

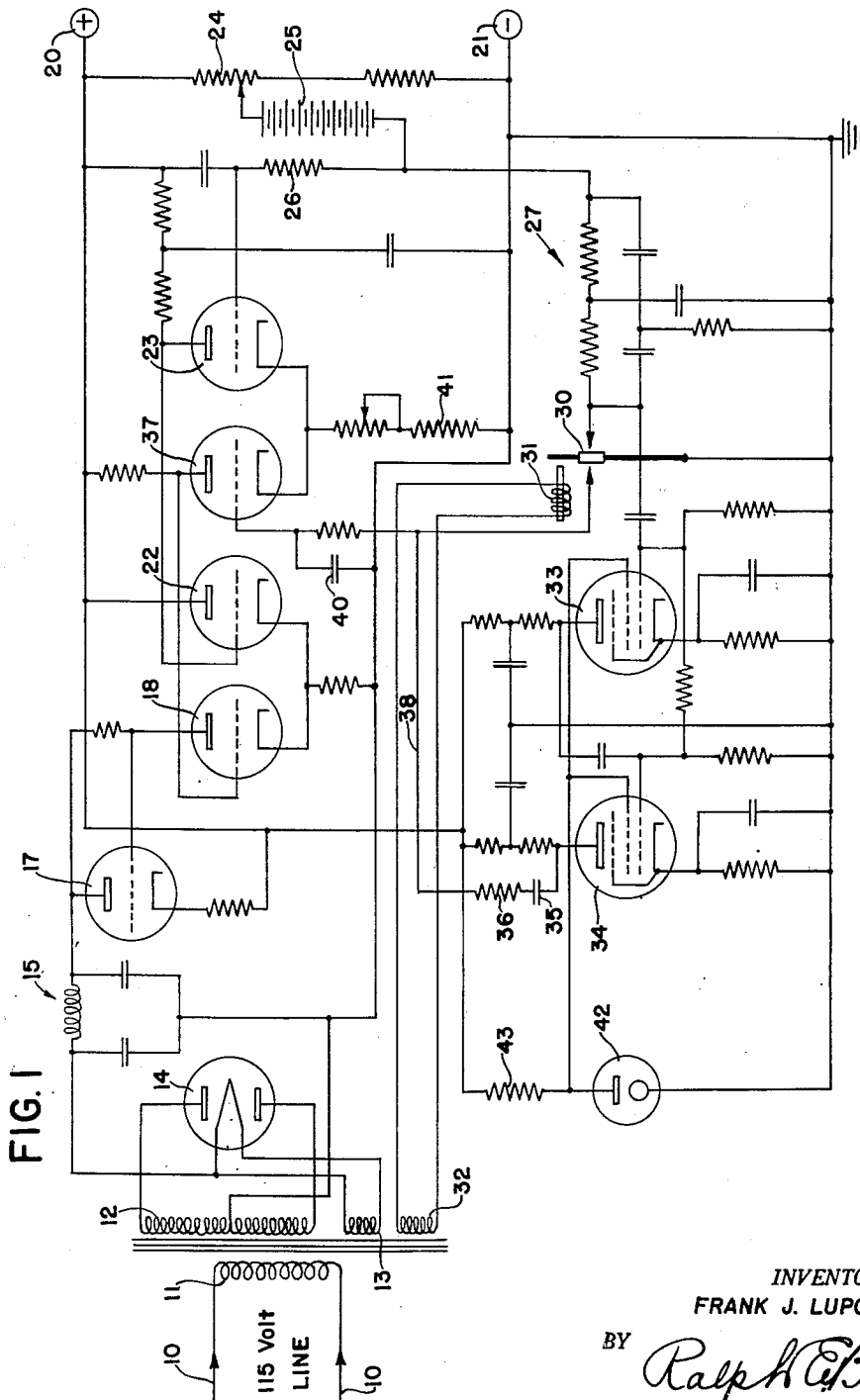
April 29, 1952

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VOLTAGE REGULATOR

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Filed June 5, 1951

2 SHEETS—SHEET 1



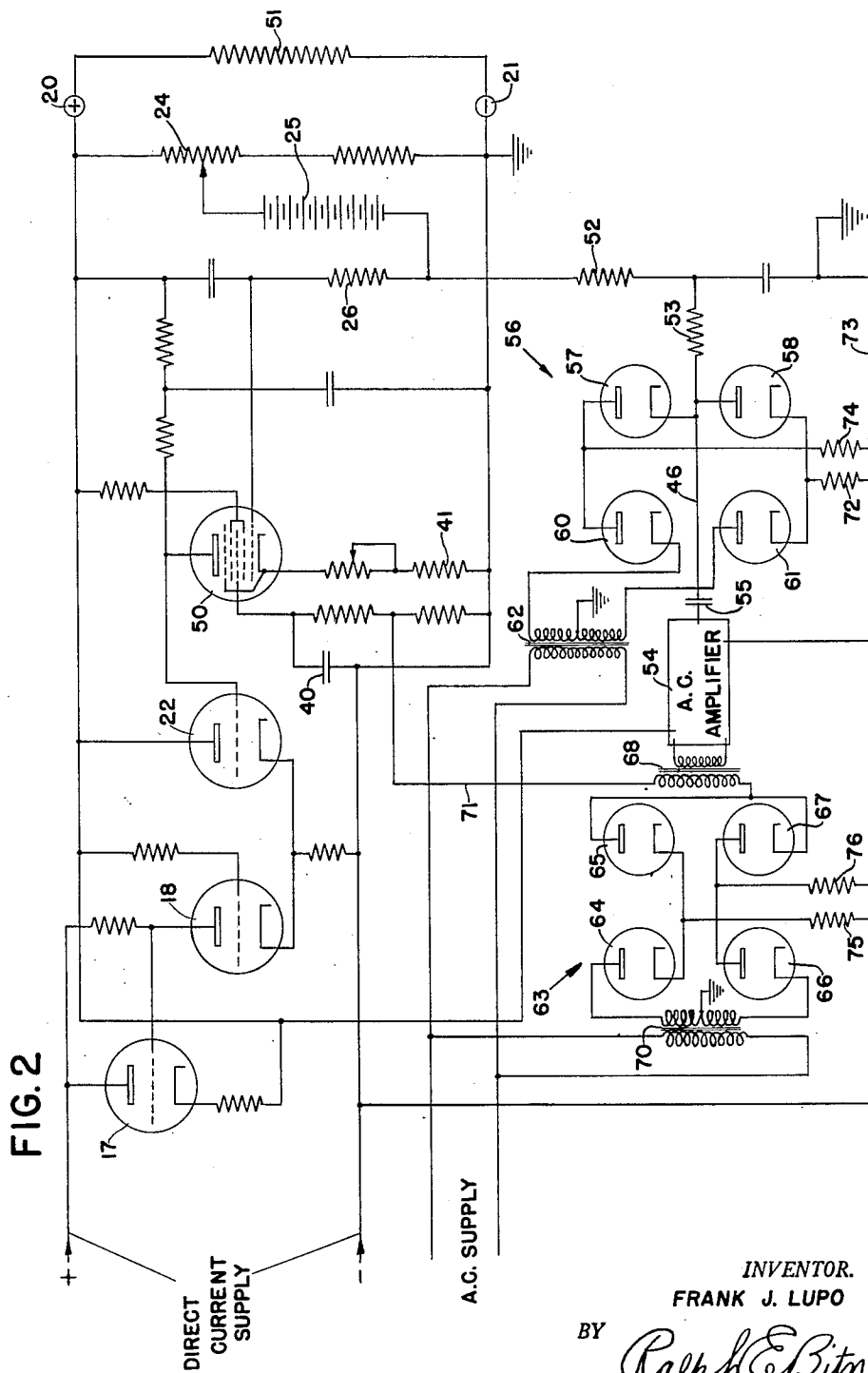
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2 SHEETS—SHEET 2



INVENTOR.
FRANK J. LUPO
BY *Ralph E. Bitner*
ATTORNEY

UNITED STATES PATENT OFFICE

2,594,572

VOLTAGE REGULATOR

Frank J. Lupo, Hackensack, N. J., assignor to
Chatham Electronics Corporation, Newark,
N. J., a corporation of New Jersey

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6 Claims. (Cl. 323-22)

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This invention relates to voltage regulators of the type which receive power from an unregulated alternating current source and deliver direct current to a load circuit. The invention has particular reference to voltage regulators capable of delivering a voltage which is constant to one part in 600,000 with respect to a reference voltage source which is used as a standard.

