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AUTOMATIC ELECTRIC POWER REGULATOR

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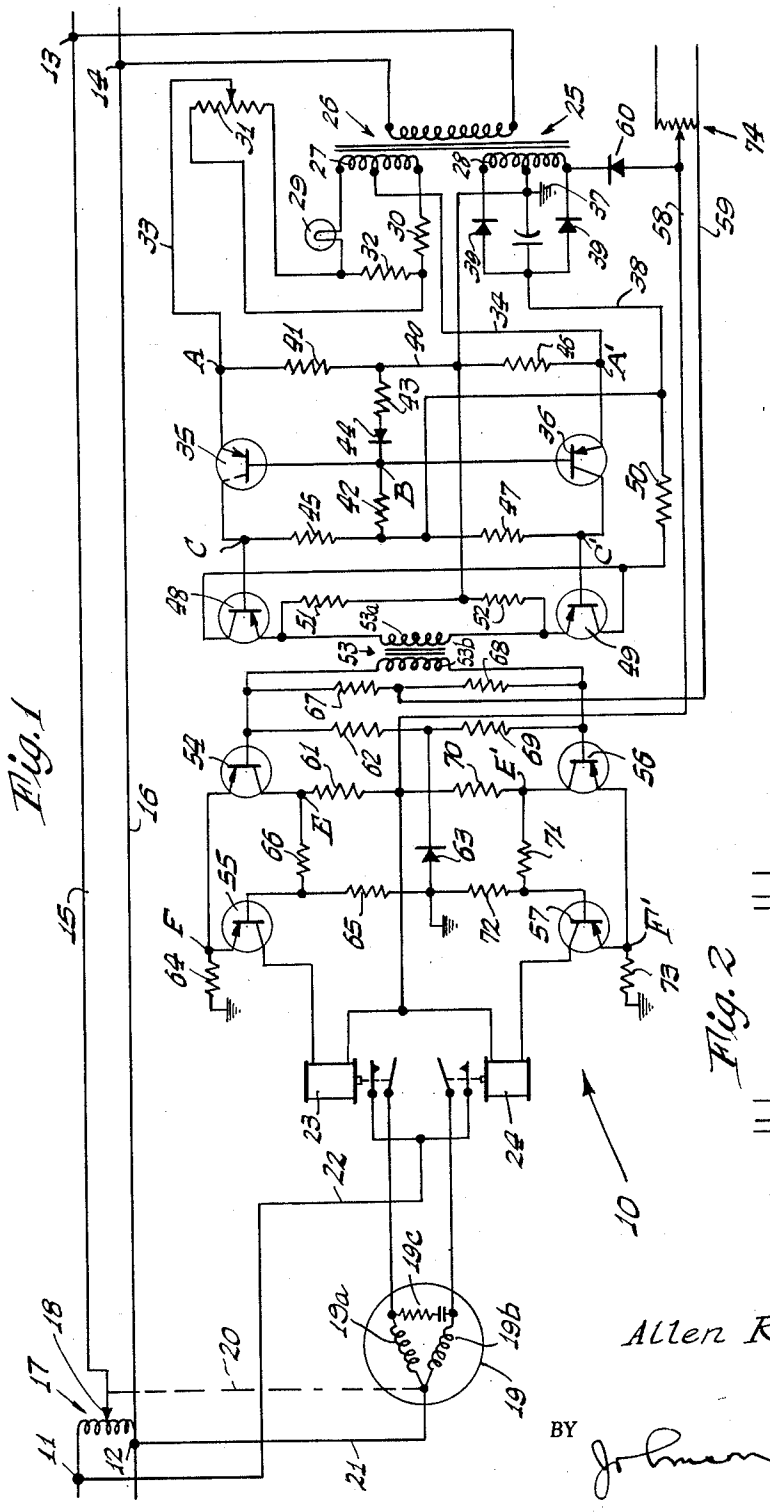


Fig. 1

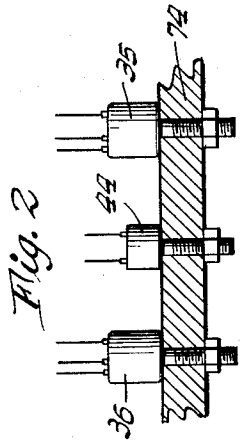


Fig. 2

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AUTOMATIC ELECTRIC POWER REGULATOR

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The present invention relates to an automatic power regulator which maintains a substantially constant output voltage or current over a relatively wide range of input voltages.

