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- (54) **Title:** OVERHEAT DETECTION OF MOSFET

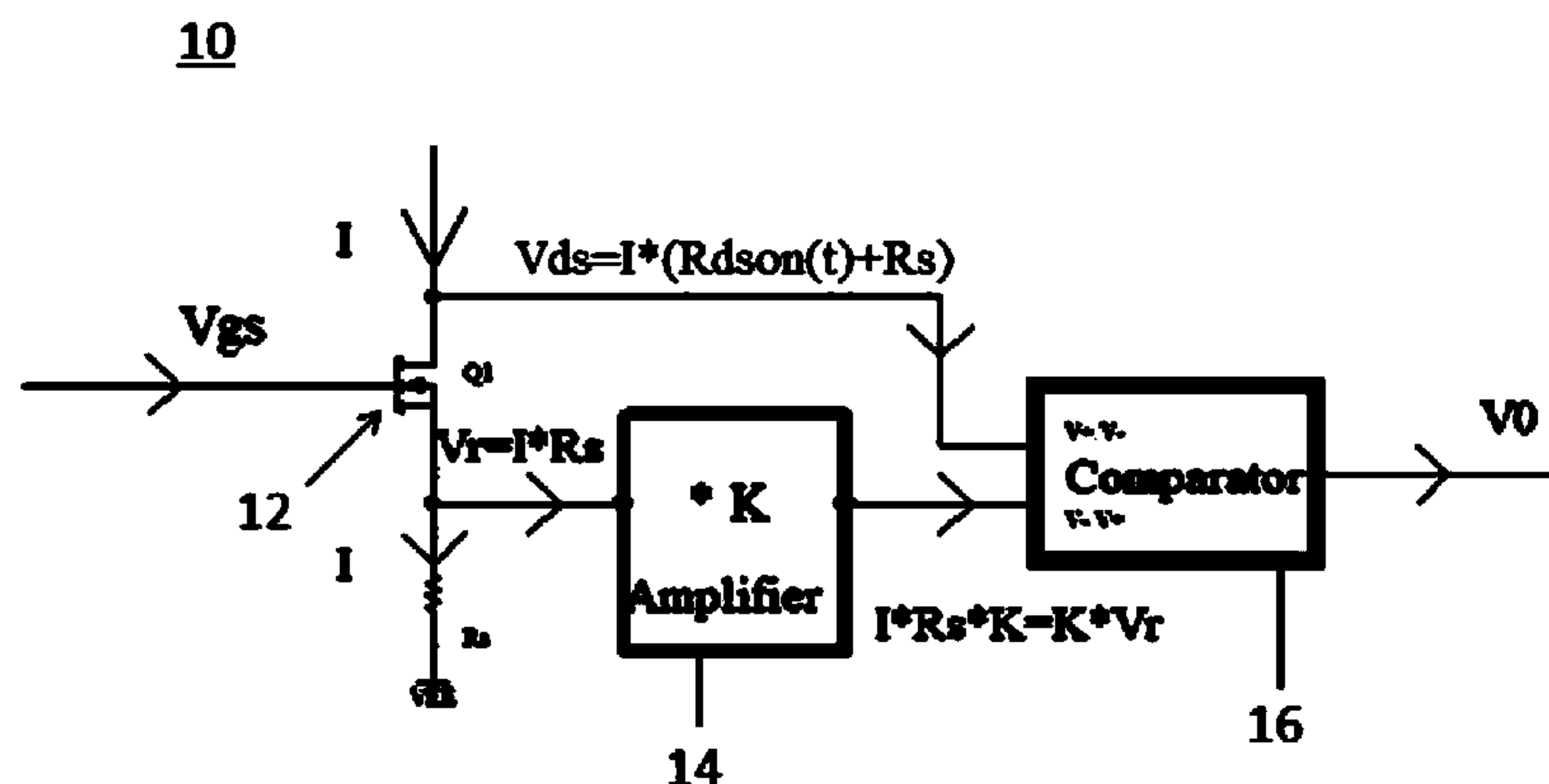


FIG. 5

- (57) **Abstract:** There is provided a circuit (10) for detecting junction temperature of a MOSFET (12). The circuit (10) comprises a MOSFET (12), a sense resistor (R_s) connected in series to drain or source of the MOSFET (12), an amplifier (14) for amplifying a voltage (V_r) across the sense resistor (R_s) by a predetermined value (K), and a comparator (16) for comparing the the amplified voltage (KV_r) with a drain voltage (V_{ds}) of the MOSFET (12).

OVERHEAT DETECTION OF MOSFET

FIELD OF THE INVENTION

[0001] The present invention relates to overheat detection of a MOSFET. More particularly, the present invention relates to a method and a circuit for detecting over temperature of MOSFET junction.

BACKGROUND OF THE INVENTION

[0002] MOSFETs are used for various electrical applications including a brushless motor. It is known to provide a temperature sensor to a MOSFET for overheat protection. A negative temperature coefficient (NTC) thermistor is generally used as a temperature sensor to detect an overheat condition of MOSFET junction.

[0003] FIG. 1 illustrates schematic diagrams of conventional circuits for detecting junction temperature of a MOSFET using a temperature sensor such as a NTC thermistor (NTC1 or NTC2). When the NTC thermistor is surface mounted package, it cannot contact the MOSFET very well therefore there is high tolerance. When the NTC thermistor is through hole package, it can contact MOSFET directly, but it requires more time for thermal conduction and sensing, which causes slower response time. In addition, it can only detect surface temperature of the MOSFET.

[0004] FIG. 2 shows a graph of resistance of a 33k NTC thermistor as a function of temperature. It is observed that when temperature is lower than 0 degree, the resistance increases sharply as the temperature goes lower, and when temperature is higher than 60 degree, resistance reduces very slowly as the temperature goes higher, which makes it difficult to identify temperature.

[0005] Therefore, there is a need for an improved method and circuit for overheat detection of the MOSFET junction without using the temperature sensor.

SUMMARY OF THE INVENTION

[0006] In accordance with an embodiment of the present invention, there is provided a circuit for detecting junction temperature of a MOSFET. The circuit includes a MOSFET, a sense resistor connected in series to drain or source of the MOSFET, an amplifier for amplifying a voltage (V_r) across the sense resistor by a predetermined value (K), and a comparator for comparing the amplified voltage (KV_r) with a drain voltage (V_{ds}) of the MOSFET.

[0007] A Drain-to-Source On Resistance (R_{dson}) of the MOSFET may represent junction temperature based on a linear relation between the R_{dson} and junction temperature of the MOSFET.

