(12) EUROPEAN PATENT APPLICATION

(54) Switching type bandgap controller

(57)   The invention relates to an integrated self-powered and switching electronic circuit (10) for regulating a stable reference voltage (Vr), comprising a band-gap voltage generator to produce said stable reference voltage (Vr) for a system circuit block (2, 12) that is generally supplied by the output of the band-gap generator through a comparator and an error amplifier. A regulating loop is provided between the output of the system block (12) and the input of the voltage generator circuit (10) to supply a voltage signal (SENSE) produced by the output of the system block. Advantageously, the voltage generator circuit incorporates both the comparator and the error amplifier.
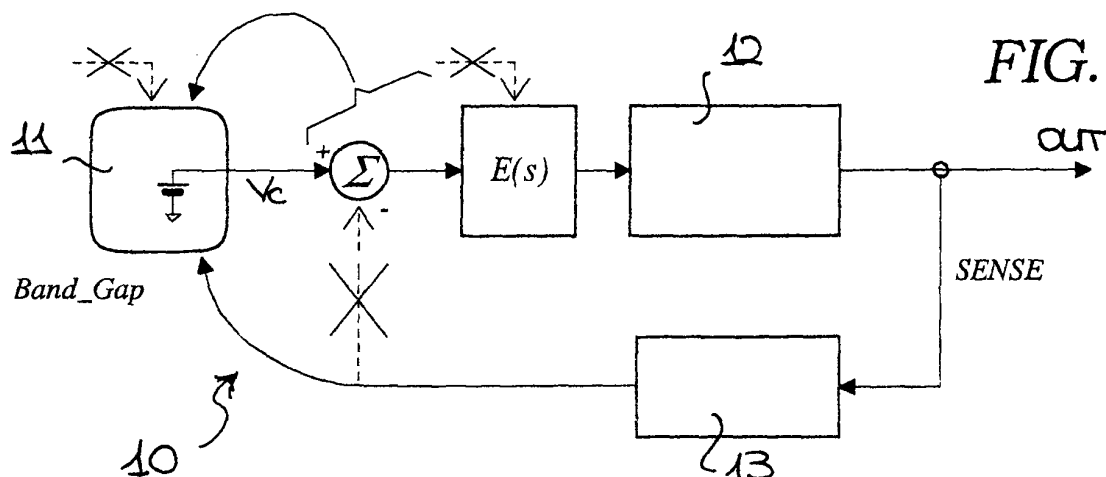
FIG. 3

EP 1 186 983 A2

Description

<u>Field of the Invention</u>

5   **[0001]**   This invention relates to a switching type bandgap controller.

[0002]   More specifically, but not exclusively, the invention relates to a self-powered electronic circuit for regulating a stable reference voltage, which circuit comprises a band-gap generator to produce said stable reference voltage, comprises a system circuit block supplied by a controlled voltage obtained from said reference voltage through a comparator and an error amplifier to output a regulated voltage, and comprises a regulating loop inserted between

10   said output and the output of the band-gap generator and including a normalizer block.

[0003]   The invention also relates to a regulating method implemented by said electronic circuit.

[0004]   More particularly though not exclusively, the invention relates to a voltage regulator for automotive applications, and the following description will cover this application field for convenience of illustration.

15   <u>Prior Art</u>

[0005]   As it is well known in this field, electronic regulating systems for generating stabilized voltage references are usually supplied by a voltage deriving from an external source.

[0006]   For instance in the technology of electronic microcircuits, a so-called band-gap regulating system is often
20   used which is intended to generate a stable voltage reference from a usually pre-stabilized dedicated supply line.

[0007]   For example, let's consider a first prior art solution disclosed in the US patent No. 4,388,586 relating to a voltage regulator for an automotive alternator. This voltage regulator is provided with a precision reference voltage source 28 of the band-gap type.

[0008]   The alternator output voltage 26 is compared with the band-gap reference voltage inside the comparator 44.
25   The reference voltage source 28 is an independent block.

[0009]   The German patent No. DE 196 20 181 C relates to a circuit block for producing a reference output voltage Vout. The circuit block determines an absolute voltage value Vr(To), set for a specific temperature value, and a temperature coefficient Tc = dVr/dT that is constant in specific working temperature range. The reference output voltage is obtained from these two values.

30   **[0010]**   Another know solution is disclosed in the EP application No. 0751451 concerning a reference voltage regulator having a double slope temperature characteristic. The reference voltage is produced using a couple of voltage references VrA, VrB each having a predetermined temperature behaviour.

[0011]   A further prior art solution is disclosed in the US patent No. 5,963,082 concerning a circuit arrangement for producing a D.C. current. An output current having a negative voltage coefficient is produced on the output terminal
35   27. This output current is obtained by a final mirroring of a current flowing through the resistor 17 and by a mirror circuit portion including the circuit components 24, 25, 28 and 29.

[0012]   All the above prior art solutions work with voltages or currents that are just variable in temperature, but not variable in time.