Electronic regulator circuits are old in the art and many different circuits have been proposed and used. The most popular arrangements generally employ one or more triode discharge devices in series connection between the supply line and the load with a voltage sensitive circuit coupled between the load and control electrode of the series tube. The voltage sensitive circuit may use a battery or a gaseous discharge tube as a reference voltage. Such circuits regulate quite well, especially those using a battery as a reference voltage. When properly adjusted these circuits provide a compensation for voltage variations of the power source and also for variations of the load impedance.

Prior art regulators, however, have not been designed to give perfect regulation, and there has always existed a small variation in the load voltage when the supply voltage varies by several percent. The greatest defect of prior art regulators is the slow drift in load voltage which occurs over a period of several minutes or hours, and which is caused by ambient temperature changes and variations in contact potential in the voltage sensitive part of the circuit.

One of the objects of this invention is to provide an improved voltage regulator which avoids one or more of the disadvantages and limitations of prior art regulators.

Another object of the invention is to deliver a constant unvarying potential to a load circuit using a controlled variable current through a cathode resistor to correct and compensate for the slow drift caused by variable characteristics in the voltage sensitive circuit.

Another object of the invention is to improve the voltage regulation in electronic regulator circuits so that a variation of ten percent in the supply voltage will cause the load voltage to vary less than one part in 600,000.

Still another object of the invention is to improve the voltage regulation in the presence of abrupt variations in load impedance and low frequency variations in load current, thereby reducing the effective internal impedance (as measured at the output terminals) of the power supply.

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The invention includes an electron discharge device in series arrangement between a rectified source of direct current and the load. The bias potential of the control electrode of the discharge device is derived from the output of a three stage direct current amplifier. The input of this amplifier is connected to the variable contact of a voltage divider in series with a battery which is urged as a voltage reference. The voltage divider is connected to the load terminals. A novel feature of the invention comprises an inverter system for converting a direct current error voltage into a pulsating current, amplifying and rectifying this pulsating current and applying it to the direct current amplifier to change its output and reduce the error voltage to zero.

For a better understanding of the present invention, together with other and further objects thereof, reference is made to the following description taken in connection with the accompanying drawings.

Fig. 1 is a schematic diagram of connections showing a circuit of a voltage regulator using vibrating contacts for inversion and rectification.

Fig. 2 is a diagram showing an alternate circuit using a system of diodes for inversion and rectification.

Referring now to Fig. 1, power lines 10 are connected to the usual 60 cycle commercial supply. A primary 11 of an iron-cored transformer is connected across the power lines and secondaries 12 and 13 supply power to the anodes and filament of rectifier tube 14. A pulsating voltage is obtained between the mid-point of the anode secondary and the filament and a filter 15 is employed to eliminate the alternating components and deliver direct current power to the voltage regulator circuit.

One or more electron tubes 17 are connected in series with the positive power conductor and constitute the means for regulating the load voltage. The control electrodes of the series tubes 17 are connected to the anode of an amplifier tube 18 and the cathodes of the series tubes are connected to the positive line which runs directly to output terminal 20. The negative terminal 21 is grounded and connected to the mid-point of secondary winding 12.

Triode 18 is the output stage of a three stage direct current amplifier which includes a second stage triode 22 and an input stage triode 23.

The voltage sensitive circuit includes a voltage divider 24, a reference battery 25, and two coupled circuits. One of these circuits connects to the control electrode of amplifier triode 23

through a coupling resistor 26. The second coupled circuit connects through a low pass filter circuit 27 to a vibrating contact 30. The vibrating contact is operated by an iron-core winding 31 which is directly connected to a low voltage winding 32 on the power transformer.