[0008] The drain voltage (V_{ds}) can be described as $V_{ds} = I * (R_{dson}(t) + R_s)$, where $R_{dson}(t)$ is a Drain-Source on Resistance of the MOSFET as a function of junction temperature (t) of the MOSFET, R_s is a resistance of the sense resistor, and I is the current flow through the MOSFET and the sense resistor.

[0009] A (+) input of the amplifier can be connected between the MOSFET and the sense resistor.

[0010] The circuit may further include a variable resistor provided across the (-) input of the amplifier and an output of the amplifier. The variable resistor may be provided to predetermine an over temperature value.

[0011] The comparator can be provided to receive the amplified voltage (KV_r) and the drain voltage (V_{ds}) of the MOSFET as inputs. The comparator can be configured to generate an over temperature signal (V_0) based on the comparison. The comparator can be configured to generate the over temperature signal (V_0) when the drain voltage (V_{ds}) of the MOSFET is determined to be larger than the amplified voltage (KV_r).

[0012] The circuit may further include an AND gate or an XOR gate configured to receive the over temperature signal. The AND gate or the XOR gate may receive gate bias (V_{gs}) of the MOSFET and output a signal to a controller.

[0013] In accordance with an embodiment of the present invention, there is provided a method for detecting junction temperature of a MOSFET including turning on the MOSFET, amplifying a voltage (V_r) across a sense resistor by a predetermined value (K), the sense resistor being connected in series to drain or source of the MOSFET, comparing the amplified voltage (KV_r) with a drain voltage (V_{ds}) of the MOSFET, determining if the drain voltage (V_{ds}) of the MOSFET is larger than the amplified voltage (KV_r), and generating an over temperature signal based on the determination.

[0014] In the method, generating an over temperature signal based on the determination may include generating an over temperature signal when the drain voltage (V_{ds}) of the MOSFET is larger than the amplified voltage (KV_r).

[0015] A Drain-to-Source On Resistance (R_{dson}) of the MOSFET can represent junction temperature based on a linear relation between the R_{dson} and junction temperature of the MOSFET.

[0016] The drain voltage (V_{ds}) can be described as $V_{ds} = I * (R_{dson}(t) + R_s)$, where $R_{dson}(t)$ is a Drain-Source on Resistance of the MOSFET as a function of junction temperature (t) of the MOSFET, R_s is a resistance of the sense resistor, and I is the current flow through the MOSFET and the sense resistor.

[0017] Other features and aspects of the invention will become apparent by consideration of the following detailed description, drawings and claims.

[0018] Before any independent constructions of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other independent constructions and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting.

[0019] Use of “including” and “comprising” and variations thereof as used herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Use of “consisting of” and variations thereof as used herein is meant to encompass only the items listed thereafter and equivalents thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] These and other features of the invention will become more apparent from the following description, by way of example only, with reference to the accompanying drawings.

[0021] FIG. 1 shows schematic diagrams of conventional circuits for detecting junction temperature of a MOSFET using a temperature sensor.

[0022] FIG. 2 shows a graph of resistance of a 33k NTC thermistor as a function of temperature.

[0023] FIG. 3 shows a graph of a MOSFET R_{dson} (drain-to-source on resistance) curve as a function of junction temperature.

[0024] FIG. 4 shows a graph of a MOSFET curve of R_{dson} as a function of gate bias (V_{gs}) and drain current (I_d).

[0025] FIG 5 shows a schematic diagram of a circuit for detecting over temperature of MOSFET junction in accordance with an embodiment of the present invention.

[0026] FIG. 6 shows a schematic diagram of a circuit for detecting over temperature of MOSFET junction in accordance with another embodiment of the present invention.

[0027] FIG. 7 shows a schematic diagram of a circuit for detecting over temperature of MOSFET junction in accordance with yet another embodiment of the present invention.

[0028] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of embodiment and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting.

DETAILED DESCRIPTION

[0029] Hereinafter, embodiments of the present disclosure will be described in detail with reference to the drawings.

[0030] FIG. 3 shows a graph of a MOSFET R_{dson} (drain-to-source on resistance) curve as a function of junction temperature. It is observed that as the junction temperature increases, the drain-to-source on resistance (R_{dson}) increases approximatively linearly.

[0031] FIG. 4 shows a graph of a MOSFET R_{dson} (drain-to-source on resistance) curve as a function of gate bias (V_{gs}) and drain current (I_d). It is observed that when the gate bias (V_{gs}) is larger than a certain value (for

example, 5.5V), the drain-to-source on resistance (R_{dson}) is independent of the drain current (I_d). Under this condition, the drain-to-source on resistance (R_{dson}) is only relevant to the junction temperature.

[0032] Based on the R_{dson} features of the MOSFET explained above, provided is a method for detecting overheat condition of MOSFET junction.

[0033] FIG 5 shows a schematic diagram of a circuit for detecting over temperature of MOSFET junction in accordance with an embodiment of the present invention. With reference to FIG. 5, a circuit (10) is provided for detecting over temperature of junction of a MOSFET (12). The circuit (10) includes the MOSFET (12), a sense resistor (R_s) connected in series to source or drain of the MOSFET (12), an amplifier (14) for amplifying a voltage (V_r) across the sense resistor (R_s) by a predetermined value (K), and a comparator (16) for comparing the amplified voltage (KV_r) with a drain voltage (V_{ds}) of the MOSFET (12) and generating an over temperature signal (V_0) based on the comparison.

[0034] Setting Parameter

With reference to FIG. 5, when the MOSFET (12) is turned on (i.e., $V_{gs}=1$) and temperature is lower than a certain temperature (T), it can be described as, $< K * V_r$. When the temperature increases and becomes higher than the certain temperature (T), the drain voltage (V_{ds}) will be larger than the amplified voltage (KV_r).

[0035] Circuit Work Theory

The comparator (16) is designed to generate the over temperature signal based on the comparison of the drain voltage (V_{ds}) of the MOSFET and the amplified voltage (KV_r). When $V_{gs}=1$ and the drain voltage (V_{ds}) exceeds the amplified voltage (KV_r), the output (V_0) of the comparator (16) will change from 0 to 1, or from 1 to 0 according to the specific circuit arrangement. When $V_{gs}=1$ and the drain voltage (V_{ds}) exceeds the amplified voltage (KV_r) but the drain voltage (V_{ds}) and the amplified voltage (KV_r) are almost equal, it can be

described as in equations (1) and (2) according to the circuit in FIG. 5. I is the current flow through the MOSFET and the sense resistor (R_s).

$$V_{ds} = K * V_r \quad (1)$$

$$I * (R_{dson}(T) + R_s) = I * R_s * K \quad (2)$$

[0036] From these equations, K can be derived as,

$$K = 1 + R_{dson}(T)/R_s \quad (3)$$

[0037] Now, based on the graph showing the relation of the drain-to-source on resistance (R_{dson}) and the junction temperature as in FIG. 3, the equation (4) below is obtained.

$$R_{dson}(T) = J * R_{dson}(25^\circ C) \quad (4)$$

[0038] For a certain MOSFET, $R_{dson}(25^\circ C)$ and J are certain values. Then, K is obtained as below based on the equations (3) and (4).

$$K = 1 + J * R_{dson}(25^\circ C)/R_s \quad (5)$$

[0039] Result

If an operator wants to protect the MOSFET (12) at a temperature T_1 , then J_1 can be obtained, and then K_1 can be obtained as described above. The amplifier (14) can be set to amplify the voltage (V_r) by K_1 . Accordingly, the circuit (10) operates to generate an over temperature signal (V_0) when the MOSFET junction temperature exceeds T_1 .