[0013]   Now, for a better understanding of the invention, we will examine hereinafter the problem of controlling an
40   automotive alternator by a regulated voltage. However, differently from the above cited prior art solutions, the invention doesn't relate to the generation of a voltage ramp for controlling a PWM signal.

[0014]   In Figure 1 of the accompanying drawings, a block diagram (A) is shown that provides an example of how a reference voltage signal Vr is generated. The reference voltage signal Vr, also known as the set-point signal, is generated by a Band-Gap block 11 connected to a supply line 5. A regulator loop circuit 1 produces an output signal Vsense
45   = k•Vr. Therefore, the voltage signal Vr is the "set point" signal for the regulator loop 1.

[0015]   The signal SENSE at the output node OUT represents the variable to be controlled, that is the output signal of a system block 2 which may be for example a drive circuit portion of an alternator. This signal SENSE, following to a normalizing phase inside a block 3 placed in a feedback loop, is compared with the reference voltage signal Vr, through the block 4, in order to generate a control voltage of the system block 2.

50   **[0016]**   The regulator loop, specifically the normalizing block 3, functions to make the value of the signal SENSE K tunes greater than the reference signal Vr, that is: Vsense = k•Vr.

[0017]   Usually, the signals involved in the loop regulator circuit 1 are translated into voltage signals using small amounts of electric power.

[0018]   The supply line, designated at 5 in the scheme of Figure 1 is not always stabilized. In fact, in some applications
55   as the ones of the voltage regulators for automotive alternators, the supply voltage on the line 5 may show negative pulses of considerable depth and duration, as shows the diagram of Figure 2.

[0019]   The ordinate of this diagram is the output voltage VGO (Voltage Generator Output) of an automotive alternator, which also represents the supply to the regulator circuit 1 on the line 5. The controlled signal SENSE is represented

by the battery voltage of the vehicle. It can be understood that, since the average voltage of the controlled signal is of 14.5V and the fast surges of about 15V, the minimum voltage on the supply line 5 may drop to zero volt and below.

[0020]　Heretofore, it has been trying to solve surge situations, as the ones shown in Figure 2, by setting a lower voltage limit, under which the designer of the alternator or, more generally, of the supply line should not go.

[0021]　Alternatively, a regulator circuit of hybrid structure, that is of the type comprising a monolithically integrated portion and a discrete component portion, could be used. This alternative solution allows to solve the surge problem, since the hybrid technology provides for sufficient capacitance values to counterbalance the voltage drops. However, the same structure available in hybrid form is obviously not proposable in a totally integrated form, since the capacitances of the required value can practically not be integrated.

[0022]　Although in many ways advantageous and currently used for several applications, the above-discussed technical solutions tend to be economically disadvantageous, from both standpoints of electric power consumption and technical complexity.

[0023]　The underlying technical problem of this invention is to provide an integrated electronic circuit for regulating a stable reference voltage, which circuit has such structural, functional and consumption features such that it can be realised by a reduced number of components. Moreover, the electronic circuit of the invention should be supplied by one of the voltage signals produced inside the circuit itself, thereby lowering the overall power consumption and improving the stable characteristics of the generated reference voltage signal Vr.

[0024]　A further aim is that of realising an electronic circuit able to follow dynamically the system block, thus operating in a switching mode.

Summary of the Invention

[0025]　The resolution idea on which this invention stands is that of using, as the supply voltage, the controlled signal SENSE produced by the system block itself, and applying such supply voltage to a band-gap regulator which additionally includes comparing and error amplifying means.

[0026]　In other words, the band-gap circuit portion, intended to generate a stable voltage reference from the supply voltage, is to carry out the following functions:

1) generating the reference, that is the "set point" signal Vr;

2) comparing the reference with a normalized controlled signal; and

3) providing an error controller function.

[0027]　Based on this resolution idea, the technical problem is solved by an electronic regulator circuit as previously indicated and defined in the characterizing portions of the appended claims.

[0028]　The invention further relates to a regulating method as defined in Claim 10.

[0029]　The features and advantages of the circuit and the method according to the invention will be apparent from the following description of embodiments thereof, given by way of non-limitative examples with reference to the accompanying drawings.

In the drawings:

Brief Description of the Drawings

[0030]

- Figure 1 shows a schematic block view of an electronic circuit for regulating a stable reference voltage, according to the prior art.

- Figure 2 shows a diagram voltage vs. time schematically showing the pattern of a supply voltage present in the supply line of Figure 1.
  Figure 3 shows a schematic block view of an electronic circuit for regulating a stable reference voltage, according to this invention.

- Figure 4 shows a schematic view of a conventional band-gap generator circuit.

- Figure 5 shows a schematic view of a band-gap generator for use in the electronic circuit of Figure 3, according

to the invention.

- Figure 6 is a diagram of current vs. temperature schematically showing the pattern of the current consumption signal present in the regulator circuit of figure 3 according to this invention.

Figure 7 schematically shows a modified embodiment of the generator of Figure 5.

