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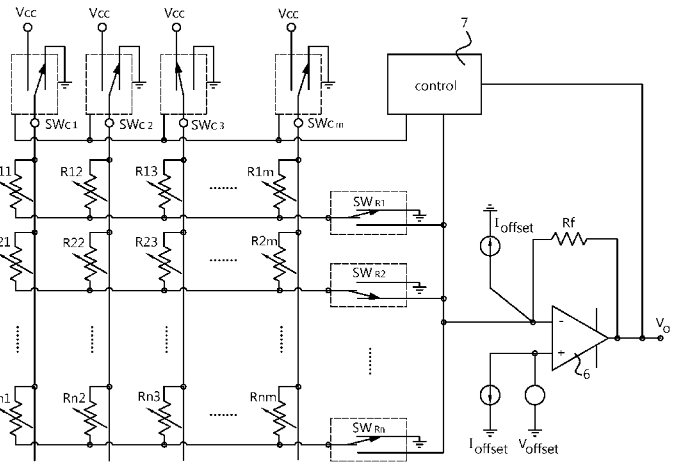
(54) Title: READ-OUT CIRCUIT AND METHOD FOR READING OUT LARGE-ARRAY RESISTIVE SENSORS

Fig. 2



(57) **Abstract**: Read-out circuit and method for reading out a large array of resistive sensors having *m* column connection lines and n row connection lines. Each of a plurality of resistive sensors (R_{mn}) is connected between one of the m column connection lines and one of the n row connection lines. Measuring a sensor value of a single one of the resistive sensors (R_{mn}) is accomplished by connecting the measurement circuit (5) to the row connection line associated with the single one resistive sensor, grounding all column connection lines and measuring a first sensor value, connecting a column connection line associated with the single one resistive sensor to a supply voltage and measuring a second sensor value, and determining the sensor value of the single one resistive sensor by subtracting the first sensor value and second sensor value.

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Read-out circuit and method for reading out large-array resistive sensors

Field of the invention

The present invention relates to a method of reading out a large array of resistive sensors having *m* column connection lines and *n* row connection lines, each of a plurality of resistive sensors being connected between an associated one of the *m* column connection lines and an associated one of the *n* row connection lines. In a further aspect, the present invention relates to a read-out circuit for a large array of resistive sensors having *m* column connection lines and *n* row connection lines, each of a plurality of resistive sensors being connected between an associated one of the *m* column connection lines and an associated one of the *n* row connection lines.

Prior art

American patent publication US2005/0200732 discloses a read-out circuit for a pixel array employing an offset error compensation by subtracting from a value sensed by a color sensor a dark current offset value.

American patent publication US2013/0088247 discloses offset compensation using a dedicated offset correction circuit in a pressure sensing array.

American patent publication US2005/0207234 discloses an offset error compensation scheme for an array forming a data storage device by subtracting a pre-determined offset value from a measured value for each cell in the array. An array of resistive probes P are connected to columns C and rows R connection lines. Each probe P can be connected to a corresponding row R connection line with a subtraction stage in the form of a differential amplifier having one input connected to the corresponding row line R and another connected to the offset signal generator for receiving an offset compensation signal $s_c(t)$. The output of each differential amplifier is connected via a low pass filter, having a bypass switch, to a sampler represented by a switch.

The article by Akavia Kaniel, “Substractor eliminates op-amp offset, common mode errors” in Electronics, vol. 51, no. 8, 1 April 178, pages 135-137, discloses a circuit eliminating an offset voltage of an operational amplifier with switches, two memories, and a subtractor.

Summary of the invention

The present invention seeks to provide a low complexity solution for a read-out circuit for large-array resistive sensors, having improved performance over prior art circuitry with regard to sensitivity of error sources related to the measurement circuit used (e.g. operational amplifiers).

According to the present invention, a method according to the preamble defined above is provided further comprising, measuring a sensor value of a single one of the plurality of resistive sensors by:

- connecting a measurement circuit to the row connection line associated with the single one resistive sensor,
- grounding all column connection lines and measuring a first sensor value,
- connecting a column connection line associated with the single one resistive sensor to a supply voltage and measuring a second sensor value, and
- determining the sensor value of the single one resistive sensor by subtracting the first sensor value and second sensor value.