[0040] One example circuit arrangement for detecting over temperature of MOSFET junction is described with reference to FIG. 6. A circuit (20) for detecting over temperature of MOSFET junction includes a MOSFET (22). The MOSFET (22) can be N-type or P-type. Here, N-type MOSFET is used for description. The circuit (20) further includes an amplifier (U2A), a

comparator (U1A) and an AND gate (U3A). A sense resistor (R_{s1}) can be provided to be connected in series to source of the MOSFET (22). A (+) input of the amplifier (U2A) is connected between the MOSFET (22) and the sense resistor (R_{s1}). Another resistor (R_2) is provided to a (-) input of the amplifier (U2A). A variable resistor (R_3) can be provided across the (-) input of the amplifier (U2A) and an output of the amplifier (U2A) in order to predetermine an over temperature value. The output of the amplifier (U2A) is explained as the equation (6), and the amplification value (K) is provided as the equation (7). I is the current flow through the MOSFET (22) and the sense resistor (R_{s1}).

$$K * V_r = I * R_{s1} * K \quad (6)$$

$$K = \frac{R_3}{R_2} + 1 \quad (7)$$

[0041] The output of the amplifier (U2A) is connected to the (-) input of the comparator (U1A). The comparator (U1A) is also provided with a drain voltage (V_{ds}) of the MOSFET (22) at the (+) input of the comparator (U1A). The drain voltage (V_{ds}) is explained as the equation (8) below.

$$V_{ds} = I * (R_{dson}(t) + R_{s1}) \quad (8)$$

[0042] The comparator (U1A) is designed to compare the drain voltage (V_{ds}) with the output value of the amplifier (U2A), that is, the amplified voltage (KV_r), and determine if the drain voltage (V_{ds}) is larger than the output value of the amplifier (U2A). The comparator (U1A) then can generate an over temperature signal (V_0) based on the comparison.

[0043] The over temperature signal (V_0) of the comparator (U1A) and the gate bias (V_{gs}) of the MOSFET (22) can be inputted to the AND gate (U3A) and the AND gate (U3A) generates a signal to a controller.

When the MOSFET (22) is turned on (that is, when $V_{gs}=1$), V_r is a current sense value which is explained as equation (9) when I is the current flow through the MOSFET (22) and the sense resistor (R_{s1}).

$$V_r = I * R_{s1} \quad (9)$$

[0044] The V_r can be inputted to the amplifier (U2A) so that it is amplified to $I * R_{s1} * K$, where $K=R_3/R_2+1$.

[0045] Parameters can be set under the condition that $V_{gs}=1$. First, when junction temperature is less than a temperature such as T degree, it can be described as,

$$V_{ds} = I * (R_{dson}(T) + R_{s1}) < K * I * R_{s1} \quad (10)$$

[0046] Then, the comparator (U1A) will output a low level, for example, $V_0=0$. When junction temperature is higher than a temperature such as T degree, it can be described as,

$$V_{ds} = I * (R_{dson}(T) + R_{s1}) > K * I * R_{s1} \quad (11)$$

[0047] Then, the comparator (U1A) will output a high level, for example, $V_0=1$. The over temperature signal (V_0) and the value of the gate bias (V_{gs}) can be inputted to the AND gate (U3A), and the AND gate (U3A) will output a high level signal to the controller when $V_{gs}=1$ and the comparator (U1A) outputs $V_0=1$. The AND gate (U3A) will output a low level signal to the controller when $V_{gs}=1$ and $V_0=0$, or when $V_{gs}=0$.

[0048] FIG. 7 shows another example circuit arrangement for detecting over temperature of MOSFET junction. With reference to FIG. 7, an XOR gate (U3A) is provided instead of the AND gate in FIG. 6. The other elements of the circuit are the same as provided in FIG. 6.

[0049] A circuit (30) for detecting over temperature of MOSFET junction includes a MOSFET (22) which can be N-type or P-type. Here, N-type MOSFET is used for description. The circuit (30) further includes an amplifier (U2A), a comparator (U1A) and an XOR gate (U3A). A sense resistor (R_{s1}) can be provided to be connected in series to source of the MOSFET (22). A (+) input of the amplifier (U2A) is connected between the MOSFET (22) and the sense resistor (R_{s1}). Another resistor (R_2) is provided to a (-) input of the amplifier (U2A). A variable resistor (R_3) can be provided across the (-) input of the amplifier (U2A) and an output of the amplifier (U2A) in order to predetermine an over temperature value. The output of the amplifier (U2A) is explained as the equation (1), and the amplification value (K) is provided as the equations (6) and (7), as described above.

[0050] The output of the amplifier (U2A) is connected to the (+) input of the comparator (U1A). The comparator (U1A) is also provided with a drain voltage (V_{ds}) of the MOSFET (22) at the (-) input of the comparator (U1A). The drain voltage (V_{ds}) is explained as, $V_{ds} = I * (R_{dson}(t) + R_{s1})$.

[0051] The comparator (U1A) is designed to compare the drain voltage (V_{ds}) with the output value of the amplifier (U2A), that is, the amplified voltage (KV_r), and determine if the drain voltage (V_{ds}) is larger than the output value of the amplifier (U2A). The comparator (U1A) then can generate an over temperature signal (V_0) based on the comparison.

[0052] The over temperature signal (V_0) of the comparator (U1A) and the gate bias (V_{gs}) of the MOSFET (22) can be inputted to the XOR gate (U3A) and the XOR gate (U3A) generates a signal to a controller.

[0053] When the MOSFET (22) is turned on (that is, when $V_{gs}=1$), V_r is explained as, $V_r = I * R_{s1}$, when I is the current flow through the MOSFET (22) and the sense resistor (R_{s1}). The V_r can be inputted to the amplifier (U2A) so that it is amplified to $I * R_{s1} * K$, where $K=R_3/R_2+1$, as described with reference with FIG. 6.