When the load voltage changes due to a changing load or a voltage change on the input line, the voltage sensitive circuit is thrown out of its equilibrium condition and a higher or lower voltage is applied to the control electrode of triode 23. This change is amplified by triodes 22 and 18 in sequence and the output applied to the control electrode of series tube 17, thereby compensating for the change and returning the system to a balanced condition. This is the usual and well known system of voltage regulation and is accurate if there is no change in amplification of the three stage direct current amplifier.

If a change in amplification occurs due to changing tube characteristics or to changing contact potentials, the system will return to a balanced condition but an error voltage will be introduced and be applied to the vibrating contacts 30. Making and breaking a connection to ground at this point applies a pulsating voltage to the control electrode of amplifier tube 33. This voltage may be either positive or negative, depending upon the polarity of the error voltage. The pulsating voltage is amplified by tubes 33 and 34, and is delivered by way of conductor 38 through an output circuit containing a coupling capacitor 35 and resistor 36 to the left side of contacts 39 and to the control electrode of a compensating triode 37.

The output signal which leaves tube 34 and passes through capacitor 35 contains no direct current component, but the vibrating contacts 39 act as a short circuit for one-half of each cycle and produce a rectified series of pulses which have the same polarity as the error voltage. The pulse train is filtered by capacitor 40, the net result being an increase (or decrease) of anode-cathode current through triode 37 and through cathode resistor 41 which is common to both tubes 37 and 23. When this current changes in triode 37 the potential of the cathode of triode 23 is changed and the characteristics of the direct current amplifier are altered to again establish the equilibrium of the system and reduce the error voltage to zero.

The above described regulator circuit depends upon a constant and unvarying reference source 25 which is preferably made up of standard cells which are maintained at a fixed temperature. The regulator also depends upon the constancy of the amplification ratio of the two-stage A. C. amplifier 33, 34, and in order to insure more dependable action, the screen grids of these tubes are connected to one side of a gaseous regulator tube 42 which receives its current supply through a ballast resistor 43 from the positive side of the regulated voltage line.

Fig. 2 shows an alternate circuit having similar characteristics but employing no mechanical motion. Two bridge circuits, each containing four diodes, are used in place of the vibrating contacts. Other components of the circuit are the same as shown in Fig. 1 except an alternate type of mixer circuit is shown in which a pentagrid tube replaces two triodes.

The series tube 17 is connected between direct current supply and the positive load terminal 20. This tube, as before, has its impedance varied by voltage variations impressed on its control

electrode to keep a constant predetermined voltage applied to a load 51. The voltage sensitive circuit, as before, includes a reference battery 25 applied through a voltage divider 24. One circuit, which transmits an unbalance or error voltage, is connected from the battery 25 through a resistor 26 and is applied to the control electrode (grid No. 1) of a pentagrid tube 50. This tube together with tubes 22 and 18 forms a direct current amplifier, the output of which is connected to the control electrode of the series tube 17 to effect the desired regulation.

A second circuit is connected to battery 25 to act as an auxiliary control and adjust the direct current amplifier so that it always provides constant gain. This circuit includes resistors 52 and 53 and is connected to an A. C. amplifier 54 by conductor 46 through a blocking condenser 55. A bridge circuit 56 contains four diodes 57, 58, 60, 61 which act to introduce an alternating component in an error voltage if the system is out of balance. The cathode of tube 57 and the anode of tube 58 are connected to the input line 46 between resistor 53 and capacitor 55. Tubes 60 and 61 have their respective cathode and anode connected to an alternating current power source derived through transformer 62. The bridge system acts as a partial short circuit for half the A. C. cycle and as a high parallel impedance for the other half of the cycle.