This will ensure a proper and robust determination of a specific single sensor value without adding complex circuitry (thus with less cost than prior art methods) and with high accuracy.

In a further aspect, the present invention relates to a read-out circuit for a large array of resistive sensors as defined in the preamble above, the read-out circuit comprising a measurement circuit (e.g. an operational amplifier based circuit) providing an output signal, *m* column switches each connected to one of the *m* column connection lines and to either ground or a supply voltage, and *n* row switches each connected to one of the *n* row connection lines and to either ground or the measurement circuit. By properly actuating the switches (e.g. under control of a control unit), the sensor values of each individual sensor in the array can be determined with high accuracy, yet without necessitating any complex measurement circuitry.

Short description of drawings

The present invention will be discussed in more detail below, using a number of exemplary embodiments, with reference to the attached drawings, in which

Fig. 1 shows a circuit diagram of a read-out circuit for an exemplary 4x4 array of resistive sensors, according to an embodiment of the present invention; and

Fig. 2 shows a circuit diagram of a read-out circuit according to an embodiment of the present invention for a generic m x n resistive sensor array.

Detailed description of exemplary embodiments

Large arrays of resistive sensors have a wide range of applications from industrial systems (e.g. pressure and gas sensors) to biomedical wearable devices (e.g. in the form of textile sensors). Several types of read-out circuits are known in the art and have been presented for such sensors, however, these suffer from drawbacks mainly due to the large number of sensing elements, or when the ratio of the maximum and minimum resistor values is very high. Also, non-idealities of the operational amplifier(s) employed in such circuits provide further disadvantages.

According to the present invention embodiments, a high-accuracy yet simple read-out circuit architecture is proposed wherein the problems caused by several main non-ideality sources and errors are overcome. In this way, not only the accuracy of the read-out circuit is increased but also its complexity and therefore cost is reduced.

This was accomplished after studying the effects of two main non-idealities of an operational amplifier, i.e. the offset voltage and the input current, on the accuracy of the read-out circuit.

In general terms, a double-sampling scheme is proposed to improve the accuracy of the read-out circuit. Both simulation and measurement results have confirmed the effectiveness of the proposed method for large arrays of resistive sensors.

Fig. 1 shows a circuit diagram of a read-out circuit for an exemplary 4x4 array of resistive sensors R_{mn}, according to an embodiment of the present invention. In generic terms, the present invention read-out circuit is especially suited for a large array of resistive sensors having m column connection lines and n row connection lines (m and n being positive integers), each of a plurality of resistive sensors R_{mn} being connected between an associated one of the m column connection lines and an associated one of the n row connection lines.

It is noted that in most if not all resistive sensor arrays, the individual sensor terminals are not accessible, but only the column and row terminals.

The read-out circuit itself comprises a measurement circuit 5 providing an output signal V_o, m column switches SW_{Cm} each connected to one of the m column connection lines and to either ground or a supply voltage V_{cc}, and *n* row switches SW_{Rn} each connected to one of the *n* row connection lines and to either ground or the measurement circuit.

In the specific embodiment shown in Fig. 1, the switches SW_{Cm} and SW_{Rn} are operated for measuring a second sensor value of the single resistive sensor R_{23} from the plurality of resistive sensors R_{mn}, i.e. the second column switch SW_{C2} is connected to a supply voltage V_{CC} and the third row switch SW_{R3} is connected to the measurement circuit 5.

This is actually one of the steps of the method embodiments of the present invention, which in general can be described as measuring a sensor value of a single one of the plurality of resistive sensors R_{mn} by:

- connecting a measurement circuit 5 to the row connection line associated with the single one resistive sensor,
- grounding all column connection lines and measuring a first sensor value,
- connecting a column connection line associated with the single one resistive sensor to a supply voltage and measuring a second sensor value, and
- determining the sensor value of the single one resistive sensor by subtracting the first sensor value and second sensor value (e.g. in the digital domain).

