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[54] **BANDGAP VOLTAGE REFERENCE USING A POWER SUPPLY INDEPENDENT CURRENT SOURCE**

[75] Inventors: **Paul T. Bennett**, Phoenix; **Robert B. Davies; David F. Mietus**, both of Tempe, all of Ariz.

[73] Assignee: **Motorola, Inc.**, Schaumburg, Ill.

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[51] **Int. Cl.**[5] **G05F 3/30**

[52] **U.S. Cl.** **323/313**; 323/316

[58] **Field of Search** 323/313, 314, 315, 316, 323/901, 907; 307/296.1, 296.6, 310

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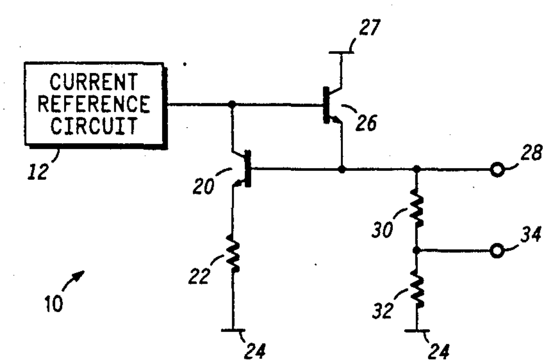
Primary Examiner—Peter S. Wong

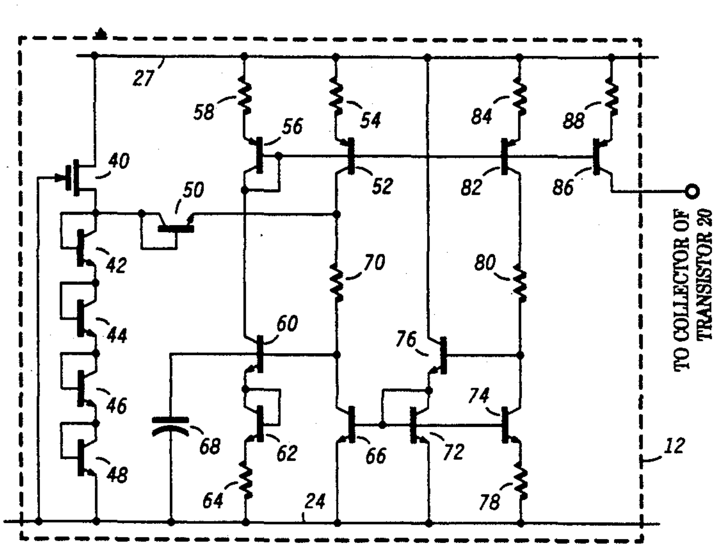
Attorney, Agent, or Firm—Robert D. Atkins

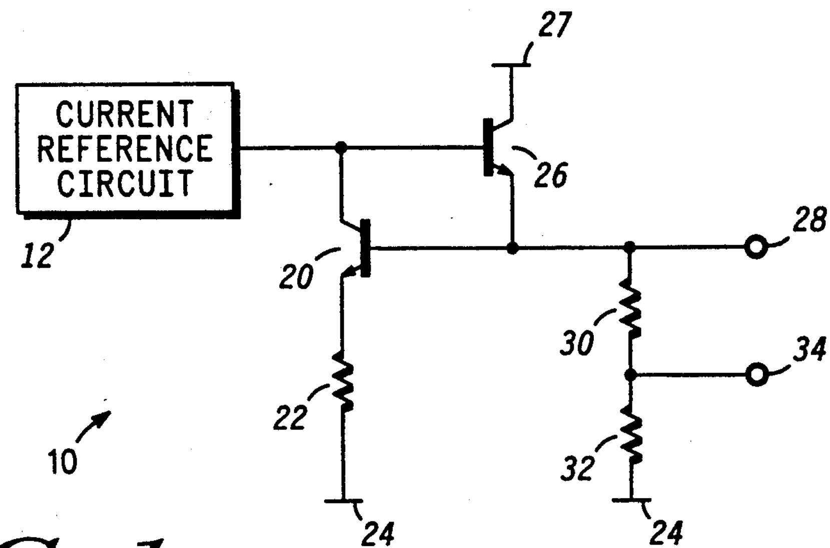
[57] **ABSTRACT**

A voltage reference circuit is provided for developing an output voltage operating independent of temperature and power supply variation. A current reference circit provides a current reference signal operating independent of power supply variation and having a predetermined temperature coefficient and flowing through a first transistor and a first resistor each having opposite temperature coefficients. The output voltage is established as the sum of the base-emitter junction potential of the first transistor and the potential developed across the first resistor. The temperature coefficient of the potential developed across the first resistor substantially cancels the temperature coefficient across the base-emitter junction of the first transistor thereby providing the output voltage operating independent of temperature and power supply variation.

