

July 11, 1961

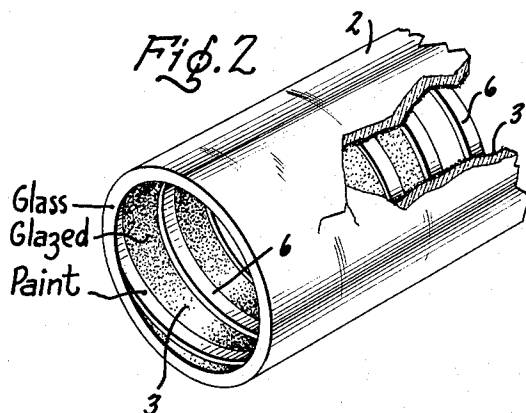
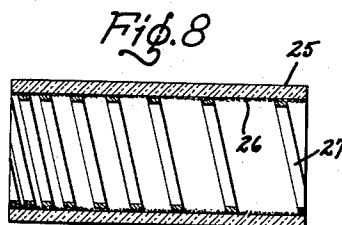
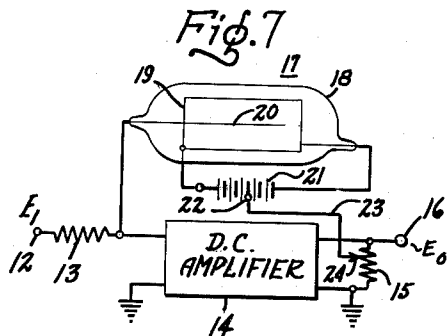
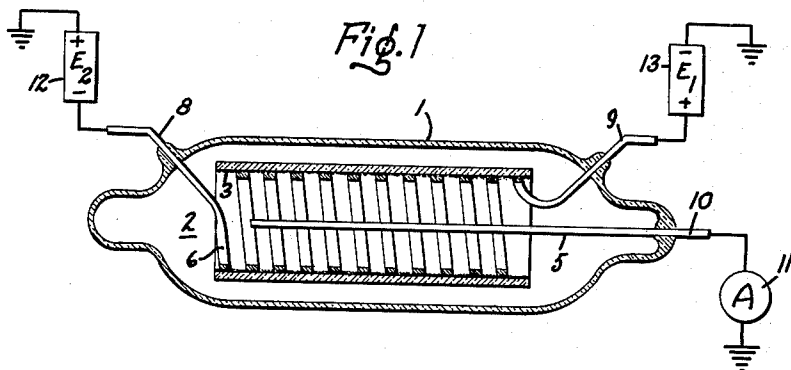
T. A. RICH

