

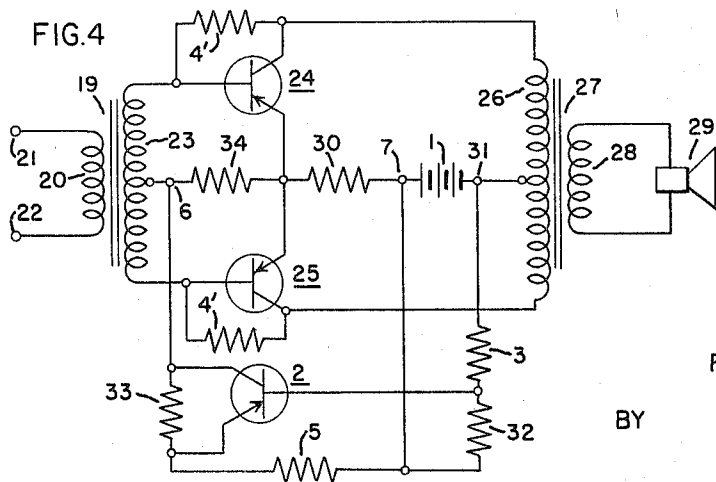
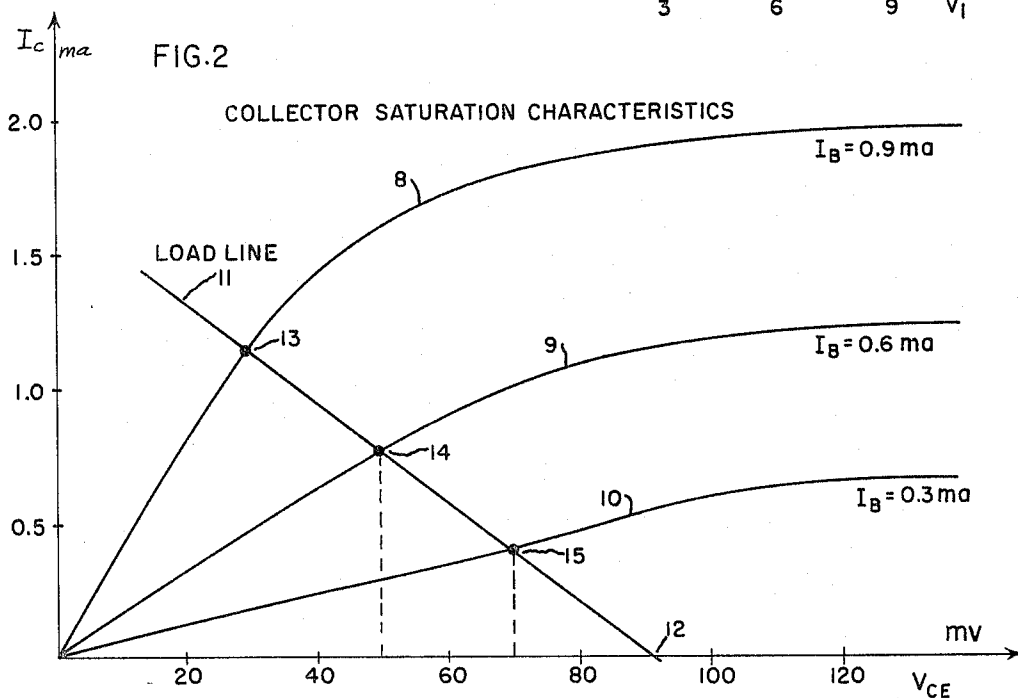
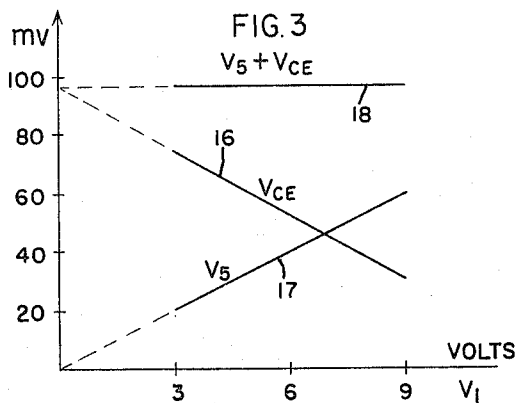
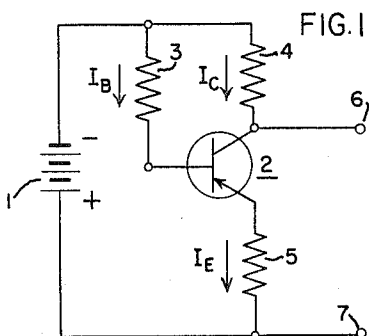
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DIRECT-CURRENT LOW VOLTAGE REGULATOR UTILIZING A TRANSISTOR

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DIRECT-CURRENT LOW VOLTAGE REGULATOR UTILIZING A TRANSISTOR

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This invention relates to voltage regulators which are adapted to provide a regulated low voltage direct-current output from an unregulated direct-current power source.