17 Claims, 1 Drawing Sheet






CURRENT
REFERENCE
CIRCUIT
12
10
20
22
24
27
26
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30
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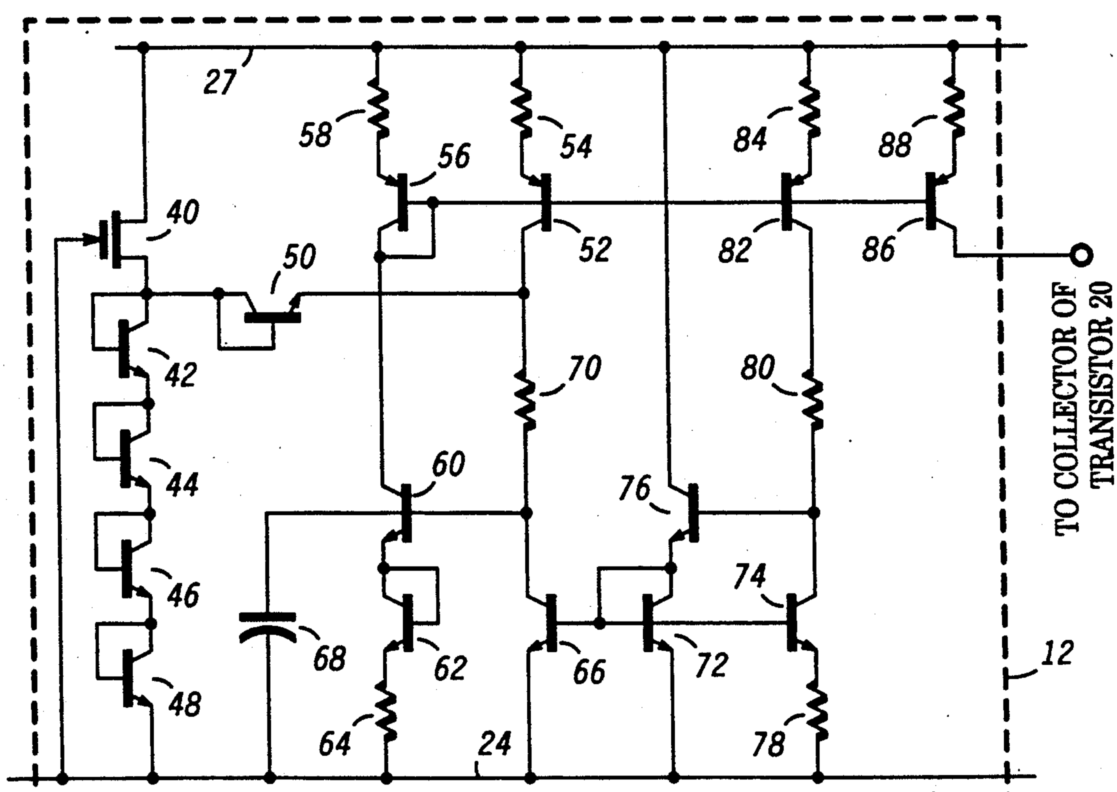
32
24

FIG. 1

FIG. 2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78
12
TO COLLECTOR OF
TRANSISTOR 20

BANDGAP VOLTAGE REFERENCE USING A POWER SUPPLY INDEPENDENT CURRENT SOURCE

BACKGROUND OF THE INVENTION

This invention relates to voltage reference circuits, and more particularly, to a bandgap voltage reference circuit for providing a stable output voltage operating independent of temperature and power supply variations.