2,992,395

FEEDBACK AMPLIFIER CIRCUIT

Filed Dec. 30, 1958

2 Sheets-Sheet 1



Inventor
Theodore A. Rich
by *Merton D. Funn*
His Attorney

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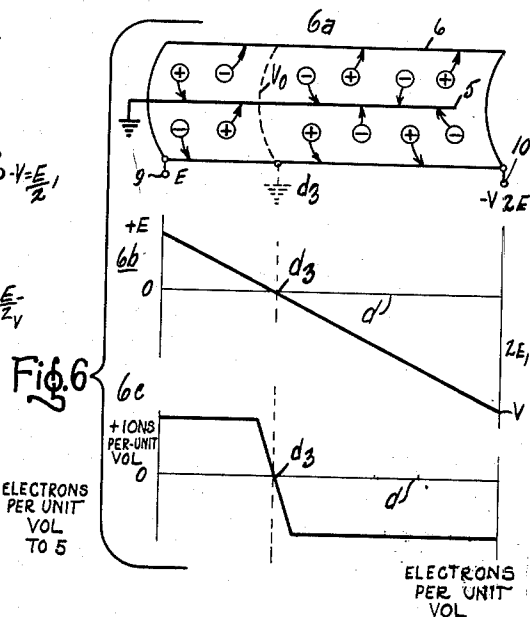
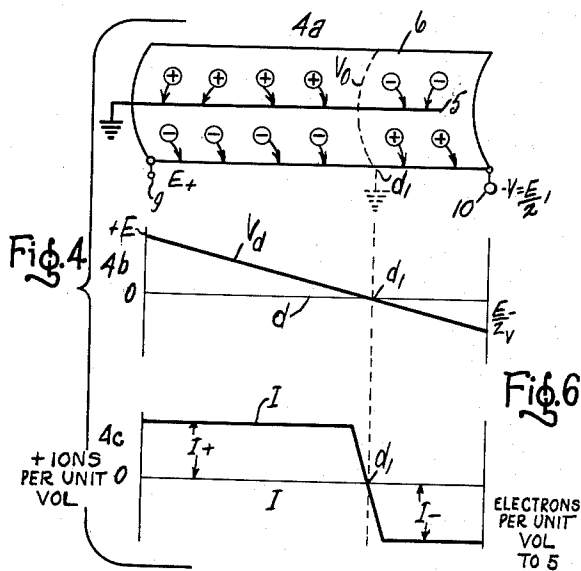
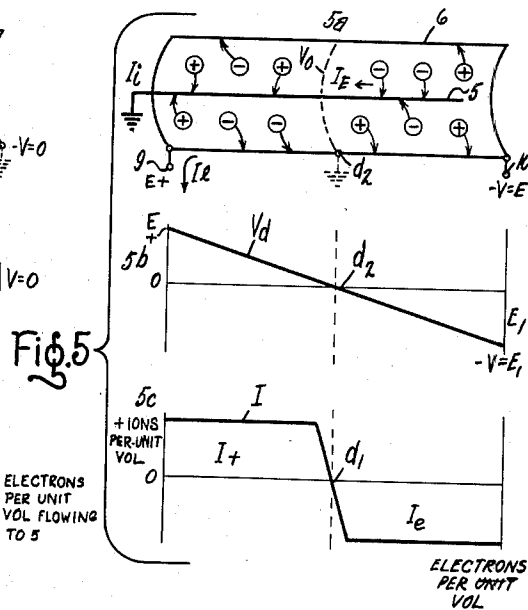
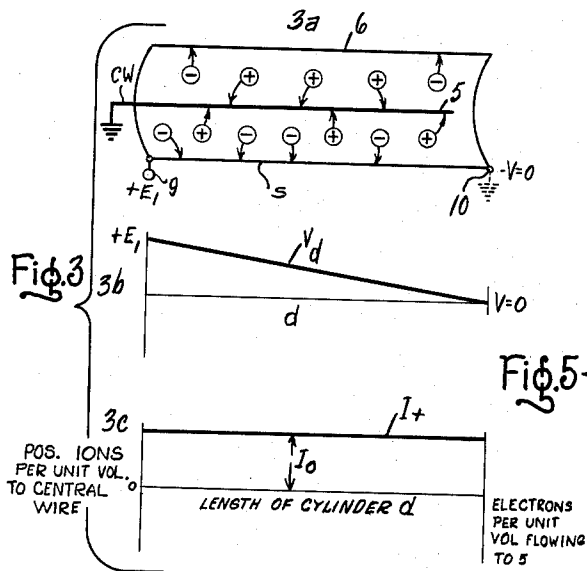
T. A. RICH

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FEEDBACK AMPLIFIER CIRCUIT

Filed Dec. 30, 1958

2 Sheets-Sheet 2



Inventor
Theodore A. Rich
by *Merton D. Moore*
His Attorney

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2,992,395

FEEDBACK AMPLIFIER CIRCUIT

Theodore A. Rich, Schenectady, N.Y., assignor to General Electric Company, a corporation of New York
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5 Claims. (Cl. 330-110)

This invention relates to a feedback amplifier circuit utilizing a novel radioactive circuit component. In particular, a radioactive resistance element is utilized, the resistance of which is proportional to the ratio of two voltages.

