(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
16 November 2023 (16.11.2023)

WIPO | PCT

(10) International Publication Number
WO 2023/217356 A1

(51) **International Patent Classification:**
G01R 33/00 (2006.01) *G01R 33/02* (2006.01)
G01R 33/09 (2006.01)

(21) **International Application Number:**
PCT/EP2022/062668

(22) **International Filing Date:**
10 May 2022 (10.05.2022)

(25) **Filing Language:** English

(26) **Publication Language:** English

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(54) Title: VECTORIAL MAGNETIC FIELD SENSOR AND MANUFACTURING METHOD OF A VECTORIAL MAGNETIC FIELD SENSOR

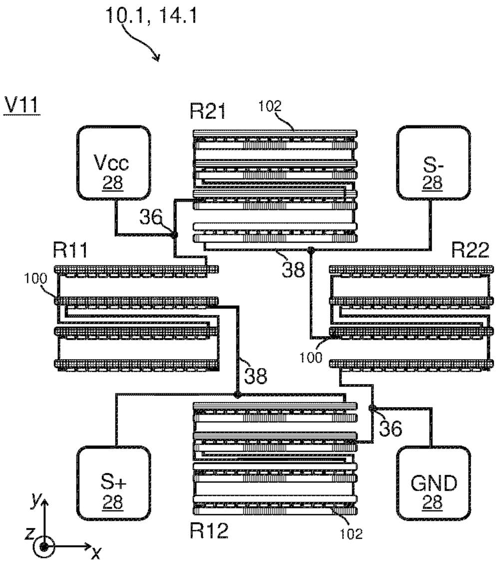

Fig. 3

(57) Abstract: The invention relates to a vectorial magnetic field sensor (10, 12, 14) for measuring at least a Z-magnetic field component perpendicular to an X/Y-plane in which a Wheatstone-bridge configuration (V11, V12 V13, V21, V22, V23) of four magnetic sensitive resistors (R11, R12, R21, R22) is arranged, two of said resistors (R11, R12, R21, R22) form a half-bridge (R11-R12, R21-R22) of said Wheatstone-bridge configuration (V11, V12 V13, V21, V22, V23), Z-component magnetic sensitivity directions of each of said pair of resistors (R11, R12, R21, R22) of each half-bridge (R11-R12, R21-R22) are opposite to each other, and Z-component magnetic sensitivity directions of parallel aligned resistor (R11, R12, R21, R22) of both half-bridges (R11-R12, R21-R22) are opposite to each other. It is suggested, that each resistor (R11, R12, R21, R22) comprises at least two or more resistor stripes (100, 102, 104, 106, 108, 110) connected in series, each resistor stripe (100, 102, 104, 106, 108, 110) consists of a series connection of a plurality of TMR-elements (16) aligned along a stripe path (30), an ferromagnetic flux-guiding element (24) is disposed adjacent to each resistor stripe (100, 102, 104, 106, 108, 110) in immediate vicinity, a contourline (34) of said flux-guiding element (24) follows said stripe path (30), and in-plane pinning directions (f,|) of TMR-elements (16) of pairwise diagonally arranged resistors (R11-R22, R12-R21) are perpendicular oriented either towards to, or away form said contourline (34), such that sensor signal terminals (S+, S-) of both half-bridges (R11-R12, R21-R22) of the Wheatstone-bridge configuration (V11, V12 V13, V21, V22, V23) are sensitive to a Z-magnetic field component. In a further aspect, the invention relates to a manufacturing method of said vectorial magnetic field sensor (10, 12, 14).