Voltage reference circuits are common in many modern electronic designs for providing a stable reference signal. The bandgap voltage reference circuit is well suited for this niche due to its temperature independent characteristics as discussed in an article entitled "A SIMPLE THREE-TERMINAL IC BANDGAP REFERENCE" by A. Paul Brokaw, IEEE Journal of Solid State Circuits, Vol. SC-9, No. 6, December, 1974. Briefly, the Brokaw article discloses a two transistor configuration conducting equal currents, but having dissimilar emitter areas, say eight-to-one, creating different current densities and base-emitter junction potentials (V_{be}). The first transistor typically possesses the larger emitter area and, correspondingly, the lower current density and the lesser V_{be}. By connecting two resistors in series with the emitter path of the first transistor and coupling the emitter of the second transistor to the interconnection thereof, a delta V_{be} having a positive temperature coefficient is developed across the upper resistor. If the currents flowing through the first and second transistors are made of appropriate and constant magnitude and equal in value, the positive temperature coefficient of the voltage across the upper resistor tends to cancel the inherent negative temperature coefficient of the base-emitter junction of the first transistor thereby providing an output voltage at the collector of the second transistor which is insensitive to temperature variation, as is understood.

The current flowing through the first and second transistors is typically provided by a PNP transistor current mirror configuration having the emitters thereof coupled to the positive power supply conductor. Any transients appearing on the positive power supply are reflected in the current flowing through the first and second transistors, inducing variation in the V_{be}'s thereof and the potential developed across the emitter resistors. This translates to movement in the collector potential of the second transistor, thus, the output voltage is dependent upon the power supply voltage. The fluctuation in the circuit signal levels attributed to power supply variation is commonly known as the Early voltage effect and is an undesirable condition which adversely influences the regulated output signal.

Hence, there is a need for an improved voltage reference circuit having an output voltage operating independent of temperature and power supply variations.

SUMMARY OF THE INVENTION

Accordingly, an objective of the present invention is to provide an improved voltage reference circuit.

Another object of the present invention is to provide an improved voltage reference circuit having an output voltage operating independent of temperature.

Yet another object of the present invention is to provide an improved voltage reference circuit having an output voltage operating independent of the power supply.

Still yet another object of the present invention is to provide an improved voltage reference circuit having a controllable temperature coefficient.

In accordance with the above and other objectives there is provided an improved voltage reference circuit for providing an output voltage comprising a first circuit including an output for supplying a current having a predetermined temperature coefficient. A first transistor is also provided having a collector coupled to the output of the first circuit, a base coupled to the output of the voltage reference circuit and an emitter coupled through a first resistor to a first source of operating potential for conducting the current having a predetermined temperature coefficient which develops a potential across the first resistor having a temperature coefficient opposing the temperature coefficient across the base-emitter junction of the first transistor. A second circuit is coupled between the collector and base of the first transistor for supplying base drive thereto.

In another aspect, the present invention comprises a method of developing an output voltage operating independent of temperature. A first current is supplied having a predetermined temperature coefficient and passed through a first resistor and a first transistor having a temperature coefficient across the base-emitter junction thereof. The potential developed across the first resistor has a temperature coefficient opposing the temperature coefficient across the base-emitter junction of the first transistor for substantially canceling temperature induced variation in the output voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic and block diagram illustrating the preferred embodiment of the present invention; and

FIG. **2** is a schematic diagram illustrating further detail of the current reference circuit.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1**, voltage reference circuit **10** is shown comprising current reference circuit **12** having an output for providing a current reference signal flowing into the collector of transistor **20**. The emitter of transistor **20** is coupled through resistor **22** to power supply conductor **24**, operating at ground potential. The collector and base of transistor **20** are coupled to the base and emitter of transistor **26**, respectively, while the collector of transistor **26** is coupled to power supply conductor **27**, typically operating at a positive potential such as V_{CC}. An output voltage operating independent of temperature and power supply variation is provided at output terminal **28** that is the base of transistor **20**. In addition, resistors **30** and **32** are serially coupled between output terminal **28** and power supply conductor **24** for providing a divider ratio of the output voltage at output **34**.