Feedback amplifiers, such as are used in computer circuits for summing or multiplying purposes, usually consist of a direct current amplifier having a very large forward gain and a feedback network between the amplifier input and output which includes a resistance element of large magnitude. The feedback resistance produces a current flow to the amplifier input which is equal to and opposes the input current, thus maintaining the amplifier input electrode at ground potential. The output voltage from such a feedback amplifier is defined by the equation:

$$E_0 = -E_i \times \frac{R_0}{R_1} \quad (1)$$

where E_0 =the output voltage, E_i =the input voltage, R_0 =the feedback resistance and R_1 =the input resistance. It can be seen from this equation that it is highly desirable that the feedback resistance R_0 be very large in order to produce a large output voltage. Consequently, such feedback resistors customarily range in value from 10^7 to 10^{12} ohms.

Resistors of such high values are usually made by vacuum depositing a resistive material on a glass base. As a result, such resistances usually have appreciable temperature and voltage coefficients so that the resistance varies with operating conditions. In addition, at high ambient temperatures the glass base upon which the resistive material is deposited becomes an appreciable fraction of the total resistance and thus introduces further inaccuracies.

One possible solution is to utilize an entirely different type of resistance component which is not susceptible to such fluctuations. One suitable construction is the so-called radioactive resistors which are simply ionization chambers having a source of radiation such as radium or uranium included in the chamber. In such radioactive resistors the current flow is directly proportional to the applied voltage up to that value of voltage at which all of the ions are collected. Beyond this value of voltage known as the saturation voltage, the current is independent of the applied voltage, there being no further increase as a result of additional applied voltage. In order to utilize the resistor of the radioactive type, the construction thereof must be such that the current flowing therefrom must be variable for voltage values beyond the normal saturation value at which all the ions are collected.

Therefore, it is an object of this invention to provide a feedback amplifier utilizing a feedback resistor of the radioactive type;

Another object of this invention is to provide a feedback amplifier utilizing a radioactive feedback resistor which produces a current proportional to the output voltage of the amplifier over a wide range of voltages;

A further object of this invention is to provide a feedback amplifier assembly which utilizes a radioactive feedback resistor which produces a current proportional to the ratio of two voltages;

Yet another object of this invention is to provide a radioactive resistor of novel construction which produces

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an output current proportional to the ratio of two voltages;

An additional object of this invention is to provide a radioactive resistor of novel construction which causes an output current to flow which is proportional to the ratio of a fixed and a varying voltage;

Still another object of this invention is to provide a radioactive resistor of novel construction which produces an output current which is non-linearly related to the ratio of two voltages;

Yet another object of this invention is to provide a radioactive resistor of novel construction which may be utilized as a multi-range resistor;

Other objects and advantages of this invention will become apparent as the description thereof proceeds.

In accordance with the invention, the foregoing objects are accomplished by constructing a feedback amplifier which includes a radioactive feedback resistor which is characterized by the fact that by applying voltages of opposite polarity to one of the electrodes a voltage gradient is established which controls the distribution of the charged particles produced by ionization between the electrodes. Thus, the number of these particles collected on the remaining electrode may be varied to produce a net current which is directly proportional to the ratio of the voltages. In an alternative embodiment, a radioactive resistor is disclosed which is so constructed that the net current flowing in the remaining electrode can be made a non-linear function of a voltage ratio applied to one of the electrodes of the resistor.

The novel features which are characteristic of this invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with other objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings in which:

FIG. 1 is a cross-sectional view of the novel radioactive resistor;

FIG. 2 is a perspective detail of one of the electrodes of the resistor of FIG. 1;

FIGS. 3, 4, 5, and 6 are diagrammatic illustrations of the manner in which the novel resistor operates;

FIG. 7 is a schematic diagram of a feedback amplifier utilizing such a radioactive resistor;

FIG. 8 is an alternative embodiment of one of the electrodes of the feedback resistor.

Referring now to FIG. 1, an envelope 1, generally of glass, is employed to house the various electrodes of the radioactive resistor. A cylinder 2 formed of ceramic or similar insulating material is mounted within the envelope 1 and contains a small quantity of radioactive material 3, such as radium for example, positioned on its interior surface. The radium may be retained by baking it onto the ceramic in the form of a glaze, or may be positioned thereon as a metallic foil secured to the cylinder 2 by an adhesive and covered by an insulating layer. In FIGS. 1 and 2 the radioactive material 3 is shown on the inner surface of the cylinder 2 in the form of a glaze.