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[Continued on next page]

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

VECTORIAL MAGNETIC FIELD SENSOR AND MANUFACTURING METHOD OF A VECTORIAL MAGNETIC FIELD SENSOR

The invention relates to a vectorial magnetic field sensor for measuring at least a Z-magnetic field component perpendicular to an X/Y-plane in which a Wheatstone-bridge configuration of four magnetic sensitive resistors R11, R12, R21, and R22 is arranged. Two of said resistors R11-R12 and R21-R22 form a half-bridge of said Wheatstone-bridge configuration. A Z-component magnetic sensitivity directions of each of said pair of resistor R11-R12 and R21-R22 of each half-bridge are opposite to each other, and a Z-component magnetic sensitivity directions of parallel aligned resistor R11-R21 and R12-R22 of both half-bridges R11-R12, R21-R22 are opposite to each other.

Furthermore the invention relates to a method for manufacturing said vectorial magnetic field sensor.

BACKGROUND ART

Magnetic field sensors for measuring a Z-component of a magnetic field within an X/Y plane by magnetic sensitive resistors arranged on a substrate within said X/Y plane are widely known.

For example EP 3 045 926 A1 discloses a single-chip Z-axis magnetic field sensor. The sensor comprises a substrate, magnetoresistive sensing elements as magnetic field resistors and flux-guiding elements for guiding a Z-oriented magnetic field into X/Y-oriented magnetic field components. The magnetoresistive sensing elements are mutually electrically connected to form push arms and pull arms of a Wheatstone bridge; the push arms and the pull arms are alternately arranged, and the magnetoresistive sensing elements on the push arms and the pull arms are respectively located at two sides beneath the flux-guiding elements. The magnetization direction of a pinning layer of each magnetoresistive sensing element is the same and is in an X-axis direction. An external magnetic field in a

Z-axis direction is converted into a magnetic field with components in an X-axis direction by the flux-guiding elements, and thus the magnetoresistive sensing elements beneath the flux-guiding elements can detect this component. The magnetoresistive sensing elements are completely covered under the flux-guiding element which makes a manufacturing process difficult.

EP 3 025 162 A proposes magnetic field sensor apparatus for determining two or three components of a magnetic field. The sensor apparatus includes at least one Wheatstone bridge with two half-bridges, wherein each half-bridge includes at least two bridge resistors. At least one of the two bridge resistors is a magnetic-field-sensitive resistor with respect to a magnetic field component in an X/Y magnetic field sensor plane. Arranged symmetrically between the two magnetic-field-sensitive bridge resistors is a ferromagnetic flux guiding element which generates magnetic field components which are anti-symmetric with respect to a Z magnetic field component oriented perpendicular to the X/Y magnetic field sensor plane and are in the X/Y magnetic field sensor plane.

Similarly EP 3 006 896 A reveals a three-axis digital compass is proposed which comprises two X-axis magnetic sensors, two Y-axis magnetic sensors, a flux-guiding element, a signal sampling unit, a signal processing unit, and a signal output unit. The X-axis and Y-axis magnetic sensors are arranged along a periphery of the flux-guiding element. An external magnetic field is distorted when passing through the flux-guiding element. A Z axis component of the external magnetic field is converted into X-axis or Y-axis magnetic field components when passing through the flux-guiding element, and the so converted components of the external magnetic field act on the X-axis and Y-axis magnetic sensitive sensors. An output signal of the X-axis and Y-axis magnetic sensitive sensors is sent to the signal processing unit through the signal sampling unit, and it is used to calculate the three orthogonal components of the external magnetic field. These calculated external magnetic field components are output in a digital format through the signal output unit.

Document JP 2012 127 788 A teaches a magnetic sensor capable of detecting external magnetic fields of a plurality of axes. Said magnetic sensor includes a plurality of magneto resistance effect elements S1 to S3 which are formed by laminating magnetic layers and non-magnetic layers and exert magneto resistance effects; and a soft magnetic material provided at a non-contact position through each magneto resistance effect element and insulating layer. The magneto resistance effect elements S1 to S3 in which fixed magnetization directions P1 of fixed magnetic layers are directed toward an X1-X2 direction are arranged in plane view at two sides X1-X2 of a soft magnetic material acting as a flux guiding element, respectively. The magneto-resistance effect elements S1 and S3, and the magneto-resistance effect element S2 have a fixed magnetization directions P1 in a reverse direction to each other. It is required that pinning directions on the same side of a flux guide element are pinned in opposite directions.