After the inverted error signal has been amplified by the A. C. amplifier 54 it is applied to a diode rectifier circuit 63. The rectifier circuit includes four diodes 64, 65, 66, and 67. The input is through a transformer 68 and the A. C. supply line applies A. C. power to the rectifier through a second transformer 70. The correction voltage output is taken over conductor 71 and applied to grid number 3 of tube 50. A change in potential of the number 3 grid changes the gain of the tube when acting as a direct current amplifier hence the correction voltage from the rectifier circuit 63 alters the gain of the amplifier to reduce the error voltage to zero.

Inverter 56 operates as follows: When the error voltage is zero there is no input voltage to the amplifier 54 since the circuit is balanced and the center point of the secondary of transformer 62 is grounded. Now, let it be assumed that because of changes in one of the tubes 50, 22, or 18, the circuit does not regulate and a positive error voltage appears on conductor 46. When the A. C. supply, acting through transformer 62, makes the cathode of tube 60 positive and the anode of tube 61 negative, tubes 60 and 61 do not conduct and do not transmit any voltage to tubes 57 or 58. In this condition the anode of tube 57 and the cathode of tube 58 are at ground potential and the positive error voltage on conductor 46 causes a current through tube 58 and resistor 72 to ground. When the potentials are reversed during the next half-cycle, the anode of tube 61 is positive and the cathode of tube 60 is negative, thereby making them both conductive and passing current through resistors 72 and 74 to ground. The voltage drop across these resistors applies a negative voltage to the anode of tube 57 and a positive voltage to the cathode of tube 58 making both tubes non-conductive and presenting a high impedance to the error voltage on conductor 46. In this manner the direct current error voltage is inverted to an alternating current having the same frequency as the A. C. supply.

After amplification by the A. C. amplifier 54;

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rectifier 63 changes the A. C. output to direct current having the same polarity as the error voltage. The amplifier output is applied through transformer 68 and impresses an alternating voltage on conductor 71. If this voltage is pure A. C. it has no effect on stage 50 because capacitor 40 is large (about 1 microfarad) and shunts all of the current to ground. The A. C. supply is applied to the four diodes by means of transformer 70, the mid-point of the secondary being connected to ground. When this supply makes the anode of tube 64 positive and the cathode of tube 66 negative, both tubes conduct and send current through resistors 75 and 76 to ground. The voltage drops across these resistors makes the cathode of tube 65 positive and the anode of tube 67 negative. Tubes 65 and 67 therefore cannot conduct and the full voltage induced in the secondary of transformer 68 is applied on conductor 71.

During the next half-cycle the anode of tube 64 is negative and the cathode of tube 66 is positive and these two tubes cannot conduct. The cathode of tube 65 and the anode of tube 67 are at ground potential hence a positive or negative voltage applied from the secondary of transformer 68 passes through one of the tubes to ground and considerably reduces the voltage on conductor 71. This action creates a direct current component in the voltage on conductor 71 which charges capacitor 40 and is impressed on grid number 3 of tube 50 to change the gain of the direct current amplifier and reduce the error voltage to zero.

Since the same A. C. supply is applied to both the inverter 56 and the rectifier 63, a change in polarity on conductor 46 causes a simultaneous change in polarity on conductor 71. The transformers 62, 68, and 70 are connected so as to make the polarity on conductor 71 positive when the error voltage is positive.

The above described voltage rectifier circuits are improvements over the rectifier circuit described and claimed in a patent application filed March 16, 1951, Serial No. 216,069, by Frank Lupo.

While there have been described and illustrated specific embodiments of the invention, it will be obvious that various changes and modifications may be made. A direct current amplifier having different types of tubes or a different number of stages may be used. Also a different type of A. C. amplifier may be employed to amplify the chopped error voltage. The above modifications do not depart from the field of the invention which should be limited only by the scope of the appended claims.

What is claimed is:

1. An electronic voltage regulator circuit comprising, a source of direct current power, an electron discharge device connected in series arrangement between the source and a load circuit, a voltage sensitive circuit connected across the load circuit for sensing a variation of load voltage, a direct current amplifier for amplifying said voltage variations having its input connected to the voltage sensitive circuit and its output connected to a control electrode in the series electron discharge device, an inverter for converting said voltage variations into a series of pulses, an alternating current amplifier with its input connected to the inverter for amplifying the pulses, and a control circuit connected to the output of the alternating current amplifier for altering the characteristics of the direct current amplifier.