The envelope 1 is filled with an ionizable medium, such as the inert gases nitrogen, argon, etc., maintained at atmospheric pressure or higher. These gases are ionized by the radiations from the radioactive radium glaze, which ionized particles are collected in a manner presently to be described. Radium is a suitable radio-active material for this purpose because it gives off alpha particles which cause strong gas ionization. It is to be understood, however, that other radioactive materials may be used in place of radium as long as they emit radiations to ionize the gas within the envelope 1.

To collect the ionized gas particles, a pair of electrodes 5 and 6 having lead in conductors 8, 9, and 10 are mount-

ed within the envelope 1. Electrode 5, which is of the wire type, is a current collecting electrode having an output current flowing which, when measured by an ammeter 11 connected between the lead 10 and ground, is proportional to the ratio of two voltages applied to the electrode 6. The electrode 6 is constructed to act as a resistive voltage divider and establish a voltage gradient which varies along the length of the electrode. To this end, the electrode 6 should be formed from a material with a high resistivity per unit length so that a voltage applied thereto establishes a potential drop along the electrode. As may be seen most clearly in FIG. 2, electrode 6 is formed as a cylindrical helix of resistance material positioned on the inner surface of the cylinder 2. The helix 6 may be produced by spraying a high resistance conductive paint along the inner surface of the tubular member 2 in the form of the helix. Alternately, electrode 6 may be produced by securing a helix of metal foil to the inner surface of the tube 2 by means of any suitable adhesive. Furthermore, the electrode 6 need not necessarily be in the form of a helix, but may be a continuous cylindrical surface as long as the resistivity of the material utilized to form the cylinder is sufficiently high to establish a voltage gradient along the cylinder.

By applying voltages of opposite polarity to the electrode 6, a voltage gradient is established along the axis of the helix 6 and at some intermediate point the helix is at ground potential, thus dividing the collecting volume defined by the helix into two portions, one of which has a positive voltage gradient and the other a negative voltage gradient. To this end, conductors 8 and 9 are connected, respectively, to negative and positive terminals, relative to ground, of the voltage sources 12 and 13. As a result of the two volumes with voltage gradients of different polarities, the output current flowing in the electrode 5 is proportional to this difference in volume. By varying the voltages E_1 and E_2 , the relative magnitudes of the volumes with the positive and negative voltage gradient are varied, correspondingly varying the output current on electrodes.

FIGS. 3-6 illustrate schematically the manner in which the volumes are varied to control the output current. Referring directly to FIG. 3, the cylindrical electrode 6 and the coaxial wire electrode 5 are illustrated schematically with the electrode 5 shown at ground potential. The left hand end cylinder 6 has a positive potential of magnitude $+E_1$ applied thereto at terminal 9, whereas the right hand end is shown at zero volts or ground potential. Since the amount of radioactive material 3 within the envelope 1 is fixed, the amount of ionization is constant producing, as is well known to those skilled in the art, ion pairs by removing and adding electrons to the neutral gas atoms. In most practical embodiments, relatively few negative ions are formed by the attachment of electrons to neutral molecules, and as a result electrons and positive ions (rather than positive and negative ions) are formed in the gas, however the essential operation is unaffected by the mobility of the charged particles. For a further discussion of this phenomenon reference is made to the volume Electron and Nuclear Counters, Korff, Van Nostrand Company, Inc. (New York) 1946.

