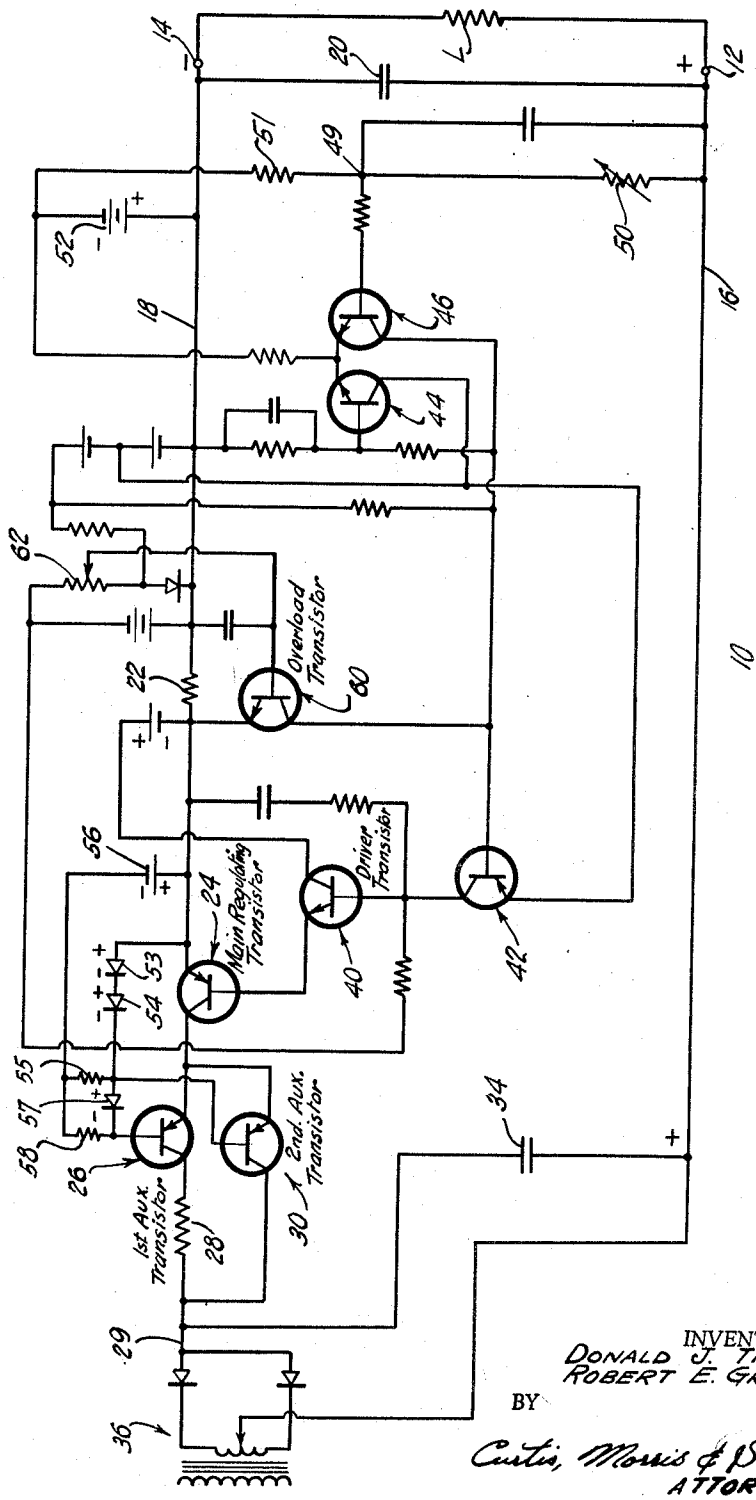
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REGULATED POWER SUPPLY

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REGULATED POWER SUPPLY

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This invention relates to a transistorized power supply and more particularly to such a supply giving a precisely regulated output voltage which can be adjusted over a wide range by the user.

An object of this invention is to provide a transistorized power supply having improved efficiency and operating characteristics.

Another object is to provide a wide range, all-transistor voltage regulator of this kind which is also relatively simple and inexpensive.

These and other objects will in part be understood from and in part pointed out in the following description.

