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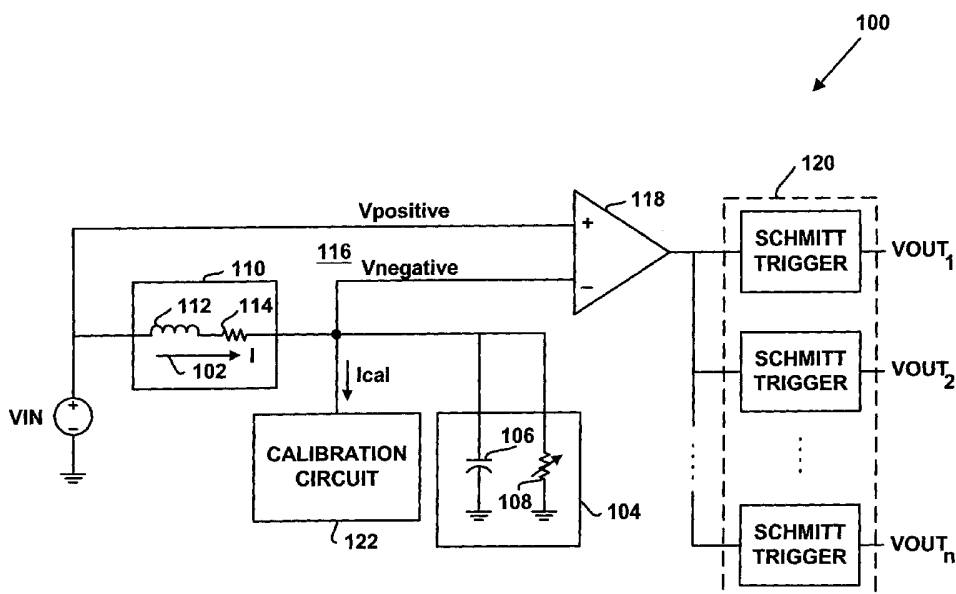
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- (71) Applicant: **SHAKTI SYSTEMS, INC.** [US/US]; 2259 Palmer Circle, Naperville, IL 60564 (US).
- (72) Inventors: **SHENAI, Krishna**; 2259 Palmer Circle, Naperville, IL 60564 (US). **MCSHANE, Erik, A.**; 17312 S. Parker Road, Lockport, IL 60441 (US).
- (74) Agent: **IRVINE, Robert, J.**; McDonnell Boehnen Hulbert & Berghoff, 300 South Wacker Drive, Suite 3200, Chicago, IL 60606 (US).
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(54) Title: CURRENT DERIVATIVE SENSOR



(57) Abstract: A system and method for detecting, measuring, and reporting a time derivate of a current signal (di/dt) is provided. A sensing element (110) detects current from a load (104). The sensing element includes an inductor (112). The inductor is located in series with the load and includes associated parasitic resistance (114). A differential potential develops across the inductor and the parasitic resistance. The differential potential is amplified and converted to a single-ended value. The single-ended value is then fed to an analog to digital converter (120) that provides an output representative of di/dt .



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Current Derivative Sensor

RELATED APPLICATION

This application claims priority to and incorporates by reference U.S. Provisional
5 Application Serial No. 60/311,653 filed August 10, 2001.

FIELD

The present invention relates generally to current sensors, and more particularly,
relates to a current derivative sensor.

10

BACKGROUND

The ability to detect, measure, and record a rate of current change may be critical
in high-speed electronic applications. The rate of current change may be referred to as a
slope of a current signal, or alternatively, as a time derivative of a current signal (di/dt).
15 The rate of the current change may be important when accounting for unwanted noise,
such as electromagnetic interference (EMI) and radio-frequency interference (RFI),
generated by high-speed circuits. However, most current sensors detect and measure only
the magnitude of the current, and not the rate of current change.

Often the slope of the current signal is determined using computer simulation
20 techniques, such as finite element analysis, lumped element simulation, and behavioral
modeling. These computer techniques can become computationally intensive and include
limiting assumptions, which may reduce the accuracy of the simulation result. Therefore,
it would be beneficial to make a direct measurement of di/dt using a current derivative
sensor.

25

SUMMARY

A current derivative sensor and a method for detecting, measuring, and recording a time derivative of a current signal (di/dt) are provided. A sensing element detects current. The current flows through the sensing element, generating a differential potential across the sensing element. A gain circuit amplifies and converts the differential potential to a single-ended output. An analog to digital converter converts the single-ended output and provides an output representative of di/dt .

BRIEF DESCRIPTION OF THE DRAWINGS

Presently preferred embodiments are described below in conjunction with the appended drawing figures, wherein like reference numerals refer to like elements in the various figures, and wherein:

Fig. 1 is a circuit diagram of a current derivative sensor, according to an exemplary embodiment;

Fig. 2A is a circuit diagram of a current derivative sensor, according to another exemplary embodiment;

Fig. 2B is a circuit diagram of a current derivative sensor, according to another exemplary embodiment;

Fig. 3A is a circuit diagram of a calibration circuit, according to an exemplary embodiment;

Fig. 3B is a circuit diagram of a calibration circuit, according to another exemplary embodiment;

Fig. 4 is a graph of selectivity of the sensor, according to an exemplary embodiment; and

Fig. 5 is a flow chart diagram of a method of measuring a time derivative of a current signal (di/dt), according to an exemplary embodiment.

DETAILED DESCRIPTION

5 Fig. 1 is a circuit diagram of a current derivative sensor 100, according to an exemplary embodiment. The current derivative sensor 100 may include a sensing element 110, a gain circuit 118, an analog to digital (A/D) converter 120, and a calibration circuit 122. The sensor 100 may be a standalone device that can be inserted into a desired circuit to make measurements, or it may be fabricated on a die and
10 interconnected to circuits on a separate die, or may be fabricated on the same die as the circuit being measured.

