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(54) **INTEGRATED CIRCUIT AND SEMICONDUCTOR MODULE**

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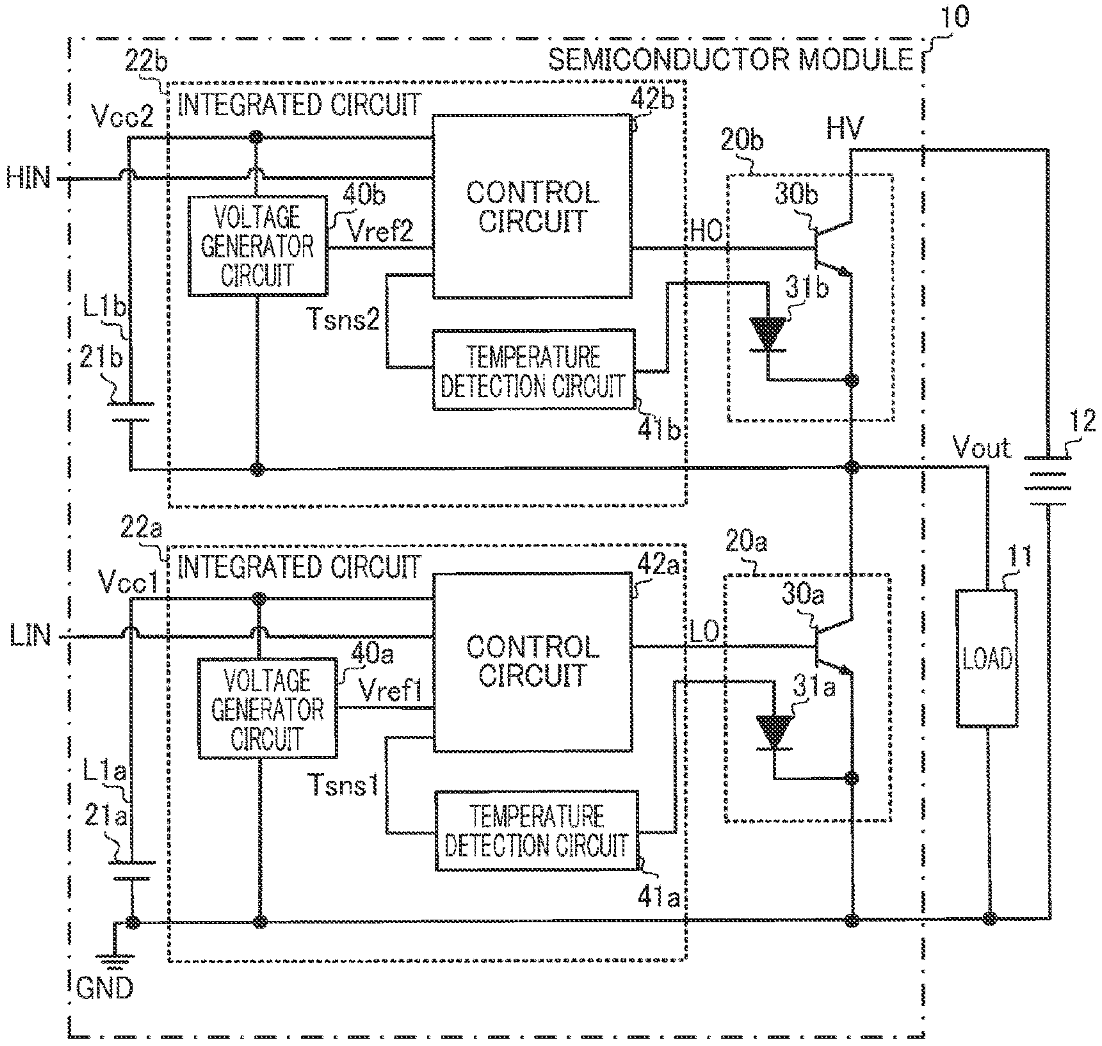
CPC *G05F 1/59* (2013.01)

(57) **ABSTRACT**

An integrated circuit includes: a power supply line configured to receive a power supply voltage; a constant current source electrically coupled to the power supply line;

a reference voltage circuit electrically coupled to the constant current source; and a first resistor having two ends, one end thereof being electrically coupled to the constant current source, and the other end thereof being electrically coupled to the reference voltage circuit. The reference voltage circuit is a bandgap circuit including a plurality pf bipolar devices. The first resistor is configured to decrease a leakage current in the bipolar devices when a temperature thereof rises.



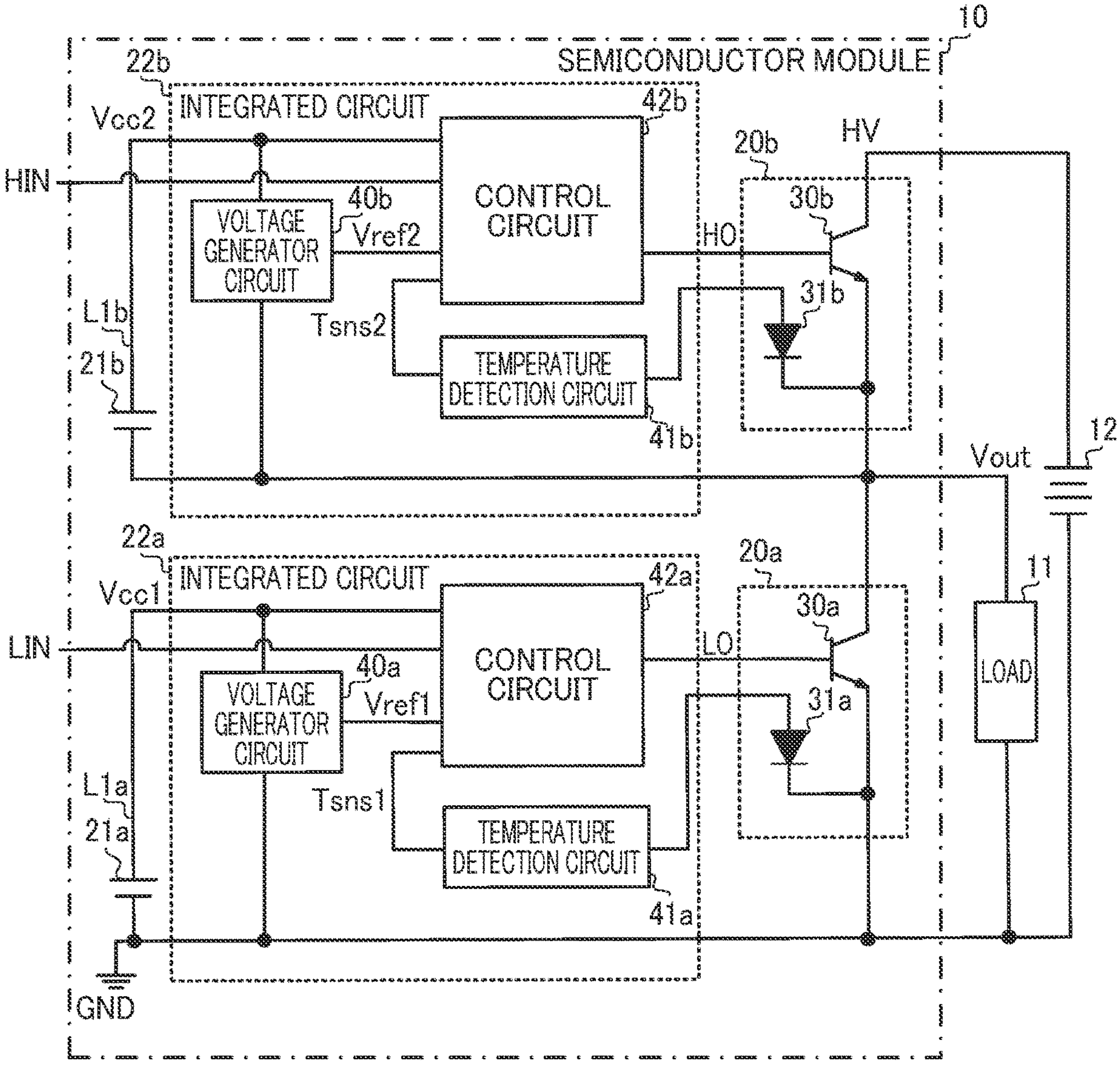

10
SEMICONDUCTOR MODULE
22b
INTEGRATED CIRCUIT
42b
Vcc2
HIN
VOLTAGE GENERATOR CIRCUIT
40b
Vref2
CONTROL CIRCUIT
HO
20b
HV
30b
31b
Tsns2
TEMPERATURE DETECTION CIRCUIT
41b
L1b
21b
Vout
12
22a
INTEGRATED CIRCUIT
42a
Vcc1
LIN
VOLTAGE GENERATOR CIRCUIT
40a
Vref1
CONTROL CIRCUIT
LO
20a
30a
31a
Tsns1
TEMPERATURE DETECTION CIRCUIT
41a
L1a
21a
11
LOAD
GND