As a result, the ratio of the maximum measurable resistance to the minimum measurable resistance is increased (i.e. the dynamic range), and this is achieved simultaneously with a reduced complexity of the read-out circuit.

In the embodiment shown in Fig. 1, the measurement circuit 5 comprises a simple feedback circuit with an operational amplifier 6 (opamp) and a feedback resistor R_f connected between the opamp output and its positive input. The negative input of the opamp 6 is connected to ground, and the positive input to the instantaneous measurement value (as determined by the positions of row switches SW_{Rn}).

One of the error sources in measurement circuits is the opamp offset, the effect of which can be described for the read-out circuit of Fig. 1 as follows:

It can be shown that the output voltage V_O of the read-out circuit (i.e. output of measurement circuit 5) is affected by the opamp offset voltage V_{offset} using:

$$V_o = R_f\left(\frac{-V_{cc}}{R_{23}} + V_{offset}\left(\frac{1}{R_{21}} + \frac{1}{R_{22}} + \frac{1}{R_{23}} + \cdots + \frac{1}{R_{2m}}\right)\right) + V_{offset}$$

Another non-ideality source is the opamp input current (which is not zero for many commercial non-CMOS opamps). The effect of this input current on the output voltage can be considered in the following equation:

$$V_o = R_f\left(\frac{-V_{cc}}{R_{23}} + I_{offset}\right)$$

The present invention embodiments work as follows: using a double-sampling scheme, the digitized version of the output of the circuit for the case when the input switch (i.e. SW_{C3} in Fig. 1) is connected to V_{CC} (second sensor value) is subtracted from that obtained when the input is grounded (first sensor value). The subtraction result is therefore, an error-free value which is much less dependent on the offset voltage and the input current of the opamp 6. There are several problems that the present invention embodiments described herein have offered solutions for:

1. Cross-talk between different sensors in an array arrangement: in the present invention embodiments, the effect of cross-talk is reduced.

2. Limited value for the Rmax/Rmin ratio (i.e. the dynamic range): this parameter is considerably increased in the present invention embodiments.

Fig. 2 shows a circuit diagram of a read-out circuit according to an embodiment of the present invention for a generic *m* x *n* resistive sensor array. In this case, *m* column switches SW_{Cm} are connected to the respective *m* column connection lines of the array, and *n* row switches SW_{Rn} are connected the respective *n* row connection lines of the array. In further method embodiments, connecting the measurement circuit 5 to the row connection line associated with the single one resistive sensor is implemented using a row switch SW_{Rn}, and connecting the column connection line associated with the single one resistive sensor to a supply voltage is implemented using a column switch SW_{Cm}. The row and column switches may be actual hardware switches, controlled switches, semiconductor switches, etc.

As shown in the Fig. 2 embodiment, the row and column switches SW_{Rn}, SW_{Cm}, are controlled or actuated using a control unit 7. Or in other words, the read-out circuitry comprises a control unit 7 connected to each of the *m* column switches SW_{Cm} and each of the *n* row switches SW_{Rn}. The control unit 7 can then be used to provide proper control and timing of all switches, e.g. for determining the actual sensor value of each of the plurality of resistive sensors by subsequently connecting the associated ones of the *m* column connection lines and *n* row connection lines. Thus, the entire array of resistive sensors R_{mn} can be read out with improvement of sensitivity for the opamp inherent error sources in this array read-out circuit.

In an even further embodiment, the control unit 7 is connected to the measurement circuit 5 for receiving the output signal V_o thereof, and the control unit 7 is further arranged to execute the method steps of any one of method embodiments as described above. For example, the first sensor value and second sensor value are stored and subsequently processed. This can e.g. be achieved by adding processing circuitry (e.g. data processor, memory, input signal digitization, etc.) to the control unit 7.

Both simulation results of a 40*50 array and also the measurement results confirm the effectiveness of the read-circuit of the present invention embodiments in improving the accuracy of the read-out mechanism without introducing additional complexity. The present invention embodiments will lead to more accurate yet less complex read-out circuits for large arrays of read-out (resistive) sensors. One of the examples is a platform measuring the pressure profile under the feet with more than 2000 resistive sensors. With this invention, the accuracy of the measurement system will be increased without additional circuit complexity overhead.