The current derivative sensor 100 may be designed to monitor current 102. The current 102 may be composed of both a DC component and a transient component. The current 102 may be generated by a load 104. The load 104 may be any conductor that can
15 generate a transient current signal, such as integrated circuit interconnect metallization, integrated circuit polysilicon, silicided silicon connectors, printed circuit board traces, insulated wires, and non-insulated wires. For the sake of simplicity, the load 104 is depicted in Fig. 1 as a parallel combination of a capacitor 106 and a variable resistor 108.

The current 102 may be detected by the sensing element 110. The sensing
20 element 110 preferably includes an inductor 112 placed in series with the load 104. A parasitic resistance may be associated with the inductor 112. The parasitic resistance is depicted in Fig. 1 as a resistor 114 located in series with the inductor 112. Other devices may also be included within the sensing element 110.

The current 102 may cause a differential potential 116 to develop across the series
25 combination of the inductor 112 and the resistor 114 between the electrical nodes labeled

in Fig. 1 as V_{positive} and V_{negative} . The differential potential 116 may be generated from substantially three origins. A first origin may be a DC potential produced when the current 102 flows through the resistor 114. A second origin may be a transient potential produced when the current 102 flows through the resistor 114. A third origin may be transient potential produced when the current 102 flows through the inductor 112. The differential potential 116 may be defined by the following equation:

$$v(t) = (I + i(t))R + L(di/dt) \quad \text{Equation 1}$$

where: $v(t)$ is the differential potential 116;

I is the DC current flowing through the resistor 114;

10 $i(t)$ is the transient current flowing through the resistor 114;

R is the resistance from resistor 114;

L is the inductance from inductor 112; and

di/dt is the transient current flowing through the inductor 112.

The current derivative sensor 100 may be designed to measure substantially the third origin of the differential potential 116, which is the transient current di/dt flowing through the inductor 112.

The calibration circuit 122 may be used to calibrate the current derivative sensor 100. The calibration circuit 122 may be used to measure the parasitic resistance. Additionally, the calibration circuit 122 may be used to determine an accurate value of inductance of the inductor 112, which may be needed to correlate the differential potential 116 to the magnitude of the di/dt event. The details of the calibration circuit 122 are discussed below.

The gain circuit 118 may be used to amplify and convert the differential potential 116 to a single-ended output. The gain circuit 118 may be a differential-input, single-ended output operational amplifier (op amp). The addition of single-ended gain circuits

202 located at an output of the op amp may be beneficial for amplifying small differential potentials, as shown in Fig. 2A. Alternatively, additional differential-input, single-ended output gain circuits 204 located at the output of the op amp may be used to provide additional amplification for small differential potentials, as shown in Fig. 2B.

5 Referring back to Fig. 1, an output of the gain circuit 118 may be connected to the A/D converter 120, one embodiment of which is shown as a plurality of switches. While Schmitt triggers are used in a preferred embodiment, other switching devices or combination of devices that can be triggered may also be employed.

The Schmitt triggers may be configured such that LOW-to-HIGH input transition
10 voltages are monotonically increasing from substantially a ground potential to a maximum supply voltage. The LOW-to-HIGH input transition voltage may be a value of voltage that causes a switch to change states from off to on. Alternatively, the LOW-to-HIGH input transition voltages may be monotonically increasing for a range of voltages located between the ground potential and the maximum supply voltage.

15 Additionally, the Schmitt triggers may be configured such that HIGH-to-LOW input transition voltages are substantially at the maximum supply voltage. The HIGH-to-LOW input transition voltage may be a value of voltage that causes a switch to change states from on to off.

In further alternative embodiments, the A/D converter 120 may be implemented
20 using a series of voltage comparators having different reference voltages. Other suitable alternative analog to digital conversion techniques and circuits may also be used.

When a small di/dt event occurs, only the Schmitt triggers with a LOW-to-HIGH input transition voltage near the ground potential may change to a HIGH output. A larger di/dt event may cause an increasing number of the Schmitt triggers to change to a HIGH

output. A change in state to a HIGH output may be maintained until the A/D converter 120 is reset.

Before being reset, the output of the A/D converter 120 may be detected providing an actual measurement of di/dt . The output of the A/D converter 120 may be displayed
5 on a thermometer-type scale readout. (The thermometer-type scale readout is not shown in Fig. 1.) For example, if none of the switches have changed to a HIGH output, then the readout may be substantially zero or at the bottom of the scale. As the number of switches that have changed to a HIGH output increases, the readout may be increased accordingly up the scale. When all of the switches have changed to a HIGH output, the
10 readout may be substantially at full scale. This scale readout may be recorded. While the thermometer-type scale readout is used in a preferred embodiment, other methods of displaying the output of the A/D converter 120 may also be employed.

In an alternative embodiment, the switch values may be converted to a binary number representing the number of switches in the HIGH state. For example, if there are
15 seven switches, and a given output of gain circuit 118 causes the first five switches to change state (e.g., to a HIGH output from a LOW output), then the switch outputs may be converted by an encoder circuit (not shown) into the binary value "101". A suitable encoder circuit may be implemented using a digital counter to count the number of switch outputs in the HIGH state, a look-up table, a combinational logic circuit, etc.

20 Alternatively, the output of the A/D converter 120 may correspond to a memory address, such as a Read-Only-Memory (ROM) address. For this example, "101" may be stored in a ROM address corresponding to the first five switches being in the HIGH state.

Fig. 3A is a circuit diagram of a calibration circuit 300, according to an exemplary embodiment. The calibration circuit 300 is substantially the same as the calibration
25 circuit 122 as shown in Fig. 1. The calibration circuit 300 includes a plurality of

precision matched current sources 302 of substantially the same DC magnitude, I . The plurality of current sources 302 may be connected in parallel through independently controlled switches 304. Fig. 3A depicts the switches as field-effect transistors; however, other switches may be used. The independently controlled switches 304 may be
5 controlled by a variety of devices, such as a microcontroller.