In a transistor voltage regulating unit, its output voltage is kept at a given value in spite of load current changes by varying the voltage drop across a main regulating transistor in series with an unregulated input voltage source and the output. Now, because of limitations in the power handling capabilities of transistors, and the danger of ruining them because of excessive heating due to overload it is desirable that the voltage drop across the main regulating transistor be kept relatively low. This becomes particularly a problem where the output voltage of the unit is settable over a wide range. For example, if the output voltage is set near zero then the main regulating transistor has across it almost the entire input voltage. On the other hand, where the output voltage is set at its maximum value, then the main regulating transistor has across it only a few volts drop, namely the difference between the input and output voltages.

To compensate for these different conditions, voltage regulators have previously been provided with variable transformers or with magnetic amplifiers which control the input voltage and change it in proportion to the output voltage. Thus the voltage drop across the main regulating transistor is kept nearly constant regardless of the output voltage setting. However, these additional elements are bulky and expensive, and moreover they do not have fast response time. The present invention provides a voltage regulating unit wherein the voltage drop across the main regulating transistor is kept nearly constant by means of two auxiliary transistors. This new unit is very efficient in its utilization of these transistors, and moreover the unit is considerably less bulky and expensive than a comparable one using a variable transformer to control the input voltage. In addition, this new unit has much faster response time in correcting for sudden transients in the load.

In accordance with the present invention in one specific embodiment thereof, there is provided a voltage regulating unit with a main regulating transistor directly controlled by a transistorized feedback amplifier to keep the output voltage constant at whatever value to which it has been set. Placed in series between the main regulating transistor and a nominally constant but unregulated direct voltage supply is a first auxiliary transistor having a voltage dropping resistor in series with it. This auxiliary transistor is controlled by the voltage drop across the main regulating transistor and conducts more and more when this voltage drop decreases below a first value, for example, 1.6 volts. Shunting this first auxiliary transistor and the voltage dropping resistor is a second auxiliary transistor. The latter is also controlled by the main regulating transistor and conducts only when

the voltage drop across the main transistor falls to a second value, for example 1 volt, which is slightly lower than the first value. In other words, the first auxiliary transistor conducts when the voltage across the main regulating transistor falls below the first value, and thereafter the second transistor conducts when this voltage falls still further to the second value. As a result, for any values of output voltage and current the voltage drop across the main regulating transistor tends to stay between the first and second values. The response time of this all-transistor circuit is excellent, and the power handling capabilities of the main and auxiliary transistors are effectively utilized. This eases the requirements on the heat sink for these transistors and otherwise simplifies the problems of adequate cooling. This arrangement is particularly suitable for a constant current mode of operation because it maintains the voltage across the main regulating transistor essentially constant. Thus this transistor is prevented from seeing changes in the load voltage and the main regulating loop does not have to respond to these changes.

A better understanding of the invention together with a fuller appreciation of its many advantages will best be gained from the following description given in connection with the single figure of the drawing which shows the schematic circuit for a voltage regulator embodying the invention.

The circuit **10** shown in the drawing has at its right a pair of output terminals **12** and **14** across which a load L can be connected. Terminal **12**, which is positive, is connected to a common or ground bus **16** and terminal **14** is connected to a negative output lead **18**. Leads **16** and **18** are bypassed by a large filter capacitor **20**.

Negative lead **18** is connected on its left end through a low ohmage current sensing resistor **22** (for example 3 ohms), a main regulating transistor **24**, a first auxiliary transistor **26** and a voltage dropping resistor **28** to a negative input lead **29**. Resistor **28** has a relatively high ohmage, for example, 100 ohms. Shunting first auxiliary transistor **26** and resistor **28** is a second similar auxiliary transistor **30**. Lead **29**, which is bypassed to bus **16** by a large filter capacitor **34**, is supplied with unregulated direct voltage from a transformer-rectifier arrangement generally indicated at **36**.

During operation of the unit, main regulating transistor **24** is directly controlled through a driver transistor **40**, an intermediate control amplifier transistor **42** and a pair of transistors **44** and **46** connected as a differential amplifier. The latter senses the difference between the voltage on output lead **18** and the voltage at a point **49** determined by the setting of a variable resistor **50** to which the base of transistor **46** is connected. Resistor **50** is connected at junction **49** to a resistor **51** and a reference battery **52**, these resistors forming a voltage divider. If the output voltage between leads **16** and **18** deviates from the value to which it has been set, then transistors **40–46** apply to the main regulating transistor a signal which increases or decreases the voltage drop across it to compensate for the change in output voltage.