FIG. 1

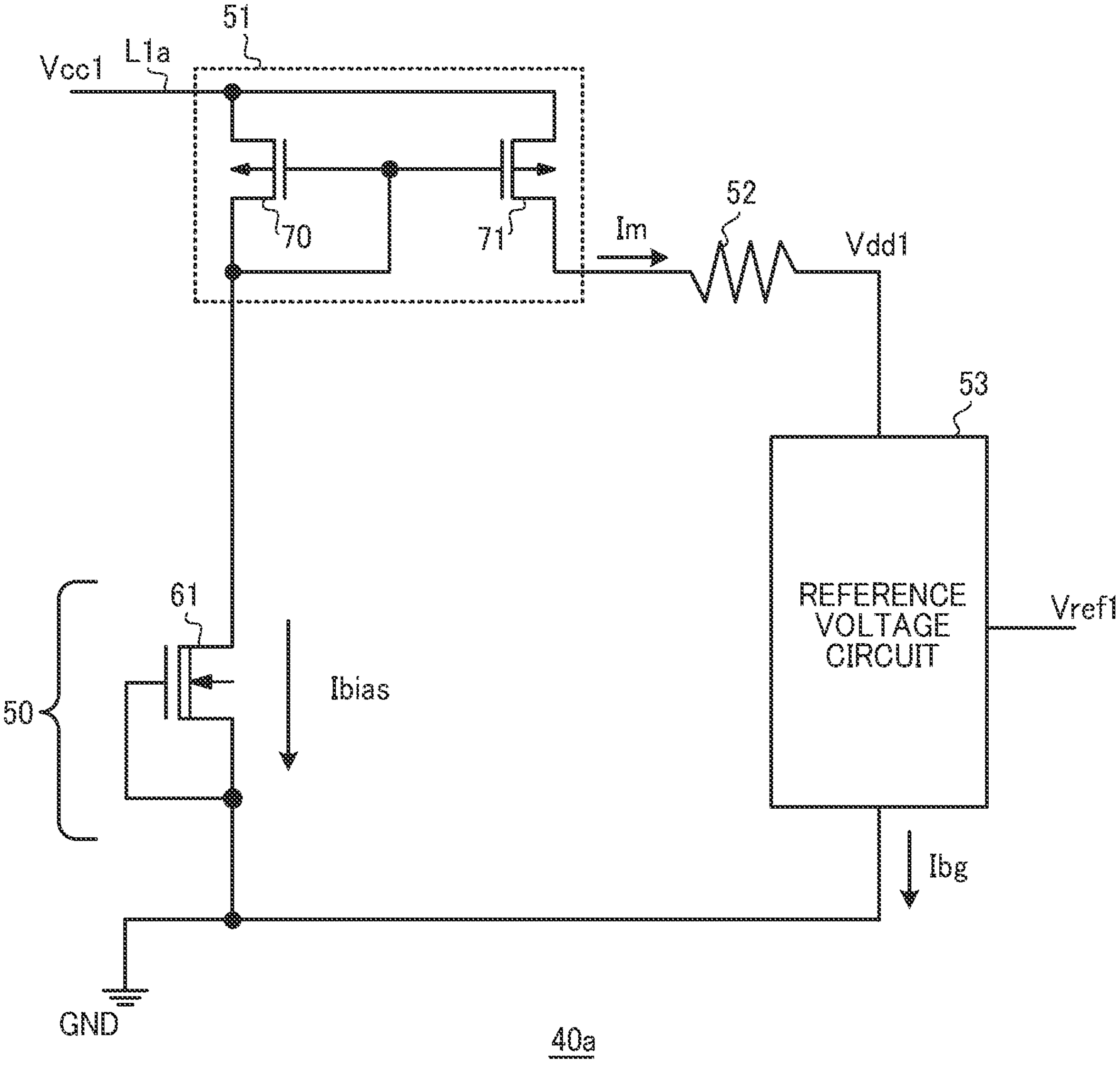

51
Vcc1
L1a
70
71
Im
52
Vdd1
53
REFERENCE VOLTAGE CIRCUIT
Vref1
61
50
Ibias
Ibg
GND
40a

FIG. 2

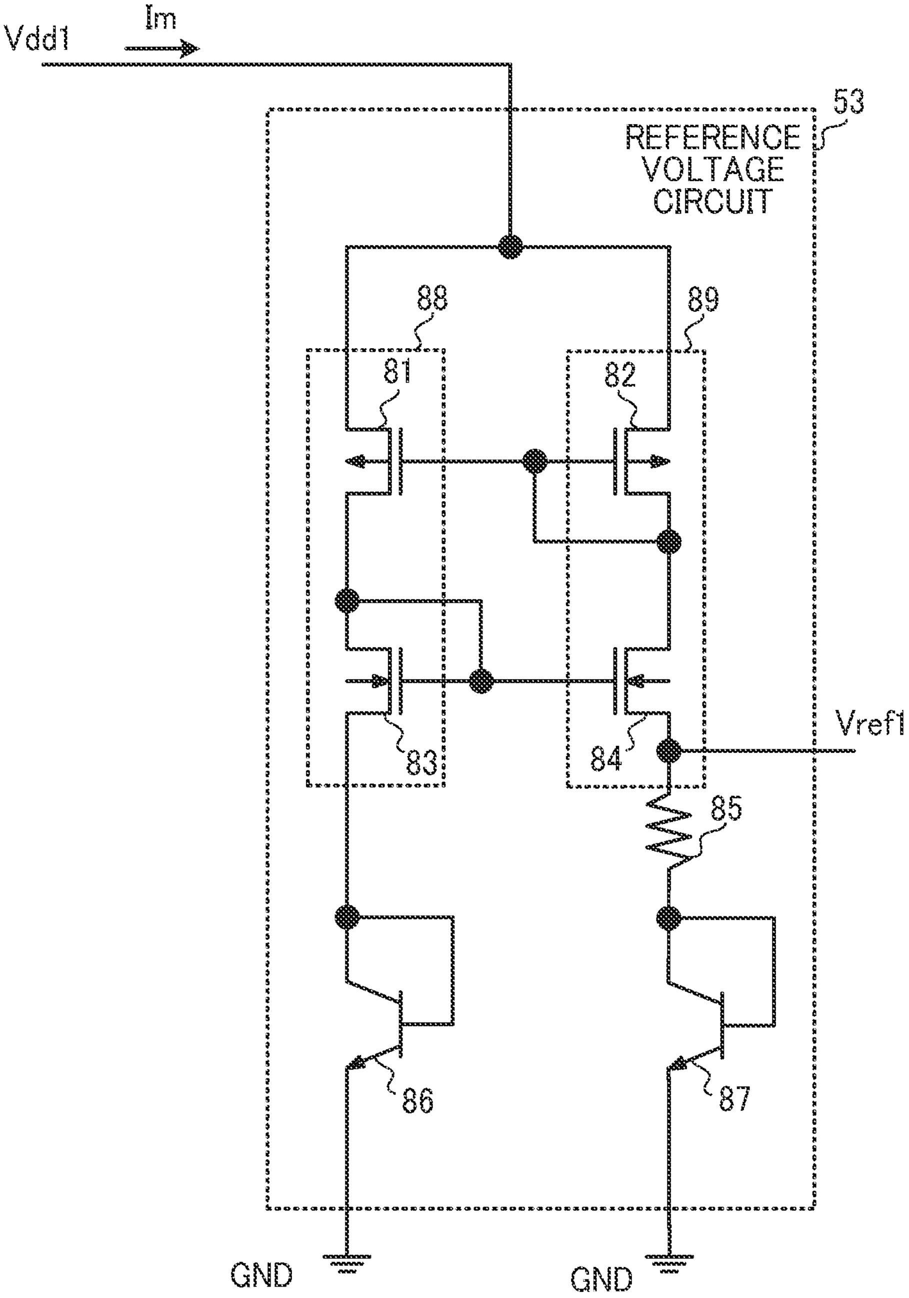

Vdd1
Im
53
REFERENCE VOLTAGE CIRCUIT
88
89
81
82
83
84
Vref1
85
86
87
GND
GND

FIG. 3

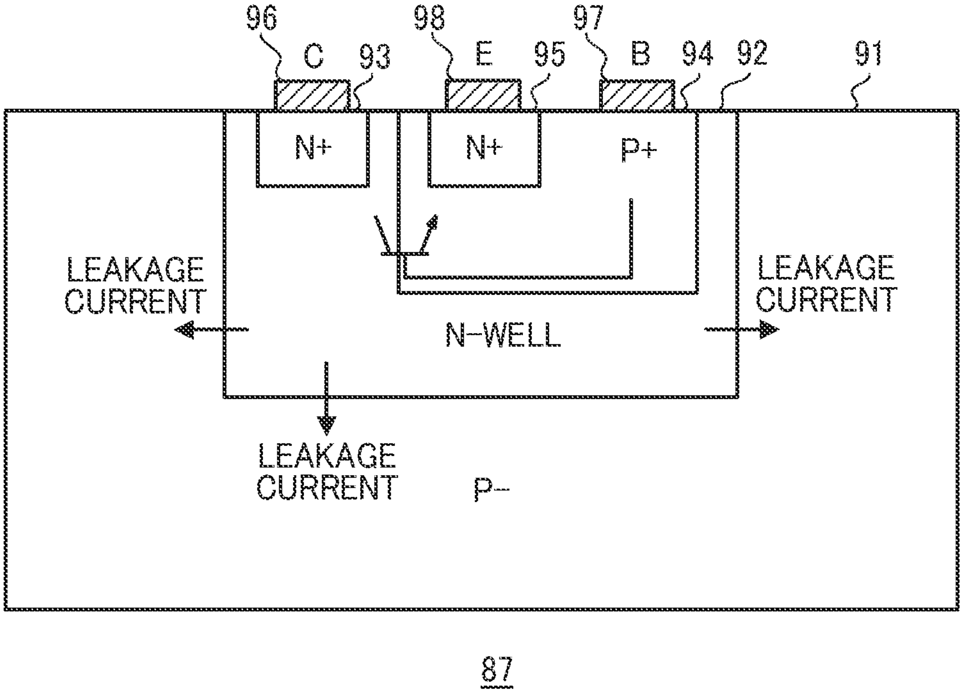

96
C
93
98
E
95
97
B
94
92
91
N+
N+
P+
LEAKAGE CURRENT
LEAKAGE CURRENT
N-WELL