The large arrays of resistive sensors as discussed above have a wide range of applications from medical to industrial, and the present invention method embodiments and read-out circuit embodiments may equally be applied in these applications. An example is textile sensors which are becoming smarter. In wearing biomedical devices, another booming application field is emerging. Other examples include, but are not limited to Barefoot Pressure Analysis; In-Shoe Planar Pressure Analysis; Seating & Positioning Pressure Analysis; Human Joint Analysis; Animal Gait Analysis; Body Pressure Mapping (Seating & Mattress); Occlusal Analysis (Dentistry); Tire Footprint Pressure Measurement; Wiper Force Measurement; Grip Pressure Measurement.

It is noted that the array indications (column, row) in the exemplary embodiments described above can be interchanged of course, without departing from the scope of protection as defined in the appended claims.

The present invention embodiments have been described above with reference to a number of exemplary embodiments as shown in the drawings. Modifications and alternative implementations of some parts or elements are possible, and are included in the scope of protection as defined in the appended claims.

CLAIMS

1. Method of reading out a large array of resistive sensors having *m* column connection lines and *n* row connection lines, each of a plurality of resistive sensors (R_{mn}) being connected between an associated one of the *m* column connection lines and an associated one of the *n* row connection lines,
comprising
measuring a sensor value of a single one of the plurality of resistive sensors (R_{mn}) by:
- connecting a measurement circuit (5) to the row connection line associated with the single one resistive sensor,
- grounding all column connection lines and measuring a first sensor value,
- connecting a column connection line associated with the single one resistive sensor to a supply voltage and measuring a second sensor value, and
- determining the sensor value of the single one resistive sensor by subtracting the first sensor value and second sensor value.

2. Method according to claim 1, further comprising
determining the actual sensor value of each of the plurality of resistive sensors by subsequently connecting the associated ones of the *m* column connection lines and *n* row connection lines.

3. Method according to claim 1 or 2, wherein the measurement circuit (5) comprises an operational amplifier (6).

4. Method according to any one of claims 1-3, wherein connecting the measurement circuit (5) to the row connection line associated with the single one resistive sensor is implemented using a row switch (SW_{Rn}) (thus *n* row switches being present).

5. Method according to any one of claims 1-4, wherein connecting the column connection line associated with the single one resistive sensor to a supply voltage is implemented using a column switch (SW_{Cm}) (thus *m* column switches being present).

6. Method according to any one of claims 1-5, wherein the first sensor value and second sensor value are stored and subsequently processed.

7. Read-out circuit for a large array of resistive sensors having *m* column connection lines and *n* row connection lines, each of a plurality of resistive sensors (R_{mn}) being connected between an associated one of the *m* column connection lines and an associated one of the *n* row connection lines,
the read-out circuit comprising

- a measurement circuit (5) providing an output signal (V_o),
- *m* column switches (SW_{Cm}) each connected to one of the *m* column connection lines and to either ground or a supply voltage (V_{cc}), and
- *n* row switches (SW_{Rn}) each connected to one of the *n* row connection lines and to either ground or the measurement circuit (5).

8. Read-out circuit according to claim 7, further comprising a control unit (7) connected to each of the *m* column switches (SW_{Cm}) and each of the *n* row switches (SW_{Rn}).

9. Read-out circuit according to claim 7 or 8, wherein the measurement circuit (5) comprises an operational amplifier (6).

10. Read-out circuit according to claim 7, 8 or 9, wherein the control unit (7) is connected to the measurement circuit (5) for receiving the output signal (V_o) thereof, and wherein the control unit (7) is further arranged to execute the method steps of any one of the embodiments 1-6.