An automatic power regulator of the type herein disclosed to which the present invention is directed may also hereinafter be referred to as an automatic voltage regulator and includes a regulating circuit which adjusts the input voltage to the selected value of output voltage in response to a signal from a sensing circuit that is indicative of the deviation of the output voltage from a selected value both in magnitude and in direction. The signal from the sensing circuit is both amplified and detected in order to achieve the regulation. Normally this has been done by electronic means such as electron tubes; however, with the advent of transistors and the desirable characteristics of these elements, such as durability, it has been found advantageous to employ transistors to amplify and detect the signal from the sensing bridge in preference to or as an alternative for electron tubes. Difficulties, though, have been encountered when transistors are used in maintaining a constant sensitivity of the regulator over a wide range of ambient temperatures because the characteristics of the transistors vary substantially with ambient temperatures.

An object of the present invention is to provide an automatic voltage regulator which uses transistors and yet which maintains a substantially constant regulation over a wide range of ambient temperatures.

Another object of the present invention is to achieve the above result with a circuitry that has a minimum number of parts that are relatively economical.

A further object of the present invention is to provide a regulator which is durable in use even with wide changes in temperature, and which inherently obviates malfunctioning.

Other features and advantages will hereinafter appear.

In the drawing:

FIGURE 1 is an electrical schematic diagram of the automatic voltage regulator of the present invention.

FIG. 2 is a detail showing a manner of mounting some of the elements to maintain them at the same ambient temperature.

Referring to the drawing, the automatic voltage regulator of the present invention is generally indicated by the reference numeral 10 and includes a pair of input terminals 11 and 12 and a pair of output terminals 13 and 14. Connected between the terminals are leads 15 and 16 with an adjustable voltage autotransformer 17 positioned in the leads between the input and output terminals. While the regulator of the present invention may employ a "buck-boost" connection between the terminals so that the output of an adjustable voltage autotransformer is added to or subtracted from the input voltage to maintain the output voltage at the substantially selected constant, the present invention as herein described employs directly the output of the autotransformer 17 for regulation.

For varying the movement of a movable brush 18 on the winding of the autotransformer 17, there is provided a reversible electric motor 19, mechanically connected to the brush 18, as diagrammatically indicated by the dotted line 20. The motor is of the reversible type and has two windings 19*a* and 19*b*, each having one end connected together by a common lead 21 to the input terminal 12.

Either of the windings 19*a* and 19*b* may be energized inphase with the input A.C. voltage as by the lead 22 operating through a relay 23 for energizing the winding 19*a* or the relay 24 for energizing the winding 19*b*. A phase shifting circuit 19*c* is interposed between the two windings. Inphase energization of one winding causes rotation in one direction while inphase energization of the other winding causes rotation of the motor in a reverse direction to thus either increase or decrease the voltage to maintain the output voltage substantially constant.

