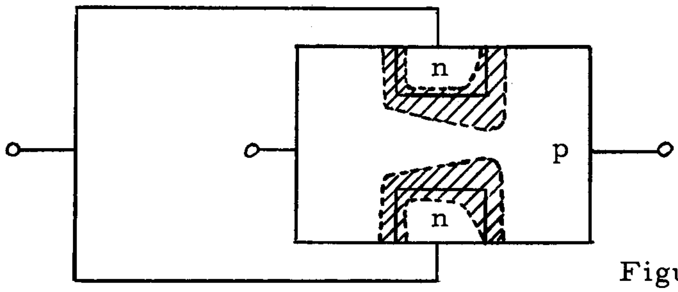


Figure 3b

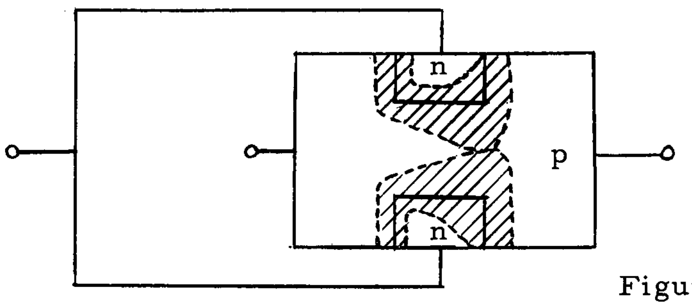


Figure 3c

Figure 3. Schematic cross-sections of a p-channel field-effect transistor showing depletion layers (shaded regions) at three reverse-bias voltages.

contacts called the source and the drain (1, p. 1). When a reverse bias is applied to the pn junctions which form the channel boundary, depletion layers are formed on each side of the channel which are essentially non-conducting (Figure 3a).

The conducting cross-section of the channel decreases as the reverse bias is increased (Figure 3b) until the two depletion layers join (Figure 3c) causing the conductivity between source and drain to drop essentially to zero.

## The Differential Amplifier

The second stage is an emitter-coupled differential amplifier (Figure 4). This stage takes its input directly from the source of the field-effect transistor in the source-follower stage. The output of the differential amplifier appears as a voltage difference between the collectors of the two transistors, $T_1$ and $T_2$. The gain may be controlled by placing a variable resistance in series with the output.

## The Constant Voltage Source

A 9-volt battery serves as a power supply for the amplifier. Battery voltage, however, tends to decrease slowly as the battery is used. This variation in supply voltage changes the bias conditions of the amplifier and causes drift in the output. Drift due to varying battery voltage is controlled by placing a zener diode and a small