Activating a single leg of the parallel network of current sources 302 by closing one or more of the switches 304 may generate a known value of DC current when the current through the inductor 112 has reached steady state. Using the known value of DC current, a differential potential 116 may develop across resistor 114 and be amplified by
10 the gain circuit 118. The A/D converter 120 may detect the amplified differential potential signal. The output of the A/D converter 120 may be used to determine the value of the parasitic resistance, depicted in Fig. 1 as resistor 114.

Using the value of the parasitic resistance, the calibration circuit 300 may determine an accurate value of inductance of inductor 112, which may be needed to
15 correlate the differential potential 116 to the magnitude of the di/dt event. A current with a known di/dt may be generated by incrementally activating successive legs of the parallel network of current sources 302 by closing the switches 304 one at a time. With each successive activation, the current generated may be increased by substantially the DC magnitude, I , of the current sources 302. Because the calibration circuit 300 is able to
20 account for the contribution of the parasitic resistance, the circuit may accurately determine, or measure, the inductance. As seen with reference to Equation 1, the inductance is equal to the difference between the differential potential 116 and the contribution of the parasitic resistance, divided by the known di/dt .

A clock circuit or a timer may be used to control the successive activation of the
25 legs of the parallel network of current sources 302. (The clock circuit and timer are not

shown in Fig. 3A.) As shown in Fig. 3B, a filter 306 may be added to the calibration circuit 300, as the current waveform generated will have a staircase response. For example, the filter 306 may be a low pass filter. The addition of the low pass filter 306 may smooth the waveform, which may be a closer approximation of a ramp with a
5 constant di/dt . Alternatively, because the ramp response ideally contains only odd-order harmonics, a filter 306 operable to remove even-order harmonics may be added to the calibration circuit 300.

In an alternative embodiment, the calibration circuit 300 may include a control circuit. (The control circuit is not shown in Fig. 1.) The control circuit may include a
10 microcontroller. Alternatively, the control circuit may include a logic circuit providing combinational and/or sequential logic. For example, the logic circuit may be a state machine.

The control circuit may be operable to provide the known value of DC current by controlling the operation of independently controlled switches 304. The control circuit
15 may open and close switches 304 based on what type of calibration is being performed.

In addition, the control circuit may receive voltage information from the output of the gain circuit 118 and/or the A/D converter 120. The control circuit may receive the voltage information for various DC current values. For example, the control circuit may receive the voltage information for different combinations of switches 304 being opened
20 and closed. The control circuit may store the voltage information for the various DC current values.

When the current derivative sensor 100 is operating, the control circuit may receive the voltage information from the output of the gain circuit 118 and/or the A/D converter 120 and subtract the previously stored voltage information for the

corresponding DC level. As such, the control circuit may provide an output signal that has been compensated for the DC component of current.

Additionally, the control circuit may provide an offset value based on the DC component of current to the gain circuit 118. Furthermore, for the A/D embodiment
 5 using voltage comparators, the control circuit may provide the different reference voltages to the voltage comparators. The different reference voltages may or may not be linearly spaced.

To maximize the sensitivity of the current derivative sensor 100, the inductive component of the differential potential 116 may be emphasized, minimizing the resistive
 10 component. Referring back to Equation 1, to emphasize the inductive component, the following equation holds true.

$$L(di/dt) \gg (I + i(t))R \quad \text{Equation 2}$$

The inductive component is related to the quality factor Q of the inductor. The quality factor can be defined as:

$$15 \quad Q = \omega L/R = 2\pi f L/R \quad \text{Equation 3}$$

where: ω is the angular frequency of an AC signal and f is the equivalent frequency in Hertz. If the AC signal is represented by only its fundamental frequency then:

$$di/dt = 2\pi f i \quad \text{Equation 4}$$

Combining Equations 2, 3, and 4 yields the following design equation:

$$20 \quad Q \gg \pi(1 + I/i). \quad \text{Equation 5}$$

The significance of the design equation, Equation 5, on the performance of the sensor is shown graphically in Fig. 4. Fig. 4 depicts the selectivity of the current derivative sensor 100. The selectivity of the current derivative sensor 100 may be defined as the percentage of the differential potential 116 due to the inductive contribution,
 25 $L(di/dt)$.

A ratio is defined between the DC current I and the transient current i . A high ratio may imply that the total current 102 is nearly constant with small transient variations. In this situation, the inductive contribution would not be emphasized, and the selectivity would be low. This may cause the scaled output to be largely a result of the parasitic resistance. On the other hand, a low ratio may imply that the current 102 is dominated by the transient current i .

The impact of the quality factor is also depicted in Fig. 4. A larger value of Q results in a higher selectivity of the inductive contribution. A high value of Q may be indicative of either a high value of di/dt or a low value of resistance 114. Conversely, a low value of Q may be indicative of either a low value of di/dt or a high value of resistance 114.

Fig. 5 depicts a flow chart diagram of a method 500 of measuring a time derivative of a current signal (di/dt). Step 502 is sensing the current. The sensing element 110 may be used to sense the current 102 generated by the load 104. The differential potential 116 may be generated as the current 102 flows through the sensing element 110.

Step 504 is amplifying the differential potential 116. The gain circuit 118 may be used to amplify the differential potential 116. The gain circuit 118 may include additional gain circuits 202, 204 to provide more amplification for small differential potentials. In an alternative embodiment, results from the calibration circuit 300, such as the inductance value, may be used to set the gain of the gain circuit 118.

Step 506 is converting the differential potential 116 to a singled-ended output. This step may be accomplished using the same gain circuit 118 used for amplification in Step 504.