[0054] Parameters can be set under the condition that $V_{gs}=1$. First, when junction temperature is less than a temperature such as T degree, it can be described as,

$$V_{ds} = I * (R_{dson}(T) + R_{s1}) < K * I * R_{s1} \quad (10)$$

[0055] Then, the comparator (U1A) will output a high level, for example, $V_0=1$. When junction temperature is higher than a temperature such as T degree, it can be described as,

$$V_{ds} = I * (R_{dson}(T) + R_{s1}) > K * I * R_{s1} \quad (11)$$

[0056] Then, the comparator (U1A) will output a low level, for example, $V_0=0$. The over temperature signal (V_0) and the gate bias (V_{gs}) can be inputted to the XOR gate (U3A), and the XOR gate (U3A) will output a high level signal to the controller when $V_{gs}=1$ and the comparator (U1A) outputs $V_0=0$. The XOR gate (U3A) will output a low level signal to the controller when $V_{gs}=0$ and $V_0=0$, or $V_{gs}=1$ and $V_0=1$.

[0057] According to the present invention, the over temperature signal can be generated at a programmable temperature using the relation between $R_{dson}(t)$ and the junction temperature as shown in FIG. 3. Without using a temperature sensor, the junction temperature can be detected directly with high precision, high speed of detection and high response rate.

[0058] It should be understood that the above only illustrates and describes examples whereby the present invention may be carried out, and that modifications and/or alterations may be made thereto without departing from the spirit of the invention.

[0059] It should also be understood that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention which are, for brevity, described

in the context of a single embodiment, may also be provided or separately or in any suitable subcombination.

CLAIMS

1. A circuit for detecting junction temperature of a MOSFET, comprising:
a MOSFET;
a sense resistor connected in series to drain or source of the MOSFET;
an amplifier for amplifying a voltage (V_r) across the sense resistor by a predetermined value (K), and
a comparator for comparing the amplified voltage (KV_r) with a drain voltage (V_{ds}) of the MOSFET.
2. The circuit of claim 1, wherein a Drain-to-Source On Resistance (R_{dson}) of the MOSFET represents junction temperature based on a linear relation between the R_{dson} and junction temperature of the MOSFET.
3. The circuit of claim 2, wherein the drain voltage (V_{ds}) is described as $V_{ds} = I * (R_{dson}(t) + R_s)$, where $R_{dson}(t)$ is a Drain-Source on Resistance of the MOSFET as a function of junction temperature (t) of the MOSFET, R_s is a resistance of the sense resistor, and I is the current flow through the MOSFET and the sense resistor.
4. The circuit of claim 1, wherein a (+) input of the amplifier is connected between the MOSFET and the sense resistor.
5. The circuit of claim 1, further comprising a variable resistor provided across a (-) input of the amplifier and an output of the amplifier.
6. The circuit of claim 5, wherein the variable resistor is provided to predetermine an over temperature value.
7. The circuit of claim 1, wherein the comparator is provided to receive the amplified voltage (KV_r) and the drain voltage (V_{ds}) of the MOSFET as inputs.

8. The circuit of claim 1, wherein the comparator is configured to generate an over temperature signal (V0) based on the comparison.
9. The circuit of claim 8, wherein the comparator is configured to generate the over temperature signal (V0) when the drain voltage (Vds) of the MOSFET is determined to be larger than the amplified voltage (KVr).
10. The circuit of claim 1, further comprising an AND gate or an XOR gate configured to receive the over temperature signal.
11. The circuit of claim 10, the AND gate or the XOR gate receives gate bias (Vgs) of the MOSFET and outputs a signal to a controller.
12. A method for detecting junction temperature of a MOSFET comprising:
 - turning on the MOSFET;
 - amplifying a voltage (Vr) across a sense resistor by a predetermined value (K), the sense resistor being connected in series to drain or source of the MOSFET;
 - comparing the amplified voltage (KVr) with a drain voltage (Vds) of the MOSFET;
 - determining if the drain voltage (Vds) of the MOSFET is larger than the amplified voltage (KVr); and
 - generating an over temperature signal based on the determination.
13. The method of claim 12, wherein generating an over temperature signal based on the determination comprises generating an over temperature signal when the drain voltage (Vds) of the MOSFET is larger than the amplified voltage (KVr).
14. The method of claim 12, wherein a Drain-to-Source On Resistance (Rdson) of the MOSFET represents junction temperature based on a linear relation between the Rdson and junction temperature of the MOSFET.

15. The circuit of claim 14, wherein the drain voltage (V_{ds}) is described as $V_{ds} = I * (R_{dson}(t) + R_s)$, where $R_{dson}(t)$ is a Drain-Source on Resistance of the MOSFET as a function of junction temperature (t) of the MOSFET, R_s is a resistance of the sense resistor, and I is the current flow through the MOSFET and the sense resistor.