LEAKAGE CURRENT
P-
87

FIG. 4

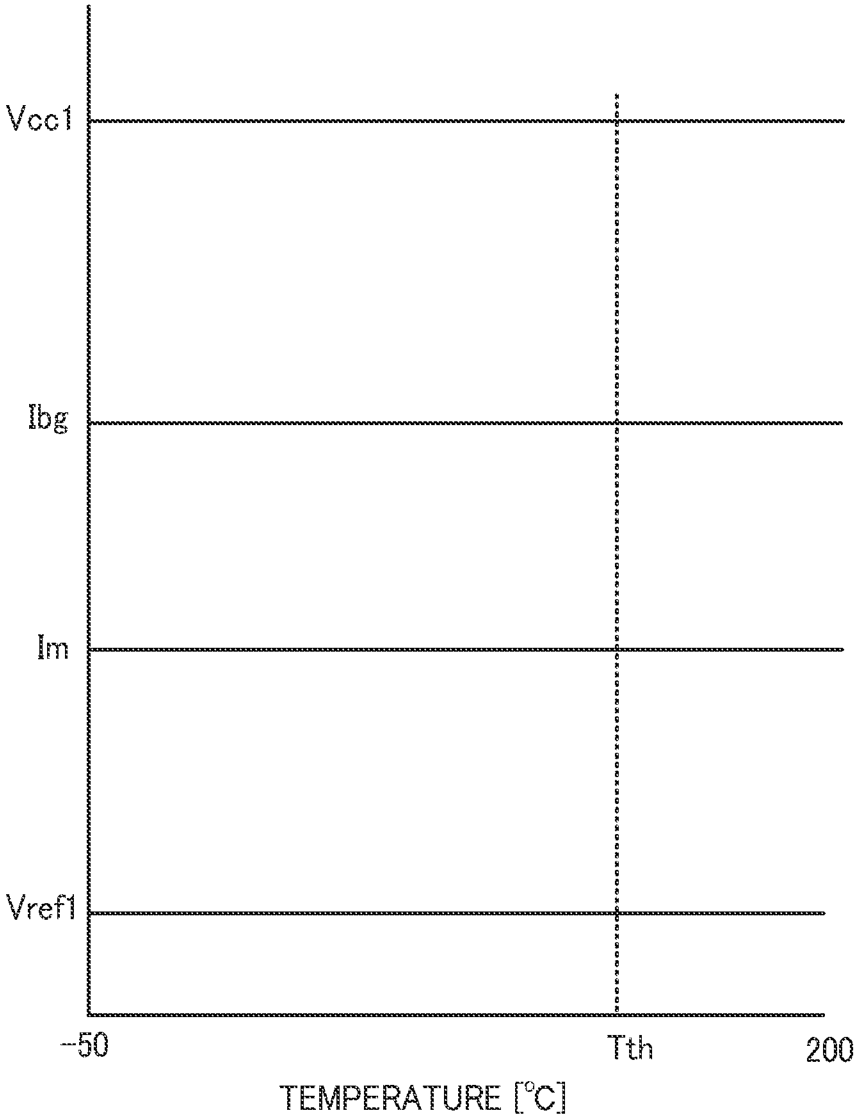


FIG. 5

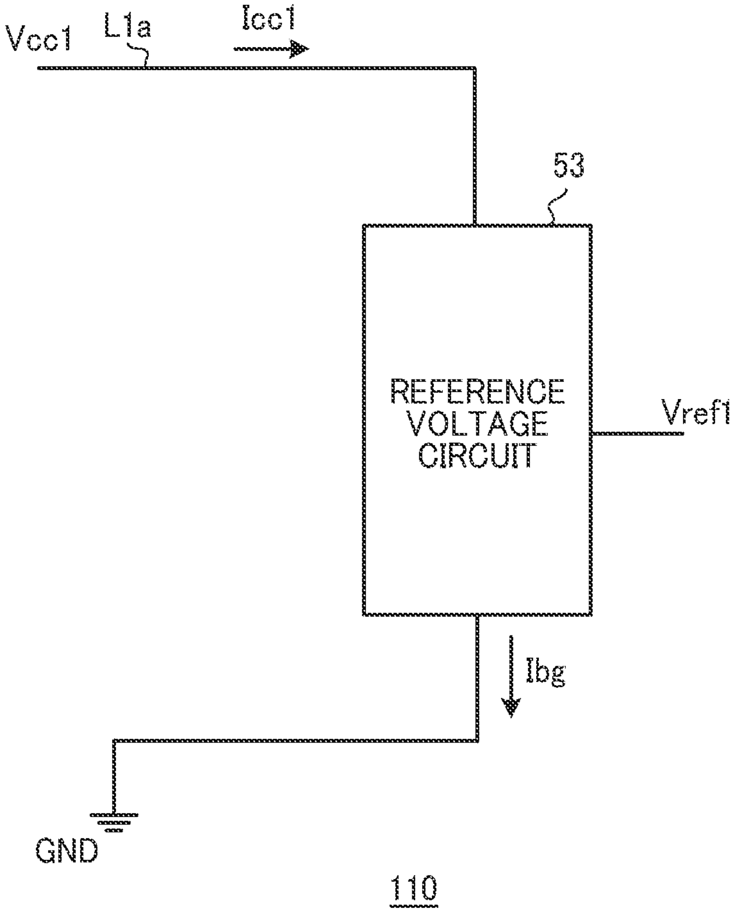

Vcc1
L1a
Icc1
53
REFERENCE VOLTAGE CIRCUIT
Vref1
Ibg
GND
110

FIG. 6

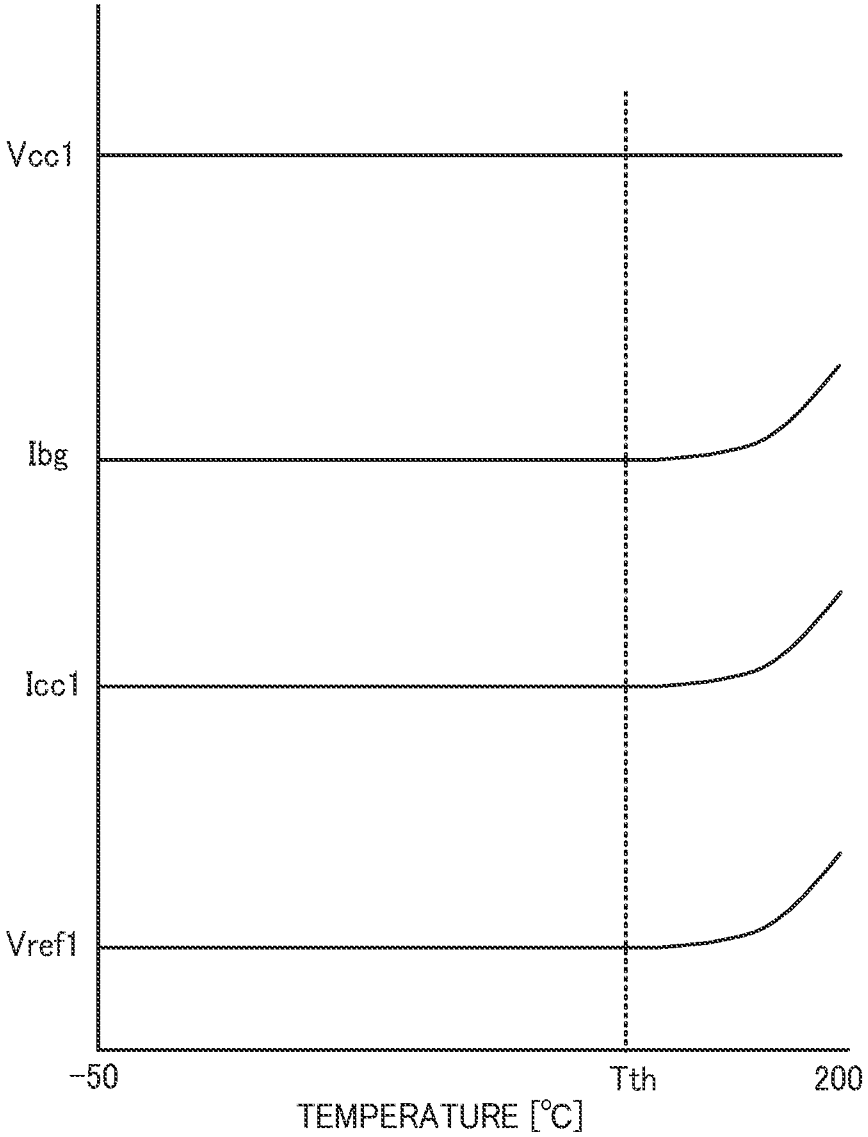


FIG. 7

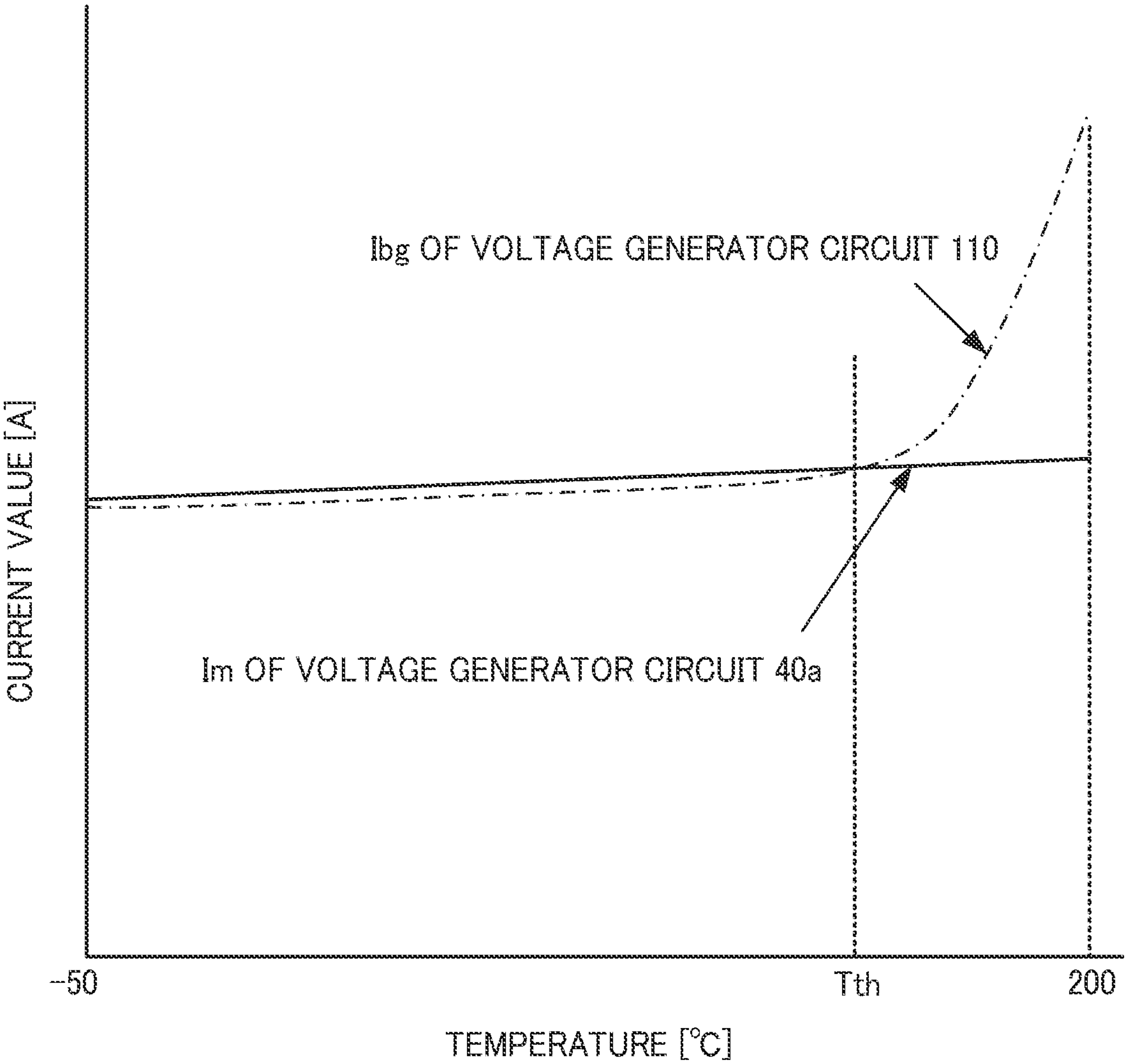

Ibg OF VOLTAGE GENERATOR CIRCUIT 110
Im OF VOLTAGE GENERATOR CIRCUIT 40a
CURRENT VALUE [A]
−50
Tth
200
TEMPERATURE [°C]