It is frequently necessary or highly desirable to provide a relatively constant low voltage from a higher voltage source having an unregulated output which varies between predetermined voltage limits. For example, a precisely regulated voltage of less than one-half volt is often required to properly bias the transistor amplifier stages of battery-powered equipment. This is particularly so where a class B, push-pull, transistorized amplifier stage is utilized since such stages are particularly sensitive to variation in bias voltage level. A reduction of bias voltage is attended by a seriously degraded output due to cross-over distortion, as is well known in the art.

In the prior art, forward-biased semiconductor junctions have been used to provide a relatively constant low voltage. However, such a solution is limited to the particular voltage characteristic of the semiconductor junction selected and is usually wasteful of power when wide ranges of input voltage are supplied. In addition it is desirable to provide a regulated voltage lower than that obtained by forward-biasing a conventional junction in order to conserve power dissipated in transistor amplifiers when in the quiescent, or no signal, state. It is also advantageous to provide a regulator which itself consumes a minimum of power from the source.

In many applications even lower voltages are desirable. An example of a situation where even lesser magnitudes are required may be found in tunnel diode amplifiers. In such amplifiers, the required bias voltage may be less than one-tenth volt, and frequently this bias level must be sustained from an associated battery voltage source which varies in voltage by more than 50% during the course of its useful life.

Accordingly it is an object of this invention to provide an improved direct-current low voltage regulator.

It is another object of this invention to provide a voltage regulator having an output voltage which may be less than one-tenth volt.

In the preferred embodiment of the voltage regulator of this invention, a transistor is used having its base and collector electrodes each connected through a resistor to one terminal of an unregulated source of voltage. The transistor emitter electrode is connected to the other terminal of the voltage source through an emitter resistor. The emitter resistor has a low value of resistance and the base and collector resistors have resistance values in the same order of magnitude, whereby the transistor is operated in its collector saturation region. The output voltage is taken from the collector and includes the summation of transistor collector-emitter voltage and the emitter resistor voltage. A proper selection is made of resistance value for the emitter resistor such that complete compensation is achieved and a constant output voltage derived.

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FIG. 1 is a schematic diagram of a basic form of the invention,

FIG. 2 shows transistor collector saturation characteristic curves,

FIG. 3 is a graphical representation of the voltage relationships of the circuit shown in FIG. 1, and

FIG. 4 is a schematic diagram of this invention in combination with a push-pull transistorized amplifier.

The schematic diagram of FIG. 1 features a power source 1, which may be a battery, having a voltage output which is subject to change between predetermined useable voltage limits. In the case of a battery, for example, the voltage would have some initial value and thereafter decay as the useable battery life became exhausted.

A transistor 2 is shown having a base resistor 3 and a collector resistor 4 connected to one terminal of source 1, for supplying current to the transistor 2. An electric circuit is completed by emitter resistor 5 which is connected from the emitter electrode to the other source terminal. The output voltage from the circuit of FIG. 1 is supplied from terminal 6, which is connected to the collector of transistor 2, and terminal 7, which is connected to the junction of emitter resistor 5 and source 1.

Assuming the electron current flow convention, and neglecting the load current flowing from terminal 6, it is apparent that the current flowing from transistor 2 through emitter resistor 5 is the sum of the current flowing to the transistor through base resistor 3 and collector resistor 4. Also, the voltage appearing between output terminals 6 and 7 is the summation of the transistor collector-emitter voltage (V_{ce}) and the voltage developed across the emitter resistor (v_5).

For the circuit of FIG. 1 to provide a substantially constant output voltage between terminals 6 and 7, in the presence of variations in voltage of source 1, the following equation must be satisfied:

$$(1) \quad V_{ce} + (I_B + I_C)R_5 = \text{constant}$$

where

V_{ce} is the transistor collector-emitter voltage, I_B is the base current through base resistor 3, I_C is the collector current through collector resistor 4, and R_5 is the resistance of emitter resistor 5.