Detailed Description

[0031] Referring to the drawing views and in particular to the example of Figure 3, an integrated electronic circuit according to the invention, for regulating a stable reference voltage Vr, is generally shown at 10 in schematic form. The circuit 10 may be defined as a switching type band-gap controller.

[0032] The circuit 10 comprises a band-gap generator 11 intended to provide a control voltage Vc to a system block 12. A voltage signal SENSE is picked up at the output OUT of the system block 12 and it is directly transferred to the band-gap generator 11 through a normalizing block 13.

[0033] Advantageously in this invention, the voltage signal SENSE is therefore used to power the band-gap, error amplification and comparison circuit portions which are inserted in the regulating loop of the circuit 10.

[0034] The circuit 10 is useful in automotive applications, and accordingly, would be installed on an automobile vehicle which is also equipped with an alternator associated to propulsion means. The alternator output voltage VGO, although affected by noise, is used in this invention to power less critical areas of the vehicle own electronic circuitry.

[0035] Such areas as digital circuits and power stages show, in fact, a greater consumption.

[0036] Advantageously in this invention, and in order to keep down consumption, the band-gap generator 11 combines the functions of:

- a reference generator;

- an error amplifier; and

- a comparator.

[0037] This is specially advantageous in that the line on which the signal SENSE is present cannot be overloaded with current (<1 mA) lest the regulation effectiveness is impaired by unavoidable voltage drops to resistances along the connection.

[0038] In the example of Figure 4, the circuit layout of a conventional band-gap generator is schematically shown. This layout is modified in this invention to incorporate the aforementioned functions.

[0039] The circuit of Figure 4 includes an operational amplifier OP1 effective to regulate the voltage of a node A so that the potentials of the nodes B and B' can be made to coincide. Since the nodes B and B' are connected to the node A through resistors R1 with the same value, and are coupled to ground through respective transistors Q1 and Q2 diode-connected in the generator, the same current Io will be flowing through the respective circuit legs containing such transistors.

[0040] Thus, said transistors Q1, Q2 are forced to operate on the same current value Io, and with the transistor Q2 being selected larger (at least ten times larger) in area than the transistor Q1, a voltage "∆Vbe" would drop across the resistor Ro interconnecting the resistor R1 and transistor Q2 which is given by:

$$\Delta Vbe = VT * \ln (areaQ2/areaQ1) \qquad (1)$$

where, VT is the thermal voltage.

[0041] The value of the reference voltage Vr output from the generator of Figure 4 is given by equation (2) below.

$$Vr = Vbe(Q1) + \Delta Vbe * R1/R0 \qquad (2)$$

[0042] The value of the controlled voltage,- designated Vs, presented on the SENSE line can be obtained from equation (3) below on account of the regulating loop.

$$Vs = K * Vr = K * (Vbe(Q1) + \Delta Vbe * R1/R2) \qquad (3)$$

[0043] Now, the generator 11 incorporated to the circuit 10 of this invention (Figure 3) has been modified from the just described basic structure, and the outcome of this modification is shown in Figure 5.

[0044] The circuit of this invention, shown in Figure 5, allows equation 3 to be applied directly to the signal Vs from the band-gap reference generator of Figure 4.

[0045] As can be appreciated from the diagram of Figure 5, the band-gap generator 11 of this invention is powered from the line SENSE directly picked up from the output OUT of the system block 12 (Figure 3). In a possible alternative embodiment even the block 13 may be considered incorporated inside the new block 11, as will be clarified in the following lines.

[0046] The generator 11 comprises a first circuit leg connecting the SENSE line to ground and including a complementary pair of bipolar transistors, namely a pnp transistor Q7 connected to an npn transistor Q4 at a node C.

[0047] A second circuit leg connects the SENSE line to ground and includes a complementary pair of bipolar transistors, namely a pnp transistor Q6 connected to an npn transistor Q3.

[0048] The bases of the transistors Q7, Q6 are connected together. Also, the transistor Q6 is a diode configuration so as to form a current mirror in combination with the transistor Q7. Thus, a current Io will flow through each of said legs.

[0049] In essence, the first and second circuit legs form an external current mirror, as against the internal current mirror of the band-gap generator of Figure 4, in place of the error amplifier provided by the prior art.

[0050] A third circuit leg connects the SENSE line to ground, but branches off into additional legs as described herein below.

[0051] A first connection of the third leg includes a resistive divider 15 connecting a node S, that is the SENSE line, to ground through a resistor pair connected to a node R from which the signal Vr is picked up.

[0052] A second connection of the third leg includes an npn bipolar transistor Q5 which is connected in series with a resistor R2. The base of the transistor Q5 is connected to said node R of the divider 15. The transistor Q5 and the divider 15 implement the block 13 in Figure 3.

[0053] The unconnected end of the resistor R2 to the transistor Q5 provides a node A whence the following branch off:

a connection including a resistor R1 and an npn bipolar transistor Q1;

a connection including a series of two resistors R1 and R0 and an npn bipolar transistor Q2.