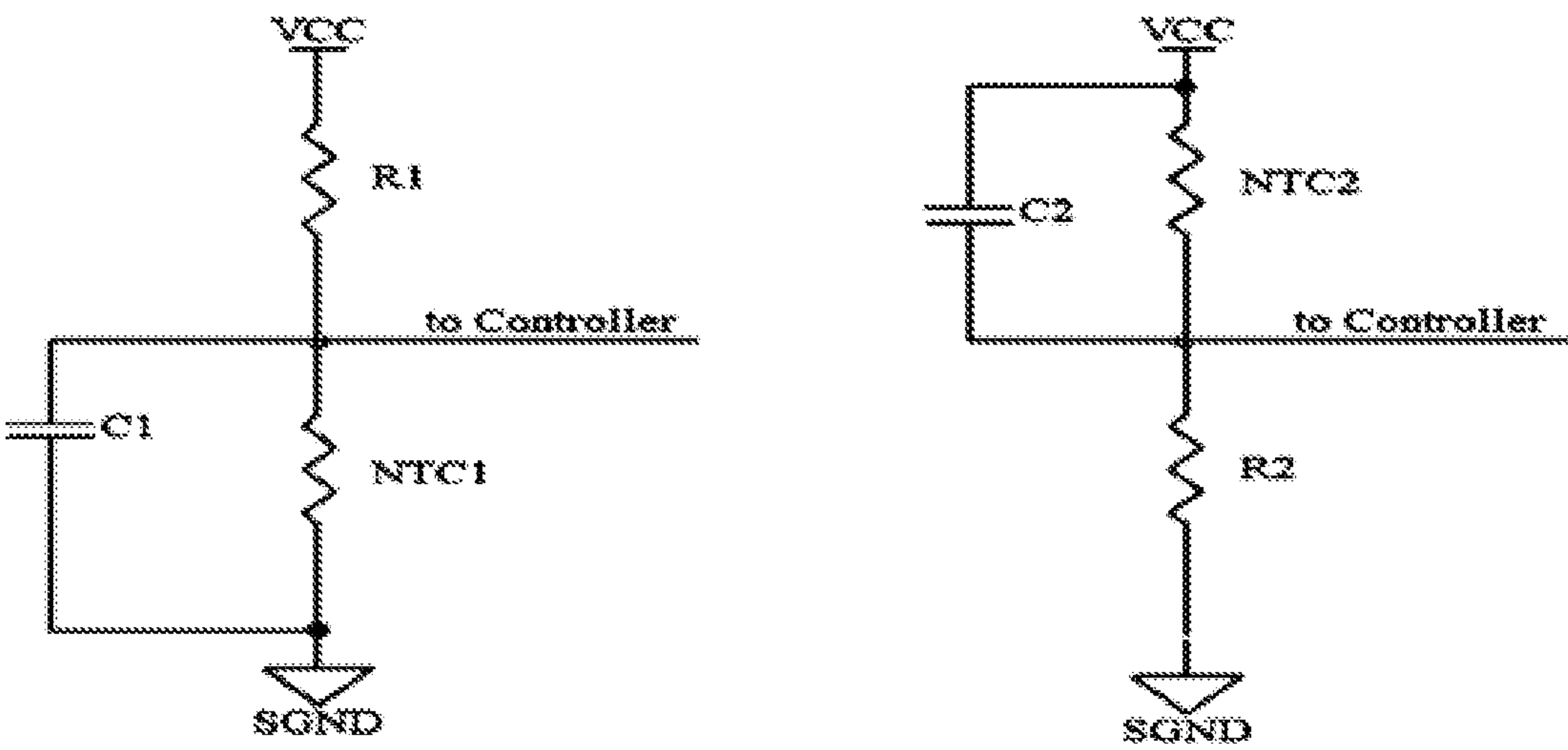


FIG. 1

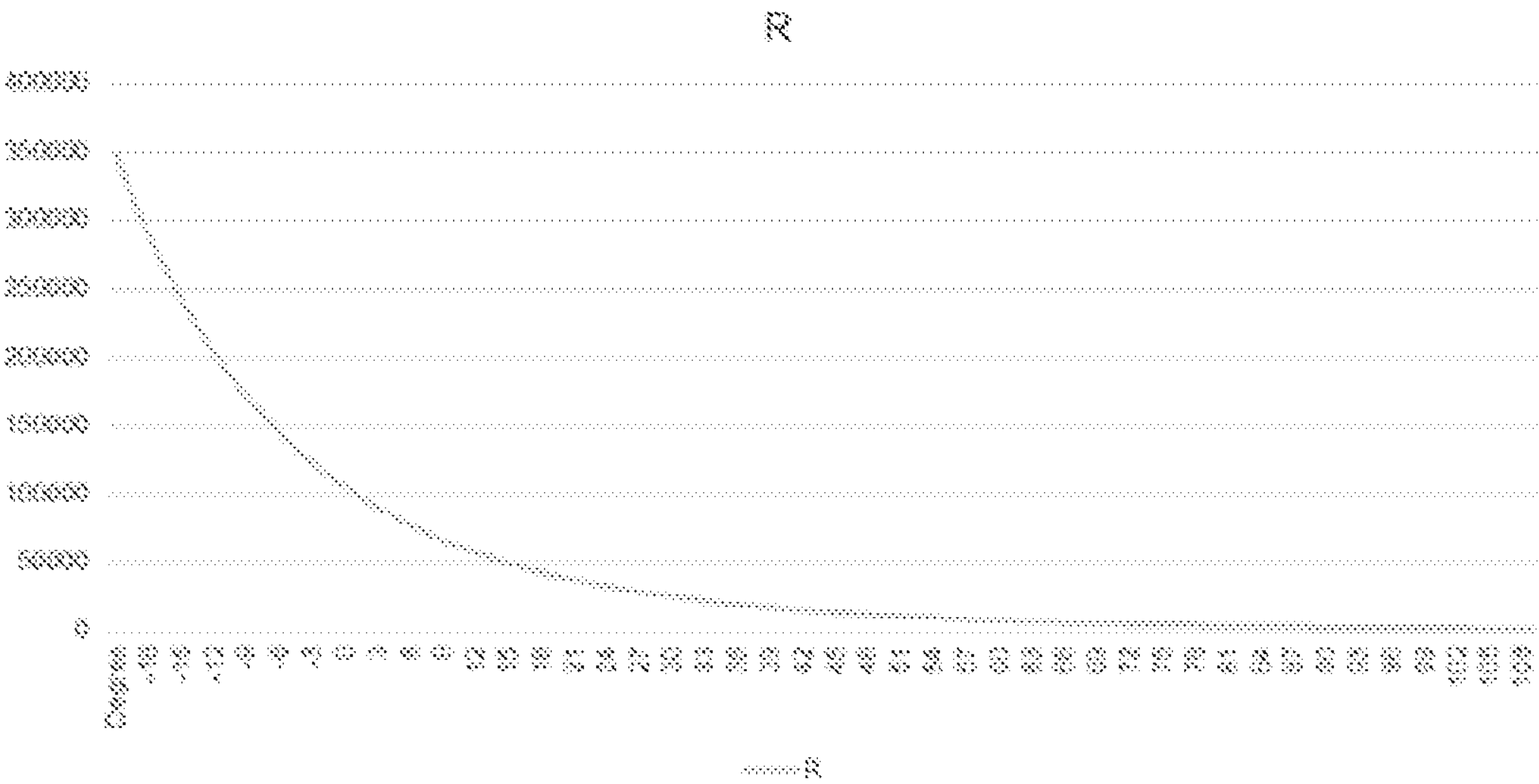