Further detail of current reference circuit **12** is shown in FIG. **2** including FET transistor **40** operating as a resistor and having a source coupled to power supply conductor **27**, a gate coupled to power supply conductor **24** and a drain coupled to the base and collector of diode configured transistor **42**. The emitter of transistor **42** is coupled to the collector and base of transistor **44**, while the emitter of transistor **44** is coupled to the base and collector of transistor **46**. The emitter of transistor **46** is coupled to the base and collector of transistor **48**, and the emitter of the latter is coupled to power supply conductor **24** thereby forming a diode stack for developing a voltage of four base-emitter junction potentials ($4V_{be}$'s) at the collector and base of transistor **50**. The emitter of transistor **50** is coupled to the collector of transistor **52**, and the emitter of transistor **52** is coupled through resistor **54** to power supply conductor **27**, while the emitter of transistor **56** is coupled through resistor **58** to power supply conductor **27**, and the base and collector of transistor **56** are coupled together to the collector of transistor **60**. The emitter of transistor **60** is coupled through diode configured transistor **62** and resistor **64** to power supply conductor **24**, and the base of transistor **60** is coupled to the collector of transistor **66**, through capacitor **68** to power supply conductor **24** and through resistor **70** to the collector of transistor **52**. The base of transistor **66** is coupled to the base and collector of transistor **72**, to the base of transistor **74** and to the emitter of transistor **76**. The emitters of transistors **66**, **72** and **74** are coupled to power supply conductor **24**, the latter path including resistor **78**. The collector and base of transistor **76** are coupled to power supply conductor **27** and to the collector of transistor **74**, respectively, and the collector of transistor **74** is also coupled through resistor **80** to the collector of transistor **82**, which includes an emitter coupled through resistor **84** to power supply conductor **27** and a base coupled to the bases of transistors **52** and **56** for developing a reference potential. The base of transistor **82** is also coupled to the base of transistor **86** which includes an emitter coupled through resistor **88** to power supply conductor **27** and a collector that is the output of current reference circuit **12** for providing the current reference signal.

The discussion of voltage reference circuit **10** begins with the operation of current reference circuit **12** as a positive potential, V_{CC}, is applied at power supply conductor **27**. FET transistor **40** is selected for providing approximately 100K ohms of resistance between power supply conductor **27** and the top of the diode stack formed of transistors **42–48** for limiting the current flowing therethrough. The potential applied at the collector of transistor **52** is thus $3V_{be}$'s above ground potential ($4V_{be}$'s less the V_{be} of transistor **50**) which is sufficient to conduct current through resistor **70** and turn on transistors **60** and **62**. The current flowing through transistor **60** reduces the voltage at the base and collector of transistor **56** turning the latter on and completing a first conduction path between power supply conductors **27** and **24** through resistor **58**, transistors **56**, **60** and **62** and resistor **64**. The low potential at the base of transistor **56** also truns on transistors **52** and **82** creating a second conduction path through resistor **54**, transistor **52**, resistor **70** and transistor **66**, and a third conduction path through resistor **84**, transistor **82**, resistor **80**, transistor **74** and resistor **78**. Once current reference circuit **12** is started, the voltage developed at the collector of transistor **52** reverse biases the base-emitter junction of transistor **50** thereby removing transistors **40–50** from consideration.

The current flowing through the collector-emitter conduction path of transistor **76** supplies the base drive for transistors **66**, **72** and **74**. This diverts negligible current from the collector of transistor **74** as the base current is effectively divided by the forward current gain of transistor **76**. Transistor **72** helps maintain a stable V_{be} across the base-emitter junction of transistor **66** as very little current flows through the collector-emitter conduction path thereof. Resistors **54**, **58** and **84** are matched (e.g., 2K ohms) for establishing identical V_{be}'s for transistors **52**, **56** and **82** and equal currents, say 50 microamps, flowing through the first, second and third conduction paths defined above. Resistors **70** and **80** are also matched (e.g., 28K ohms) as are resistors **64** and **78** (e.g., 720 ohms) for providing equal potentials at the collectors of transistors **52** and **82** and equal potentials at the collectors of transistors **66** and **74**, respectively. That is, the collector voltage of transistor **74** is the V_{be} of transistor **76** plus the V_{be} of transistor **74** plus the current flowing through the third conduction path times the value of resistor **78**, while the collector voltage of transistor **66** is the V_{be} of transistor **60** plus the V_{be} of transistor **62** plus the potential developed across resistor **64**. It is important to note that the emitter areas of transistors **62** and **74** are sized larger than the emitter areas of transistors **60** and **76** and therefore conduct a fraction of the current density. For example, transistors **62** and **74** may be selected with four times the emitter area of transistors **60** and **76** and correspondingly conduct one-fourth the current density. Thus, with the V_{be}'s of transistors **60** and **62** equal, the V_{be}'s of transistor **62** and **74** equal and the potentials developed across resistors **64** and **78** equal, the collectors of transistors **66** and **74** are also equal.