Step 508 is triggering the A/D converter. The A/D converter may be a plurality of Schmitt triggers configured such that the input transition voltage operable to trigger a switch from off to on is monotonically increasing from switch to switch. Only the switches with transition voltages at or below the voltage applied by the gain circuit 118 will turn on. The number of switches that turn on for a given period of time is representative of the time derivative of the current signal 102. The greater the value of voltage at the output of the gain circuit 118, the greater the number of switches that will turn on, which represents a greater rate of current change.

The output of the A/D converter 120 may be displayed on a thermometer-type scale readout, which may then be recorded. In an alternative embodiment, the switch values may be converted to a binary number representing the number of switches in the HIGH state as previously discussed.

The current derivative sensor 100 may be able to detect electromagnetic interference and/or radio-frequency interference. For example, the current derivative sensor 100 may be able to detect di/dt events ranging from 10^3 amps/second (or 1 amp/millisecond) to 10^{12} amps/second (or 1 amp/picosecond). However, other results may be possible based on the effects of the parasitic resistance depicted in Fig. 1 as resistor 114, the quality factor of the inductor 112, and a limit on the gain circuit 118, which may be imposed by the maximum supply voltage. The ability to measure such a wide range of di/dt events makes the current derivative sensor 100 ideally suited for applications involving integrated circuits, printed circuit boards, insulated and non-insulated wiring, and other electrical conductors.

It should be understood that the illustrated embodiments are exemplary only and should not be taken as limiting the scope of the present invention. The claims should not be read as limited to the described order or elements unless stated to that effect.

Therefore, all embodiments that come within the scope and spirit of the following claims and equivalents thereto are claimed as the invention.

WE CLAIM:

1. A current derivative sensor, comprising in combination:
a sensing element operable to detect current, wherein the current flows through the sensing element, thereby generating a differential potential across the sensing element; and
5 an analog to digital converter providing an output representative of a time derivative of a current signal (di/dt).
2. The current derivative sensor of Claim 1, further comprising a gain circuit operable to amplify and convert the differential potential to a single-ended output.
3. The current derivative sensor of Claim 2, wherein the gain circuit is an operational amplifier.
4. The current derivative sensor of Claim 3, wherein the gain circuit includes a single-ended gain circuit located at an output of the operational amplifier.
5. The current derivative sensor of Claim 3, wherein the gain circuit includes a second differential-input, single-ended gain circuit located at an output of the operational amplifier.
6. The current derivative sensor of Claim 1, wherein a load generates the current.

7. The current derivative sensor of Claim 6, wherein the load is a conductor operable to generate a transient current signal.
8. The current derivative sensor of Claim 6, wherein the load is a conductor selected from the group consisting of integrated circuit interconnect metallization, integrated circuit polysilicon, silicided silicon connectors, printed circuit board traces, insulated wires, and non-insulated wires.
9. The current derivative sensor of Claim 1, wherein the sensing element is an inductor located in series with a load.
10. The current derivative sensor of Claim 9, wherein parasitic resistance is associated with the inductor.
11. The current derivative sensor of Claim 1, wherein the differential potential consists of a DC potential produced as the current flows through parasitic resistance located in the sensing element, a transient potential produced as the current flows through the parasitic resistance, and a transient potential produced as the current flows through an
5 inductor in the sensing element.
12. The current derivative sensor of Claim 1, further comprising a calibration circuit operable to determine a parasitic resistance value.
13. The current derivative sensor of Claim 12, wherein the calibration circuit determines an inductive value using the parasitic resistance value.

14. The current derivative sensor of Claim 12, wherein the calibration circuit includes a plurality of precision matched current sources connected in parallel through independently controlled switches.
15. The current derivative sensor of Claim 14, wherein the plurality of precision matched current sources provides substantially identical current magnitudes.
16. The current derivative sensor of Claim 14, wherein the independently controlled switches are field-effect transistors.
17. The current derivative sensor of Claim 1, wherein the analog to digital converter includes a plurality of Schmitt triggers.
18. The current derivative sensor of Claim 17, wherein the plurality of Schmitt triggers are configured with LOW-to-HIGH input transition voltages that are monotonically increasing from substantially a ground potential to a maximum supply voltage.
19. The current derivative sensor of Claim 17, wherein the plurality of Schmitt triggers are configured with HIGH-to-LOW input transition voltages that are substantially at maximum supply voltage.
20. The current derivative sensor of Claim 17, wherein the plurality of Schmitt triggers stay on until reset.

21. The current derivative sensor of Claim 1, wherein the output is displayed on a thermometer-type scale readout.
22. A current derivative sensor, comprising in combination:
- an inductor operable to detect current, wherein the current flows through the inductor, thereby generating a differential potential across the inductor;
 - an operational amplifier operable to amplify and convert the differential potential to a single-ended output; and
 - a plurality of Schmitt triggers configured to switch from off to on at monotonically increasing transition voltages, wherein the plurality of Schmitt triggers provide an output representative of a time derivative of a current signal (di/dt).
23. The current derivative sensor of Claim 22, wherein a single-ended gain circuit is located at an output of the operational amplifier.
24. The current derivative sensor of Claim 22, wherein a differential-input, single-ended gain circuit is located at an output of the operational amplifier.
25. The current derivative sensor of Claim 22, wherein a load generates the current.
26. The current derivative sensor of Claim 25, wherein the load is a conductor operable to generate a transient current signal.

27. The current derivative sensor of Claim 25, wherein the load is a conductor selected from the group consisting of integrated circuit interconnect metallization, integrated circuit polysilicon, silicided silicon connectors, printed circuit board traces, insulated wires, and non-insulated wires.
28. The current derivative sensor of Claim 22, wherein the inductor is located in series with a load.
29. The current derivative sensor of Claim 22, wherein parasitic resistance is associated with the inductor.
30. The current derivative sensor of Claim 22, wherein the differential potential consists of a DC potential produced as the current flows through parasitic resistance located in the sensing element, a transient potential produced as the current flows through the parasitic resistance, and a transient potential produced as the current flows through an
5 inductor in the sensing element.
31. The current derivative sensor of Claim 22, further comprising a calibration circuit operable to determine a parasitic resistance value.
32. The current derivative sensor of Claim 31, wherein the calibration circuit determines an inductive value using the parasitic resistance value.