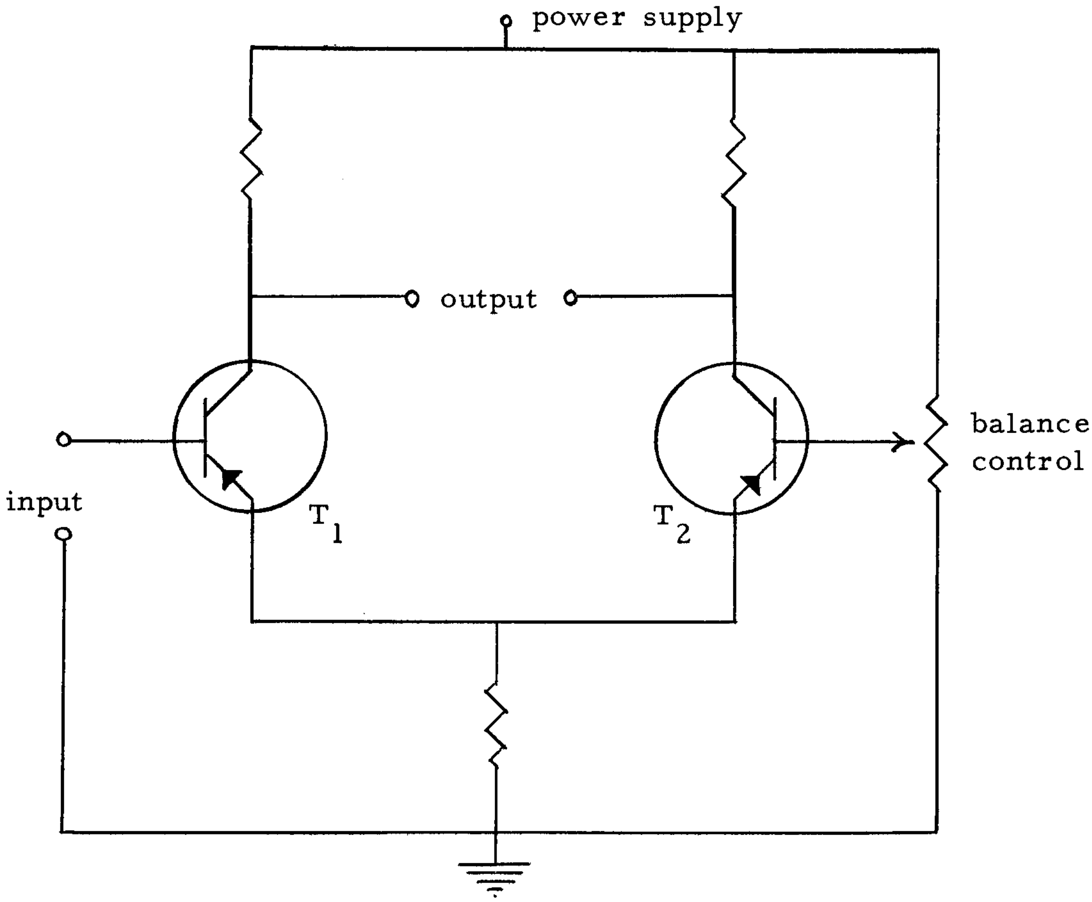


Figure 4. An emitter-coupled differential amplifier.

resistance, R, in series with the battery.

The diode has a reverse-bias breakdown voltage, $V_z$, of 6.0 volts (Figure 5). When the diode is operating in the breakdown region, the current through the diode may change considerably, but the voltage across the diode remains essentially constant at a value equal to $V_z$ (3, p. 75).

Figure 6 shows schematically a power supply which uses a zener diode as a voltage regulator. $R_L$ represents the total load resistance of the amplifier. If $R_L$, $V_z$, and the battery voltage, $V_B$, are all known, the current through the diode can be selected by choosing an appropriate value for R. The following equations apply to Figure 6:

$$R = \frac{V_B - V_z}{i_R} = \frac{V_B - V_z}{i_L + i_z} = \frac{V_B - V_z}{\frac{V_z}{R_L} + i_z}$$

So, if $V_B = 9$ volts, $V_z = 6$ volts, and $R_L = 1000$ ohms; $i_z$ will be 2 milliamperes, if