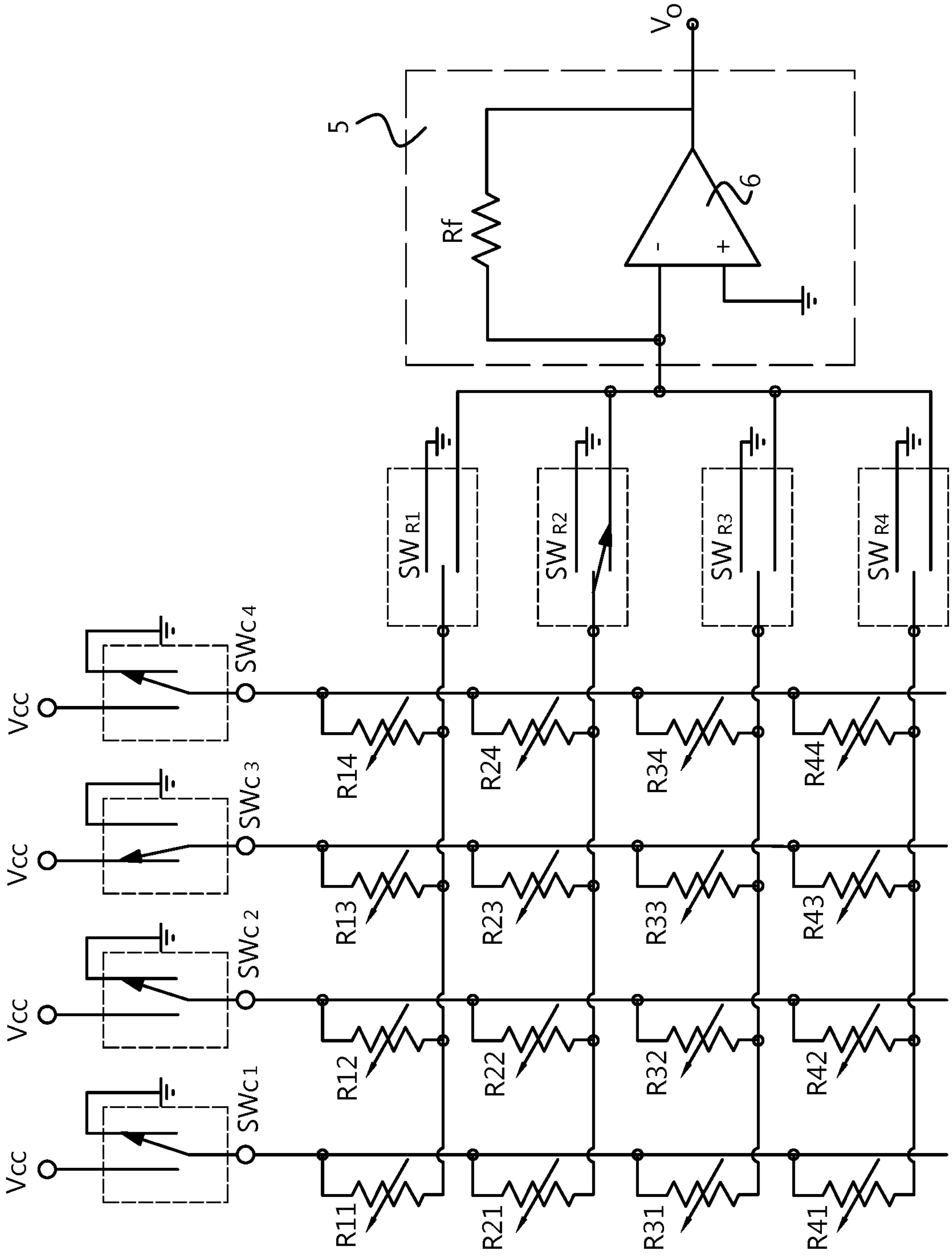
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Fig. 1