FIG. 2

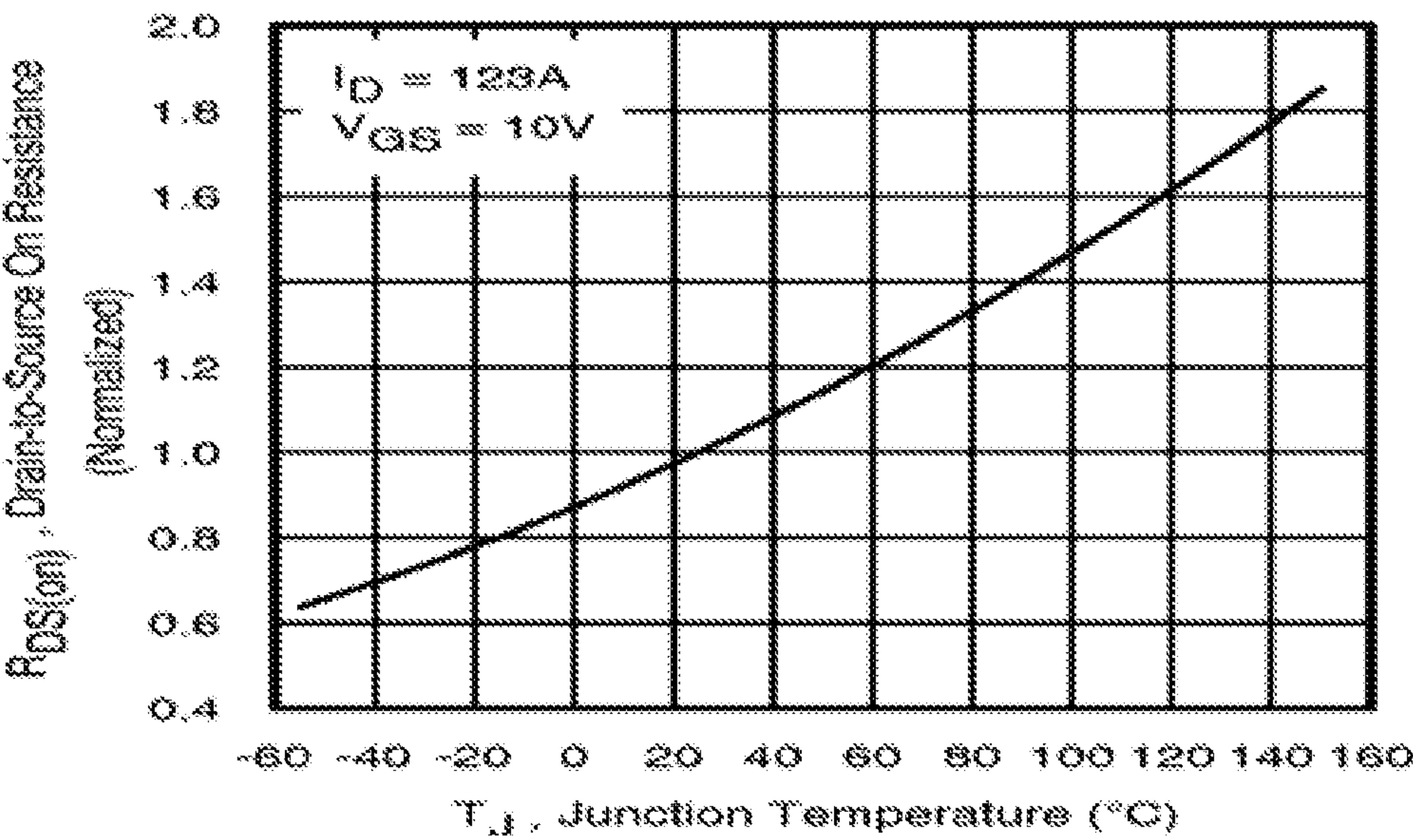


FIG. 3

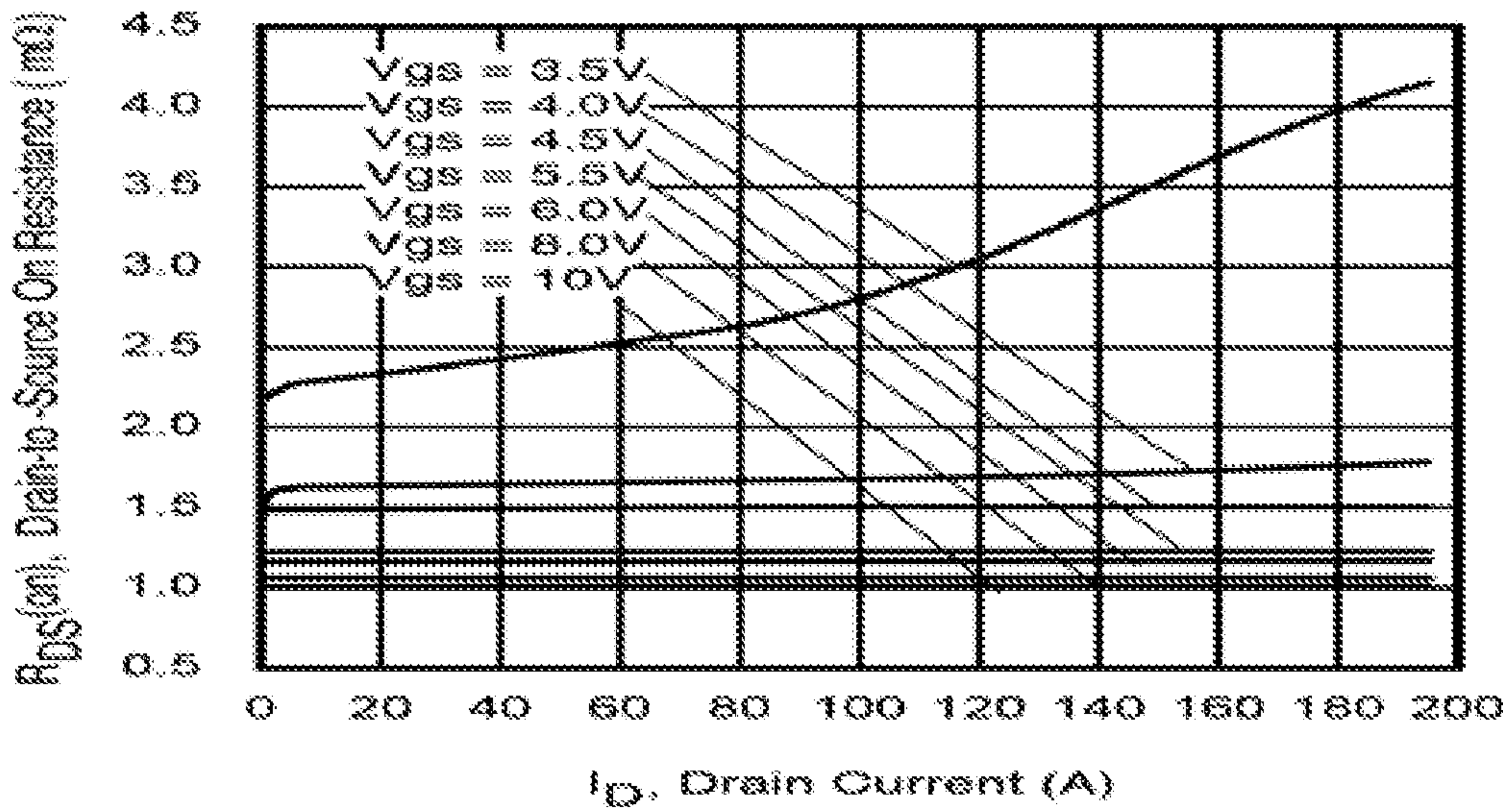