R_5 of Equation 1 will normally be of a predetermined constant value; therefore, transistor 2 must operate in a mode wherein its collector-emitter voltage V_{ce} varies inversely with the summation of base current I_B , and collector current I_C . In laboratory experiments leading to the present disclosure it was discovered that a transistor biased near the origin of its collector saturation characteristics yields the requisite voltage and current relationship. The following detailed description is offered to explain the observed phenomenon and enable those skilled in the art to comprehend the subject invention.

FIG. 2 illustrates the collector saturation characteristics of a transistor, such as transistor 2. An expanded view of the characteristics near the origin is shown. The curves are constructed from laboratory measurements, since transistor detailed characteristics in such a low voltage region are not known to be available.

The collector saturation characteristics of FIG. 2 are presented in graphical form with collector current I_C as the ordinate and collector-emitter voltage V_{ce} as the abscissa. A plurality of curves, such as 8, 9 and 10, give

the transistor characteristics for specific values of base current I_B . The graph may be readily recognized as showing the collector saturation characteristics by noting that the base currents are in the same order of magnitude as the collector currents. In the collector saturation mode of operation, the collector current is not limited by the transistor equivalent resistance, but rather by the parameters of an associated power supply and external impedances.

In order to determine suitable resistance values for the circuit of FIG. 1, load line 11 is selected to cross the horizontal axis at a point 12 representing the desired output voltage from terminals 6 and 7 of FIG. 1. In the example shown, the intersection 12 is at a value of 90 millivolts. For a close approximation to linear operation, preferably, the slope of load line 11 is selected such that equal lengths along load line 11 define equal base current increments.

It should be understood that linearity of operation may not always be the primary consideration and other slopes of load line 11 are possible. For example, point 13, which is the intersection of load line 11 with curve 8, represents the operating point wherein maximum current is drawn by the regulator. At point 13, the base current is equal to 0.9 milliamp. and the associated collector current is approximately 1.2 milliamps., for a total regulator current of 2.1 milliamps. The primary consideration in some applications may be total current, and it is apparent that a lesser maximum current will attend a lower intersection 13 of load line 11 on curve 8, though some linearity may be sacrificed.

As stated above, the total current at point 13 is 2.1 milliamps., and a similar computation at point 15 yields a corresponding current of 0.3 milliamp. plus 0.4 milliamp. for a total of 0.7 milliamp. The corresponding collector voltages, obtained by reference to the horizontal axis, are 30 millivolts at point 13 and 70 millivolts at point 15. Therefore, the total current through the transistor is seen to vary inversely with transistor collector-emitter voltage V_{ce} . It will be recalled that this was the necessary criterion to satisfy Equation 1.

Since Equation 1 must be satisfied along the entire extent of load line 11, it must be satisfied at points 13 and 15 thereon. Setting the left side of Equation 1 at point 13 equal to the left side of Equation 1 at point 15, since both equations are equal to the same constant, yields a solution for the only unknown, R_5 , as:

$$(2) \quad R_5 = \frac{V_{ce}(15) - V_{ce}(13)}{I_B(13) - I_B(15) + I_C(13) - I_C(15)}$$

wherein V_{ce} is the collector-emitter voltage as derived from the abscissa of the collector saturation characteristics of FIG. 2, I_B is the transistor base current as specified on curves 8, 9 and 10, and I_C is the collector current as indicated on the ordinate of collector saturation characteristics in FIG. 2.

Substituting the specific values from the collector saturation characteristics of FIG. 2 into Equation 2 and solving for the value of resistance R_5 yields:

$$(3) \quad R_5 = 28.6 \text{ ohms}$$

The remaining determination of specified values for resistors 3 and 4, in the circuit of FIG. 1, may be simplified by noting that the collector-emitter voltage V_{ce} , and the voltage developed across resistor 5 at all times total less than $\frac{1}{10}$ of a volt. Also, the base-emitter junction of transistor 2 is forward-biased, therefore, its associated voltage drop will likewise be small. Therefore, if the voltage of source 1 is in excess of one volt, an excellent approximation to the values of resistors 3 and 4 may be obtained by neglecting the aforementioned small voltage drops in the circuit.