FIG. 8

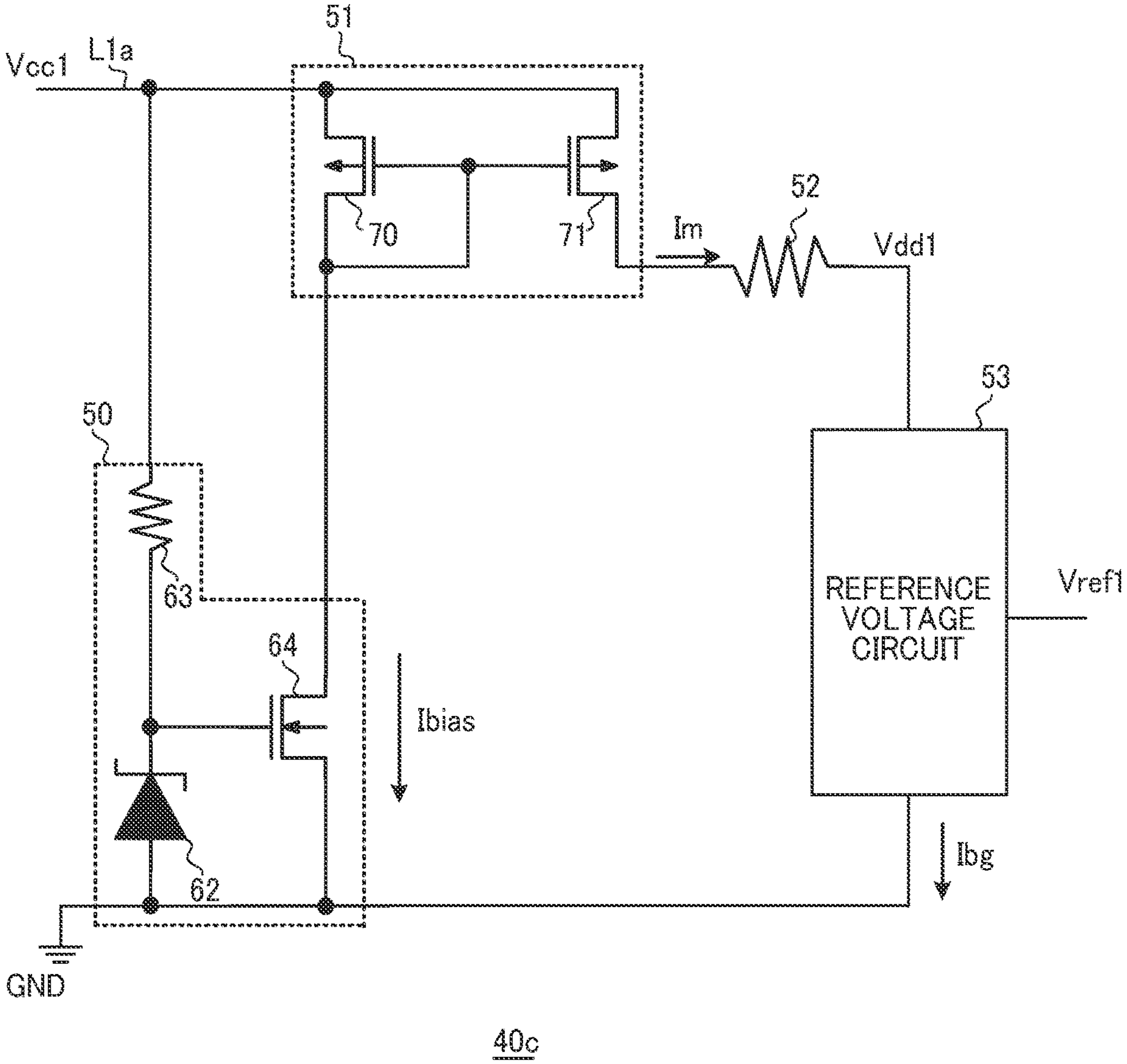

51
Vcc1
L1a
70
71
Im
52
Vdd1
53
50
63
64
Ibias
REFERENCE VOLTAGE CIRCUIT
Vref1
Ibg
62
GND
40c

FIG. 9A

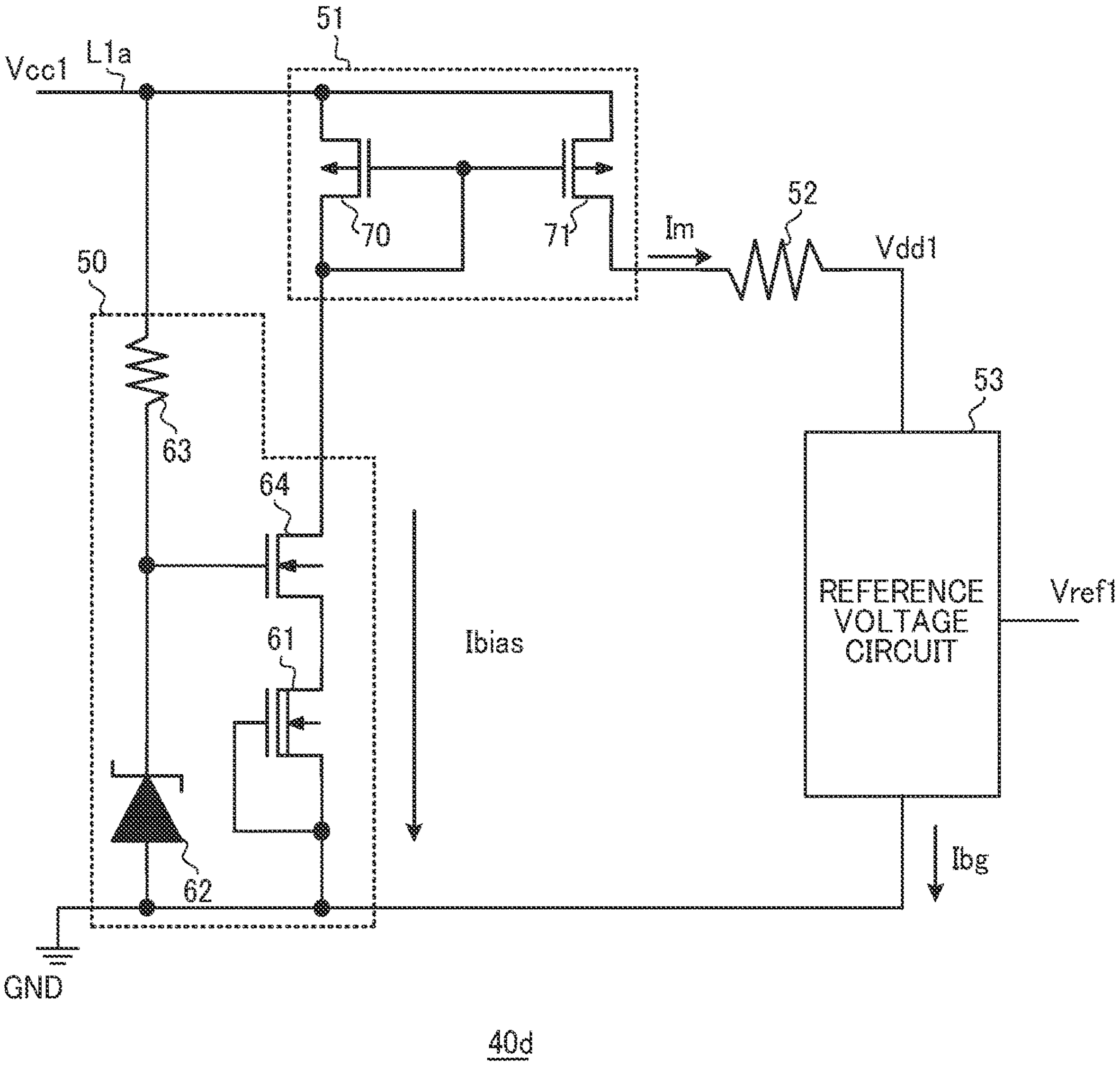

51
Vcc1
L1a
70
71
Im
52
Vdd1
50
63
64
53
REFERENCE VOLTAGE CIRCUIT
Vref1
Ibias
61
62
Ibg
GND
40d

FIG. 9B

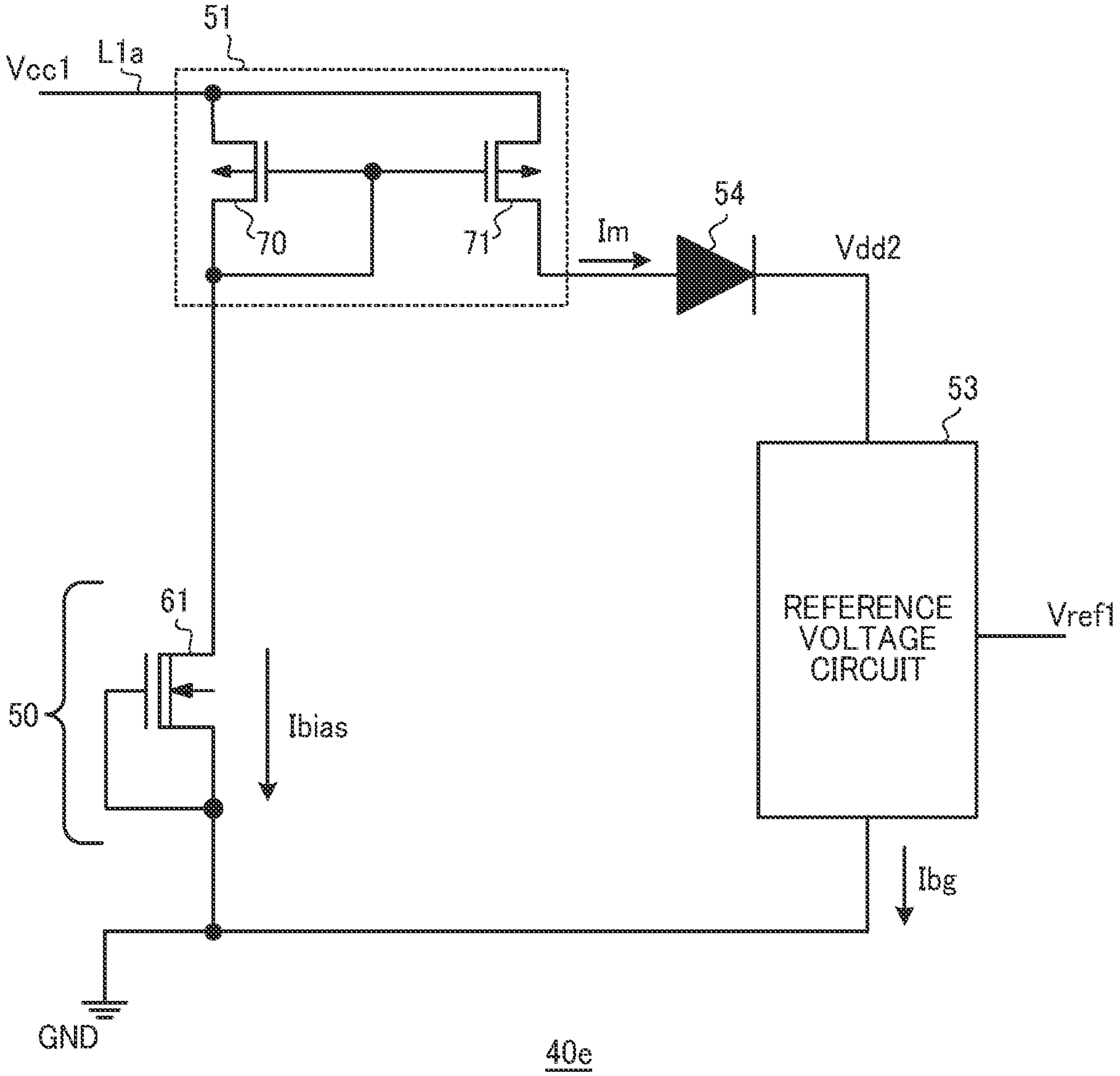

51
Vcc1
L1a
70
71
Im
54
Vdd2
53
REFERENCE VOLTAGE CIRCUIT
Vref1
61
50
Ibias
Ibg
GND
40e

FIG. 10A

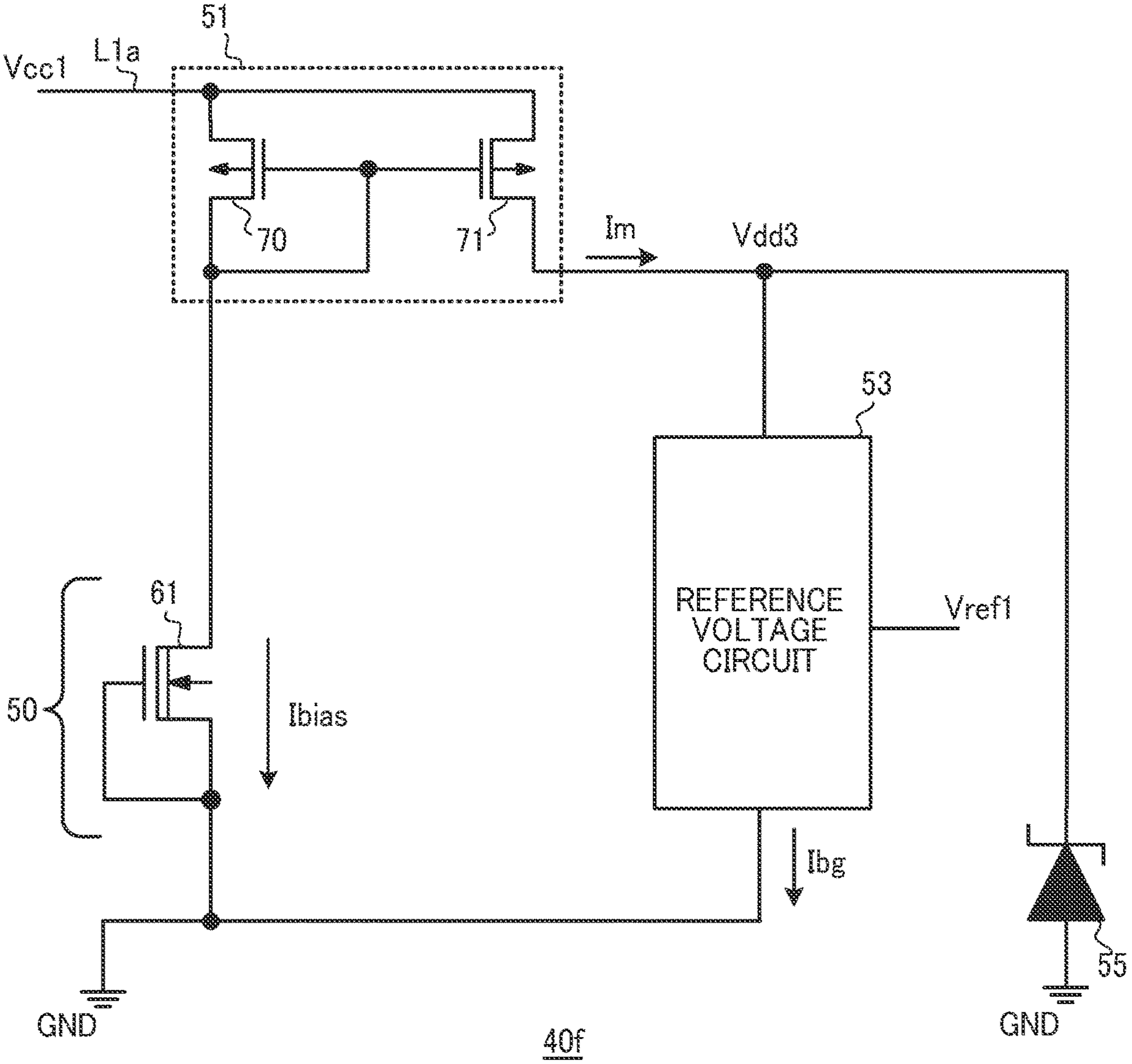

51
Vcc1
L1a
70
71
Im
Vdd3
53
REFERENCE VOLTAGE CIRCUIT
Vref1
61
50
Ibias
Ibg
55
GND
GND
40f

FIG. 10B

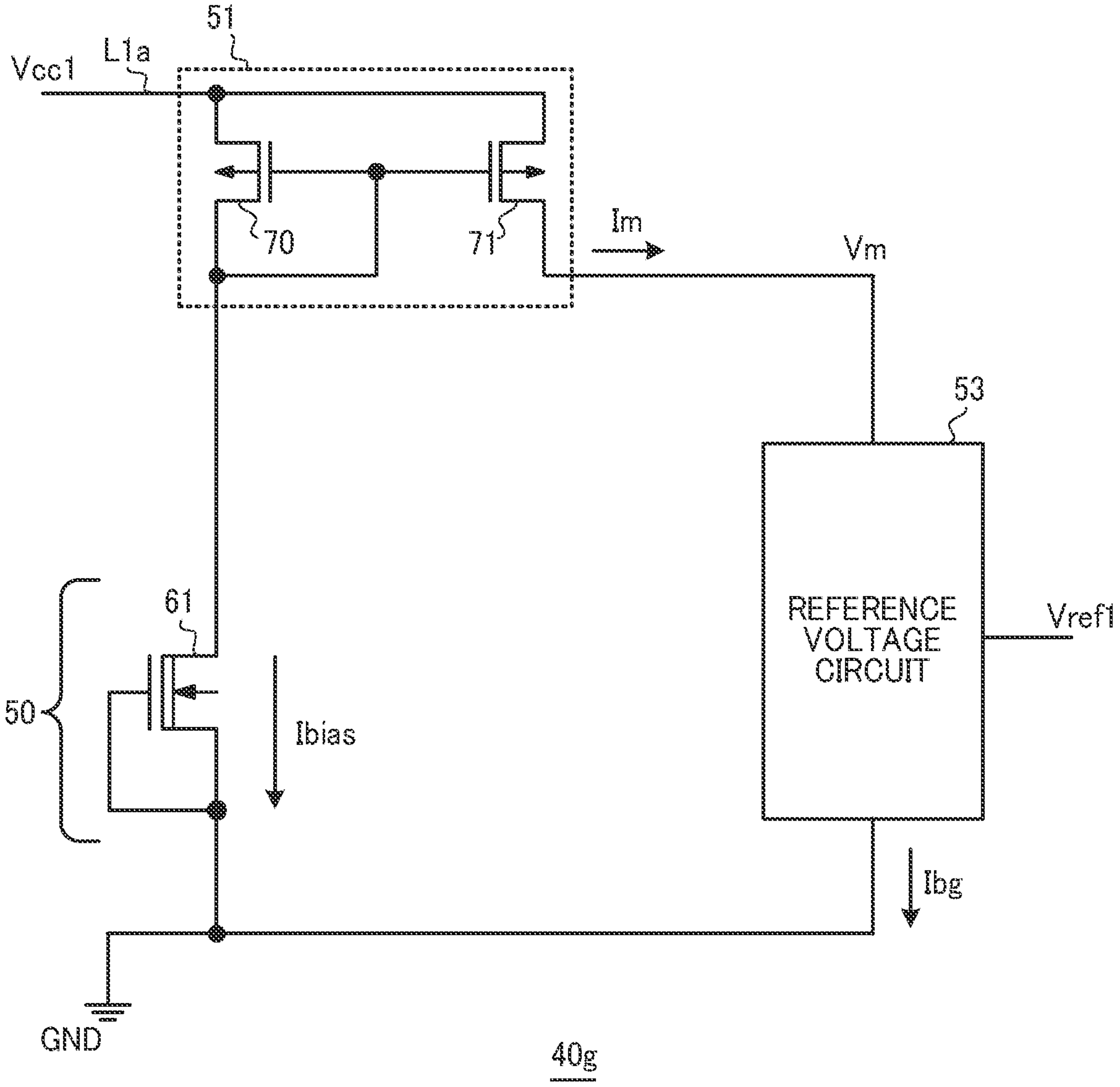

51
Vcc1
L1a
70
71
Im
Vm
53
REFERENCE VOLTAGE CIRCUIT
Vref1
61
50
Ibias
Ibg
GND
40g

FIG. 10C

INTEGRATED CIRCUIT AND SEMICONDUCTOR MODULE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This is a continuation application of International Patent Application No. PCT/JP2022/016144 filed Mar. 30, 2022, which claims the benefit of priority to Japanese Patent Application No.2021-082486 filed May 14, 2021, the entire contents of each of which the entire contents of each of which are incorporated herein by reference.

BACKGROUND

Technical Field

[0002] The present disclosure relates to an integrated circuit and a semiconductor module.

Description of the Related Art

[0003] Reference voltage circuits utilizing bandgap voltage of semiconductor are known (see, for example, Japanese Patent Application Publication No.2005-202704).

[0004] In bandgap reference voltage circuits including bipolar transistors, when the temperature of such a bipolar transistor rises, leakage current may be generated between an N-well region covering a collector terminal and a substrate. Accordingly, the current outputted from the substrate of such a reference voltage circuit may increase, and the voltage outputted from the reference voltage circuit may also rise.

SUMMARY

[0005] A first aspect of an embodiment of the present disclosure is to provide an integrated circuit comprising: a power supply line configured to receive a power supply voltage; a constant current source electrically coupled to the power supply line; a reference voltage circuit electrically coupled to the constant current source; and a first resistor having two ends, one end thereof being electrically coupled to the constant current source, and the other end thereof being electrically coupled to the reference voltage circuit, wherein the reference voltage circuit is a bandgap circuit including a plurality of bipolar devices, and the first resistor is configured to decrease a leakage current in the plurality of bipolar devices when a temperature rises.

[0006] A second aspect of an embodiment of the present disclosure is to provide a semiconductor module comprising the integrated circuit.

[0007] Note that the above summary does not list all of the features of the present disclosure. Subcombinations of these feature groups may also be the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** illustrates an example of a configuration of a semiconductor module **10**.

[0009] FIG. **2** illustrates an example of a circuit diagram of a voltage generator circuit **40***a*.

[0010] FIG. **3** illustrates an example of a circuit diagram of a reference voltage circuit **53**.

[0011] FIG. **4** is an example of a conceptual diagram illustrating generation of leakage current in a bipolar transistor **87** of a reference voltage circuit **53**.

[0012] FIG. **5** is an example of a schematic diagram illustrating change with temperature in currents and voltages in a voltage generator circuit **40***a*.

[0013] FIG. **6** illustrates an example of a circuit diagram of a voltage generator circuit **110** according to a comparative example.

[0014] FIG. **7** is an example of a schematic diagram illustrating change with temperature in currents and voltages in a voltage generator circuit **110**.

[0015] FIG. **8** is an example of a schematic diagram illustrating change with temperatures of current Im of a voltage generator circuit **40***a* and current Ibg of a voltage generator circuit **110**.

[0016] FIG. **9**A illustrates an example of a circuit diagram of a voltage generator circuit **40***c*.

[0017] FIG. **9**B illustrates an example of a circuit diagram of a voltage generator circuit **40***d*.

[0018] FIG. **10**A illustrates an example of a circuit diagram of a voltage generator circuit **40***e*.

[0019] FIG. **10**B illustrates an example of a circuit diagram of a voltage generator circuit **40***f*.

[0020] FIG. **10**C illustrates an example of a circuit diagram of a voltage generator circuit **40***g*.

DETAILED DESCRIPTION

[0021] Hereinafter, the present disclosure will be described through embodiments of the disclosure. However, the following embodiments do not limit the disclosure according to the scope of the claims. In addition, not all the combinations of the features described in the embodiments are necessarily essential for solution in the disclosure.