$$R = \frac{9 - 6}{\frac{6}{1000} + 0.002} = 375 \text{ ohms.}$$

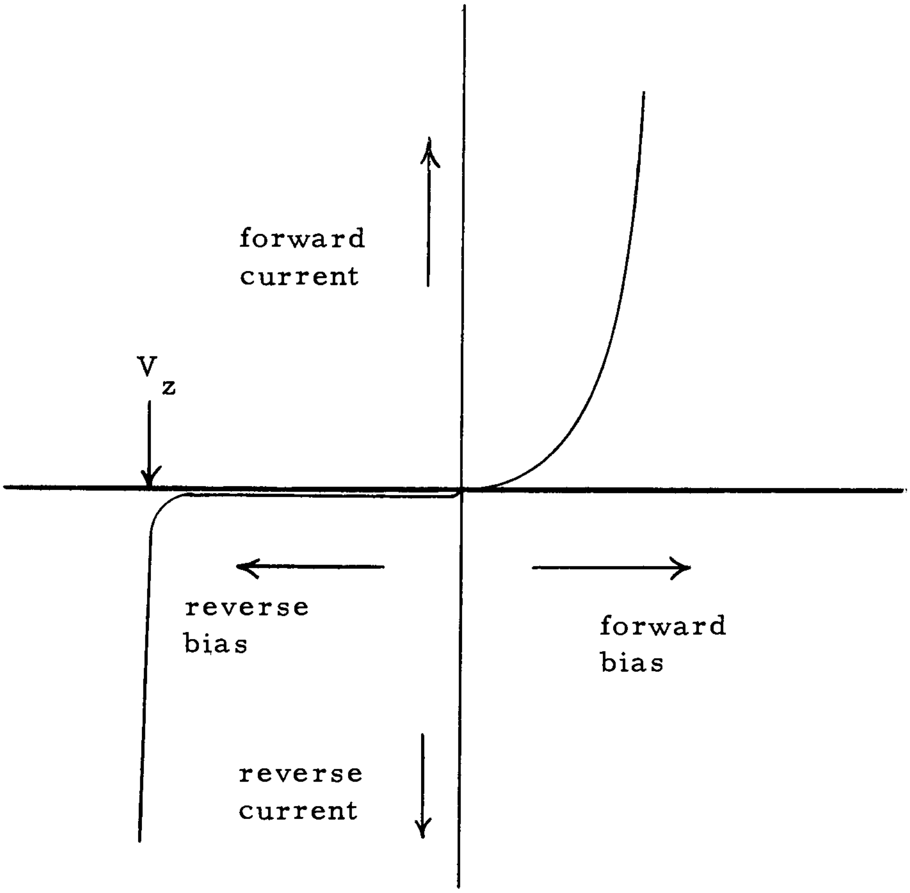


Figure 5. Current through a zener diode as a function of the voltage across the diode.

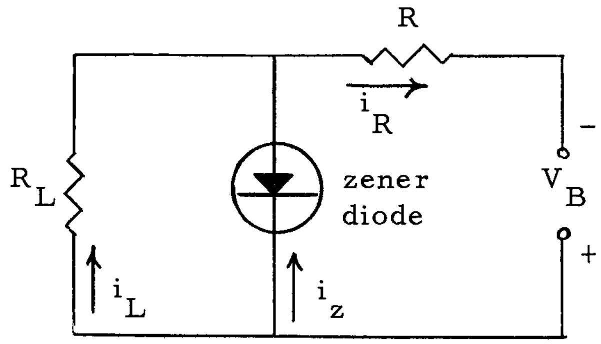


Figure 6. Constant voltage power supply.

Also, referring to Figure 6,

$$i_z = i_R - i_L = \frac{V_B - V_z}{R} - \frac{V_z}{R_L}.$$

So, if $V_B$ decreases slightly to a new voltage, $V_B - \Delta V$, the current through the diode decreases by $\Delta i_z$, where,

$$\Delta i_z = \frac{V_B - V_z}{R} - \frac{V_z}{R_L} - \frac{(V_B - \Delta V) - V_z}{R} - \frac{V_z}{R_L} = \frac{\Delta V}{R}.$$

But, the voltage across the diode remains essentially constant at a value of $V_z$. Using a zener diode and an appropriate resistor in series with the battery causes the supply voltage across the diode to remain essentially constant even if the battery voltage decreases, and drift due to this source is minimized.

In the completed power supply, the emitter-base junction of a 2N 3638 pnp transistor serves as a zener diode which has a reverse-bias breakdown voltage, $V_z$, equal to six volts.

## Temperature Stability

It is well known that the current gain of a transistor, as well as other DC parameters, varies with temperature. These variations produce a corresponding change in the bias conditions of the transistor and the output of the device is changed. This change in output (drift) is best reduced by using two transistors in an emitter-coupled differential amplifier circuit (2, p. 111).