The feedback loop formed of transistors **56**, **60** and **62** provides the immunity from power supply variations. If the voltage applied at power supply conductor **27** falls, the potential at the emitters of transistors **52**, **56** and **82** also drops thereby decreasing the V_{be}'s thereof and the current flow through the second and third conduction paths. The collector voltage of transistors **66** and **74** tends to rise as less potential is developed across resistors **70** and **80** thereby increasing the V_{be} of transistor **60**, drawing more collector current and reducing the voltage developed at the collector of transistor **56** which compensates the V_{be}'s of transistors **52**, **56** and **82** re-establishing the nominal current flow through the second and third conduction paths. Alternately, if the voltage applied at power supply conductor **27** rises, the potential at the emitters of transistors **52**, **56** and **82** increases the V_{be}'s thereof and the current flow through the second and third conduction paths. The collector voltage of transistors **66** and **74** falls as more potential is developed across resistors **70** and **80**, decreasing the V_{be} of transistor **60** which draws less collector current and increases the collector voltage of transistor **56** and compensating the V_{be}'s of transistors **52**, **56** and **82** again re-establishing the nominal current flow through the second and third conduction paths. Capacitor **68** is provided for decoupling the high frequency components at the base of transistor **60** slowing and stabilizing the response of the feedback loop. Hence, the potential developed at the bases of transistors **52**, **56** and **82** is substantially independent of variation in power supply conductor **27** so as to eliminate the Early voltage effect. Moreover, the base currents of transistors **60** and **76** are equal, and the collector voltage of transistors **52** and **82** are equal and constant regardless of the supply voltage.

The reference signal developed at the base of transistors **52**, **56** and **82** is determined by the V_{be} of transistor **82** and the current flowing through the third conduction path (I_C) times the value of resistor **84**. Since transistors **66** and **74** operate at different current densities, their V_{be}'s are dissimilar and a delta V_{be} is developed across resistor **78** having a positive temperature coefficient. Thus, the current I_C flowing through resistor **78** may be calculated as follows:

$$V_{66} = V_{74} + I_C \times \quad (1)$$

$$R_{78}\frac{kT}{q}\ln\left(\frac{I_{C66}}{I_{S66}}\right) = \frac{kT}{q}\ln\left(\frac{I_{C74}}{I_{S74}}\right) + I_C \times R_{78}$$

where:

V_{66} = V_{be} of transistor **66**
V_{74} = V_{be} of transistor **74**
R_{78} = value of resistor **78**
k = Boltzman's constant
T = absolute temperature
q = the electron charge
I_{C66} = collector current through transistor **66**
I_{S66} = saturation current through transistor **66**
I_{C74} = collector current through transistor **74**
I_{S74} = saturation current through transistor **74**

As stated, the emitter area of transistor **74** is four times (4A) the emitter area of transistor **66** (1A). By combining terms and dividing out the collector current and saturation current ratios, equation (1) may be reduced to:

$$I_C \times R_{78} = \frac{kT}{q}\ln\left[\left(\frac{I_{C66}}{I_{C74}}\right)\left(\frac{I_{S74}}{I_{S66}}\right)\right] \quad (2)$$

$$I_C = \frac{\frac{kT}{q}\ln(4)}{R_{78}}$$

The current I_C is determined by resistor **78** from equation (2); however, observe that the current flowing through the first, second and third conduction paths and correspondingly the reference signal provided at the bases of transistors **52, 56** and **82** is still of function of temperature. This temperature dependency may be used advantageously as will be shown.

Returning to FIG. **1**, the value of resistor **88** is matched with resistors **54, 58** and **84** for providing a current reference signal flowing through transistor **86** and transistor **20** and resistor **22** equal to that of the third conduction path, current I_C, and having a similar temperature coefficient and operating independent of the power supply. The base current for transistor **20** is supplied through the collector-emitter conduction path of transistor **26** thereby diverting negligible current from the collector of transistor **20** due to its forward current gain. The temperature and power supply regulated output voltage provided at output terminal **28** is thus equal to the V_{be} of transistor **20** plus the value of resistor **22**, say 10K ohms, times the current I_C, or approximately 1.18 volts. Resistors **30** and **32** form a conventional voltage divider circuit for providing a reduced output voltage at output **34**. Furthermore, the output voltage is independent of power supply because the current refernce signal provided by the current reference circuit **12** as shown is also independent of power supply variation.