[0022] Herein, the terms “electrically couple” and “couple” are used, and the term “couple” means to “electrically couple” unless otherwise noted.

EMBODIMENT EXAMPLES

Configuration Example of Semiconductor Module **10**

[0023] FIG. **1** illustrates an example of a configuration of a semiconductor module **10**. The semiconductor module **10** is a module to drive a load **11** in response to an instruction from an externally provided microcomputer (not illustrated).

[0024] The semiconductor module **10** uses an externally provided power supply **12** as a main power supply. The power supply **12** applies a voltage HV to the semiconductor module **10**. The semiconductor module **10** includes semiconductor chips **20***a*, **20***b*, power supplies **21***a*, **21***b*, and the integrated circuits **22***a*, **22***b*.

[0025] Here, among the chips and the like configuring the semiconductor module **10**, the semiconductor chip **20***a*, the power supply **21***a*, and the integrated circuit **22***a* are provided on the low side, and the semiconductor chip **20***b*, the power supply **21***b*, and the integrated circuit **22***b* are provided on the high side. Further, in an embodiment of the present disclosure, the circuits on the low side and the circuits on the high side are the same in configuration, and thus the following mainly describes the circuits on the low side.

[0026] The load **11** is, for example, a motor coil, and is driven by a voltage Vout outputted from a node of contact between the semiconductor chips **20***a* and **20***b*.

[0027] The semiconductor chip **20***a* includes a switching device to drive the load **11** and a temperature sensing element. The semiconductor chip **20***a* according to an embodiment of the present disclosure includes an insulated gate bipolar transistor (IGBT) **30***a* as the switching device, and a diode **31***a* for the IGBT **30***a* as the temperature sensing element.

[0028] However, the switching device provided in the semiconductor chip **20***a* is not limited to the IGBT **30***a*, and the switching device may be a metal-oxide-semiconductor (MOS) transistor or a bipolar transistor. Further, the semiconductor chip **20***a* may include a diode to communicate load current to the IGBT **30***a*.

[0029] The power supply **21***a* is a power supply for the integrated circuit **22***a*, and applies the power supply voltage

[0030] Vcc**1** to a power supply line L**1***a*. Note that the power supply **21***a* according to an embodiment of the present disclosure is generated by a power supply circuit (not illustrated) provided inside the semiconductor module **10**, but may be supplied from the outside, for example.

[0031] The integrated circuit **22***a* is a low-voltage integrated circuit (LVIC), and outputs a driving signal LO to the gate electrode of the IGBT **30***a* in response to signal LIN inputted from a microcomputer (not illustrated), to thereby control the IGBT **30***a*. The integrated circuit **22***a* includes a voltage generator circuit **40***a*, a temperature detection circuit **41***a*, and a control circuit **42***a*.

[0032] The voltage generator circuit **40***a* according to an embodiment of the present disclosure generates a reference voltage Vref**1**, based on the power supply voltage Vcc**1** of the power supply line L**1***a*.

[0033] The temperature detection circuit **41***a* supplies predetermined current to the diode **31***a*, and outputs a temperature sensing signal Tsns**1** corresponding to the temperature of the IGBT **30***a* to the control circuit **42***a*, based on the forward voltage of the diode **31***a*.

[0034] The control circuit **42***a* controls the operation of the IGBT **30***a*, based on the signal LIN from the microcomputer (not illustrated), the reference voltage Vref**1**, and the temperature sensing signal Tsns**1**.

[0035] Specifically, the control circuit **42***a* controls switching of the IGBT **30***a* in response to the signal LIN. In addition, the control circuit **42***a* detects overheating of the semiconductor chip **20***a*, based on the reference voltage Vref**1** and the temperature sensing signal Tsns**1**. When detecting overheating of the semiconductor chip **20***a*, the control circuit **42***a* protects the IGBT **30***a* from heat by turning off the IGBT **30***a*, for example.

[0036] The semiconductor chip **20***b* includes an IGBT **30***b* and a diode **31***b*, as corresponding components on the high side, and the power supply **21***b* applies a power supply voltage Vcc**2** to a power supply line L**1***b*. Further, the integrated circuit **22***b* includes a voltage generator circuit **40***b*, a temperature detection circuit **41***b*, and a control circuit **42***b*.