In an emitter-coupled differential amplifier circuit, any signal generated by a temperature change in one transistor tends to be cancelled by an equal and opposite signal from the second transistor. This method of common-mode rejection works well if the current gains of the transistors are matched, and if both transistors are maintained at the same temperature.

The two 2N404 pnp transistors used in the finished amplifier were selected from several similar transistors after matching their current gains on a transistor curve tracer. The two matched transistors were then equipped with a common heat sink to help maintain equal temperatures in both. (Differential amplifier packages are available in which two matched transistors are mounted on a single header; this method insures that both transistors are maintained at the same temperature.)

## Circuit Analysis

Figure 7 shows the schematic diagram of the complete amplifier. The input of the amplifier is connected in parallel with the Radocon indicating meter. The polarity is arranged so that the voltage, $V_G$, on the gate of the field-effect transistor goes from zero to plus 0.1 volts as the Radocon indicating meter goes from zero to full-scale. (All voltages are taken with respect to ground unless otherwise stated.)

Assume that $V_G = 0$, (which is the case when the Radocon indicating meter reads zero), and that the reverse bias on the field-effect transistor is not great enough to make the channel non-conducting. The potentials of the other points in the circuit, measured when $V_G = 0$, are shown in Figure 7. If the transistors, $T_1$ and $T_2$, are matched, and if $R_1$ and $R_2$ have the same value, the collector voltages will be equal if the base voltages are equal. For a given $V_G$, the base voltage of $T_1$ is determined by $R_4$, but the base voltage of $T_2$ can be varied by adjusting $P_1$ until the two transistors are balanced and the voltage between the two collectors is zero. The projection meter will now register zero.

If $V_G$ is increased to some positive value less than or equal to 0.1 volt, (which is the case when the Radocon indicating meter reads some positive value less than or equal to full-scale), the