Now, it will be noted that the base of auxiliary transistor **30** is connected to the emitter of transistor **24** through a pair of forward biased silicon diodes **53** and **54**, each providing a voltage drop of 0.6 volt, for example. These diodes are kept conducting by a bias resistor **55** connected to the negative side of a battery **56**. The base of auxiliary transistor **26** is similarly connected through a silicon diode **57** and diodes **53** and **54** to the emitter of transistor **24**. Diode **57** is held conducting by a bias resistor **58** connected to battery **56**.

When the emitter-to-collector voltage of transistor **24** drops below a first value slightly less than the voltage drop across diodes **53**, **54**, and **57**, transistor **26** begins to

conduct more and more. Under actual conditions transistor 26 and transistor 24 are never turned fully off because a small bleed current across the output even under no load conditions is assumed. When the voltage drop across main regulating transistor 24 decreases to a still lower second value (determined by the combined voltage drop across diodes 53 and 54) auxiliary transistor 30 will turn on.

Assume for the sake of illustration that transistor 26 begins to conduct more and more when the voltage drop across transistor 24 falls below 1.6 volts, and that transistor 30 begins to conduct when this voltage falls to 1.0 volt. Further assume that the input voltage is nominally 54 volts and the maximum output voltage 40 volts, then at full output voltage and zero load current, main regulating transistor will have 1.6 volts across it, and transistor 26 will have 12.4 volts across it, the voltage drop across resistor 28 being negligible at zero load current. Transistor 30 will be turned off because the voltage drop across transistor 24 is greater than 1.0 volt. Now, as the load current is increased, transistor 26 is turned on more and more until it becomes saturated. The voltage drop across resistor 28 at this point is now appreciable, in fact almost 12.4 volts, its resistance being, for example, 100 ohms. However, if still further load current is drawn, the voltage across main regulating transistor 24 begins to fall below 1.6 volts. When it reaches 1.0 volt, transistor 30 begins to conduct, the voltage drop across resistor 28 tending to remain constant. At full load current, which in this example is ½ ampere, the voltage drop across transistor 30 is about 13 volts. At full load current and near zero output voltage, the voltage across resistor 28 is about 50 volts, across transistor 26, about 2.4 volts, and across transistor 24, 1.6 volts. Transistor 30 will be off, and therefore dissipates no power though it has about 52.4 volts across it.

For circuit 10 the maximum power dissipated in transistor 30 is $(I/2)^2R$ where I is full load current and R is the resistance of resistor 28. Assuming zero output voltage the maximum power dissipated in transistor 26 is $(E-V)^2/4R$ where E is the input voltage and V the drop across transistor 24. The maximum power dissipated in transistor 24 is VI. In the example given, the maximum power loss in transistor 30 is reached at full load current and about 27 volts output. The maximum loss in transistor 26 for the example given, occurs when the output voltage is near zero and the load current is 0.26 ampere. It will be seen, therefore, that these three maximums do not occur at the same times. Accordingly, the thermal load placed on a heat sink by the three transistors is averaged, this load being only about one fourth the maximum input power to circuit 10.

It is advantageous to make the maximum power loss in transistor 26 equal to the maximum power loss in transistor 30 (though of course these maximums do not occur simultaneously). This is accomplished by proper choice of R for a given maximum load current. If the voltage V is small relative to the input voltage E, then the optimum value of R is

$$\frac{E \text{ max.}}{I \text{ max.}}$$

Since the fast responses of transistors 26 and 30 keep the voltage across transistor 24 essentially constant, this transistor can be operated near its optimum operating point. This results in exceptionally fast and efficient response to sudden transients or changes in the load or line on circuit 10. This circuit is an improvement over the circuit described and claimed in co-pending application, Serial No. 777,959, filed December 3, 1958.