In the prior art the manufacturing process is rather complicated, time-consuming and costly. Furthermore a majority of known Z-axis sensors are sensitive to in-plane magnetic field components thus not precise in measuring a Z-component alone. The reason is that magnetoresistive elements located at opposite sides of a flux-guiding element have identical pinning directions which makes a sensor sensitive to external in-plane magnetic field components in the X/Y-direction and deteriorates precision of a pure Z-component measuring.

In contrast to the above-stated prior art, the object of the invention is to reduce the disadvantages of known arrangements. Specifically a vectorial magnetic field sensor for measuring a Z-component perpendicular of a X/Y-plane in which the various elements of the sensor are arranged shall be insensitive for in-plane magnetic field components in the X/Y plane and shall be inexpensive in manufacturing and have smaller dimensions as the prior art.

The above-stated disadvantages are solved by a vectorial magnetic field sensor and a method for manufacturing said vectorial magnetic field sensor according to the independent claims. Advantageous further developments of the invention constitute the subject matter of the dependent claims.

SUMMARY OF THE INVENTION

In a first inventive aspect a vectorial magnetic field sensor for measuring at least a Z-magnetic field component perpendicular to an X/Y-plane is proposed. Said sensor comprises a Wheatstone-bridge configuration of four magnetic sensitive resistors R11, R12, R21, R22 arranged in said X/Y plane for measuring at least a Z-component of an external magnetic field. Two of said resistors R11, R12, R21, R22 form a half-bridge R11-R12, R21-R22 of said Wheatstone-bridge configuration. A Z-component magnetic sensitivity directions of each of said pair of resistors R11, R12, R21, R22 of each half-bridge R11-R12, R21-R22 are opposite to each other, and a Z-component magnetic sensitivity directions of parallel aligned resistor R11-R21, R12-R22 of both half-bridges R11-R12, R21-R22 are opposite to each other.

It is proposed that each resistor R11, R12, R21, R22 comprises at least two or more resistor stripes connected in series. Each resistor stripe consists of a series connection of a plurality of TMR-elements aligned along a stripe path. A ferromagnetic flux-guiding element is disposed adjacent to each resistor stripe in immediate vicinity. A contour line of said flux-guiding element follows said stripe path. In-plane pinning directions of TMR-elements of pairwise diagonally arranged resistors R11-R22, R12-R21 are perpendicular oriented either towards to, or away form said contour line, such that sensor signal terminals S+, S- of both half-bridges R11-R12, R21-R22 of the Wheatstone-bridge configuration are sensitive to a Z-magnetic field component.