In order to control the movement of the motor, there is provided a sensing circuit, generally indicated by the reference numeral 25, which is connected across the output terminals 13 and 14. The circuit includes a transformer 26 having its primary winding connected to the output terminals and having two center tapped secondary windings 27 and 28. The winding 28 provides bias voltages for the regulator as will be hereinafter explained, while the winding 27 constitutes a pair of adjacent legs in a sensing bridge with the other legs including a nonlinear voltage sensitive resistance 29 (such as a tungsten filament lamp) and a linear resistor 30. Connected between resistances 29 and 30 in parallel to each other is an adjustable resistor 31 and a linear resistor 32. Resistance 31 is connected to permit setting the bridge to be balanced, i.e. produce a signal of zero magnitude at the desired value of output voltage to be maintained constant. The output of the sensing bridge, which is an A.C. signal, indicates the deviation of the output voltage from the value set by the resistor 31 by its magnitude and its direction of the deviation by its polarity with respect to the output voltage of the regulator, and the output signal appears across a lead 33 connected to the adjustable resistance 31 and a lead 34 connected to the center tap of the winding 27. This signal is fed to a pair of transistors 35 and 36 which are connected to amplify the signal, particularly to increase the voltage thereof.

For providing the bias voltage in the circuit the winding 28 is center tapped and connected to a ground 37 which becomes the positive side since the transistors employed in the herein disclosed embodiment of the invention are PNP types, though if NPN types were employed, the polarity must be reversed. The negative side of the power supply is the lead 38 in view of the direction of the rectifiers 39 which provide full-wave rectification. To provide the bias on the emitter-base circuit of the transistor 35, a lead 40 is connected to the plus ground 37 through a resistor 41 to the emitter while the base is connected to the lead 40 through a resistor 43 and a diode 44 and hence the emitter-base bias voltage is the difference between the voltage drop across the resistance 41 and the drop across the resistance 43 and diode 44, the latter being the larger to make the base negative with respect to the emitter. The value of bias voltage is sufficient to bias the transistor 35 into its linear operating range.

The transistor 35 is connected to have its output appear as a voltage across a resistance 45 as a result of current flow through its collector-emitter output circuit of transistor 35, resistance 45, lead 38, diodes 39, winding 28, lead 40 and resistance 41. It will be appreciated that when a signal appears at the point A and of a positive polarity from the sensing bridge that the transistor 35 will amplify the signal by increasing the current in the collector-emitter circuit, with the voltage across the resistance 45 being increased.

The transistor 36 is connected in a manner identical to transistor 35, employing common resistor 43 and diode 44 in its emitter-base circuit while a resistance 46 identical to resistance 41 is also present while the collector-emitter circuit has a resistor 47 identical to resistor 45 therein. The collector-emitter circuit of transistor 36 is rendered more

conducting when a positive voltage appears in the line 34. Thus the transistors 35 and 36 act as class A push pull amplifiers and serve to amplify the A.C. signal from the sensing bridge.

The amplified signal from the transistors 35 and 36 appears as a potential of varying magnitude between the points C and C' which is then amplified, particularly current amplified by a pair of transistors 48 and 49 respectively connected as push pull emitter-followers which have their collectors common to the input and output circuits. The base of the transistor 48 is connected to the point C while its collector is connected through a resistance 50 to the negative lead 38. The positive lead 40 is connected to the emitter of the transistor 48 through a resistance 51. The transistor 49 is connected in an identical manner employing a resistance 52 identical to resistance 51 with the resistance 50 being common to collector circuits of both transistors. The primary winding of an isolation transformer 53 is connected between the emitter of the transistors 48 and 49 and is connected across the resistances 51 and 52 so that the signal amplified by the transistors 48 and 49 appears as a voltage across the winding.

The above elements operate so that as the voltage at C varies by reason of the current flow in the collector circuit of transistor 35, the current through the emitter circuit of transistor 48 will also vary and because the bias on the transistor is sufficient to operate it in its linear range, the voltage appearing across the resistor 51 (and hence the transformer 53) will vary substantially linearly with the voltage appearing at the point C. Similarly for the polarity of signal amplified by the transistor 36, the potential at the point D varies, producing a potential change across the resistor 52 (even though the transistors 48 and 49 are primarily connected to be current amplifiers) and both potentials appear across the secondary winding 53*b* of the transformer 53.