[0037] The voltage generator circuit **40***b* supplies a reference voltage Vref**2** to the control circuit **42***b*, as in the voltage generator circuit **40***a*. The temperature detection circuit **41***b* outputs a temperature sensing signal Tsns**2** corresponding to the temperature of the IGBT **30***b* to the control circuit **42***b*, based on the forward voltage of the diode **31***b*, as in the temperature detection circuit **41***a*. The control circuit **42***b* controls the operation of the IGBT **30***b*, based on a signal HIN from the microcomputer (not illustrated), the reference voltage Vref**2**, and the temperature sensing signal Tsns**2**. The control circuit **42***b* includes a level converter circuit to convert the signal HIN whose reference voltage is GND into a signal whose reference voltage is Vout.

[0038] As such, the voltage generator circuit **40***b* and the temperature detection circuit **41***b* have the same functions and configurations as the voltage generator circuit **40***a* and the temperature detection circuit **41***a* have, respectively. Accordingly, the description of the integrated circuit **22***b*, which includes the voltage generator circuit **40***b*, the temperature detection circuit **41***b*, and the control circuit **42***b* on the high side, is omitted below.

Configuration Example of Voltage Generator Circuit 40*a*

[0039] FIG. **2** illustrates an example of a circuit diagram of the voltage generator circuit **40***a*. The voltage generator circuit **40***a* generates the temperature-compensated reference voltage Vref**1** of a predetermined level. The voltage generator circuit **40***a* according to an embodiment of the present disclosure includes a bias current source **50***a*, a current mirror circuit **51**, a resistor **52**, and a reference voltage circuit **53**.

[0040] The bias current source **50***a* generates a predetermined bias current Ibias. A bias current source **50** according to an embodiment of the present disclosure includes a depletion type MOS transistor **61** whose gate terminal and source terminal are diode-coupled.

[0041] Here, the bias current source **50***a* is configured with a single device, in other words, the depletion type MOS transistor **61**. Accordingly, with the use of the bias current source **50***a* according to an embodiment of the present disclosure, the circuit size of the voltage generator circuit **40***a* is reduced.

[0042] The current mirror circuit **51** supplies constant current Im to the reference voltage circuit **53**, based on the bias current Ibias. The current mirror circuit **51** is electrically coupled to the power supply line L**1***a*, to which the power supply voltage Vcc**1** is applied. The current mirror circuit **51** according to an embodiment of the present disclosure includes a MOS transistor **70**, through which the bias current Ibias flows, and a MOS transistor **71**. Note that the MOS transistors **70**, **71** according to an embodiment of the present disclosure are P-channel metal-oxide-semiconductor (PMOS) transistors.

[0043] The gate terminal and source terminal of the MOS transistor **70** are diode-coupled. The gate terminal of the MOS transistor **70** and the gate terminal of the MOS transistor **71** are electrically coupled each other. Accordingly, based on the bias current Ibias flowing through the MOS transistor **70**, the current Im is supplied from the MOS transistor **71**.

[0044] The resistor **52** generates voltage Vdd**1** to operate the reference voltage circuit **53**, from the current Im of the current mirror circuit **51**. The resistor **52** has one end electrically coupled to the current mirror circuit **51**, and the other end electrically coupled to the reference voltage circuit **53**.

[0045] The reference voltage circuit **53** outputs the reference voltage Vref**1**, which is to be used in other circuits, based on the inputted current Im and voltage Vdd**1**. Note that, although details will be described later, in the reference voltage circuit **53** according to an embodiment of the present disclosure, a node different from a node from which the reference voltage Vref**1** is to be outputted is grounded.

[0046] Accordingly, when leakage current is not generated in the reference voltage circuit **53**, the current Ibg results in the current Im.

[0047] Note that the current mirror circuit **51** according to an embodiment of the present disclosure corresponds to a “constant current source”, and the current Im corresponds to “first current”. Further, the MOS transistor **70** corresponds to a “first MOS transistor”, the MOS transistor **71** corresponds to a “second MOS transistor”. Further, the resistor **52** corresponds to a “first resistor”.

[0048] Here, a description has been given, as an example, of the voltage generator circuit **40***a* on the low side, which uses the power supply voltage Vcc**1**, the power supply line L**1***a*, GND as a power supply reference voltage, the power supply line L**1***a* and the reference voltage Vref**1** to be outputted. The voltage generator circuit **40***b* on the high side also has a similar configuration using the power supply voltage Vcc**2**, the power supply line L**1***b*, Vout as a power supply reference voltage, and the reference voltage Vref**2** to be outputted in place of those on the low side.

Configuration Example of Reference Voltage Circuit 53

[0049] FIG. **3** illustrates an example of a circuit diagram of the reference voltage circuit **53**. The reference voltage circuit **53** according to an embodiment of the present disclosure includes MOS transistors **81** to **84**, a resistor **85**, and bipolar transistors **86**, **87**. In other words, the reference voltage circuit **53** according to an embodiment of the present disclosure is a bandgap circuit including bipolar devices. Note that the MOS transistors **81**, **82** according to an embodiment of the present disclosure are PMOS transistors, and the MOS transistors **83**, **84** are NMOS transistors.

[0050] The gate terminal and source terminal of each of the MOS transistors **82**, **83** are diode coupled. The MOS transistors **81**, **82** configure a P-channel current mirror circuit, and the MOS transistors **83**, **84** configure an N-channel current mirror circuit.

[0051] In response to the current Im being supplied to the diode-coupled MOS transistor **82** from the current mirror circuit **51**, the MOS transistor **81** is turned on. Accordingly, the MOS transistor **81** outputs current, based on the current flowing through the MOS transistor **82**. As a result, the MOS transistors **81**, **82** supply current to the MOS transistors **83**, **84**, respectively.

[0052] Further, in response to the current being supplied to the diode-coupled MOS transistor **83**, the MOS transistor **84** is turned on. Accordingly, the MOS transistor **84** outputs current, based on the current flowing through the MOS transistor **83**. As a result, the MOS transistor **83** supplies current to the bipolar transistor **86**, and the MOS transistor **84** supplies current to the resistor **85**.

[0053] Further, in an embodiment of the present disclosure, the MOS transistors **81**, **82** have the same size, and the MOS transistors **83**, **84** have the same size. Accordingly, the currents from the current mirror circuit including the MOS transistors **83**, **84** are equal to each other.

[0054] Accordingly, the current Im from the current mirror circuit **51** is supplied to the MOS transistors **81**, **83**, and the MOS transistors **81**, **83** can be considered as configuring a current source **88** to supply current to the bipolar transistor **86**. The current source **88** according to an embodiment of the present disclosure corresponds to a “first current source”.

[0055] Similarly, the current Im from the current mirror circuit **51** is supplied to the MOS transistors **82**, **84**, and the MOS transistors **82**, **84** can be considered as configuring a current source **89** to supply current to the resistor **85**. Further, the current source **89** is electrically coupled in parallel with the current source **88**. The current source **89** according to an embodiment of the present disclosure corresponds to a “second current source”.

[0056] Here, the current source **88**, **89** is a current source in which the magnitude of the current to be outputted changes with the level of the power supply voltage Vdd**1** applied to the current source **88**, **89**, unlike such a “constant current source” as the current mirror circuit **51** configured to generate the current Im, based on the bias current Ibias. In other words, herein, the “current source” is different from the “constant current source” in that although current is supplied, the magnitude of the current to be supplied is not constant.

[0057] The resistor **85** has one end coupled to the output of the MOS transistor **84**, and the other end coupled to the collector terminal of the bipolar transistor **87**. The current from the MOS transistor **84** is supplied to the resistor **85**, and the resistor **85** is electrically coupled to the bipolar transistor **87**.

[0058] The base terminal and collector terminal of the bipolar transistor **86** are electrically coupled and the base terminal and collector terminal of the bipolar transistor **87** are electrically coupled, and the emitter terminals of the bipolar transistors **86**, **87** are grounded.

[0059] The bipolar transistors **86**, **87** are respectively configured such that the base-emitter voltages thereof are different from each other. Specifically, the bipolar transistor **86** according to an embodiment of the present disclosure includes a single bipolar transistor, meanwhile the bipolar transistor **87** includes a plurality of bipolar transistors coupled in parallel. Accordingly, the base-emitter voltage of the bipolar transistor **86** is greater than the base-emitter voltage of the bipolar transistor **87**. Note that both of the base-emitter voltages of the bipolar transistors **86**, **87** have positive temperature coefficients.

[0060] Further, in an embodiment of the present disclosure, the currents from the current sources **88**, **89** are equal to each other, which results in the voltages at source terminals of the MOS transistors **83**, **84** being equal to each other. Accordingly, voltage with a negative temperature coefficient is generated across the resistor **85**, in accordance with the difference between the base-emitter voltage of the bipolar transistor **86** and the base-emitter voltage of the bipolar transistor **87**.

[0061] As a result, the voltage obtained by adding the base-emitter voltage of the bipolar transistor **87** with a positive temperature coefficient and the voltage across the resistor **85** with a negative temperature coefficient is generated, as the reference voltage Vref**1**, at the node at which the MOS transistor **84** and the resistor **85** are coupled. Note that, in an embodiment of the present disclosure, for example, the resistance value of the resistor **85** and the number of the bipolar transistors **87** are adjusted such that the temperature coefficient of the reference voltage Vref**1** is zero.

[0062] Accordingly, the temperature-compensated reference voltage Vref**1** is supplied from the reference voltage circuit **53**.

[0063] The resistor **85** according to an embodiment of the present disclosure corresponds to a "second resistor". Further, the bipolar transistor **86** corresponds to a "first bipolar transistor", and the bipolar transistor **87** corresponds to a "second bipolar transistor".

[0064] As described above, the reference voltage circuit **53** according to an embodiment of the present disclosure is capable of outputting the temperature-compensated reference voltage Vref1. Incidentally, when a temperature rises, the leakage current is generated from the bipolar transistors **86**, **87**, which may cause the reference voltage Vref1 to fluctuate greatly in accordance with the temperature. The following describes the leakage current generated in the bipolar transistors **86**, **87**.

Leakage Current Generated in Bipolar Transistor

[0065] FIG. **4** is an example of a conceptual diagram illustrating generation of the leakage current in the bipolar transistor **87** of the reference voltage circuit **53**. In an embodiment of the present disclosure, the bipolar transistor **87** is formed such that an N-well region **92** is provided in a substrate **91** in the semiconductor, and a dopant diffusion region for each terminal to function is provided in the N-well region **92**. In an embodiment of the present disclosure, the substrate **91** has P-type conductivity.

[0066] An N+ collector region **93** is provided around a region in which a collector terminal **96** is provided in the N-well region **92**, and a P+base region **94** is provided around a region in which a base terminal **97** is provided. Further, an N+ emitter region **95** is provided around a region in which an emitter terminal **98** is provided in the P+ base region **94**.

[0067] Note that, in a region marked with each conductivity type, a region prefixed with "+" means that a doping concentration therein is higher than that in a region without "+", and a region prefixed with "−" means that a doping concentration therein is lower than that in a region without

[0068] In the bipolar transistor **87** as such, the surface area of a PN junction portion between the substrate **91** and the N-well region **92** is large. When the temperature of a semiconductor device rises, the larger the surface area of the PN junction portion, the greater the possibility of the leakage current being generated. Accordingly, in the bandgap reference voltage circuit **53** using bipolar devices, it is effective to reduce the leakage current.

[0069] In the bipolar transistor **87**, the current flowing from the collector terminal **96** into the bipolar transistor is reduced, thereby being able to restrain the leakage current even when the temperature rises. Accordingly, the current Im inputted to the reference voltage circuit **53** is reduced and the voltage Vdd1 is lowered, thereby restraining the leakage current.

[0070] Note that the bias current source **50***a* and the current mirror circuit **51** according to an embodiment of the present disclosure include no bipolar device, and thus the voltage generator circuit **40***a* is configured such that the leakage current is less likely to be generated from those other than the reference voltage circuit **53**.