For the temperature compensation feature, the goal is balance the negative temperature coefficient of the V_{be} of transistor **20**, approximately −1.68 mV/°K., against the positive temperature coefficient of the potential developed across resistor **22**. The positive temperature coefficient as seen in equation (2) in combination with resistor **22**, which is fabricated from the same base material (125 ohms/square) of similar geometries as resistor **78** and therefore matched with a temperature coefficient of about 688 ppm/°K., substantially cancels the negative temperature coefficient of transistor **20** thereby providing an output voltage independent of temperature. The cancellation of the temperature coefficients between the potential across resistor **22** and the V_{be} of transistor **20** is further demonstrated as follows. The output voltage provided at output terminal **28** is given as:

$$V_{28} = V_{20} + I_C \times R_{22} \quad (3)$$

Taking the derivative with respect to temperature yields:

$$\frac{\partial V_{28}}{\partial T} = \frac{\partial I_C}{\partial T} \times R_{22} + I_C \times \frac{\partial R_{22}}{\partial T} + \frac{\partial V_{20}}{\partial T} \quad (4)$$

Substituting equation (2) into equation (4) produces:

$$\frac{\partial V_{28}}{\partial T} = \left[\frac{R_{78}\frac{k}{q}\ln(4) - \frac{kT}{q}\ln(4)\frac{\partial R_{78}}{\partial T}}{(R_{78})^2}\right]R_{22} + \frac{\frac{kT}{q}\ln(4)}{R_{78}}\left(\frac{\partial R_{22}}{\partial T}\right) + \frac{\partial V_{20}}{\partial T} \quad (5)$$

Since resistors **22** and **78** are fabricated from the same base material and have similar geometries, it can be shown that:

$$\frac{\partial R_{78}}{\partial T} = \frac{\partial R_{22}}{\partial T} = 668 \times 10^{-6}\ \text{ohms/°}K.$$

Furthermore, a typical value for the temperature coefficient of the V_{be} of transistor **20** is −1.68 mV/°K. By selecting I_C at 50 microamps, resistor **22** at 10K ohms and resistor **78** at 720 ohms with a nominal temperature of 300° K., equation (5) reduces to:

$$\frac{\partial V_{28}}{\partial T} = 1.66 + 33.4 \times 10^{-9} + (-1.68) \approx 0\ \text{mV/°}K.$$

Notably, the temperature coefficient of the output voltage can be made non-zero and easily controlled with a positive or negative slope by adjusting the values of resistors **78** and **22**. For example, by increasing the value of resistor **22**, the output voltage at output terminal **28** will have a positive slope temperature coefficient. Conversely, the temperature coefficient of the output voltage may have a negative slope by decreasing the value of resistor **22**.

Hence, what has been described is a novel voltage reference circuit using a current reference signal flowing through a first transistor and a first resistor, operating independent of the power supply and having predetermined temperature coefficient for developing a potential across the first resistor with a positive temperature coefficient which substantially cancels the negative temperature coefficient of the V_{be} of the first transistor for providing an output voltage operating independent of temperature and power supply variation.

We claim:

1. A voltage reference circuit for providing a voltage at an output, comprising:

first means including an output for supplying a current having a selectable temperature coefficient;

a first transistor having a collector, a base and an emitter, said collector being coupled for receiving said current having said selectable temperature coefficient from said output of said first means, said base being coupled to the output of the voltage reference circuit, said first transistor having a temperature coefficient across the base-emitter junction thereof;

second means coupled between said collector and base of said first transistor for supplying base drive thereto; and

a first resistor coupled between said emitter of said first transistor and a first source of operating potential for conducting said current having said selectable temperature coefficient which develops a potential across said first resistor with a temperature coefficient opposing said temperature coefficient across the base-emitter junction of said first transistor.

2. The voltage reference circuit of claim 1 wherein said second means includes a second transistor having a collector, a base and an emitter, said base being coupled to said collector of said first transistor, said emitter being coupled to said base of said first transistor, said collector being coupled to a second source of operating potential.

3. The voltage reference circuit of claim 2 wherein said first means comprises:

third means for providing a reference signal at an output;

a third transistor having a collector, a base and an emitter, said base being responsive to said reference signal, said collector being coupled to said collector of said first transistor; and

a second resistor coupled between said emitter of said third transistor and a said second source of operating potential.