[0054] The transistor Q1 is a diode configuration and has its base interconnected with the base of the transistor Q4 of the first circuit leg. This interconnection represents a circuit node B.

[0055] The diode-configured transistor Q2 has its base coinciding with a circuit node B'. The base of the transistor Q3 in the second circuit leg is connected to the inteconnection node between the resistors R1 and R0.

[0056] The node A is accessible to receive a current ramp Ipwr.

[0057] The node C of the first circuit leg is connected to ground through a Zener diode Dz1 and connected to the gate terminal of an N-channel field-effect transistor MDR to drive a circuit portion 16 which is associated with a vehicle alternator being a part of the system block 12.

[0058] A power transistor, e.g. an N-channel MOS transistor MPWR, has one conduction terminal coupled to an alternator coil through a resistor RF, and has the other conduction terminal connected to ground.

[0059] Placed in parallel to the series of the coil and the resistor RF is a loop-back diode Dr connecting a node F to a line supplying a signal VGO.

[0060] A resistive divider is placed between this supply line VGO and the ground, which divider is made of at least two resistors Rd1, Rd2 and is coupled to the supply line VGO and to the ground through respective diodes. More particularly, a diode Dd is inserted between the supply line VGO and the divider, while a Zener diode Dz2 is inserted between ground and the divider.

[0061] One conduction terminal of the drive transistor MDR of the circuit portion 16 is connected to the interconnection node D between the divider resistors Rd1, Rd2, while the other conduction terminal of the transistor MDR is connected to ground.

[0062] The features of the generator according to the invention will now be reviewed in further detail.

[0063] Compared with the circuit layout of a conventional band-gap generator, such as that shown in Figure 4, the generator 11 has the transistor pair Q3, Q4 in place of the error amplifier OP1 of Figure 4. In essence, it is as if the band-gap generator 11, as a whole, were also having an error amplifier function.

[0064] In addition, the transistor Q5, selected with twice the area than the transistor Q1 to set the desired regulation voltage at the SENSE node, takes the place of the voltage "normalizer" block according to the prior art.

[0065] The current mirror, or similar, formed from the transistors Q6 and Q7 to create the comparison function (node C), instead of the prior art comparator shown in Figure 1A;

[0066] Application to the node A of a current ramp, operating at a low voltage ($\cong$1V), allows a possible PWM regulation which is effected with a voltage ramp in conventional PWM modulators. It will be shown herein below that the "relay"

operation of the structure is made possible by removing the current ramp (Ipwm=0)).

[0067] The regulating method implemented by the generator 11 and the regulator 10 of this invention will now be reviewed.

[0068] In relay operation, or whenever the current ramp Ipwm is nil, the voltage Vs is:

$$Vs/K = Vbe(Q1)+R1/R0*\Delta Vbe+2*R2*\Delta Vbe/R0+Vbe(Q5) \tag{4}$$

[0069] The two voltage drops Vbe taken into account by the equation are related to the same current since the transistor Q5, being required to carry a double current than the transistor Q1, has been selected in its turn with a double area. In this way, equation (4) essentially represents the sum of two "band-gap" equations and is, therefore, fully controllable.

[0070] The ramp current Ipwm should be generated by a generator of a constant voltage Vpwm which may be very small (<0.5V) as indicated by the following equations. The fundamental condition is that its average value be nil. Calling IpwmM the highest value attained by the ramp current, the variations of Vs at the extremities of the duty-cycle value of the control signal, at the node C, are given by:

$$(Vs\pm\Delta Vs)/K=Vbe(Q1)+R1R0*\Delta Vbe+2*R2*\Delta Vbe/R0*(1\pm R2*IpwmM) \tag{5}$$

so that PWM gain becomes:

$$\Delta Vs = K*R2*IpwmM \tag{6}$$

[0071] Equation 6 is wholly independent of the value of slope vs. temperature assigned to Vs. This is another advantage over the prior art structure of Figure 1. Regulators for use with alternators usually require that dVs/dT be other than zero and negative. In the conventional regulator of Figure 1, this is obtained by assigning an adequate slope vs. temperature to the reference voltage signal Vr. In the PWM regulator, this compels the average value of the voltage ramp to be also made to depend on temperature and according to the same rule, in order not to miss the modulation gain.

[0072] The connection of the novel circuit to the SENSE line poses no problems because of the load level from the circuit being quite small. Referring to Figure 6, current consumption by the SENSE line is:

$$Is = (Idiv + 4*Io) \tag{7}$$

[0073] Current Idiv is impossible to suppress, same as in the state of the art of Figure 1, but can be fully controlled by acting on the values of the resistances in the normalizer K.

[0074] The additional current required for the circuit of Figure 5 to operate, is four times larger than the current Io set by the area ratio of the transistors Q1 and Q2, and the resistance value of the resistor R0. With BCD technology, putting the area of the transistor Q2 at ten times the area of the transistor Q1 of the P-body type, and putting R0 at least equal to 6000 Ohms, of the P-body type, the current $4*Io$ becomes like that shown in the experimental graph of Figure 6.