It will be appreciated that the signal appearing in the secondary winding is A.C. and may be of the same or opposite polarity with respect to the voltage at the output terminals 13 and 14 depending upon the direction of the deviation of the output voltage from its selected value. The direction of deviation determines which of the relays 23 or 24 will be energized, provided the magnitude of the signal is sufficiently large.

Each of these relays has a triggering circuit and for the relay 23 it includes transistors 54 and 55 while the relay 24 is energized by a triggering circuit including transistors 56 and 57. Power for energizing the relays and the transistors is supplied from a pair of leads 58 and 59 that are connected to a source of A.C. such as the output terminals 13 and 14 of the regulator. A rectifier 60 is connected between the lead 58 and the winding 28 so that the power to the triggering circuits for reasons which will be hereinafter apparent is pulsating direct current with the lead 59 being positive with respect to the lead 58.

The transistor 54 is normally, when no signal appears in the winding 53*b*, conducting in its emitter-collector circuit so that it is insensitive to a signal of one polarity appearing in its emitter-base circuit, while a signal of the opposite polarity decreases the conduction in the emitter-collector circuit which serves to cause the emitter-collector circuit of the transistor 55 to become conducting thereby energizing the relay 23 to operate its associated motor circuit. The transistors 56 and 57 operate in a like fashion except that they respond to energize their associated motor circuit with a signal of the opposite polarity.

The transistor 54 is connected to have the signal from the transformer 53 impressed on its emitter-base circuit to control the emitter-collector current. Thus negative lead 58 is connected through a resistance 61 to the collector while the base connects through a resistance 62 to the positive ground through a diode 63 so that a bias voltage appears across the emitter-base which has a value that places the transistor in its fully conducting state at a low impedance level which makes the collector to base leakage current small and hence negligible compared to the currents in the circuit thereby enabling the transistor to operate over a greater ambient temperature range than if the leakage currents were relatively large compared to the circuit currents. The emitters of the transistors 54 and 55 are connected together and through a resistor 64 to the positive ground so that the emitter-collector circuit for the transistor 54 includes the resistors 64 and 61. The transistor 55 is connected to the positive ground through a resistor 65 that supplies a bias potential on the base similar to the resistor 62 while a coupling resistor 66 is connected between the base of transistor 55 and the collector of transistor 54. The emitter-collector circuit of transistor 55 is in series with the relay 23 and includes the resistance 64 positioned between the positive ground and the negative lead 58. The half-wave rectified current is impressed through a resistor 67 to the base of the transistor 54 while one end of the winding 53*b* is also connected thereto.

Similarly the triggering circuit for the relay 24 includes resistances 68, 69, 70, 71, 72 and 73 which correspond and are identical to the resistances 67, 62, 61, 66, 65 and 64, respectively, while the diode 63 is common to the emitter-base circuits of the transistors 54 and 56.

In the operation of the triggering circuit it will be appreciated that on the emitter-base circuit of the transistor 54 there is a pulsating direct current potential from the lead 59 through the resistor 67 which is of a value sufficient to render the transistor 54 substantially fully conducting in its emitter-collector circuit. When a signal appears across the winding 53*a* which is of the same polarity as the pulsating potential produced through the resistor 67, the signal is negative on the base of transistor 54 at the same time that the pulsating potential is negative and triggering of the circuit does not occur since the emitter-collector circuit is maintained fully conducting. However, when a signal appears from the transformer 53 which is of the opposite polarity with respect to the pulsating potential and thus is positive on the base when the pulsating potential is negative on the base of transistor 54, it decreases voltage on the base to a value which renders the emitter-collector circuit substantially non-conducting. When this occurs, the voltage at the point E approaches the voltage of the negative lead 58 while the voltage at the point F approaches the voltage of the positive ground, thereby substantially increasing the potential between the emitter and base of the transistor 55 to a value sufficient to render it conducting in its emitter-collector circuit, thereby causing energization of the relay 23.