4. The voltage reference circuit of claim 3 wherein said third means includes:

a fourth transistor having a collector, a base and an emitter, said base being coupled to said output of said first means;

a third resistor coupled between said emitter of said fourth transistor and said second source of operating potential;

a fifth transistor having a collector, a base and an emitter, said base being coupled to said base of said fourth transistor;

a fourth resistor coupled between said emitter of said fifth transistor and said second source of operating potential;

a sixth transistor having a collector, a base and an emitter, said emitter being coupled to said first source of operating potential;

a fifth resistor coupled between said collectors of said fifth and sixth transistors;

a seventh transistor having a collector, a base and an emitter, said base being coupled to said base of said sixth transistor;

a sixth resistor coupled between said collectors of said fourth and seventh transistors; and

a seventh resistor coupled between said emitter of said seventh transistor and said first source of operating potential.

5. The voltage reference circuit of claim 4 wherein said third means further includes:

an eighth transistor having a collector, a base and an emitter, said base being coupled to said collector of said seventh transistor, said collector being coupled to said second source of operating potential, said emitter being coupled to said bases of said sixth and seventh transistors; and

a ninth transistor having a collector, a base and an emitter, said base and collector being coupled together to said base of said sixth transistor, said emitter being coupled to said first source of operating potential.

6. The voltage reference circuit of claim 5 wherein said third means further includes:

a tenth transistor having a collector, a base and an emitter, said base and collector being coupled together to said bases of said fourth and fifth transistors;

an eighth resistor coupled between said emitter of said tenth transistor and said second source of operating potential;

an eleventh transistor having a collector, a base and an emitter, said collector being coupled to said collector of said tenth transistor, said base being coupled to said collector of said sixth transistor;

a twelfth transistor having a collector, a base and an emitter, said base and collector being coupled together to said emitter of said eleventh transistor;

a ninth resistor coupled between said emitter of said twelfth transistor and said first source of operating potential; and

a capacitor coupled between said base of said eleventh transistor and said first source of operating potential.

7. The voltage reference circuit of claim 6 wherein said third means further includes:

a first diode having a cathode coupled to said first source of operating potential and having an anode;

a second diode having a cathode coupled to said anode of said first diode and having an anode;

a third diode having a cathode coupled to said anode of said second diode and having an anode;

a fourth diode having a cathode coupled to said anode of said third diode and having an anode;

a fifth diode having an anode coupled to said anode of said fourth diode and having a cathode coupled to said collector of said fifth transistor; and

a ninth resistor coupled between said anode of said fourth diode and said second source of operating potential.

8. A method of developing an output voltage operating independent of temperature, comprising the steps of:

supplying a first current having a selectable temperature coefficient;

passing said first current through a first transistor and a first resistor, said first transistor having a temperature coefficient across the base-emitter junction thereof; and

developing a potential across said first resistor having a temperature coefficient opposing said temperature coefficient across the base-emitter junction of said first transistor for substantially canceling temperature induced variation in the output voltage.

9. A circuit for providing a reference signal at an output, comprising:

a first transistor having a collector, a base and an emitter, said base being coupled to the output of the circuit;

a first resistor coupled between said emitter of said first transistor and a first source of operating potential;

a second transistor having a collector, a base and an emitter, said base being coupled to said base of said first transistor;

a second resistor coupled between said emitter of said second transistor and said first source of operating potential;

a third transistor having a collector, a base and an emitter, said emitter being coupled to a second source of operating potential;

a third resistor coupled between said collectors of said second and third transistors;

a fourth transistor having a collector, a base and an emitter, said base being coupled to said base of said third transistor;

a fourth resistor coupled between said collectors of said first and fourth transistors;

a fifth resistor coupled between said emitter of said fourth transistor and said second source of operating potential;

first means coupled between said collector of said fourth transistor and said bases of said third and fourth transistors for providing base drive thereto;

second means coupled between said collector of said third transistor and said bases of said first and second transistors for maintaining the potential developed at said bases of said first and second transistors independent of the potential applied at said first source of operating potential; and

third means for starting the operating of the circuit.

10. The circuit of claim **9** wherein said first means includes:

a fifth transistor having a collector, a base and an emitter, said base being coupled to said collector of said fourth transistor, said collector being coupled to said first source of operating potential, said emitter being coupled to said bases of said third and fourth transistors; and

a sixth transistor having a collector, a base and an emitter, said base and collector being coupled together to said base of said third transistor, said emitter being coupled to said second source of operating potential.