It is apparent, from FIG. 2, that the desired base cur-

rent change is from 0.9 milliamp. to 0.3 milliamp. The resulting value for resistor 3 is 10,000 ohms, when the source voltage range is from 9 to 3 volts, for example. For the same voltage change, it is desired to provide a collector current change of from 1.2 milliamps. to 0.4 milliamp., and the resulting value for resistor 4 is 7,500 ohms. By placing resistors of the above values in the circuit of FIG. 1, and providing a transistor having collector saturation characteristics as shown in FIG. 2, the transistor will operate along load line 11. Operation will be at point 13 when the voltage of source 1 is equal to 9 volts and operation will be at points 14 and 15 when the voltage of source 1 is equal to 6 and 3 volts, respectively.

FIG. 3 is a graph wherein the voltage of source 1 is plotted on the abscissa. Curve 16 shows the collector-emitter voltage V_{ce} for various values of source voltage, and curve 17 shows the corresponding voltage appearing across resistor 5. It will be noted that the collector-emitter voltage V_{ce} for various values of source voltage, age and voltage across resistor 5 increases with increasing battery voltage to provide a summation voltage, indicated by curve 18, which remains at a constant level. The summation voltage is the output voltage supplied by terminals 6 and 7 of FIG. 1.

A decrease in the size of resistor 5 will result in a decreased slope of line 17 thereby providing over-compensation whereby the summation voltage shown by line 18 will decrease with increasing source voltage. Similarly, the resistance value of resistor 5 may be increased to provide under-compensation. By this device, it is possible to provide an output voltage at terminals 6 and 7, of the circuit of FIG. 1, which also compensates for changes in value of an associated load impedance which may be voltage sensitive, such as the base-emitter circuit of a transistor which may receive its bias from the output terminals 6 and 7 of FIG. 1.

FIG. 4 shows the basic circuit of FIG. 1 modified to provide bias voltage for the transistors of a push-pull amplifier stage. Corresponding components in the circuit of FIG. 4 have been numbered as in FIG. 1.

The amplifier stage comprises an input transformer 19 having a primary winding 20 with terminals 21 and 22 adapted to be connected to a source of alternating current to be amplified. Center-tapped secondary winding 23, of transformer 19, supplies phase-reversed signals to the respective base electrodes of transistors 24 and 25. The transistor emitters are connected together and the respective collector electrodes serve opposite extremities of primary winding 26 of output transformer 27. Secondary winding 28 of transformer 27 supplies energy to an electric-acoustic transducer 29 which may be, for example, a radio loudspeaker. The emitters of transistors 24 and 25 are connected through a small stabilizing resistor 30 and voltage source 1 to a center tap 31 of winding 26, all as well known in the art.

Turning now to the transistor biasing circuit, which features the basic circuit of FIG. 1, it will be noted that collector resistor 4 of FIG. 1, appears as two resistors 4' in the circuit of FIG. 4. The collector of transistor 2 receives its current through one-half of each of windings 23 and 26 which are serially disposed with each of resistors 4'. This configuration is preferred to provide direct currents of opposite polarity through half-sections of windings 23 and 26 of transformers 19 and 27, respectively, to avoid partial saturation of the transformers. Since the collector of transistor 2 is effectively served through two parallel resistors, neglecting the relatively low direct-current resistance of the respective windings, it is apparent that resistors 4' should be of a value twice that obtained with reference to resistor 4 of FIG. 2. For an equivalent value of 7,500 ohms, each of resistors 4' should be equal to 15,000 ohms.

In order to provide a more stable operation of transistor 2, particularly when subjected to wide variations in

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ambient temperature, resistor 32 is disposed in series with base resistor 3, across power source 1, and the current to the base of transistor 2 is supplied from the junction of resistors 3 and 32. The addition of resistor 32 does not result in a marked difference in the previously derived value of resistor 3, for the specific example given, and a reduction in value to the next standard resistance value of 8,200 ohms has been found to provide comparable circuit performance when the resistance magnitude of resistor 32 is in the order of 120 ohms.

Also, in the interest of using relatively economical standard resistance values, resistor 5 may have a resistance of 22 ohms, rather than 28.6 ohms. This reduction in value provides over-compensation as previously discussed in connection with FIG. 3. The over-compensation may be corrected by bypassing a portion of the collector-emitter current of transistor 2 through a resistor, such as shown at 33, FIG. 4, or by providing a loading resistor across the output terminals 6 and 7, such as shown at 34. Resistor 34 is essentially connected across terminals 6 and 7, since the value of serially disposed resistor 30, which provides emitter stability for transistors 24 and 25, is normally very small (usually less than 5 ohms). In the circuit of FIG. 4, wherein both a transistor bypass resistor 33 and a loading resistor 34 are utilized, a value of 820 ohms was found to suffice for each of resistors 33 and 34. In an actual circuit, use of the aforementioned resistance values, was found to result in a substantially constant bias voltage of 90 millivolts when the voltage of source 1 varied between 9 and 3 volts.