[0071] Further, the bipolar transistor **87** is used as an example, to explain the mechanism of the leakage current in the bipolar device in the reference voltage circuit **53**, however, the leakage current may be generated based on a similar mechanism, in the bipolar transistor **86** as well. As such, in an embodiment of the present disclosure, the term "the leakage current" indicates the current flowing from the N-well region **92** to the substrate **91** when a bipolar transistor is formed, for example.

Change with Temperature in Current and Voltage Values In Voltage Generator Circuit **40***a* of Embodiment Example

[0072] FIG. **5** is an example of a schematic diagram illustrating change with temperature in current values and voltage values in the voltage generator circuit **40***a*. An embodiment of the present disclosure illustrates the relationship among the power supply voltage Vcc1, current Ibg, the current Im, and the reference voltage Vref1 when a temperature T [° C.] of the reference voltage circuit **53** is changed.

[0073] The current Ibg is the current flowing from the reference voltage circuit **53** to the ground. The substrate **91** of the bipolar transistor **87** is grounded, and thus when the leakage current flowing from the substrate **91** to the ground explained with reference to FIG. **4** increases, the current Ibg increases.

[0074] Note that the substrate of the bipolar transistor **86** is also grounded, and thus even when the leakage current in the bipolar transistor **86** increases as well, the current Ibg increases.

[0075] A temperature threshold value Tth is a temperature value at which the leakage current flowing from the bipolar device of the reference voltage circuit **53** to the ground is generated. Here, in an embodiment of the present disclosure, the phrase "the leakage current is generated" indicates, for example, that the value of the current flowing from the N-well region **92** when the bipolar transistor is formed to the substrate **91** (hereinafter, referred to as current Ix) reaches a predetermined multiple (e.g., 5 times) of the current Ix when a temperature is a predetermined temperature (e.g., 25° C.)

[0076] In an embodiment of the present disclosure, the temperature threshold value Tth at which the leakage current is generated is 100° C., however, it varies depending on the configuration of the bipolar transistor and/or the dopant concentration in the substrate **91** and/or the N-well region **92**. Accordingly, the temperature threshold value Tth may not be 100° C., but may be other temperatures such as 120° C. or the like.

[0077] In the voltage generator circuit **40***a*, the small constant current Im based on the bias current Ibias is provided from the current mirror circuit **51** to the reference voltage circuit **53**. Accordingly, even in a temperature range above the temperature threshold value Tth, the leakage current from the reference voltage circuit **53** is restrained, and the current Ibg results in being substantially the same as the current Im. The current Im is determined such that the current Ibg is limited to the value of the current Im, when the temperature becomes equal to or higher than the temperature threshold value Tth at which the leakage current flowing from the reference voltage circuit **53** to the ground is generated.

[0078] Even when the temperature exceeds the temperature threshold value Tth, the value of the current Ibg is substantially the same as the value of the current Im. As a result, the current flowing through the resistor **85** is substantially constant, irrespective of temperature. Accordingly, even when the reference voltage circuit **53** changes in temperature, the reference voltage Vref1 generated from the reference voltage circuit **53** is also substantially constant.

[0079] Note that, in an embodiment of the present disclosure, the resistor **52** is provided between the current mirror circuit **51** and the reference voltage circuit **53**. Accordingly, the voltage Vdd**1** supplied to the reference voltage circuit **53** is lower than that when the resistor **52** is not provided. This lowers the voltages at the nodes in the reference voltage circuit **53**, and lowers the voltages applied to the collector terminals of the bipolar transistors **86**, **87** as well.

[0080] The lower the voltages applied to the collector terminals of the bipolar transistors **86**, **87**, the smaller the leakage current. Accordingly, in an embodiment of the present disclosure, by lowering the voltage Vdd**1** applied as power supply for the reference voltage circuit **53**, the leakage current can be reduced smaller. This makes it possible to generate the temperature-compensated reference voltage Vref**1** with high accuracy.

Comparative Example

Voltage Generator Circuit 110 of Comparative Example

[0081] FIG. **6** illustrates an example of a circuit diagram of a voltage generator circuit **110** according to a comparative example. The following mainly describes differences between the voltage generator circuit **110** and the voltage generator circuit **40***a*.

[0082] The voltage generator circuit **110** of a comparative example does not include the current mirror circuit **51** or the resistor **52**. In other words, the reference voltage circuit **53** of the voltage generator circuit **110** according to a comparative example is directly electrically coupled to the power supply line L**1***a* to supply the power supply voltage Vcc**1**.

[0083] Current Icc**1** is supplied from the power supply line L**1***a* to the reference voltage circuit **53**. The current Icc**1** corresponds to a "second current".

[0084] FIG. **7** is an example of a schematic diagram illustrating change with temperature in currents and voltages in the voltage generator circuit **110**. FIG. **7** illustrates the power supply voltage Vcc**1**, the current Ibg, the current Icc**1** from the power supply line L**1***a*, and the reference voltage Vref**1** when the temperature T [° C.] of the reference voltage circuit **53** is changed.

[0085] In the voltage generator circuit **110**, the leakage current is generated from the bipolar devices provided in the reference voltage circuit **53**, in the temperature range above the temperature threshold value Tth. This increases the current Ibg flowing from the reference voltage circuit **53** toward the ground.

[0086] The voltage generator circuit **110** includes no mechanism to limit an increase in the current Icc**1**. Accordingly, in response to the current Ibg being generated, the current Icc**1** supplied from the power supply line L**1***a* to the reference voltage circuit **53** increases as well. At a predetermined temperature in the temperature range above the temperature threshold value Tth, the current value of the current Icc**1** exceeds the current value of the current Im in the voltage generator circuit **40***a*.

[0087] In the voltage generator circuit **110**, in accordance with an increase in the current Ibg with a rise in the temperature, the reference voltage Vref**1** from the reference voltage circuit **53** rises as well. Meanwhile, the voltage generator circuit **40***a* in FIG. **2** can provide the reference voltage Vref**1** with less temperature dependence, as compared with the voltage generator circuit **110**.

Relationship Between Im In Embodiment Example and Ibg In Comparative Example

[0088] FIG. **8** is an example of a schematic diagram illustrating change with temperature in the current Im of the voltage generator circuit **40***a* and the current Ibg of the voltage generator circuit **110**. In FIG. **8**, the translation of the current Im in the voltage generator circuit **40***a* is given by a solid line, and the translation of the current Ibg of the voltage generator circuit **110** is given by a dashed-dotted line.

[0089] In the voltage generator circuit **110**, in response to the leakage current being generated, the current Ibg also increases in the temperature range above the temperature threshold value Tth. Meanwhile, in the voltage generator circuit **40***a*, the current Ibg is limited to the current Im in the range above the temperature threshold value Tth as well.

[0090] The current Im in the voltage generator circuit **40***a* according to an embodiment of the present disclosure is considered as current sufficient to operate the reference voltage circuit **53**. However, if the value of the current Im is increased excessively, the current Ibg cannot be limited when the current Ibg increases with the temperature becoming equal to or higher than the temperature threshold value Tth, for example.

[0091] Thus, in an embodiment of the present disclosure, the current value of the current Im is determined such that the current value of the current Ibg in the voltage generator circuit **110** when the temperature is at the temperature threshold value Tth is the current value of the current Im, for example. With the value of the current Im being set as such, it is possible to restrain an increase in the leakage current in the reference voltage circuit **53** with reliability.

Modified Example of Embodiment Example

Configuration of Voltage Generator Circuit 40*c*

[0092] FIG. **9**A illustrates an example of a circuit diagram of a voltage generator circuit **40***c*. The following mainly describes differences between the voltage generator circuit **40***c* and the voltage generator circuit **40***a*. A bias current source **50***b* of the voltage generator circuit **40***c* includes a Zener diode **62**, a resistor **63**, and an MOS transistor **64**.

[0093] The Zener diode **62** and the resistor **63** coupled in series are provided between the line L**1***a* to which the power supply voltage Vcc**1** is applied and the ground. Here, the power supply voltage Vcc**1** is higher than the Zener voltage of the Zener diode **62**, and thus the gate voltage of the MOS transistor **64** results in the Zener voltage.

[0094] With provision of the Zener diode **62** as such, it is possible to apply steady-state voltage to the gate terminal of the MOS transistor **64** even when the power supply voltage Vcc**1** fluctuates.

[0095] The resistor **63** adjusts the current supplied from the power supply voltage Vcc**1** to the Zener diode **62**. The resistor **63** is electrically coupled between the gate terminal of the MOS transistor **64** and the power supply line L**1***a*.

[0096] The MOS transistor **64** generates the bias current Ibias between the drain and source thereof, based on the voltage generated from the Zener diode **62**. Note that since the stable Zener voltage is applied from the Zener diode **62** to the MOS transistor **64**, the bias current Ibias outputted from the MOS transistor **64** is stabilized.

[0097] The Zener diode **62** according to an embodiment of the present disclosure is an example of a “second Zener diode”, and the MOS transistor **64** is an example of a “third MOS transistor”.

Configuration of Voltage Generator Circuit 40*d*

[0098] FIG. **9**B illustrates an example of a circuit diagram of a voltage generator circuit **40***d*. The following mainly describes differences between the voltage generator circuit **40***d* and the voltage generator circuit **40***a*. A bias current source **50***c* of the voltage generator circuit **40***d* further includes the diode-coupled depletion type MOS transistor **61**, the Zener diode **62**, the resistor **63**, and the MOS transistor **64**.

[0099] Similarly to the case of FIG. **9**A, the Zener diode **62** and the resistor **63** coupled in series are provided between the line L**1***a* to which the power supply voltage Vcc**1** is applied and the ground. Accordingly, the Zener voltage is applied to the MOS transistor **64**.

[0100] The depletion type MOS transistor **61** is diode-coupled, and thus functions as a device to cause the magnitude of the drain-source current of the MOS transistor **64** to be the desired bias current Ibias.

[0101] Further, in an embodiment of the present disclosure, the depletion type MOS transistor **61** and the MOS transistor **64** operate as so-called source follower. Thus, the voltage corresponding to the Zener voltage is applies to the drain of the depletion type MOS transistor **61**. Accordingly, even if the level of the power supply voltage Vcc**1** is high, the stable bias current Ibias can be generated.

[0102] The Zener diode **62** according to an embodiment of the present disclosure is another example of the “second Zener diode”, and the MOS transistor **64** is another example of the “third MOS transistor”.

Configuration of Voltage Generator Circuit 40*e*

[0103] FIG. **10**A illustrates an example of a circuit diagram of a voltage generator circuit **40***e*. The following mainly describes differences between the voltage generator circuit **40***e* and the voltage generator circuit **40***a*. The voltage generator circuit **40***e* includes a diode **54** in place of the resistor **52**.

[0104] The diode **54** has an anode coupled to the current mirror circuit **51**, and a cathode coupled to the reference voltage circuit **53**. Assuming that a drop in the drain-source voltage in the MOS transistor **71** of the current mirror circuit **51** is Vds, a difference Vcc**1**−Vds obtained by subtracting the voltage Vds from the power supply voltage Vcc**1** is applied to the anode of the diode **54**.

[0105] From the cathode of the diode **54**, a voltage Vdd**2** (=Vcc**1**−Vds−0.7 [V]), which is lower than Vcc**1**−Vds by a forward voltage (here, 0.7 V) is outputted. Even in such a case, the constant current Im and the voltage Vdd**2** to operate the reference voltage circuit **53** are supplied to the reference voltage circuit **53**. Accordingly, the voltage generator circuit **40***e* according to an embodiment of the present disclosure can also improve the temperature characteristics of the reference voltage circuit **53**.

Configuration of Voltage Generator Circuit 40*f*

[0106] FIG. **10**B illustrates an example of a circuit diagram of a voltage generator circuit **40***f*. The following mainly describes differences between the voltage generator circuit **40***f* and the voltage generator circuit **40***a*. The voltage generator circuit **40***f* includes a Zener diode **55** without including the resistor **52**.

[0107] In an embodiment of the present disclosure, the Zener diode **55** has a cathode coupled to the current mirror circuit **51**, and an anode that is grounded, such that the reference voltage circuit **53** and the Zener diode **55** are coupled in parallel. Accordingly, a Zener voltage Vdd**3** of the Zener diode **55** is supplied to the reference voltage circuit **53**.