In other words a vectorial magnetic field sensor is proposed comprising a Wheatstone-bridge configuration with two half-bridges. Each half bridge comprises two resistors R11-R12 and R21-R22 connected in series. Resistor R11 and R21, and also R12 and R22 are arranged in parallel. Resistor pairs R11 and R22, and also R12 and R21 are arranged diagonally to each other. Each resistor comprises at least a single or multiple resistor stripes of TMR-elements connected in series. A flux-guiding element is assigned to each resistor stripe in immediate vicinity. Immediate vicinity means that a lateral distance between the resistor stripe and the flux-guiding element is so small that nothing else, specifically no other functional or structural element can be arranged between the resistor stripe and the flux guiding element. The flux-guiding element can also partially overlap the resistor stripe. Regularly, each resistor stripe is associated to a separate flux-guiding element. Alternatively resistor stripes of different resistors can share a flux-guiding element and are disposed on opposite sides of said flux-guiding element. TMR-elements of each resistor are pinned, i.e. have a magnetic sensitive direction which is perpendicular oriented either toward or away of a contour line of said flux-guiding element. This selective pinning can be created either by at least temporarily depositing of a ferromagnetic pinning element adjacent to a resistor stripe and imposing a Z-oriented magnetic field so that X/Y stray field created by the pinning element establishes a pinning direction perpendicular to the contour line of the pinning element. The pinning element can remain on the sensor substrate thus establishing a flux-guiding element, whereby the pinning direction of the resistor stripe is oriented perpendicular and is directed away of the contour line of the flux guiding element, or can be removed and a separate flux-guiding element can be deposited on the opposite side of the stripe path, so that the pinning direction is oriented perpendicular and is directed towards the contour line of the flux-guiding element. Due to the fact, that diagonally arranged resistors R11-R22 and R12-R21 have identical relative pinning directions either towards or away from the flux-guiding element, whereby pinning directions of both pairs R11-R22 and R12-R21 are opposite to each other relative to the flux-guiding element so that a Z-sensitivity of the Wheatstone-bridge configuration is provided. Assuming that relative to an in-plane direction, e.g. a X- or Y-direction, flux-guiding elements are all arranged on a same side of associated resistor stripes said relative pinning arrangement provides a non-sensitivity of in-plane external magnetic field components, which are external magnetic field components being oriented in-plane having at least an X-component and/or an Y-component. Insofar the sensor is sensitive to Z-components but is non-sensitive to X- or Y-components of an external magnetic field, thus decoupling sensitivity of an external vectorial magnetic field. Furthermore since the Wheatstone-bridge configuration is of compact size and scalable in view of the numbers of TMR-elements with identical resistance characteristics of all resistors an increased accuracy of the sensor design is achieved. A pinning operation of all TMR-elements can be performed simultaneously thus drastically reducing manufacturing time and complexity.

In a favorable embodiment in-plane pinning directions of the TMR-elements of each resistor stripe can be oriented in the X/Y plane. Thus a pinning direction and an axis of magnetic sensitivity is oriented within the X/Y plane, such that a pinning magnetic field, which determines axis of sensitivity can be provided as stray field of a Z-oriented processing magnetic field generating an X/Y stray field as magnetic field deflection of ferromagnetic pinning elements during a manufacturing process. Insofar arbitrary in-plane pinning directions in the X/Y plane can be provided and all TMR-elements can be pinned simultaneously.

In general a number of TMR-elements in a resistor stripe can be arbitrary. In a favorable embodiment each resistor stripe can comprise at least 6 to 8, preferably 12 TMR-elements or more. Said minimal numbers of TMR elements, preferably even more are favorable in terms of an improved SNR-ratio, ESD-sustainability (Electro Static Discharge), and Sheet Resistance Characteristics.

A usual form of a stripe path is a straight line segment. In a favorable embodiment said stripe path can be bended, curved or angled. Thus an adaptive contour form of the stripe path as bended, curved or angled segment can provide a space saving sensor design. Furthermore said contour form can provide a filtering of higher harmonic error components of the sensor design, as already proposed for instance in WO 2016/083420. Favorably said stripe path can be angled by 30°, 36° or 60° for filtering higher harmonic error components for improving non-sensitivity of in-plane components for sensing a Z-oriented magnetic field component.

In a favorable embodiment a lateral distance between the resistor stripe and the flux-guiding element can be less than a width Δw of said flux-guiding element. A distance between a contour line of the flux-guiding element and a contour line of the resistor stripe is at least smaller than a width of the flux-guiding element, and is regularly smaller than any functional element of the sensor arrangement, i.e. is so small that no other functional or structural element can be placed between the resistor stripe and the flux guiding element. It is even possible, that a distance is negative, i.e. the flux guiding element can overlap partially the resistor strip. A maximal distance between resistor stripe and flux-guiding element is less than half a distance between neighboring flux-guiding elements. Decisive for a lateral distance is a magnitude of field attenuation caused by the distance for desired field strength to be measured.