33. The current derivative sensor of Claim 31, wherein the calibration circuit includes a plurality of precision matched current sources connected in parallel through independently controlled switches.

34. The current derivative sensor of Claim 33, wherein the plurality of precision matched current sources provide substantially identical current magnitudes.

35. The current derivative sensor of Claim 33, wherein the independently controlled switches are field-effect transistors.

36. The current derivative sensor of Claim 22, wherein the plurality of Schmitt triggers are configured with LOW-to-HIGH input transition voltages that are monotonically increasing from substantially a ground potential to a maximum supply voltage.

37. The current derivative sensor of Claim 22, wherein the plurality of Schmitt triggers are configured with HIGH-to-LOW input transition voltages that are substantially at maximum supply voltage.

38. The current derivative sensor of Claim 22, wherein the plurality of Schmitt triggers stay on until reset.

39. The current derivative sensor of Claim 22, wherein the output is displayed on a thermometer-type scale readout.

40. A method of measuring a time derivative of a current signal (di/dt), comprising in combination:

- sensing current from a load, thereby generating a differential potential;
- amplifying the differential potential;
- 5 converting the differential potential to a single-ended output; and
- triggering an analog to digital converter based on the differential potential, thereby providing an output representative of a time derivative of a current signal (di/dt).

41. The method of Claim 40, wherein the step of sensing current from a load, the differential potential is generated across a sensing element.

42. The method of Claim 41, wherein the sensing element is an inductor located in series with the load.

43. The method Claim 42, wherein parasitic resistance is associated with the inductor.

44. The method of Claim 40, wherein the differential potential consists of a DC potential produced as the current flows through parasitic resistance located in the sensing element, a transient potential produced as the current flows through the parasitic resistance, and a transient potential produced as the current flows through an inductor in
5 the sensing element.

45. The method of Claim 40, wherein the load is a conductor operable to generate a transient current signal.

46. The method of Claim 40, wherein the load is a conductor selected from the group consisting of integrated circuit interconnect metallization, integrated circuit polysilicon, silicided silicon connectors, printed circuit board traces, insulated wires, and non-insulated wires.

47. The method of Claim 40, wherein a differential-input, single-ended output gain circuit is operable to amplify and convert the differential potential.

48. The method of Claim 40, wherein the analog to digital converter includes a plurality of Schmitt triggers.

49. The method of Claim 40, further comprising displaying an output of the analog to digital converter on a thermometer-type scale readout.