[0108] The voltage generator circuit **40***f* as such can lower the voltage to operate the reference voltage circuit **53** while supplying constant current to the reference voltage circuit **53**. Accordingly, in an embodiment of the present disclosure, even when the temperature changes, the reference voltage Vref**1** from the reference voltage circuit **53** can be stabilized.

[0109] Even in this embodiment of the present disclosure as well, the voltage generator circuit **40***f* results in a circuit in which the current Im being constant current and the voltage Vdd**3** being constant voltage are inputted to the reference voltage circuit **53**, and the temperature characteristics of the reference voltage circuit **53** are stabilized. The Zener diode **55** according to an embodiment of the present disclosure corresponds to a “first Zener diode”.

Configuration of Voltage Generator Circuit 40*g*

[0110] FIG. **10**C illustrates an example of a circuit diagram of a voltage generator circuit **40***g*. The following mainly describes differences between a voltage generator circuit **40***g* and the voltage generator circuit **40***a*.

[0111] In the voltage generator circuit **40***g*, the reference voltage circuit **53** is directly electrically coupled to the output from the MOS transistor **71** out of the outputs of the current mirror circuit **51**.

[0112] Even without the resistor **52** being provided, the current Im from the current mirror circuit **51** to the reference voltage circuit **53** is limited, and thus change with temperature in the reference voltage Vref**1** of the voltage generator circuit **40***g* is smaller than change with temperature in the reference voltage Vref**1** of the voltage generator circuit **110**. In other words, in the voltage generator circuit **40***g* according to an embodiment of the present disclosure, the temperature characteristics are improved as compared with the voltage generator circuit **110** in FIG. **6**.

[0113] Further, the current mirror circuit **51** has an internal resistance, and thus by appropriately setting the internal resistance of the current mirror circuit **51**, it is possible to lower voltage Vm outputted from the current mirror circuit **51**. Accordingly, when the internal resistance is adjustable, the same effects can be achieved according to this embodiment of the present disclosure as well, as in such an embodiment including the resistor **52**.

SUMMARY

[0114] Hereinabove, the semiconductor module **10** according to an embodiment of the present disclosure has been explained. For example, as illustrated in FIG. **1**, the integrated circuit **22***a* of the semiconductor module **10** includes the voltage generator circuit **40***a* electrically coupled to the power supply line L**1***a* to which the power supply voltage Vcc**1** is to be applied.

[0115] For example, as illustrated in FIG. **2**, in the voltage generator circuit **40***a*, the current mirror circuit **51** supplies constant current to the reference voltage circuit **53**. Accordingly, in the voltage generator circuit **40***a* of the integrated circuit **22***a*, the voltage value of the reference voltage Vref**1** outputted from the reference voltage circuit **53** is stabilized even when the temperature is high with a small circuit configuration, thereby being able to improve the temperature characteristics of the reference voltage circuit **53**.

[0116] For example, as illustrated in FIG. **2**, the voltage generator circuit **40***a* may include the resistor **52** to supply the voltage Vdd**1** to the reference voltage circuit **53**. Accordingly, in the voltage generator circuit **40***a* of the integrated circuit **22***a*, the voltage Vdd**1** to be inputted to the reference voltage circuit **53** results in a low voltage, thereby being able to further improve the temperature characteristics of the reference voltage circuit **53**.

[0117] For example, as illustrated in FIG. **10**A, the voltage generator circuit **40***e* may include the diode **54** to supply the voltage Vdd**2** to the reference voltage circuit **53**. Accordingly, in the voltage generator circuit **40***e* of the integrated circuit **22***a*, the voltage exceeding the forward voltage is applied to the diode **54**, thereby being able to improve the temperature characteristics of the reference voltage circuit **53**.

[0118] For example, as illustrated in FIG. **10**B, the voltage generator circuit **40***f* may include the Zener diode **55** to supply the voltage Vdd**3** to the reference voltage circuit **53**. Accordingly, in the voltage generator circuit **40***f* of the integrated circuit **22***a*, the temperature characteristics of the reference voltage circuit **53** can be improved in a range in which the Zener diode **55** can be maintained in a breakdown state.

[0119] For example, as illustrated in FIG. **3**, the reference voltage circuit **53** may be a bandgap circuit including bipolar devices such as the bipolar transistor **86** and the bipolar transistor **87**. In the reference voltage circuit **53** as such, the surface area of the PN junction portion is large as illustrated in FIG. **4**, and thus it is effective to reduce the leakage current.

[0120] For example, as illustrated in FIG. **5**, the current Im is determined such that the current Ibg is limited to the value of the current Im. This can stabilize the reference voltage Vref**1**, thereby being able to improve the temperature characteristics of the reference voltage circuit **53**.

[0121] For example, as illustrated in FIG. **7**, when the temperature is higher than the temperature threshold value Tth, the current value of the current Im supplied by the current mirror circuit **51** of the voltage generator circuit **40***a* to the reference voltage circuit **53** is smaller than the current value of the current Icc**1** supplied from the power supply line L**1***a* to the reference voltage circuit **53** in a state where the reference voltage circuit **53** is coupled to the power supply line L**1***a* as in the voltage generator circuit **110**.

[0122] As such, the voltage generator circuit **40***a* of the integrated circuit **22***a* can be designed such that the current supplied to the reference voltage circuit **53** is small.

[0123] For example, as illustrated in FIG. **2**, the voltage generator circuit **40***a* of the integrated circuit **22***a* may include the bias current source **50***a*. In this case, the constant current source of the voltage generator circuit **40***a* may be the current mirror circuit **51** including the MOS transistor **70** through which the bias current Ibias of the bias current source **50***a* is to flow, and the MOS transistor **71** to supply the constant current Im to the reference voltage circuit **53**, without including a bipolar transistor.

[0124] Accordingly, in the voltage generator circuit **40***a* of the integrated circuit **22***a*, the leakage current is less likely to be generated from the current mirror circuit **51**, which makes it easier to supply constant current to the reference voltage circuit **53**. Accordingly, the temperature characteristics of the reference voltage circuit **53** can be improved.

[0125] For example, as illustrated in FIG. **9**A or **9**B, the bias current source **50** may include the Zener diode **62** and the MOS transistor **64** to generate the bias current Ibias, based on the voltage generated at the Zener diode **62**.

[0126] Accordingly, the voltage generator circuit **40***a* of the integrated circuit **22***a* can provide the stable bias current Ibias even when the power supply voltage Vcc**1** fluctuates.

[0127] For example, as illustrated in FIG. **2** or **9**B, the bias current source **50** may include the diode-coupled depletion type MOS transistor **61**. This makes it possible for the voltage generator circuit **40***a* or **40***d* of the integrated circuit **22***a* to generate the desired bias current Ibias even at a low voltage with a small circuit configuration.

[0128] For example, as illustrated in FIG. **3**, the reference voltage circuit **53** may be such a circuit that includes the current source **88**, the current source **89**, the bipolar transistor **86** to which the current from the current source **88** is to be supplied, the resistor **85** to which the current from the current source **89** is to be supplied, the bipolar transistor **87** to be electrically coupled to the resistor **85**, and that is configured to output the temperature-compensated reference voltage Vref**1**.

[0129] In this case, the voltage generator circuit **40***a* of the integrated circuit **22***a* can output such reference voltage Vref**1** that the effects of respective temperature coefficients of the bipolar transistors **86** and **87** are compensated in a temperature range in which no leakage current is generated from the bipolar transistors **86** and **87**.

[0130] For example, as illustrated in FIG. **1**, the semiconductor module **10** includes an integrated circuit **22** according to an embodiment of the present disclosure. This makes it possible to utilize the reference voltage Vref**1** of the reference voltage circuit **53** with temperature characteristics thereof improved, in the semiconductor module **10**.

[0131] The present disclosure is directed to provision of an integrated circuit capable of stabilizing an output of a reference voltage circuit even when a temperature rises.

[0132] It is possible to provide an integrated circuit capable of stabilizing an output of a reference voltage circuit even when a temperature rises.

[0133] Hereinabove, the present disclosure has been described using embodiments. However, the technical scope of the present disclosure is not limited to the range described in above embodiments. It is apparent to those skilled in the art that above embodiments can be variously altered and modified. It is apparent from the claims that the technical scope of the present disclosure includes such altered or modified modes and equivalents thereof without departing from its essential features of the present disclosure.

[0134] It should be noted that processes such as operations, procedures, steps, stages, and the like in a device, a system, a program, and a method described in the claims, the specification, and the drawings may be performed in any order, unless a term such as "before", "prior to" or the like is explicitly used or an output of a previous process is used in a subsequent process. Even if terms such as "first", "next", and/or the like is used, for convenience, with respect to an operation flow in the claims, the specification, and the drawings, this does not mean that the flow needs to be performed in this order.

What is claimed is:

1. An integrated circuit comprising:
a power supply line configured to receive a power supply voltage;
a constant current source electrically coupled to the power supply line;
a reference voltage circuit electrically coupled to the constant current source; and
a first resistor having two ends, one end thereof being electrically coupled to the constant current source, and the other end thereof being electrically coupled to the reference voltage circuit, wherein
the reference voltage circuit is a bandgap circuit including a plurality of bipolar devices, and
the first resistor is configured to decrease a leakage current in the plurality of bipolar devices when a temperature rises.

2. An integrated circuit comprising:
a power supply line configured to receive a power supply voltage;
a constant current source electrically coupled to the power supply line;
a reference voltage circuit electrically coupled to the constant current source; and
a diode having
  an anode electrically coupled to the constant current source, and
  a cathode electrically coupled to the reference voltage circuit.

3. The integrated circuit according to claim **2**, wherein the reference voltage circuit is a bandgap circuit including a plurality of bipolar devices.

4. The integrated circuit according to claim **1**, wherein a current value of the constant current source is determined such that a current value of a current flowing from the reference voltage circuit to a ground is limited to a current value of the constant current source, when the temperature is equal to or higher than a predetermined temperature at which the leakage current is generated.

5. The integrated circuit according to claim **1**, wherein a current value of a first current, which is supplied to the reference voltage circuit by the constant current source when the temperature is a predetermined temperature, is smaller than a current value of a second current, which is supplied from the power supply line to the reference voltage circuit when the temperature is the predetermined temperature, in a state where the reference voltage circuit is coupled to the power supply line.

6. The integrated circuit according to claim **1**, wherein
the integrated circuit includes a bias current source, and the constant current source includes
a first metal-oxide-semiconductor (MOS) transistor allowing a bias current of the bias current source to flow therethrough, and
a second MOS transistor configuring a current mirror circuit with the first MOS transistor, the second MOS transistor being configured to supply a constant current to the reference voltage circuit.

7. The integrated circuit according to claim **6**, wherein the bias current source includes
a second Zener diode, and
a third MOS transistor configured to generate the bias current, based on a voltage generated at the second Zener diode.

8. The integrated circuit according to claim **6**, wherein the bias current source includes a diode-coupled depletion type MOS transistor.

9. The integrated circuit according to claim **1**, wherein
the reference voltage circuit includes
  a first current source configured to receive a current from the constant current source,
  a second current source configured to receive the current from the constant current source, the second current source being electrically coupled in parallel with the first current source,
  a first bipolar transistor electrically coupled in series to the first current source,
  a second resistor electrically coupled in series to the second current source, and
  a second bipolar transistor electrically coupled in series to the second resistor, and
the reference voltage circuit is configured to output a voltage at the second resistor as a temperature-compensated reference voltage.

10. A semiconductor module, comprising the integrated circuit according to claim **1**.

11. An integrated circuit comprising:
a power supply line configured to receive a power supply voltage;
a constant current source electrically coupled to the power supply line;
a reference voltage circuit electrically coupled to the constant current source; and
a first Zener diode having
  a cathode electrically coupled to the constant current source, and
  an anode that is grounded,
the first Zener diode being provided in parallel with the reference voltage circuit.

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