2. An electronic voltage regulator circuit com-

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prising, a source of direct current power, an electron discharge device having a control electrode connected in series arrangement between the source and a load circuit, a voltage sensitive circuit connected across the load circuit for sensing a variation of load voltage above or below a desired voltage value, a direct current amplifier for amplifying said voltage variations having its input connected to the voltage sensitive circuit and its output connected to the control electrode in the series electron discharge device, an inverter for converting said voltage variations into a series of pulses, an alternating current amplifier with its input connected to the inverter for amplifying the pulses, and a control circuit connected to the output of the alternating current amplifier for altering the characteristics of the direct current amplifier.

3. An electronic voltage regulator circuit comprising, a source of direct current power, an electron discharge device having a control electrode connected in series arrangement between the source and a load circuit, a voltage sensitive circuit including a voltage reference element connected across the load circuit for sensing a variation of load voltage above or below a desired voltage value, a direct current amplifier for amplifying said voltage variations having its input connected to the voltage sensitive circuit and its output connected to the control electrode in the series electron discharge device, an inverter for converting said voltage variations into a series of pulses, an alternating current amplifier with its input connected to the inverter for amplifying the pulses, and a control circuit connected to the output of the alternating current amplifier for altering the characteristics of the direct current amplifier.

4. An electronic voltage regulator circuit comprising, a source of direct current power, an electron discharge device having a control element connected in series arrangement between the source and a load circuit, a voltage sensitive circuit including a voltage reference element connected across the load circuit for sensing a variation of load voltage above or below a desired voltage value, a direct current amplifier for amplifying said voltage variations having its input connected to the voltage sensitive circuit and its output connected to the control electrode in the series electron discharge device, an inverter comprising a set of vibrating contacts controlled by an alternating current supply for converting said voltage variations into a series of pulses the polarity of which depends upon the polarity of the variation of load voltage, an alternating current amplifier with its input connected to the inverter for amplifying the pulses, and a control circuit connected to the output of the alternating current amplifier for altering the characteristics of the direct current amplifier.

5. An electronic voltage regulator circuit comprising, a source of direct current power, an electron discharge device having a control element connected in series arrangement between the source and a load circuit, a voltage sensitive circuit including a voltage reference element connected across the load circuit for sensing a variation of load voltage above or below a desired voltage value, a direct current amplifier for amplifying said voltage variations having its input connected to the voltage sensitive circuit and its output connected to the control electrode in the series electron discharge device, an inverter comprising a set of vibrating contacts controlled by

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an alternating current supply for converting said voltage variations into a series of pulses the polarity of which depends upon the polarity of the variation of load voltage, an alternating current amplifier with its input connected to the inverter for amplifying the pulses, a rectifier connected to the output of the alternating current amplifier for producing a direct current having a polarity which is the same as the polarity of the variation of load voltage, and a control circuit connected to the output of the rectifier for altering the characteristics of the direct current amplifier.

6. An electronic voltage regulator circuit comprising, a source of direct current power, an electron discharge device having a control element connected in series arrangement between the source and a load circuit, a voltage sensitive circuit including a voltage reference element connected across the load circuit for sensing a variation of load voltage above or below a desired voltage value, a direct current amplifier for amplifying said voltage variations having its input con-

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nected to the voltage sensitive circuit and its output connected to the control electrode in the series electron discharge device, an inverter comprising a set of vibrating contacts controlled by an alternating current supply for converting said voltage variations into a series of pulses the polarity of which depends upon the polarity of the variation of load voltage, an alternating current amplifier with its input connected to the inverter for amplifying the pulses, a rectifier connected to the output of the alternating current amplifier for producing a direct current having a polarity which is the same as the polarity of the variation of load voltage, and a control circuit connected to the output of the rectifier comprising a cathode resistor which is common to both the direct current amplifier and the control circuit for changing the gain of the direct current amplifier.

FRANK J. LUPO.

No references cited.