[0075] It can be seen that this current does not exceed the value 41E-6 A throughout the temperature range. Therefore, the value of current consumption by the SENSE line is well contained within the limit of 1E-3 A.

[0076] It can be appreciated from the foregoing description that the regulator circuit of this invention has the following advantages over the prior art shown in Figure 1:

1) The regulating loop is greatly simplified by the loop combining the following primary functions:

1.a the reference generator (Q1,Q2,R0,R1,R2);

1.b the error amplifier for the loop (the whole circuit);

1.c conditioning the voltage to be regulated (divider K and Q5);

1.d the comparator for switching regulation (Q4,Q7).

2) The structure of the generator 11 considerably simplifies the provision of the following secondary functions:

2a. very low consumption that allows using the SENSE line as the supply line (4∗Io);

2.b simplified PWM modulation control by using a current rather than a voltage ramp, which can be thus generated at a low voltage (R2,Ipwm);

2.c the control at dVs/dT (Vs slope versus temperature) other than zero requiring, unlike the circuit of Figure 1, no shifting of the voltage ramp as temperature varies;

2.d the whole circuit can also operate at very low SENSE voltages, typically of 1.2V.

[0077]   Modifications and changes can be made unto the regulator circuit of this invention within the scope of the invention as defined in the appended claims.

[0078]   For example, the generator circuit structure could be obtained using MOS instead of bipolar transistors.

[0079]   Also, in regulators which operates in the linear mode, the layout of the generator 11 can be easily adapted by inserting an npn bipolar transistor Q9 in between the SENSE line and the collector of Q5, node S. The base of the transistor Q9 would be connected in a connection node C between the transistors Q6 and Q3 of the second circuit leg and coupled to ground through a capacitor for the dynamic stabilisation.

[0080]   The node S would become the regulated output of the generator circuit in the linear mode, as schematically shown in Figure 7.

[0081]   So, the general inventive concept of the present invention is to supply all the block 11, 6, 4 and 3 of the prior art by the output signal on the output node S. In this respect, the reference voltage produced by the Band-Gap block 11 may be obtained through another kind of voltage regulator, for instance a voltage reference obtained by a zener diode.

[0082]   The electronic circuit according to the present invention is capable of directly controlling the system block 12. The control phase is advantageously performed in a switching mode, the linear mode being also available as an option.

[0083]   The circuit block 11 doesn't require an external supply voltage since it is supplied by the signal SENSE that is the output of the system block. This block 11 provides the output voltage Vc for controlling the system block 12.

[0084]   Thus, the electronic circuit of the invention allows a switching control of the system block 12 since it works in a switching mode even inside. As a matter of fact the current and voltages inside the inventive circuit are variable in time and not only with temperature.

Claims

1.   An integrated self-powered and switching electronic circuit (10) for regulating a stable reference voltage (Vr) and comprising:

   -   a voltage generator and regulator (11) to produce said stable reference voltage (Vr) for a system circuit block (2,12);

   -   a comparator and an error amplifier between said voltage generator and regulator and said system block;

   -   a regulating loop between the output of the system block and the input of the voltage generator and regulator;