The use of pulsating direct current in the transistor triggering circuit enables them to reset themselves every half-cycle of the A.C. output voltage because the transistors 54 and 55 go "off" during the non-conducting part of the cycle and hence when energized again will evaluate the value of the signal from the winding 53 every one-half cycle to determine if it has a magnitude which should cause energization of the relay.

It will also be appreciated that the transistors 56 and 57 operate to energize the relay 24 when the signal in the winding 53*b* is of the proper polarity with respect to the output voltage and does not energize the relay 24 when the signal is of the opposite polarity. Accordingly, the base potential of the transistor 56, when the signal is of the opposite polarity to the pulsating potential, will have a positive value which decreases the bias on the base thereby decreasing the current flow in the emitter-collector circuit and by the voltage difference appearing between the points E' and F', the emitter-collector of the transistor 57 is rendered conducting to thereby energize the relay 24.

When the winding 53*b* is positive on its end connected to the base of transistor 54 and the transistor 54 is energized by the leads 58 and 59 the signal polarity is such as to cause relay 23 to be energized. Though the signal

is A.C., the part thereof that appears on the bases of transistor 54 during the half cycle when there is no power in the leads 58 and 59 is accordingly of no consequence. Similarly when the winding 53*b* is positive on its end connected to the base of transistor 56, the relay 24 will be energized.

The above structure of the regulating circuit of the present invention enables the use of transistors in amplifying and detecting the deviation of the output voltage from a selected value without malfunctioning thereof by temperature changing the mean operating points of the transistors. This performance is achieved by the bias voltage on the transistors 35 and 36 in their emitter-base circuits being varied substantially identically with the characteristics of the transistors by the diode 44 which itself has parameters which similarly vary with temperature thereby maintaining the mean operating points substantially constant.

The elements 35, 36 and 44 are mounted in a common heat sink 74 or plate of heat conducting material (see FIG. 2) to be at the same temperature. Thus as the ambient temperature increases, the bias required between the emitter and base necessary to maintain the transistor at the same point in its linear operating range must be decreased (due solely to the temperature effect on the transistor). However the diode (due solely to temperature) has a decreased voltage drop thereacross and hence decreases the bias by the amount necessary to maintain the transistor at its mean operating point in its operating range. The above also applies to the diode 63 which is in the bias circuit of transistors 54 and 56.

To prevent transmission of residual direct current drift and/or unbalanced signals, the isolation transformer is positioned between the triggering circuits and the transistors 35, 36, 48 and 49 and serves to transmit amplified A.C. signals blocking the direct current variations.

If desired, the sensitivity of the regulator, i.e. the value of the signal in the winding 53*b* which causes operation of the relay, may be adjusted by an adjustable resistance 74 positioned across the leads 58 and 59.

The transistors employed are all of the PNP type though, of course, if desired NPN types may be used if the polarity of the source of power is reversed.

It will accordingly be appreciated that there has been disclosed an automatic voltage regulator which maintains its sensitivity with temperature changes even though it employs transistors in its regulating circuit. The effect of temperature on the operation of the transistors is nullified by relatively few elements which may be economically employed in the circuit and which enable the regulator to be substantially free from malfunctioning over an extended period of use within a wide range of ambient temperature.

Variations and modifications may be made within the scope of the claims and portions of the improvements may be used without others.

I claim:

1. An automatic power regulator for providing a selected value of output power, comprising input terminals; output terminals; regulating means interconnected therebetween including one circuit which when energized increases the output power and a second circuit which when energized decreases the output power to maintain the selected value of output power; sensing means for producing a signal indicative of the magnitude and direction of the deviation of the output power from the selected value; means for amplifying the signal including a first pair of transistors connected to the sensing means for primarily amplifying the voltage of the signal and a second pair of transistors connected to receive the output of the first pair of transistors for primarily amplifying the current of the signal; an isolation transformer having a primary winding connected to receive the output of the second pair of transistors and a secondary winding; a source of pulsating direct current; a trigger circuit for each of the circuits in the regulating means, each trigger circuit comprising a pair of transistors, means for applying the pulsating direct current voltage in the emitter-base circuit of one of the transistors to normally cause conduction in its emitter-collector circuit, means connecting the other transistor to the one transistor to cause conduction through the emitter-collector circuit of the other transistor upon a decrease in conduction in the emitter-collector circuit of the one transistor, means connecting the emitter-collector circuit of the other transistor to one of the circuits of the regulating means to cause energization thereof upon conduction through the emitter-collector circuit of the other transistor; and means connecting the secondary winding in the emitter-base circuits of the one transistors whereby a signal which is of the opposite polarity to the pulsating direct current renders one of the one transistors non-conducting in its emitter-collector circuit causing its associated other transistor to be conducting in its emitter-collector circuit to cause energization of its associated regulating circuit.

2. An automatic power regulator for providing a selected value of output power, comprising input terminals; output terminals; regulating means interconnected therebetween including one circuit which when energized increases the output power and a second circuit which when energized decreases the output power to maintain the selected value of output power; sensing means for producing a signal indicative of the magnitude and direction of the deviation of the output power from the selected value; means for amplifying the signal including a first pair of transistors connected to the sensing means for primarily amplifying the voltage of the signal and a second pair of transistors connected to receive the output of the first pair of transistors for primarily amplifying the current of the signal; means for supplying a bias voltage in the emitter-base circuits of the first pair of transistors including a diode connected to be common to both emitter-base circuits and having a resistance which decreases with temperature to vary the bias voltage in the circuits with temperature; an isolation transformer having a primary winding connected to receive the output of the second pair of transistors and a secondary winding; a source of pulsating direct current; a trigger circuit for each of the circuits in the regulating means, each trigger circuit comprising a pair of transistors, means for applying the pulsating direct current voltage in the emitter-base circuit of one of the transistors to normally cause conduction in its emitter-collector circuit, means connecting the other transistor to the one transistor to cause conduction through the emitter-collector circuit of the other transistor upon a decrease in conduction in the emitter-collector circuit of the one transistor, means connecting the emitter-collector circuit of the other transistor to one of the circuits of the regulating means to cause energization thereof upon conduction through the emitter-collector circuit of the other transistor; and means connecting the secondary winding in the emitter-base circuits of the one transistors whereby a signal which is of the opposite polarity to the pulsating direct current renders one of the one transistors non-conducting in its emitter-collector circuit causing its associated other transistor to be conducting in its emitter-collector circuit to cause energization of its associated regulating circuit.

3. The invention as defined in claim 2 in which the first pair of transistors in the amplifying means and the diode are mounted adjacently in a common heat conducting member to maintain them at substantially the same temperature.

4. The invention as defined in claim 1 in which there are means for applying a bias voltage in the emitter-base circuit of the one transistors of the triggering circuits which includes a diode connected to be common to both emitter-base circuits and having a voltage drop which decreases with temperature to vary the bias voltage in the circuits with temperature.

5. An automatic power regulator for providing a selected value of output power, comprising input terminals; output terminals; regulating means interconnected therebetween including one circuit which when energized increases the output power and a second circuit which when energized decreases the output power to maintain the selected value of output power; sensing means for producing a signal indicative of the magnitude and direction of the deviation of the output power from the selected value; means for amplifying the signal from the sensing means; an isolation transformer having a primary winding connected to receive the amplified signal and a secondary winding; a source of pulsating direct current; a trigger circuit for each of the circuits in the regulating means, each trigger circuit comprising a pair of transistors, means for applying the pulsating direct current voltage in the emitter-base circuit of one of the transistors to normally cause conduction in its emitter-collector circuit, means connecting the other transistor to the one transistor to cause conduction through the emitter-collector circuit of the other transistor upon a decrease in conduction in the emitter-collector circuit of the one transistor, means connecting the emitter-collector circuit of the other transistor to one of the circuits of the regulating means to cause energization thereof upon conduction through the emitter-collector circuit of the other transistor; and means connecting the secondary winding in the emitter-base circuits of the one transistors whereby a signal which is of the opposite polarity to the pulsating direct current renders one of the one transistors non-conducting in its emitter-collector circuit causing its associated other transistor to be conducting in its emitter-collector circuit to cause energization of its associate regulating circuit.