Since each ionizing event produces both a positive ion and an electron, substantially equal amounts of each are formed, a condition illustrated in FIG. 3a by an equal number of circled pluses (+) and minuses (-) within the cylinder 6. With a positive voltage $+E_1$ applied to the terminal 9 and terminal 10 being grounded, the voltage distribution along the cylinder 6 is shown by the curve V_d of FIG. 3a. As a result, the entire cylindrical element 6 is more positive than the grounded electrode 5, and all of the electrons illustrated by the circled minus signs are drawn to the cylindrical electrode 6, whereas all of the positive ions are drawn to the electrode 5. The total magnitude of this current is equal to the area under the solid line curve I of FIG. 3c and represents the num-

ber of positive ions produced per unit volume times the collection volume wherein the plus ions flow to the electrodes 5. The maximum current flow for any given resistor configuration is, of course, determined by such parameters as the quantity of radioactive material, the ionizable gas, and the total number of positive ions produced.

If a voltage of opposite polarity is now applied to the terminal 10, it is apparent that some intermediate point d_1 along the cylinder is at zero or ground potential, dividing the volume of cylinder 6 in two parts, one of which has a positive voltage gradient and the other of which has a negative voltage gradient. Thus, in effect, a movable ground is established along the cylinder 6 which establishes the relative magnitudes of these volumes. FIG. 4a illustrates the situation where a positive voltage $+E_1$ is applied to the terminal 9 and a negative voltage $-V$ having a magnitude of

$$\frac{E}{2}$$

is applied to the terminal 10. As a result, the voltage distribution along the cylinder is such that at some intermediate point d_1 the cylinder 6 is at zero or ground potential, a condition illustrated in FIG. 4b by the point d_1 at which the voltage distribution curve V_d crosses the abscissa and in FIG. 4a by the dashed semicircle V_0 and ground. Since the resistivity of the cylinder 6 is uniform, so is the voltage distribution, and the location of point d_1 is directly related to the ratio of magnitude of the positive ($+E_1$) and negative voltages ($-V$). Thus, under the conditions described, the point d_1 is two thirds

$$\frac{2d}{3}$$

of the distance from the left hand end of the cylinder.

As a result, the volume to the left of the line V_0 , which has a positive potential gradient, all of the positive ions flow to the electrode 5. In the volume to the right of the line V_0 , however, the cylindrical electrode 6 is now more negative than ground and, hence, the electrons flow to the electrode 5. The resultant current flowing from electrode 5 is the algebraic sum of the positive ions and the electrons drawn to this electrode. Since the electron current flow and the positive ion flow in a given electrode tend to cancel because of their opposite polarity, the resultant current in the electrode 5 is equal to the difference in the absolute numbers of positive ions and the electrons, or one-third of the maximum positive ion current. FIG. 4c illustrates this condition graphically with the area under the curve I to the left of d_1 (ions per unit volume times the volume to point d_1), the positive ions equaling and the area under the curve I to the right of the d_1 being equal to the electrons collected on electrode 5 (electrons per unit volume times the volume to point d_1), with the resultant current being equal to the difference in the areas under the curve I.

As shown in FIG. 5, if voltages of equal magnitudes but opposite polarities are applied to the terminals 9 and 10, the point of zero or ground potential d_2 is located at the middle of the cylinder 6 and the volumes to the left and right of the line V_0 are equal as are the amounts of positive ions and electrons collected on the electrode 5. As a result, the areas underneath the curve I in FIG. 5c are equal and the differential or output current on the electrode 5 is substantially zero.

In FIG. 6 the voltage applied to the terminal 10 is twice as large as the positive voltage $+E_1$ applied to the terminal 9 of the cylinder 6, and as a result the points of zero or ground potential is located at d_3 , one-third of the distance from the left hand terminal 9. Consequently, the positive area under the curve I of FIG. 6c representing positive ion flow to electrode 5 is one-half as large as the negative area under the curve I representing

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electron flow, and the resultant differential current is now an electron current of a magnitude

$$\frac{I}{3}$$

Thus, it may be seen that by varying the magnitude of the voltage of one polarity applied to one end of the cylinder 6 and maintaining the voltage of opposite polarity fixed, both the magnitude and the sign of the resultant current flowing from the electrode 5 is varied. It is apparent, therefore, that the resistance of this radioactive resistor component varies from infinity when equal and opposite voltages are applied to the cylinder 6 through a range of finite resistance values depending on the magnitude ratio of these respective voltages.