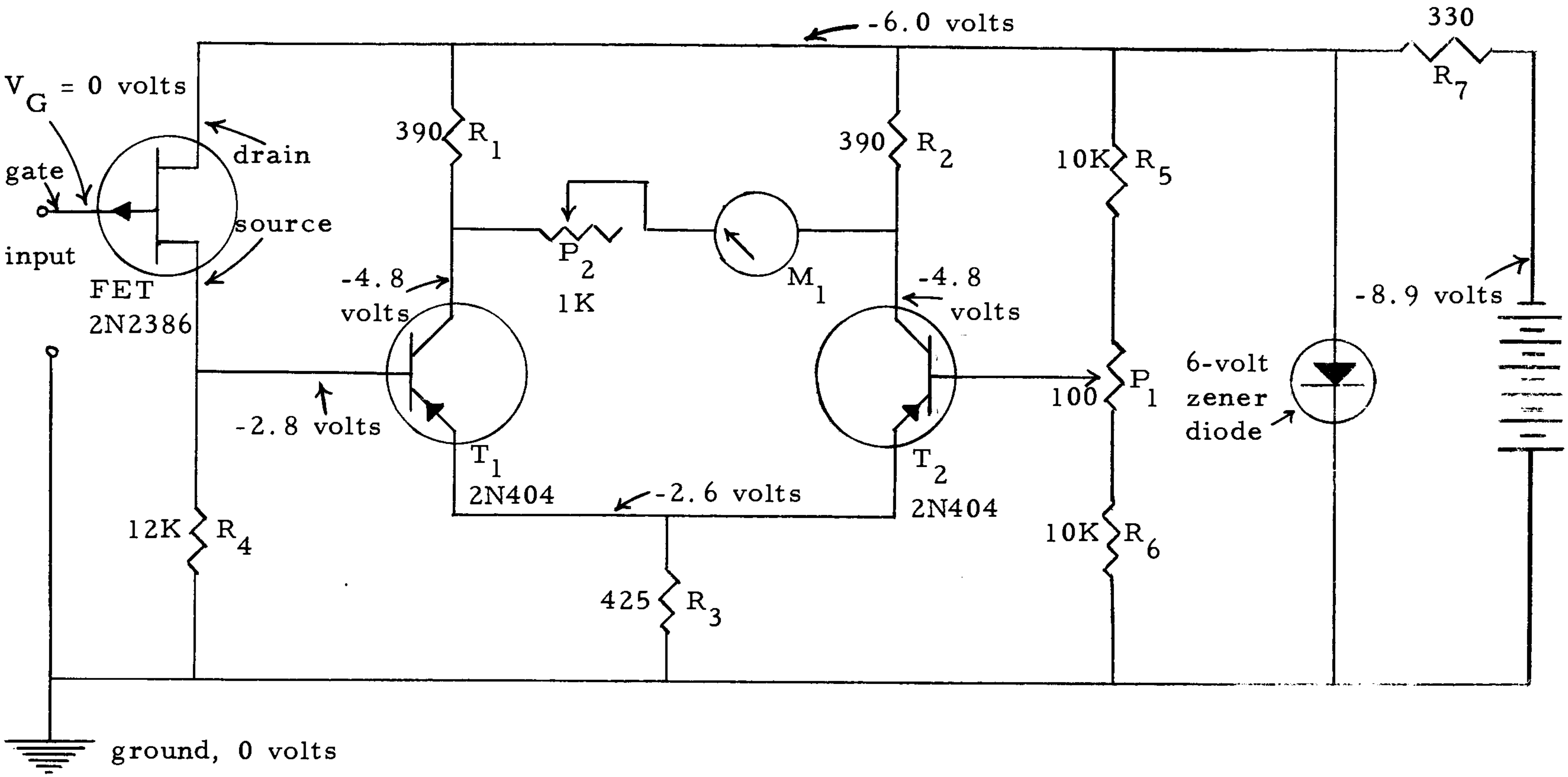


Figure 7. Solid state DC amplifier.

reverse bias on the gate of the field-effect transistor will be increased. This decreases the conductivity through the channel, and increases the voltage drop from source to drain. The voltage on the base of $T_1$, which is connected to the source of the field-effect transistor, is driven more positive. Hence, the source voltage follows the gate voltage; this explains the term, source-follower.

A more positive base decreases the forward bias between the emitter and base of $T_1$ causing less current to flow from the emitter to the base. The base and collector currents are decreased proportionally (4, p. 47). The decreased current through $R_1$ causes the voltage drop across $R_1$ to decrease, driving the collector of $T_1$ more negative by some amount $\Delta V_{C1}$.

The current through $R_3$ is essentially constant, so a decrease in current through $T_1$ causes an increase in current through $T_2$. The emitter current increases and the base and collector currents increase proportionally. The increased current through $R_2$ causes the voltage drop across $R_2$ to increase, driving the collector voltage of $T_2$ more positive by some amount, $\Delta V_{C2}$. Now the total voltage between the collectors is $\Delta V_{C1} + \Delta V_{C2}$, and current flows through the projection meter.

$P_2$ can be adjusted until the voltage across the projection meter is equal to the voltage across the input of the amplifier; this gives the required voltage gain of one. The resistance of the projection meter is 100 ohms, while that of the Radocon indicating meter is 1000 ohms. Hence, the projection meter draws ten times as much current as the Radocon indicating meter when the same voltage is applied to each.