   -   wherein said voltage generator and regulator (11) incorporates said comparator and said error amplifier and is directly supplied by a signal (SENSE) produced by the output of the system block .
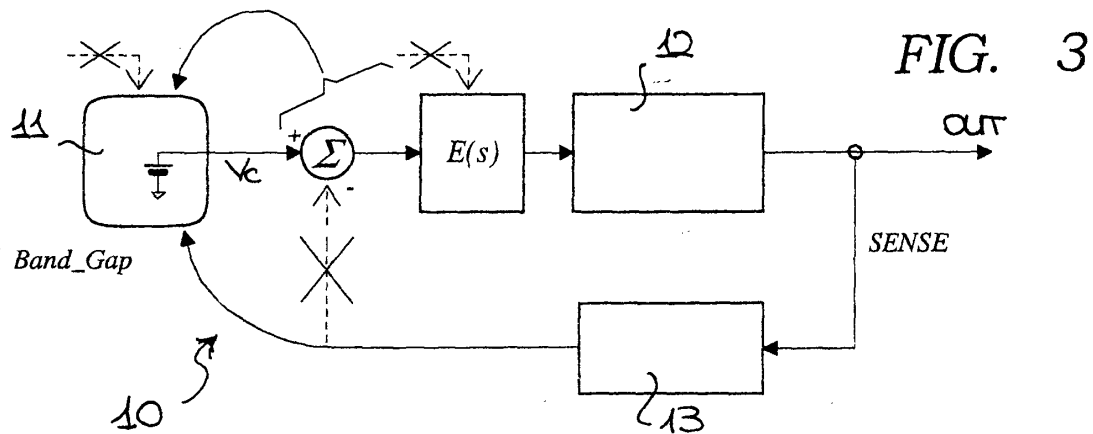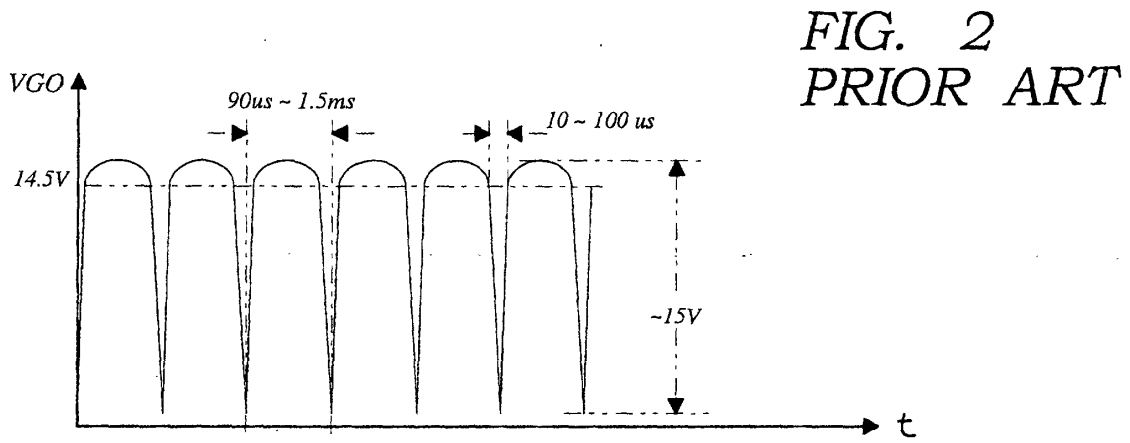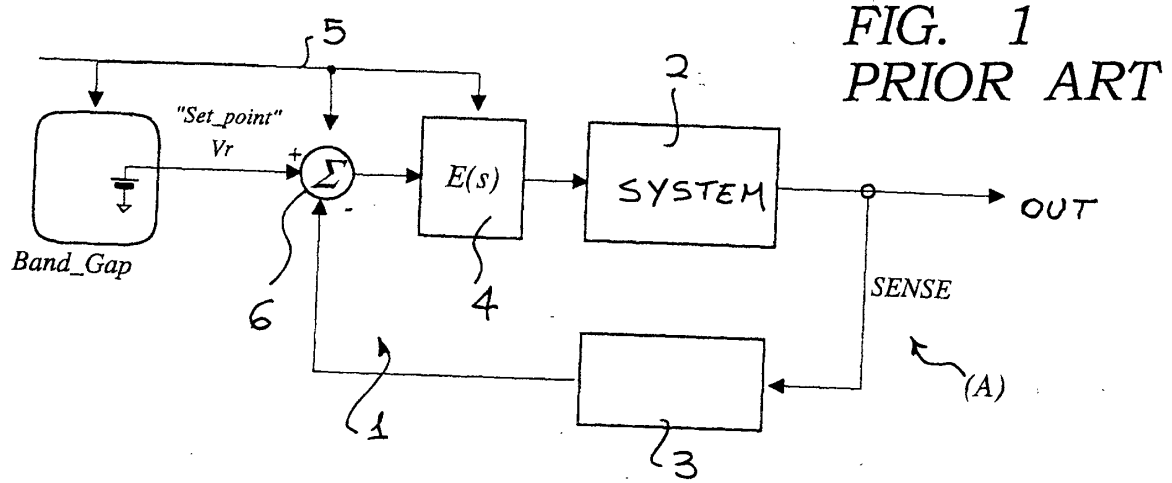
2.   A circuit according to Claim 1, wherein a normalizer block (3, 13) is inserted on the regulating loop and incorporated in said voltage generatore and regulator.

3.   A circuit according to Claim 1, wherein said voltage generator and regulator (11) comprises first and second current mirror circuit legs independently connecting a regulated voltage (Vs) supply line to ground and including an output node (C) for controlling the system circuit block (12).

4.   A circuit according to Claim 2, wherein said current mirror is outside of an internal current mirror of the generator (11) incorporating respective circuit nodes (B,B') at coinciding potentials, and that each of said legs is coupled to

a corresponding node (B,B').

5. A circuit according to Claim 1, wherein said generator (11) comprises a pair of transistors (Q1,Q2) being in a diode configuration and coupled to a common node (A) through respective resistors (R1), said node (A) being supplied by said regulated voltage (Vs) through a connection which incorporates a series of a transistor (Q5) and a resistor.

6. A circuit according to Claim 5, wherein said transistor (Q5) in said connection has twice the area of one (Q1) of said diode-configured transistors (Q1,Q2).

7. A circuit according to Claim 5, wherein said transistor (Q5) in said connection has its control terminal connected to an interconnection node (R) of a resistive divider inserted between the supply and ground.

8. A circuit according to Claim 1, wherein, for linear mode applications, a transistor (Q9) is inserted between the supply (Vs) and said connection which has a control terminal connected to one of said circuit legs and a conduction terminal connected to a node (S) forming the regulated output of the generator.