In describing the operation of the novel radioactive resistor component with reference in FIGS. 3-6, for simplicity of explanation, voltages of opposite polarity were applied individually to the terminals 9 and 10. It will be apparent, however, that the manner in which the voltages are applied to the cylindrical electrode to control the current flow and resistance is not so limited. FIG. 7 illustrates a slightly different arrangement of the radioactive resistance connected in a feedback or operational amplifier. Thus, an input terminal 12 is shown which is adapted to receive a direct current input voltage E_i and which is connected through an input resistance 13 to the input electrode of a direct current amplifier 14, shown in block diagram form. For a complete description of the structure of such a feedback amplifier which is also known to those skilled in the art as an "operational" amplifier, reference is hereby made to pages 10-14 of *Electronic Analog Computers* by Korn and Korn, first edition, published by the McGraw-Hill Book Co., Inc. of New York (1952).

Connected across the output of the amplifier 14 is an output resistance 15, one end of which is connected to an output terminal 16 and the other end of which is connected to a point of reference potential such as ground. A portion of the output voltage appearing across the resistor 15 is fed back through a radioactive resistance illustrated generally at 17 to the input electrode of the amplifier 14. The radioactive resistance 17 is generally of the type illustrated with reference to FIG. 1 and comprises an envelope 18, a cylindrical electrode 19, of the type illustrated in FIGS. 1 and 2, and a central collecting electrode 20, and connected to the input electrode of the amplifier 14.

The envelope 18 contains an ionizable gaseous medium such as argon and a radioactive ionizing source deposited on the inner surface of the cylinder 19 in the manner described previously. A source of biasing potential 21 is connected between the opposite ends of the cylinder 19 with the positive terminal connected to the left side of cylinder 19 and the negative terminal to the right end thereof. A center tap 22 on the battery 21 is connected through a suitable lead 23 to a slider 24 on the output resistance 16 to feed back a portion of the output voltage E_o . Because of the manner of connection of biasing potential 21, the opposite ends of the cylindrical electrode 19, in the absence of an input signal E_i to the terminal 12, no current flows along the wire electrode 5. That is, in the absence of an input signal at the terminal 12, no output current flows through the output resistance 15 and, hence, the slider 24 and the center tap 22 on the battery are essentially at ground potential. As a result, voltages of opposite polarity and equal magnitude applied are applied to the cylinder 19, the midpoint thereof is at ground and equal amounts of positive ions and electrons are collected on the electrode 20.

Upon appearance of an input signal at the terminal 12, current flows in the output resistance 15 and the movable slider 24 is no longer at or near ground potential but assumes some value of potential with respect to ground as does the center tap 22 of battery 21. This

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potential is applied differentially to the opposite ends of the cylinder 19 causing current to flow in electrode 20. By way of example, assuming that the magnitude of the bias potential supplied by the battery 21 is 10 volts, with no current flowing in the output resistor 15, the center tap 22 is at ground potential and, hence, the left end of cylinder 19 is five volts above ground while the right end is five volts below ground, and equal amounts of positive ions and electrons are collected. If an input voltage is now applied to the terminal 12 so that a current flows in the output resistance 15 and the slider 24 is now at minus two volts (-2 volts), for example, the center tap 22 is also at minus two volts. Adding the biasing voltages from the battery sections, +5 v. are added to the left and -5 v. going to the right so that the left hand end of cylinder 19 is at +3 volts (-2 v.+5 v.=+3 v.) above ground while the right hand end is at -7 v.

$$[-2 \text{ v.} + (-5 \text{ v.}) = -7 \text{ v.}]$$

As the input voltage E_i applied to the terminals 12 varies, the potential of the slider 24 varies correspondingly relative to ground and as does the ratio of the voltage applied to opposite ends of the cylinder 19. As a result, the output current of the resistance 17 varies with the output voltage appearing across the output resistance 15 so that the feedback amplifier operates in the desired manner.