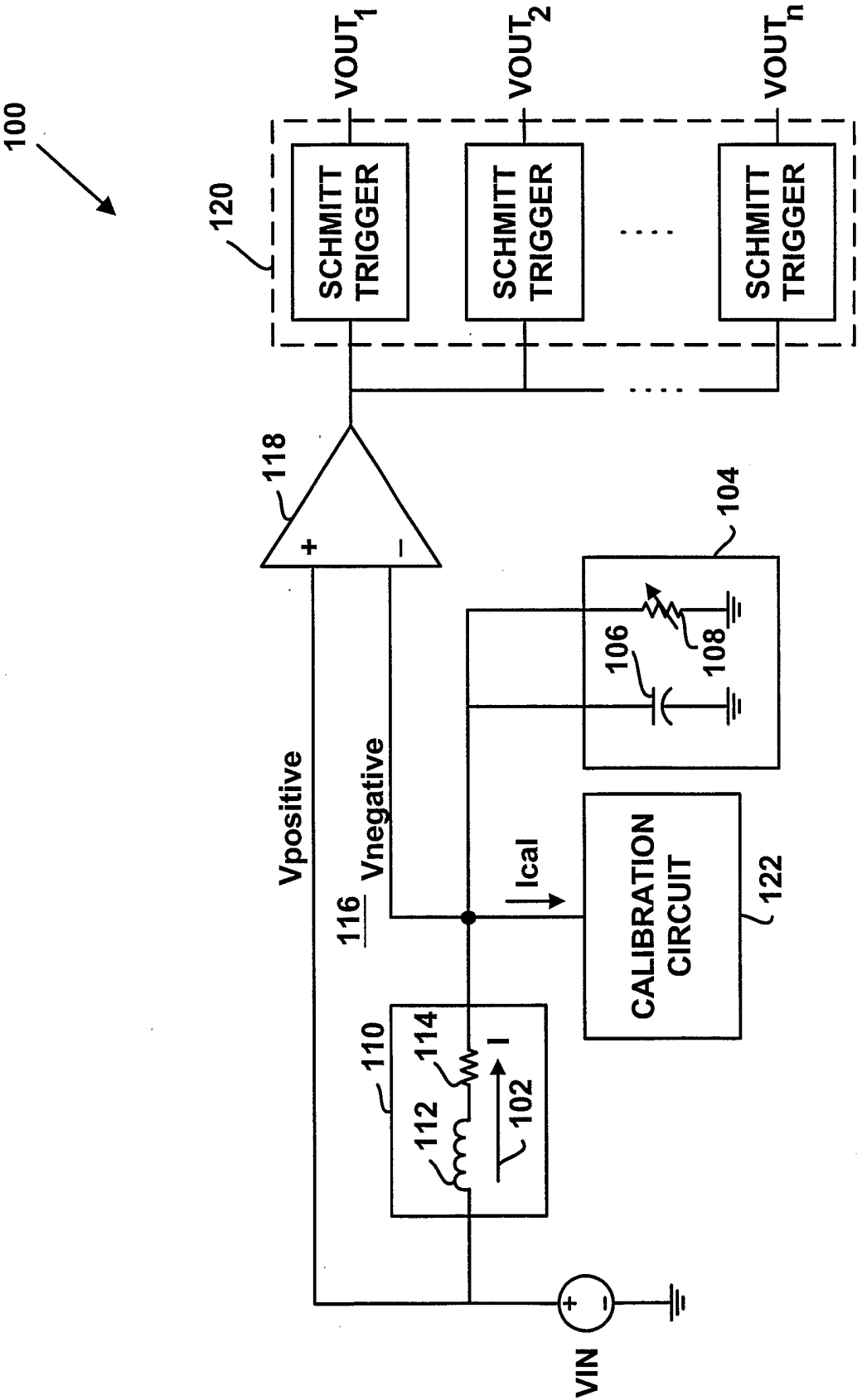


Fig. 1

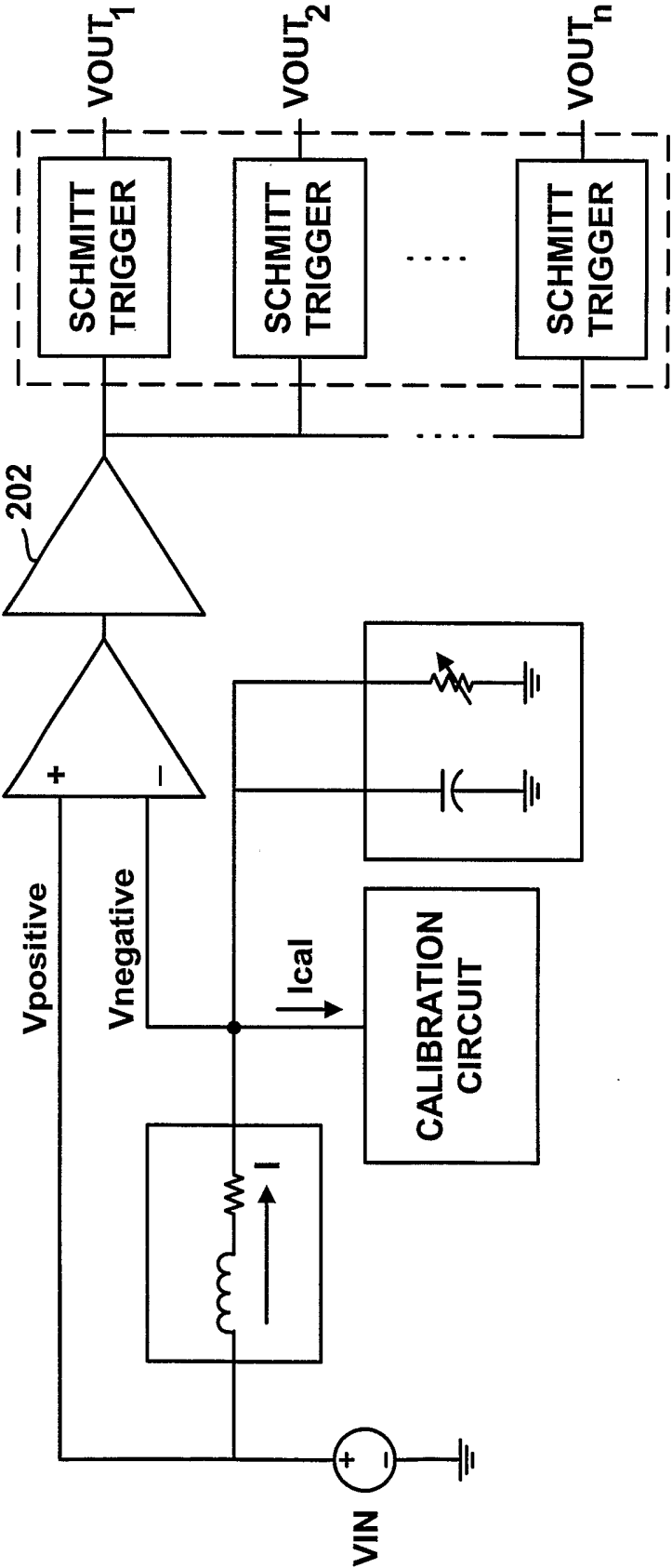


Fig. 2A

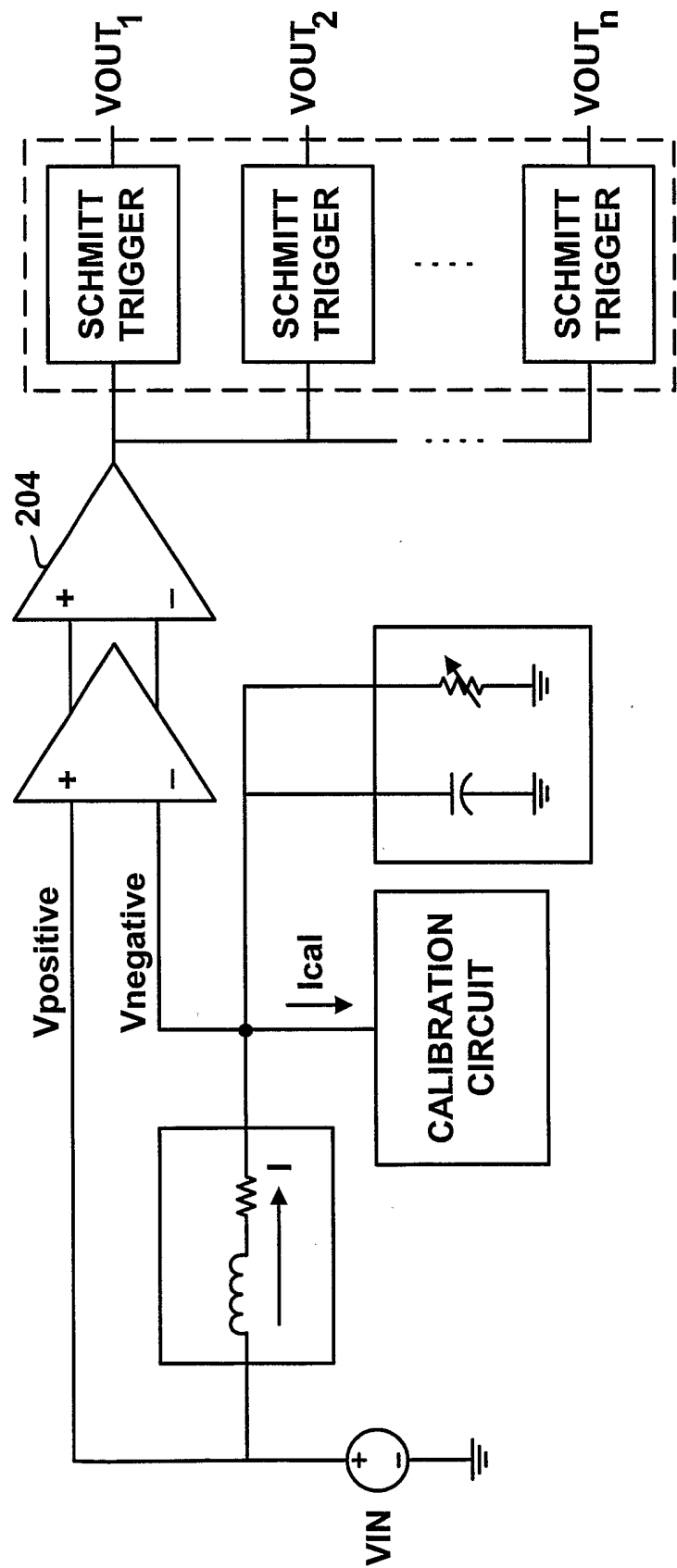


Fig. 2B

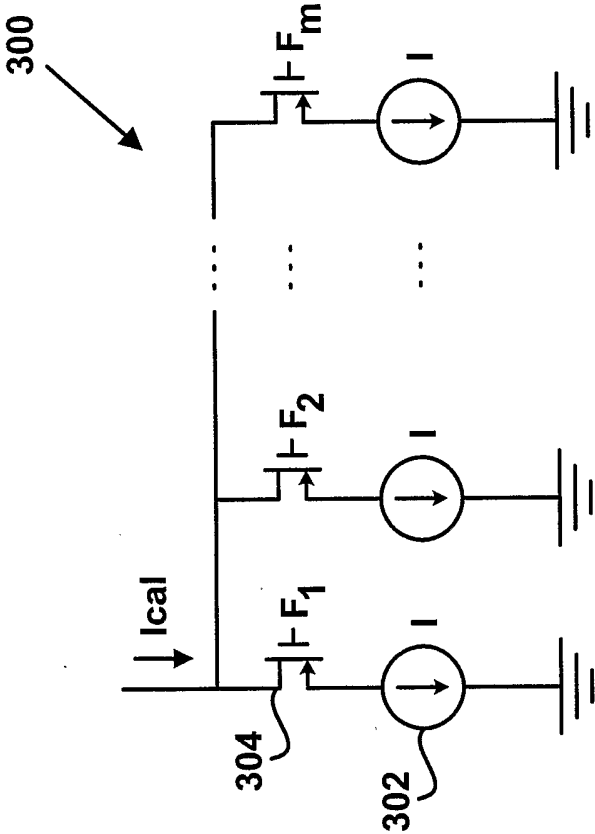


Fig. 3A

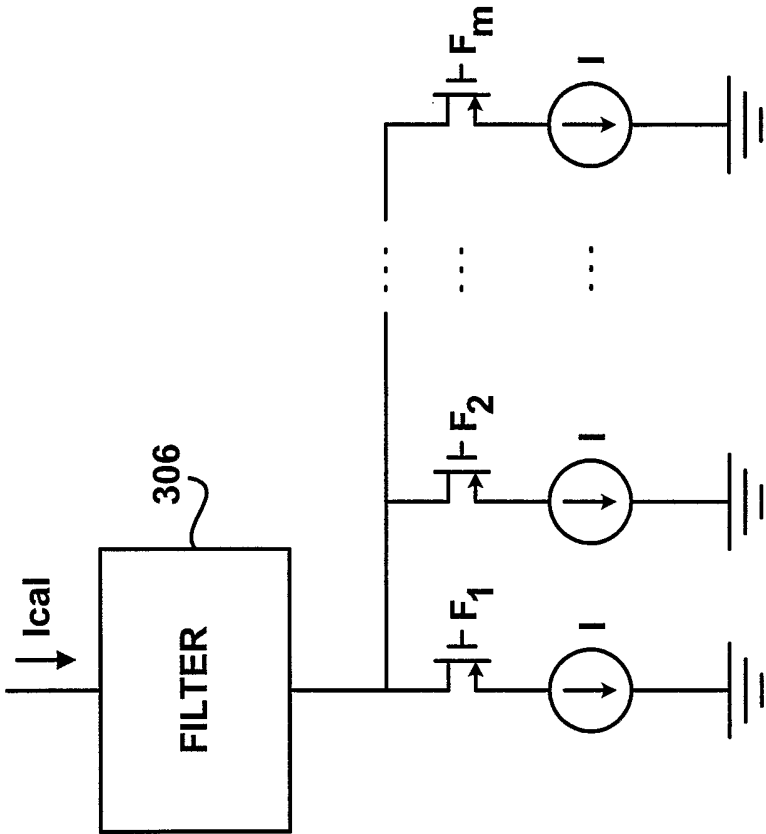


Fig. 3B

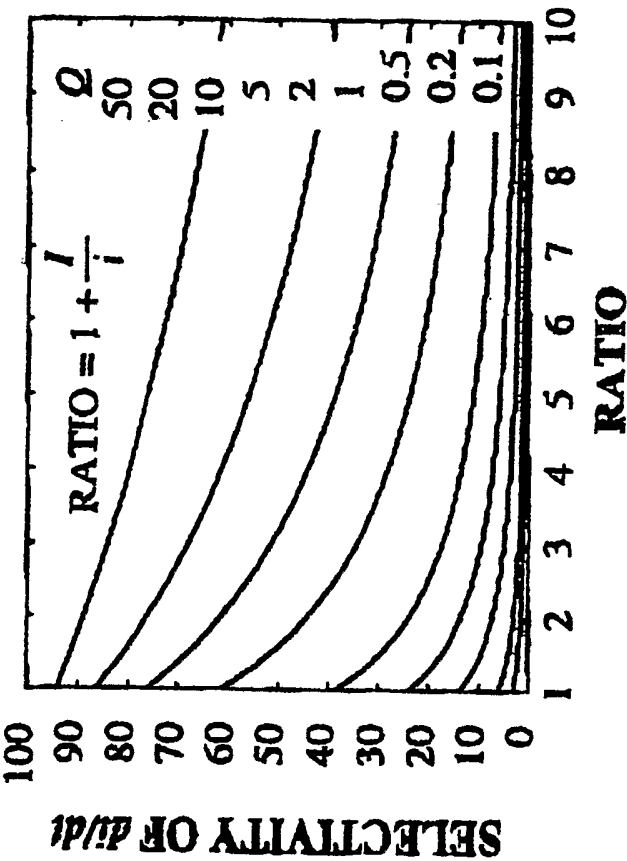


Fig. 4

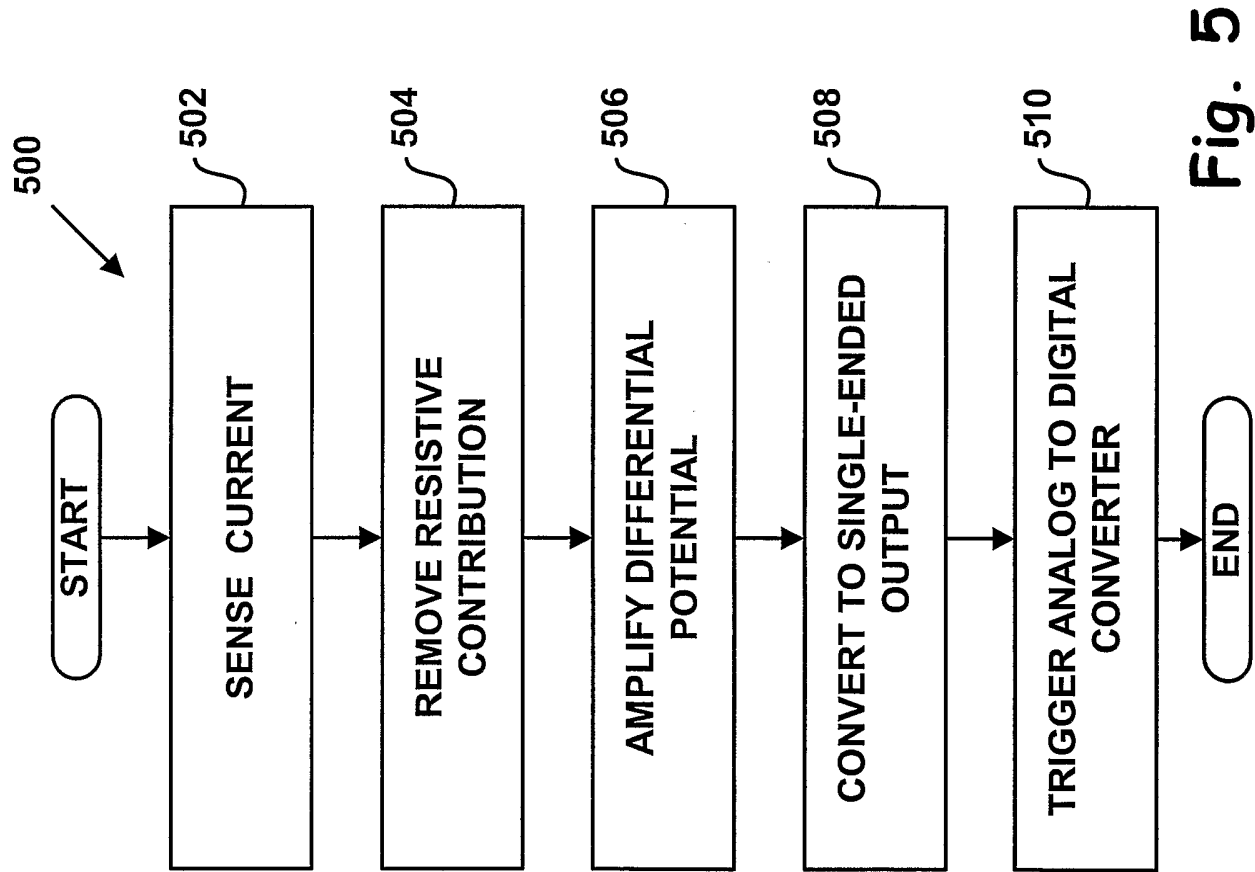


Fig. 5

INTERNATIONAL SEARCH REPORT

PCT/US 02/25641

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G01R19/12 G01R35/00 G01R27/26

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)

IPC 7 G01R H02H

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 practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 473 428 A (WESTINGHOUSE ELECTRIC CORP) 4 March 1992 (1992-03-04) column 2, line 31 - line 48; figures 1,2	1-11, 17, 40-47
Y		12, 13, 17-32, 36-39, 48, 49
Y	US 4 965 548 A (FAYFIELD ROBERT W) 23 October 1990 (1990-10-23) column 2, line 13 - column 3, line 3; figure 1	17-32, 36-39, 48, 49
Y	EP 0 441 649 A (DU PONT UK) 14 August 1991 (1991-08-14) column 3, line 44 - column 4, line 23; figure 1	12, 13, 31, 32



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
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Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Hijazi, A

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