There has been shown and disclosed herein a voltage regulator circuit which is particularly well adapted to supply a low regulated voltage from a widely varying source, such as required for proper biasing of transistors and tunnel diodes. The regulator employs a transistor near the origin of its collector saturation characteristics, wherein the current through the transistor may be made to vary inversely with the transistor collector-emitter voltage. The regulator is capable of supplying a wide range of low-voltage outputs with any given transistor. Greater flexibility may be achieved by judicious choice of a particular transistor type well suited to a given application. In addition, various modifications of the basic regulator circuit have been shown and discussed whereby economical standard resistance values may be utilized. In addition, the regulator readily adapts to provide output voltages covering the range from over-compensation to under-compensation. Many other modifications and alterations of the regulator circuit of this invention are possible and will suggest themselves to those skilled in the art. Therefore, it is intended that the scope of the subject invention be judged solely by reference to the following claims.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A direct-current low voltage regulator for providing a compensated output voltage, from a source of unregulated direct-current voltage, comprising:

- (a) a transistor having emitter, base and collector electrodes;
- (b) impedance means connected from said emitter electrode to a first terminal of said source;
- (c) impedance means respectively connecting said base and collector electrodes to a second terminal of said source, said last-named impedance means having values of impedance relatively higher than that of the first-named impedance means and being arranged to provide a bias of said transistor near the origin of its collector saturation characteristic;
- (d) whereby the collector-emitter voltage of said transistor varies inversely with changes in the voltage of said source; and
- (e) stabilized output voltage terminal means respectively connected to said collector electrode and to said first terminal of said source.

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2. A direct-current low voltage regulator for providing a substantially constant output voltage, from a source of unregulated direct-current voltage, comprising:

- (a) a transistor having emitter, base and collector electrodes;
- (b) impedance means connected from said emitter electrode to a first terminal of said source;
- (c) base and collector resistors connected from said base and collector electrodes, respectively, to a second terminal of said source;
- (d) said resistors having resistance magnitudes relatively greater than that of said impedance means and which provide a bias of said transistor near the origin of its collector saturation characteristics;
- (e) whereby the collector-emitter voltage of said transistor varies inversely with changes in the voltage of said source and a compensated voltage is provided between said collector and the first terminal of said source; and
- (f) stabilized output voltage terminal means respectively connected to said collector and said first terminal of said source.

3. A direct-current low voltage regulator for providing a substantially constant output voltage, from a source of unregulated direct-current voltage, comprising:

- (a) a transistor having an emitter, a base and a collector;
- (b) an emitter resistor connected from said emitter to a first terminal of said source;
- (c) base and collector resistors, having resistances of the same order of magnitude and relatively greater than that of said emitter resistor, connected from said base and collector, respectively, to a second terminal of said source;
- (d) said base resistor permitting a relatively high forward bias current through the base-emitter junction of said transistor to provide a bias of said transistor near the origin of its collector saturation characteristics;
- (e) whereby the collector-emitter voltage of said transistor varies inversely with changes in the voltage of said source and a compensated voltage is provided between said collector and the first terminal of said source; and
- (f) stabilized output voltage terminal means respectively connected to said collector and said first terminal of said source.

4. In a transistor push-pull Class B amplifier stage including, a pair of transistors having their respective collector electrodes connected to opposite extremities of a center-tapped output winding and having their respective emitter electrodes connected through a source of voltage to the center tap of said output winding, and a center-tapped input winding having opposite extremities connected to the respective base electrodes of said transistors, the improvement of transistor biasing means comprising:

- (a) a voltage stabilizing transistor having emitter, base and collector electrodes;
- (b) impedance means connecting the emitter of said stabilizing transistor to said emitter electrodes;
- (c) resistance means connecting the collector and base of each of said pair of transistors and having values of resistance relatively greater than that of said impedance means
- (d) conductive means connecting the collector of said voltage stabilizing transistor to the center tap of said input winding; and,
- (e) a resistor connected from the base of said voltage stabilizing transistor to the center tap of said output winding and having a value of resistance relatively greater than that of said impedance means to provide a bias of said voltage stabilizing transistor near the origin of its collector saturation characteristics;
- (f) whereby the bias voltage between the base and

emitter electrodes of said pair of transistors is maintained substantially constant.

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