FIG. 4

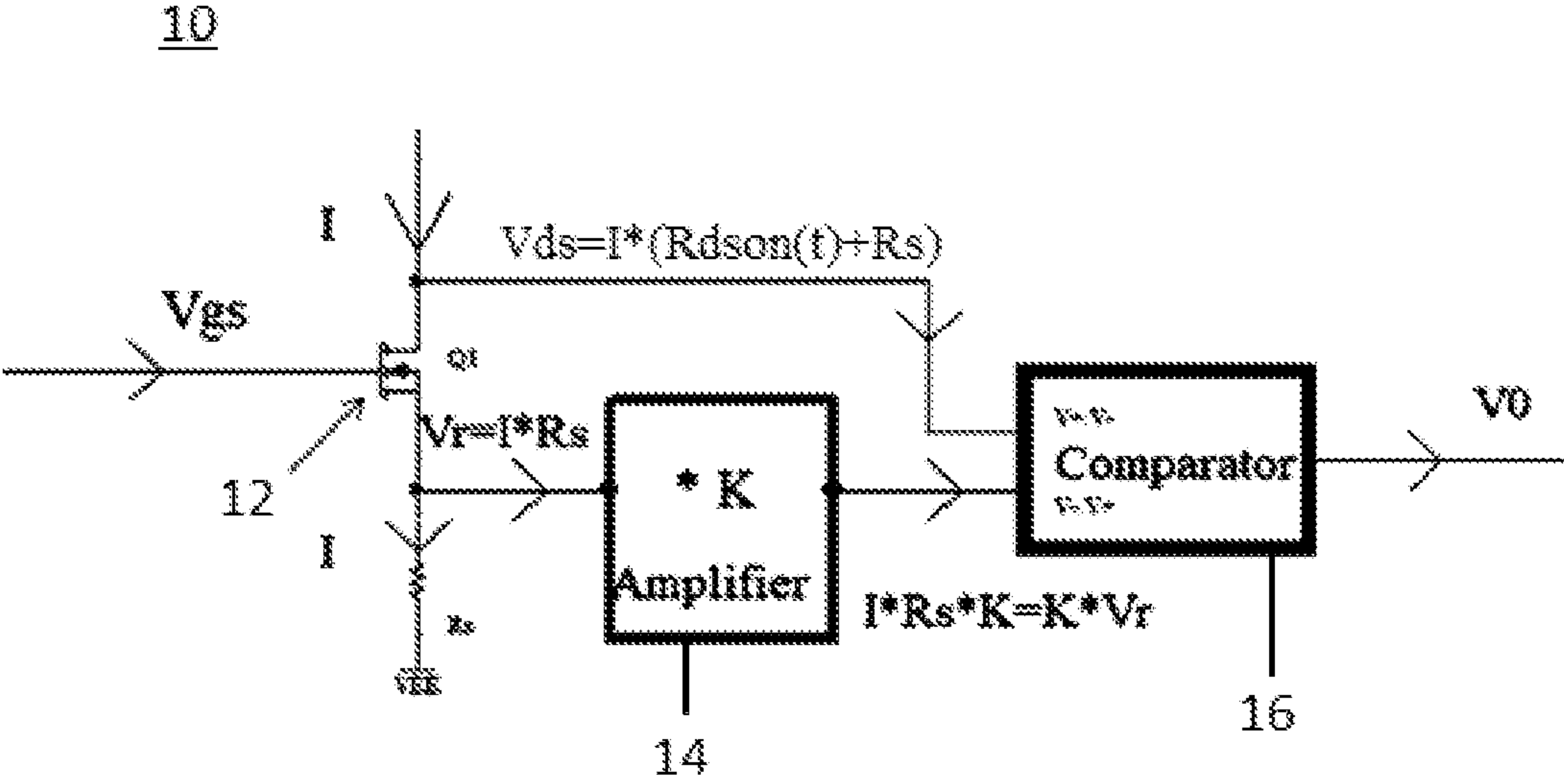
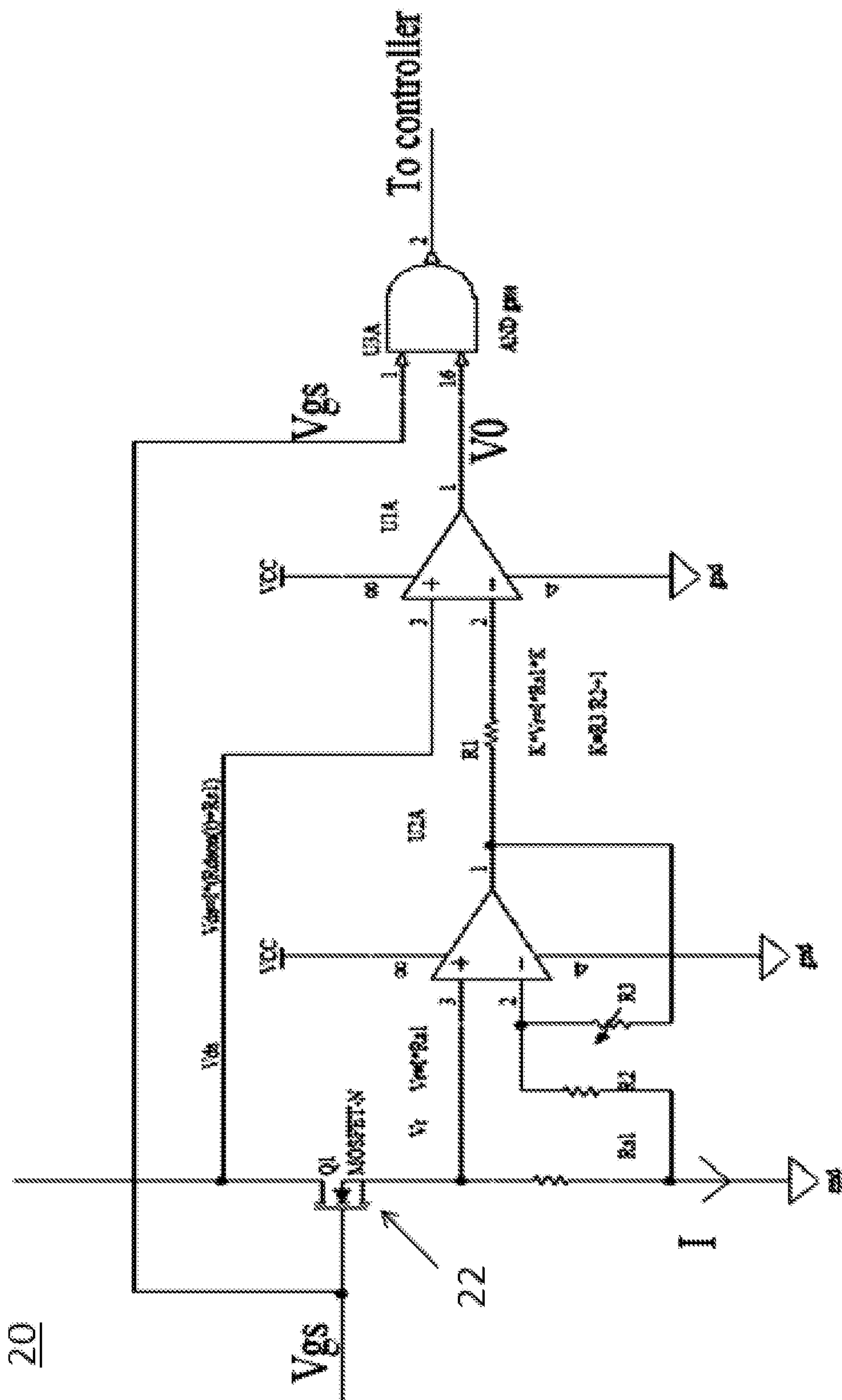