In a favorable embodiment the resistor strips of different resistors R11, R12, R21, and R22 can share the same flux-guiding element. Sharing a flux-guiding element provides a space saving sensor design and provides a homogeneous field distribution into resistor strips of different resistors. Regularly resistor strips of different resistors are arranged on opposite sides of a common shared flux-guiding element. The flux-guiding element can deflect a Z-component of a magnetic field in opposite directed X/Y components on both lateral sides thus affecting both parallel aligned resistor stripes with opposite in-plane magnetic components. If both resistor stripes are pinned in identical in-plane directions a Z-component results in opposite ohmic behavior of both resistor stripes, if both resistor stripes are pinned in opposite in-plane directions both resistor stripes behave ohmic identical.

In a favorable embodiment each resistor R11, R12, R21, R22 can comprise at least four resistor stripes arranged in a meandering form, preferably resistor stripes of a pair of resistors within a half bridge R11-R12, R21-R22 or pairs of parallel aligned resistors R11-R21, R12-R22 of both half bridges R11-R12, R21-R22 can interdigital be arranged to each other. Thus each resistor comprises a series connection of four or more resistor strips which can be arranged in a zigzag form thus providing a space saving and compact layout in the sensor design. Resistor strips of two resistors, preferable of two resistors forming a half bridge or two parallel arranged resistors of the Wheatstone-bridge can be arranged interdigital, i.e. the arrangement of resistor stripes of two resistors is nested within each other, so that the spatial arrangement of a favorably zigzag layout of the series connection of resistor stripes are interlaced in each other.

In a favorable embodiment a ferromagnetic shielding of the Wheatstone-bridge configuration can be provided by ferromagnetic shielding elements arranged along a perimeter of the Wheatstone-bridge configuration. Said ferromagnetic shielding is surrounding the arrangement of the Wheatstone-bridge for measuring a Z-component in a perimeter and is regularly constituted by ferromagnetic elements, which can be a single ferromagnetic element or multiple separate ferromagnetic blocks arranged along the perimeter. External magnetic field components in an X/Y plane are shielded and do not penetrate a sensing surface of the Z-sensor Wheatstone bridge arrangement. Thus an improved non-sensitivity of in-plane magnetic field components in arbitrary directions is provided.

In a favorable embodiment said flux-guiding element can have a length (Δl) to width (Δw) ratio of >5, preferably >10, in particular >20. Thus the flux-guiding element has a thin and long-stretched outer contour with a much smaller width in comparison to its length allowing a very dense design of each resistor comprising a series connection of multiple resistor stripes in which each resistor stripe is arranged adjacent to a flux-guiding element. Typically a ferromagnetic pinning-element can have a similar or identical shape, or a pinning-element is identical to said flux-guiding element. A length of a flux-guiding element is as long as a length of a resistor stripe and its width is typically in a same ratio as a width of a resistor stripe. The material of a flux-guiding element and a pinning element is identical and comprises ferromagnetic material such as iron, cobalt or nickel with a magnetic permeability $\mu \gg 1$.

In a favorable embodiment in-plane connection lines connecting corresponding contact pads for voltage supply VCC, GND can have identical resistance values, and corresponding in-plane connection lines connecting contact pads for sensor signal terminals S+, S- can have identical resistance values. Insofar electric properties resulting of ohmic characteristic of the Wheatstone-bridge outbalance each other. Said identical resistance values can be obtained by designing connection lines with identical cross-section, identical material and identical length, or by different lengths and different cross-sections thus providing identical ohmic resistance values for connecting contact pads with connection points of the Wheatstone bridge thus improving accuracy and sensitivity of the sensor.

In a favorable embodiment an arrangement of the resistors R11, R12, R21, and R22 in the X/Y-plane can be point symmetrical to a barycenter of the Wheatstone bridge configuration and/or mirror symmetrical to a symmetry line of the Wheatstone bridge configuration.