Circuit 10 is equipped to prevent the drawing of more than a given amount of current from it by the following means. The voltage drop across current sensing resistor 22 when a given load current is reached turns on an overload transistor 60. This transistor is normally biased off,

but when it turns on because of sufficient voltage drop across resistor 22, it seizes control of intermediate transistor 42 and prevents the main and auxiliary regulating transistors from passing more than a predetermined amount of current. The value at which the output current will be limited can be adjusted by changing the bias on the base of overload transistor through a potentiometer 52. While overload transistor 60 has control of intermediate transistor 42, differential amplifier transistors 44 and 46 are ineffective. The arrangement of transistors 24, 26, and 30 is particularly effective and advantageous in circuit 10 for this constant current mode of operation.

It will now be appreciated that the invention reduces the total power handling requirement for the main and auxiliary transistors which in turn means better performance and lower cost. Since transistor 24 is subjected to far less than the maximum input power to circuit 10, it can be a smaller transistor having faster response than a transistor capable of handling the maximum input power. Moreover, the cost of transistor 24 together with the auxiliary transistors 26 and 30 is only a little if any more than for a single high power transistor. Thus this circuit is considerably better from both a commercial and a technical standpoint than previous ones. The offset biases for auxiliary transistors 26 and 30 are provided by three inexpensive silicon diodes, for example, type IN536. Since these diodes block current flow in the backward direction, excessive current cannot circulate from the base of transistor 26 to the emitter of transistor 24. Thus this arrangement provides a particularly simple and effective way of interconnecting the main and auxiliary regulating transistors.

The description of the invention given herein is intended in illustration and not in limitation. Various changes or modifications in the embodiment set forth, and particularly in the circuit values given by way of example, may be made without departing from the spirit or scope of the invention as set forth.

We claim:

1. In a power supply having a regulating element connected to control the output power and an amplifier connected to control the conductivity of said element, a first element and a resistor connected in series with said regulating element, a second element connected in shunt with said serially connected resistor and first element, circuit means so connected to receive the voltage across said regulating element as to render one of said first and second elements more conductive as said voltage varies between first and second selected values and to render the other of said first and second elements more conductive as said voltage varies beyond said second value.

2. In a power supply having a regulating element connected to control the output power and an amplifier connected to control the conductivity of said element, an auxiliary element and a resistor connected in series with said regulating element, another element connected in shunt with said serially connected resistor and auxiliary element, circuit means so connected to receive the voltage across said regulating element as to render said auxiliary element more conductive as said voltage decreases below a first selected value and to render said other element more conductive as said voltage decreases below a second lower value.

3. In a power supply having a regulating element and an amplifier connected to control the conductivity of said element, an auxiliary element and a resistor connected in series with said regulating element, another element connected in shunt with serially connected resistor and auxiliary element, first and second bias supplies providing first and second voltages, respectively, means including the first bias supply so connecting said auxiliary element to receive the voltage across said regulating element as to render said auxiliary element more conductive as said voltage varies between the said first and second

voltages and to render said other element more conductive as said voltage varies beyond said second voltage.

4. An improved voltage regulator comprising an input adapted to receive a direct voltage, an output across which a regulated voltage is to be maintained, a main regulating transistor connected to said output, a series circuit including an auxiliary transistor and resistor and connecting said main transistor and said input, a second auxiliary transistor connected in shunt with said series circuit, an amplifier connected to said output to sense voltage variations thereacross and to control the conductivity of said main transistor in proper phase relationship to maintain the output voltage constant, and means interconnecting said first and second auxiliary transistors and said main transistor to render said first transistor more conductive as the voltage across said main transistor drops below a first value and to render said second transistor more conductive as said voltage drops below a second lower value.

5. A regulator according to claim 4 wherein said interconnecting means comprises first and second bias supplies providing respectively first and second voltages, means including said first bias supply connecting said first transistor to respond to the voltage drop across said main transistor, and means including said second bias supply and connecting said second transistor to respond to the voltage drop across said main transistor.

6. In a regulating unit of the character described and which has a main regulating transistor and an amplifier controlling the conductivity of said main transistor, an auxiliary transistor and a resistor connected in series with said main transistor, another transistor connected in parallel with said serially connected auxiliary transistor and resistor, and means connecting said auxiliary and said other transistors to said main transistor for rendering said auxiliary transistor more conductive as the load on the main transistor increases and thereafter to render said other transistor more conductive as the load on said main transistor further increases.

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