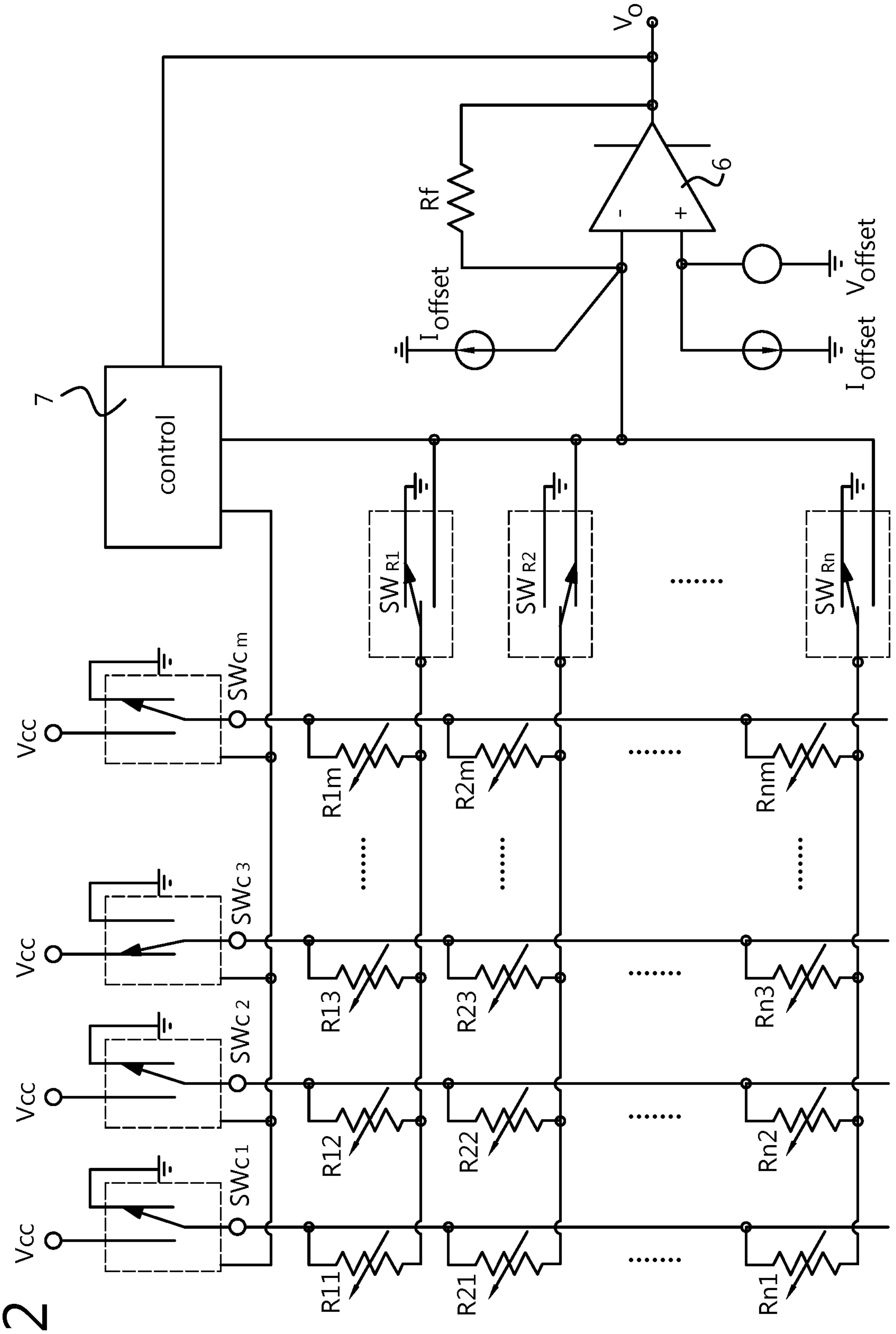
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Fig. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/062381

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01L1/22
ADD.

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)
G01L

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)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2005/207234 A1 (BAECHTOLD PETER [CH] ET AL) 22 September 2005 (2005-09-22) cited in the application the whole document -----	1-10
Y	AKAVIA KANIEL: "Subtractor eliminates op-amp offset, common-mode errors", ELECTRONICS,, vol. 51, no. 8, 1 April 1978 (1978-04-01), pages 135-137, XP001625250, the whole document -----	1-10

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

☒ See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 September 2016	14/09/2016

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2016/062381

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005207234 A1	22-09-2005	NONE	