9. A circuit according to Claim 5, wherein said node (A) receives a current ramp signal (Ipwm) for PWM modulating the generator.

10. A circuit according to Claim 9, wherein said ramp is produced by a low-voltage generator.

11. A method for regulating a stable reference voltage (Vr) to be supplied to a system block (2,12) by means of a voltage generator and regulator producing said stable reference voltage (Vr), wherein said voltage generator and regulator (10) incorporates the functions of a comparator and an error amplifier and is directly supplied by a signal (SENSE) produced by the output of said system block.
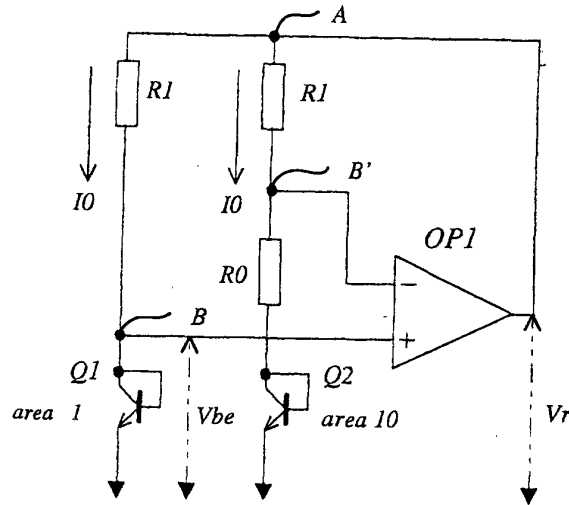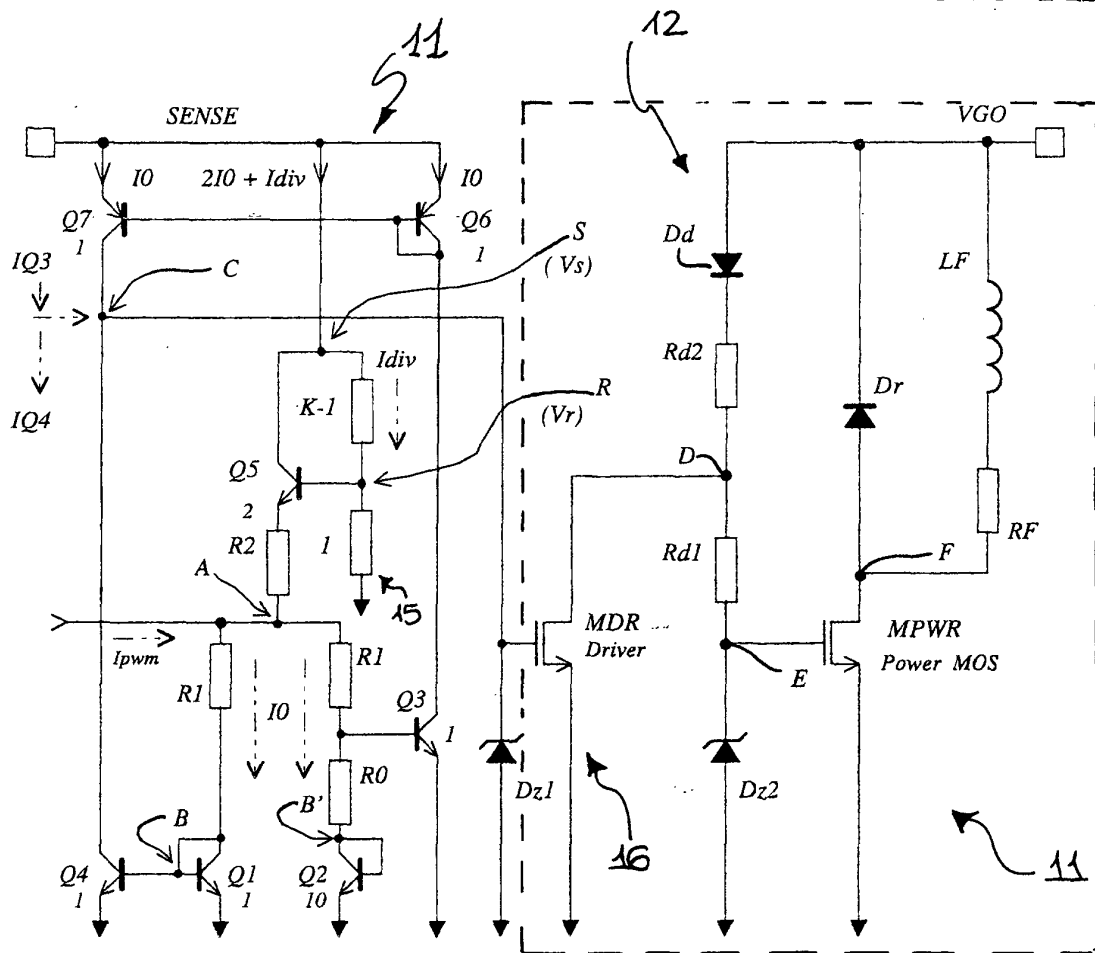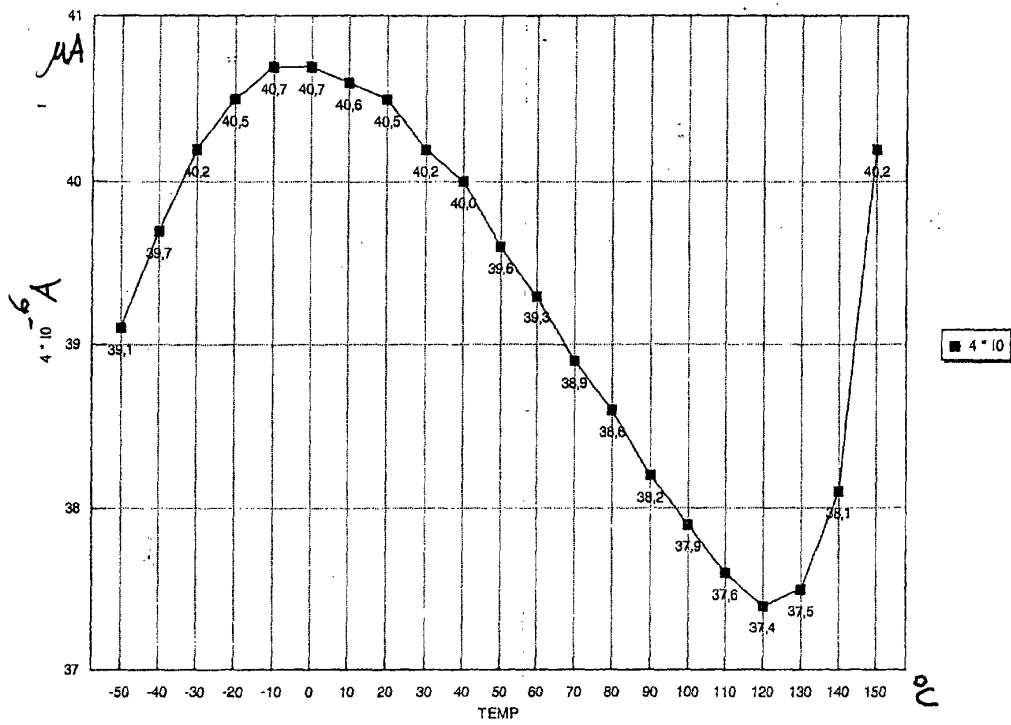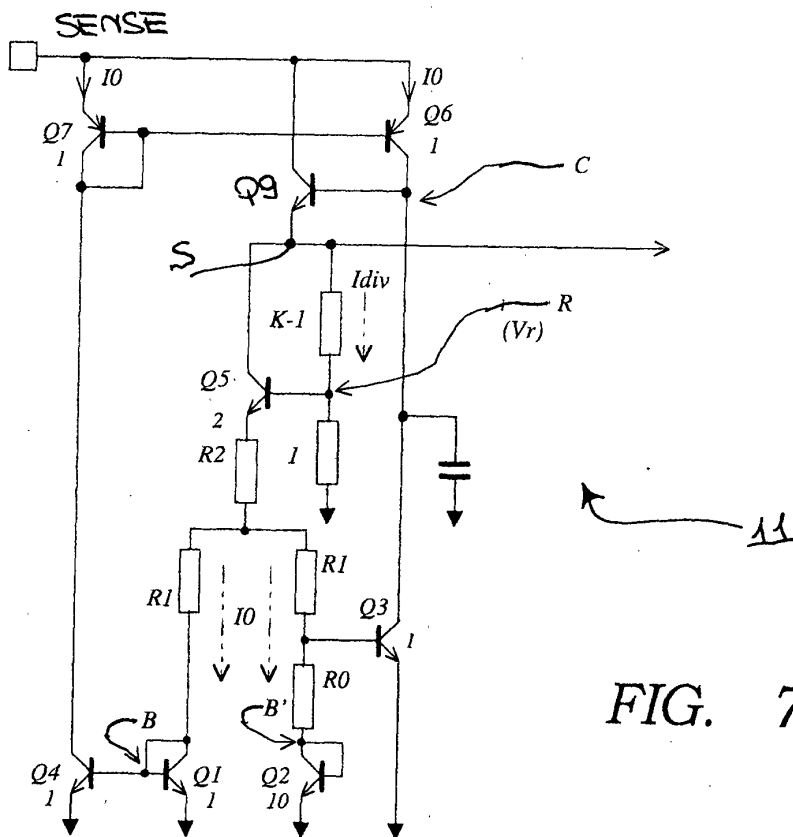
FIG. 1
PRIOR ART

FIG. 2
PRIOR ART

FIG. 3

FIG. 4
PRIOR ART

FIG. 5

FIG. 6

FIG. 7