As shown in FIG. 8, the cylindrical electrode may be so constructed that the voltage distribution along the cylinder is non-linear function and the current flow is similarly related in a non-linear manner to the voltage ratio applied to the cylinder. That is, the helix may be so constructed that the voltage distribution along the axis is not linear with distance but varies in some non-linear fashion. Thus, the cylindrical electrode illustrated in FIG. 8 comprises a tubular ceramic member 25 having a layer of radioactive material 26 deposited along the inner surface thereof and a helix 25 of conducting material deposited thereon in any suitable manner. The helix 27 is not symmetrically spaced so that the spacing between individual turns is not equal. Since the resistivity of the conducting material is equal per unit length, the voltage drop moving axially along the helix is not linear and the output current can be made proportional to or some arbitrary curve.

$$(E)^n$$

$$\frac{V}{V}$$

Alternately, the resistance per unit length moving axially along the helix can be made to vary in an arbitrary manner without changing the spacing of the helix. This may be achieved by constructing a helix having equal spacing between turns but varying the resistivity of the various turns by controlling the thickness of the material forming helix 27 in a given manner. In this fashion the output current can also be made to vary according to some arbitrary non-linear curve by varying the voltage distribution along the helix in a non-linear manner. Yet a third alternative would be to vary the volume per axial length to achieve the same results, and a fourth alternative is to vary the distribution of radioactive material over the inner surface of the cylinder to produce varying levels of radiation along the axis.

By using an external source of radiation, the intensity of which may be controlled by means of shielding or by varying the distance from the resistor, the novel radioactive resistance component may be made to function as a multi-range resistor. This can be understood more clearly by considering the fact that the maximum amount of current flowing from the resistor is determined by the total amount of ionization produced within the resistor which in turn is a function of the radiation intensity. If the radioactive material is directly incorporated within the envelope I, it will be apparent that once the resistor is fabricated the maximum ionization current is fixed.

However, by using an external source of radiation, the radiation intensity may be varied in any number of different manners to control the range of resistance obtainable by means of this construction.

While a number of particular embodiments of this invention have been shown, it will, of course, be understood that it is not limited thereto since many other modifications both in the circuit arrangement and in the instrumentalities employed may be made. It is contemplated by the appended claims to cover any such modifications as fall within the true spirit and scope of this invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a feedback amplifier circuit, the combination comprising amplifying means having input and output terminals, a feedback network connected between said input and said output terminals to produce a feedback current to said input terminal to maintain said terminal at ground potential, said network including a radioactive current source comprising an envelope having an ionizable medium and a source of ionizing radiation, voltage dividing electrode means positioned in said envelope to establish potential gradients which control the collection of charged particles produced by the ionization of said medium, biasing voltage means, said biasing voltage means being connected to said electrode means to impress a biasing voltage across opposite ends of said electrode means, means coupling a portion of the output voltage from said amplifying means to said biasing means for combining said voltages and adding the output voltage to said biasing voltage to one end of said electrode means and subtracting the output voltage from said biasing voltage at the opposite end of said electrode means to control the number of charged particles collected to vary the current flow to the input of said amplifying means.

2. A radioactive circuit component comprising an

envelope containing an ionizable medium, a radioactive material in said envelope to produce a predetermined quantity of charged particles of opposite sign in said envelope, a pair of spaced electrodes in said envelope to define a collecting volume, one of said electrodes being formed of high resistivity material to act as a voltage divider and form a voltage gradient along its length, means to apply voltages of opposite polarity to the respective opposite ends of said one electrode to divide said collecting volume into volumes having voltage gradients of opposite sign so that charged particles of different sign flow to the other electrode in the respective volumes, whereby the resultant current flowing in said other electrode depends on the ratio of the voltages applied to said one electrode.

3. The radioactive circuit component of claim 2 wherein said one electrode is a metallic helix.

4. The radioactive circuit component of claim 2 wherein said one electrode is a metallic helix, individual turns of which are equally spaced.

5. The radioactive circuit component of claim 2 wherein said one electrode is a non-linear voltage divider and consists of a metallic helix, individual turns of which have unequal spacing.

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