## Construction

Figure 8 shows the preliminary amplifier layout which was used to test the circuit. The completed amplifier is housed in a sloping panel cabinet which is approximately seven inches in each dimension. The input of the amplifier can be connected in parallel with the Radocon indicating meter by a two-conductor shielded cable. A similar cable is provided to connect the amplifier's output to the projection meter. The only controls are an on-off switch and two fluted knobs on the sloping panel. These allow the operator to turn the amplifier on and off, and to vary the values of $P_1$ and $P_2$. The cabinet has a hinged top for easy access to the three transistors and the battery supply. Access is also available to $R_3$, $R_4$, $R_5$, and $R_6$, which are trim potentiometers; if one wishes to change the bias conditions which affect the gain of the amplifier, these resistances must be varied. The power supply is designed to use either one 9-volt battery or six 1.5-volt batteries.

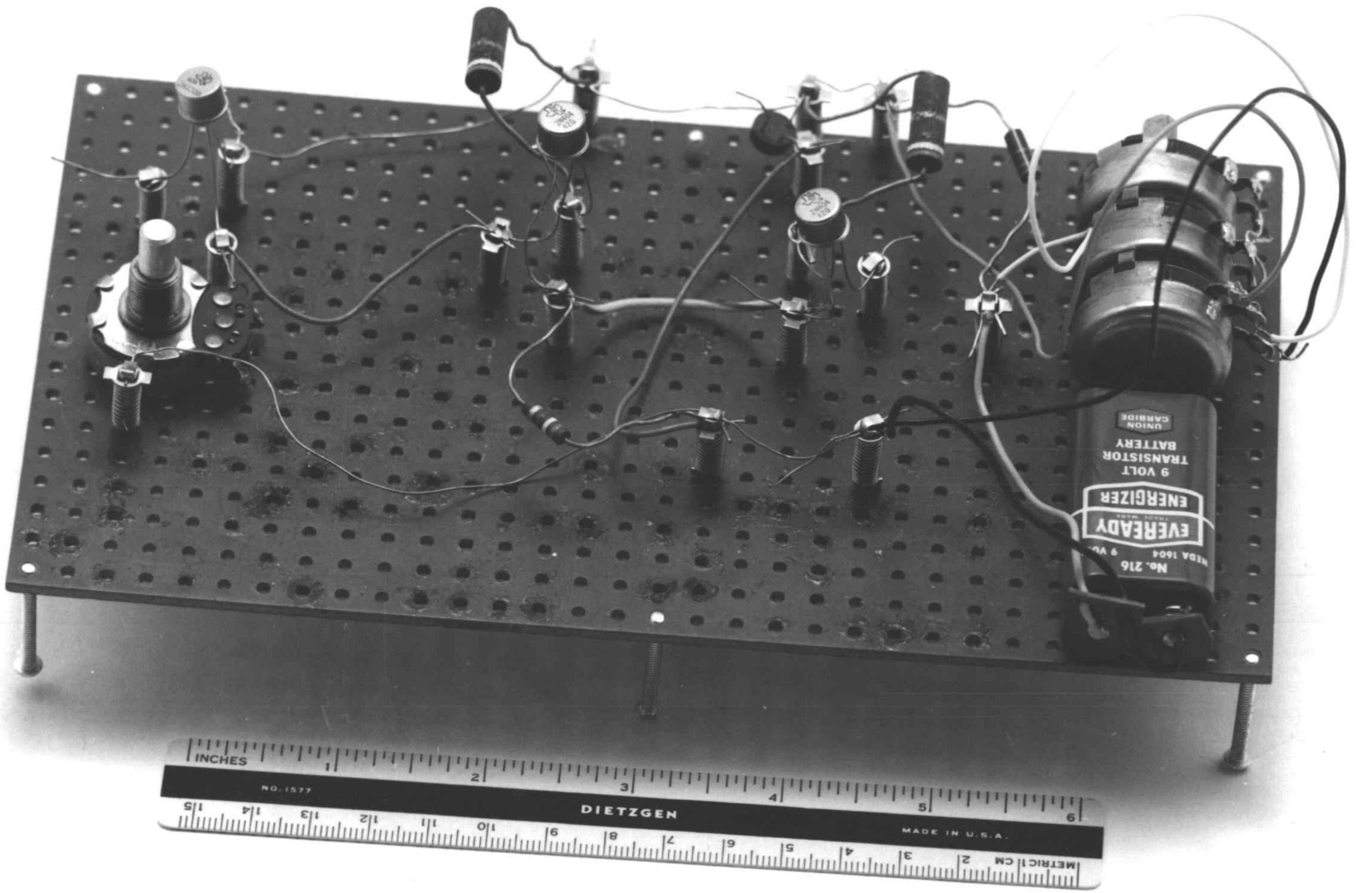


Figure 8. Preliminary amplifier layout.

# OPERATION OF THE READ-OUT ENLARGER

To operate the read-out enlarger, the amplifier's input is connected in parallel with the Radocon indicating meter, and the output to the projection meter. The projection meter is inverted and placed in a standard lantern slide projector. The projected image of the meter scale and index pointer may be displayed on a screen or lecture room wall. The Radocon is turned on and zeroed. Next, the amplifier is turned on, and, using the zero control on the amplifier which varies $P_1$, the projection meter is zeroed. Using an appropriate scale on the Radocon, the Radocon's zero control is turned until the indicating meter reads more than half-scale. Then, using the gain control on the amplifier which varies $P_2$, the gain of the amplifier is adjusted until the projection meter has a reading identical to that of the Radocon indicating meter.

Now, the projection meter will give readings which are identical to those of the Radocon indicating meter. If the readings drift apart slightly, the zero and gain adjustments should be repeated.

# SUMMARY AND CONCLUSIONS

The Victoreen Model 575 Radocon is a radiation survey instrument which could be a more valuable radiological demonstration aid if its read-out could be made clearly visible to a large audience. The problem is to accurately enlarge the read-out appearing on the Radocon indicating meter, without changing the circuit of the Radocon or affecting the value of the read-out appearing on the indicating meter.