FIG. 5



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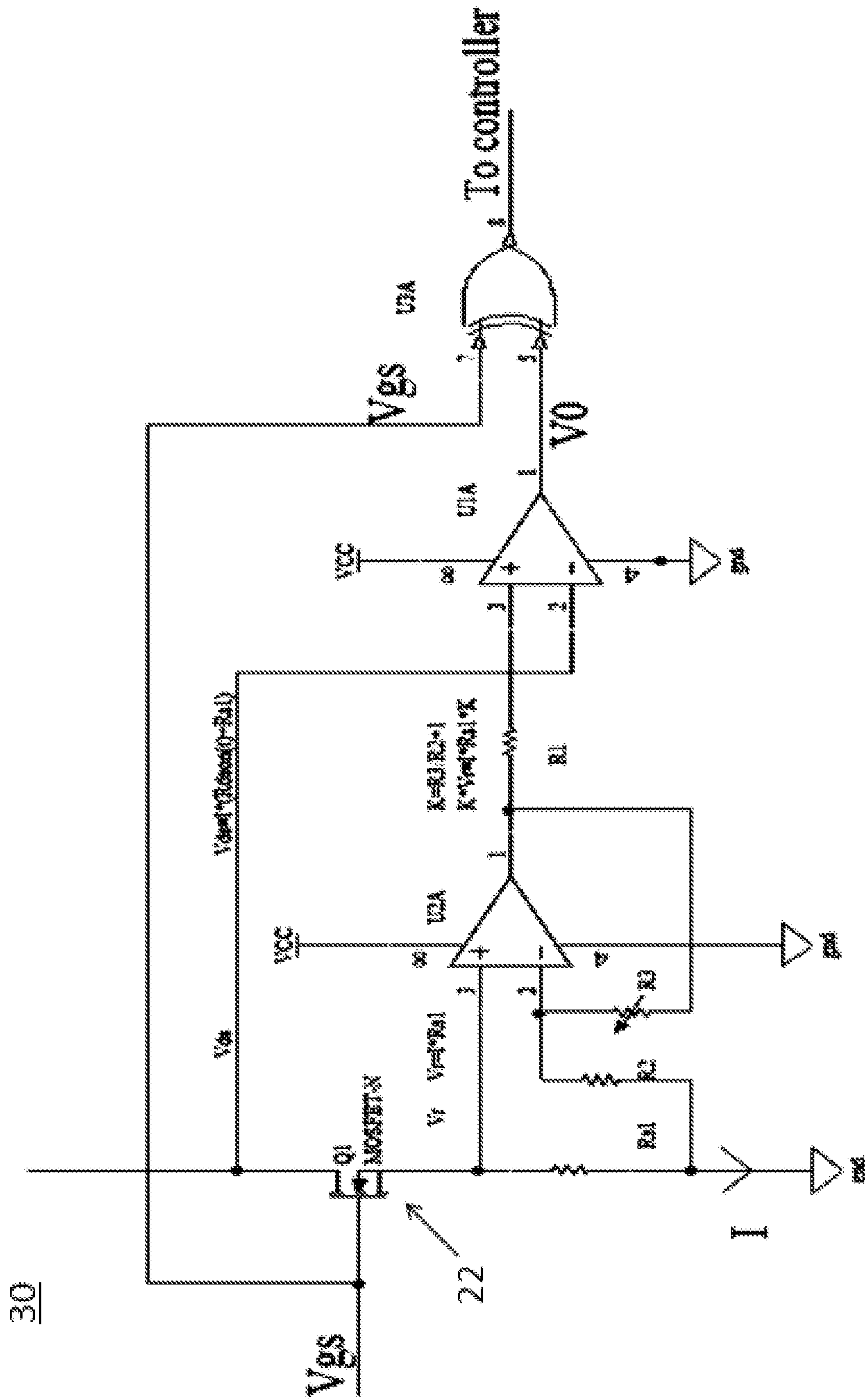


FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2019/125932

A. CLASSIFICATION OF SUBJECT MATTER

G01K 7/01(2006.01)i; G01R 31/26(2014.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01K7/-; G01R31/-

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNABS,CNTEXT,EPODOC,WPI,WOTXT,USTXT,TWABS,CNKI: circuit,junction,temperature,over,heat,NTC,MOSFET, resistor,drain,source,voltage,amplify,series,compare,response

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 209542769 U (CHINA MINING DRIVES & AUTOMATION CO., LTD.) 25 October 2019 (2019-10-25) abstract, description paragraphs [0002]-[0027], figures 1-4	1-15
A	CN 109061375 A (BEIJING JIAOTONG UNIVERSITY et al.) 21 December 2018 (2018-12-21) the whole document	1-15
A	US 5796290 A (NEC CORPORATION) 18 August 1998 (1998-08-18) the whole document	1-15
A	US 7359172 B2 (INTERNATIONAL RECTIFIER CORPORATION) 15 April 2008 (2008-04-15) the whole document	1-15
A	US 2017317669 A1 (RENESAS ELECTRONICS CORPORATION) 02 November 2017 (2017-11-02) the whole document	1-15
A	JP 6007578 B2 (FUJI ELECTRIC CO., LTD.) 12 October 2016 (2016-10-12) the whole document	1-15

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Information on patent family members

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