6. The invention as defined in claim 5 in which there are means for applying a bias voltage in the emitter-base circuit of the one transistors of the triggering circuits which includes a diode connected to be common to both emitter-base circuits and having a voltage drop which decreases with temperature to vary the bias voltage in the circuits with temperature and means mounting the diode and the one transistors of the triggering circuits in a common heat conducting member to maintain them at substantially the same temperature.

7. An automatic power regulator for providing a selected value of output power, comprising input terminals; output terminals; regulating means interconnected therebetween including one circuit which when energized increases the output power and a second circuit which when energized decreases the output power to maintain the selected value of output power; sensing means for producing a signal indicative of the magnitude and direction of the deviation of the output power from the selected value; means for amplifying the signal including a first pair of transistors connected to the sensing means for primarily amplifying the voltage of the signal and a second pair of transistors connected to receive the output of the first pair of transistors for primarily amplifying the current of the signal; an isolation transformer having a primary winding connected to receive the output of the second pair of transistors and a secondary winding; a trigger circuit for each of the circuits in the regulating means; a source of pulsating direct current; and means connecting the source and the secondary winding to each of the trigger circuits whereby a signal which is of the opposite polarity to the pulsating direct current renders one of the triggering circuits conducting to energize its associated circuit in the regulating means.

8. The invention as defined in claim 7 in which there are means for supplying a bias voltage in the emitter-base circuits of the first pair of transistors which includes a diode connected to be common to both emitter-base circuits and having a voltage drop which decreases with temperature to thereby vary the bias voltage in the circuits with temperature and in which the first pair of transistors and the diode are mounted adjacently in a common heat conducting member to maintain them at substantially the same temperature.

9. An automatic power regulator for providing a selected value of output power, comprising input terminals; output terminals; regulating means interconnected therebetween including one circuit which when energized increases the output power and a second circuit which when energized decreases the output power to maintain the selected value of output power; sensing means for producing a signal indicative of the magnitude and direction of the deviation of the output power from the selected value; means for amplifying the signal including a first pair of transistors connected to the sensing means for primarily amplifying the voltage of the signal and a second pair of transistors connected to receive the output of the first pair of transistors for primarily amplifying the current of the signal; mean for supplying a bias voltage in the emitter-base circuits of the first pair of transistors including a diode connected to be common to both emitter-base circuits and having a resistance which decreases with temperature to vary the bias voltage in the circuits with temperature; an isolation transformer having a primary winding connected to receive the output of the second pair of transistors and a secondary winding; a source of pulsating direct current; a trigger circuit for each of the circuits in the regulating means, each trigger circuit comprising a pair of transistors, means for applying the pulsating direct current voltage in the emitter-base circuit of one of the transistors to normally cause conduction in its emitter-collector circuit, means connecting the other transistor to the one transistor to cause conduction through the emitter-collector circuit of the other transistor upon a decrease in conduction in the emitter-collector circuit of one transistor, means connecting the emitter-collector circuit of the other transistor to one of the circuits of the regulating means to cause energization thereof upon conduction through the emitter-collector circuit of the other transistor; a diode connected to be common to the emitter-base circuits of the one transistors and having a resistance which decreases with temperature to vary the bias voltage in the circuits with temperature; and means connecting the secondary winding in the emitter-base circuits of the one transistors whereby a signal which is of the opposite polarity to the pulsating direct current renders one of the one transistors non-conducting in its emitter-collector circuit causing its associated other transistor to be conducting in its emitter-collector circuit to cause energization of its associated regulating circuit.

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