The read-out enlargement is accomplished by amplifying the signal across the Radocon indicating meter, and using the amplified signal to drive a projection meter. The face and back of the projection meter are made of transparent Lucite so that the meter may be placed in a standard lantern slide projector, and an enlarged image of the meter scale and index pointer projected on a screen or wall.

A field-effect transistor used as a source-follower provides the amplifier with an input impedance of over 100 megohms so that the current flowing through the Radocon indicating meter is not reduced when the amplifier input is connected in parallel with it.

An emitter-coupled differential amplifier takes its input from the source of the field-effect transistor; its output drives the projection meter. The differential amplifier provides the gain necessary to accurately drive the projection meter. Through the property of common-mode rejection, the drift in output due to variations in temperature is reduced.

Drift in output due to a gradual decrease in battery supply voltage is controlled by placing a reverse-biased diode and a small resistance in series with the battery. When the diode is operating in the reverse-bias breakdown region, the current through the diode may change considerably, but the voltage across the diode remains essentially constant.

In operation, the input of the amplifier is connected in parallel with the Radocon indicating meter. The polarity is arranged so that the voltage on the gate of the field-effect transistor goes from zero to plus 0.1 volt as the Radocon indicating meter goes from zero to full-scale. The amplified signal appears as a voltage difference between the collectors of the two transistors in the differential amplifier. The final read-out appears on the projection meter, which is placed between the two collectors.

This method of read-out enlargement makes it possible to accurately display radiation measurements to a large audience. The read-out enlarger, used with the Radocon Model 575, can be used in a large classroom to demonstrate various physical laws which involve changes in radiation intensity.

A radiation safety officer may find the enlarger helpful while lecturing to a large group of radiologists on the importance of avoiding unnecessary exposure to radiation. Using an X-ray unit, he could make measurements at various positions relative to the unit, and the entire audience could see how the radiation intensity varied.

The same method may also be used to enlarge read-outs obtained from other types of instruments. An accurate enlargement may be obtained without altering the circuit of the instrument or affecting its read-out.

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