11. The circuit of claim **10** wherein said second means includes:

a seventh transistor having a collector, a base and an emitter, said base and collector being coupled together to said bases of said first and second transistors;

a sixth resistor coupled between said emitter of said seventh transistor and said first source of operating potential;

an eighth transistor having a collector, a base and an emitter, said base being coupled to said collector of said third transistor, said collector being coupled to said collector of said seventh transistor;

a ninth transistor having a collector, a base and an emitter, said base and collector being coupled together to said emitter of said eighth transistor;

a seventh resistor coupled between said emitter of said ninth transistor and said second source of operating potential; and

a capacitor coupled between said base of said eighth transistor and said second source of operating potential.

12. The voltage reference circuit of claim **11** wherein said third means includes:

a first diode having a cathode coupled to said second source of operating potential and having an anode;

a second diode having a cathode coupled to said anode of said first diode and having an anode;

a third diode having a cathode coupled to said anode of said second diode and having an anode;

a fourth diode having a cathode coupled to said anode of said third diode and having an anode;

a fifth diode having an anode coupled to said anode of said fourth diode and having a cathode coupled to said collector of said second transistor; and

an eighth resistor coupled between said anode of said fourth diode and said first source of operating potential.

13. A voltage reference circuit for providing a voltage at an output, comprising:

first means for providing a reference signal at an output;

a first transistor having a collector, a base and an emitter, said base being responsive to said reference signal, said emitter being coupled to a first source of operating potential, said collector supplying a current having a predetermined temperature coefficient;

a first resistor coupled between said emitter of said first transistor and said first source of operating potential;

a second transistor having a collector, a base and an emitter, said collector being coupled to said collector of said first transistor, said base being coupled to the output of the voltage reference circuit, said first transistor having a temperature coefficient across the base-emitter junction thereof;

second means coupled between said collector and base of said second transistor for supplying base drive thereto; and

a second resistor coupled between said emitter of said second transistor and a second source of operating potential for conducting said current having a predetermined temperature coefficient which develops a potential across said second resistor with a temperature coefficient opposing said temperature coefficient across the base-emitter junction of said first transistor and substantially cancels the temperature induced variation in the voltage developed at the output of the voltage reference circuit.

14. The voltage reference circuit of claim **13** wherein said second means includes a third transistor having a collector, a base and an emitter, said base being coupled to said collector of said second transistor, said emitter being coupled to said base of said second transistor, said collector being coupled to said first source of operating potential.

15. The voltage reference circuit of claim **14** wherein said first means includes:

a fourth transistor having a collector, a base and an emitter, said base being coupled to said output of said first means;

a third resistor coupled between said emitter of said fourth transistor and said second source of operating potential;

a fifth transistor having a collector, a base and an emitter, said base being coupled to said base of said fourth transistor;

a fourth resistor coupled between said emitter of said fifth transistor and said second source of operating potential;

a sixth transistor having a collector, a base and an emitter, said emitter being coupled to said first source of operating potential;

a fifth resistor coupled between said collectors of said fifth and sixth transistors;

a seventh transistor having a collector, a base and an emitter, said base being coupled to said base of said sixth transistor;

a sixth resistor coupled between said collectors of said fourth and seventh transistors; and

a seventh resistor coupled between said emitter of said seventh transistor and said first source of operating potential.

16. The voltage reference circuit of claim **15** wherein said first means further includes:

an eighth transistor having a collector, a base and an emitter, said base being coupled to said collector of said seventh transistor, said collector being coupled to said second source of operating potential, said emitter being coupled to said bases of said sixth and seventh transistors; and

a ninth transistor having a collector, a base and an emitter, said base and collector being coupled together to said base of said sixth transistor, said emitter being coupled to said first source of operating potential.

17. The voltage reference circuit of claim **16** wherein said first means further includes:

a tenth transistor having a collector, a base and an emitter, said base and collector being coupled together to said bases of said fourth and fifth transistors;

an eighth resistor coupled between said emitter of said tenth transistor and said second source of operating potential;

an eleventh transistor having a collector, a base and an emitter, said collector being coupled to said collector of said tenth transistor, said base being coupled to said collector of said sixth transistor;

a twelfth transistor having a collector, a base and an emitter, said base and collector being coupled together to said emitter of said eleventh transistor;

a ninth resistor coupled between said emitter of said twelfth transistor and said first source of operating potential; and

a capacitor coupled between said base of said eleventh transistor and said first source of operating potential.

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