In a favorable embodiment the Wheatstone-bridge configuration can be non-sensitive to in-plane magnetic field components, either by in-plane magnetic sensitivity directions being identical of resistors R11, R12, R21, R22 of each half bridge R11-R12, R21-R22 of a Wheatstone bridge configuration, or by in-plane magnetic sensitivity directions being identical of parallel arranged resistors R11-R21, R12-R22 of both half bridges R11-R12, R21-R22 of a Wheatstone bridge configuration, or by in-plane magnetic sensitivity directions being opposite of diagonal arranged resistors R11-R22, R12-R21 of both half bridges R11-R12, R21-R22 of a Wheatstone bridge configuration. A magnetic sensitivity direction correlates with a pinning direction of the TMR elements comprised in the resistor stripes forming each resistor. In case of identical sensitivity directions, all pinning directions are identical, in case of opposed sensitivity directions, the pinning directions are opposed. Non-sensitivity to an overall in-plane magnetic field is achieved by identical pinning-directions of all resistor stripes of a Wheatstone-arrangement, or by a pinning-configuration which allows an output signal not to drift due to compensating ohmic behavior of the resistors involved. Thus identical magnetic sensitivity of half-bridge resistors, parallel aligned resistors or of diagonal arranged resistors contribute to non-sensitivity of an overall in-plane magnetic field component making the sensor arrangement non-sensitive to an external X- or Y-magnetic field. Insofar layout scheme of the resistor stripes, and ferromagnetic pinning elements applied in a manufacturing process dominates to said non-sensitivity of in-plane magnetic components.

In a favorable embodiment in-plane magnetic sensitivity directions of resistors R11, R12, R21, R22 of each half bridge R11-R12, R21-R22 can be angled in a Wheatstone bridge configuration, preferably can be perpendicular to each other, and / or in-plane magnetic sensitivity directions of parallel arranged resistors R11-R21, R12-R22 of both half bridges R11-R12, R21-R22 can be angled in a

Wheatstone bridge configuration, preferably being perpendicular to each other. Insofar pinning directions and/or alignment direction of resistor stripes of bridge resistors or parts of resistor stripes connected in series for forming a resistor stripe can be angled to each other thus providing a vectorial rectangular alignment of pinning directions, i.e. magnetic sensitivity directions in the X/Y-plane thus decoupling X- and Y-components. Said angled configuration reduces a number of TMR-elements being sensitive for an X- or Y-component of an external field thus reducing a sensor sensitivity of in-plane magnetic components.

In a second inventive aspect a first manufacturing method is proposed, wherein, in a first step for pinning said TMR-elements of at least one resistor stripe having a positive resistor gradient for Z-oriented magnetic field components, a ferromagnetic pinning element is deposited adjacent to a first lateral side of the stripe path of said resistor stripe on the X/Y-plane. In a next step a Z-oriented magnetic pinning field is applied for pinning said TMR-elements by an in-plane stray-field of the ferromagnetic pinning element. In a subsequent step the ferromagnetic pinning element is removed from said X/Y-plane, and in a subsequent step a flux-guiding element is deposited on a second lateral side of the stripe path opposite to the first lateral side on the X/Y-plane. At least a part of the resistor strips comprised in the Wheatstone bridge are pinned by a temporarily deposited pinning element on a first lateral side of its contour line by a Z-oriented processing field while afterwards a flux-guiding element is deposited on a second opposite lateral side. Insofar an arrangement of a flux guiding element in parallel to a resistor stripe is provided, in which a pinning direction of all TMR-elements comprised in the resistor stripe are directed perpendicular towards the flux-guiding element. Said first manufacturing method provides combinations of flux-guiding elements and resistor stripes having a reverse magnetic sensitivity characteristic to combinations of flux-guiding elements and resistor stripes, in which the flux-guiding elements also has been used as pinning element.

In a favorable embodiment of said first method, each half-bridge R11-R12, R21-R22 can comprise a first resistor R11, R12, R21, R22 comprising resistor stripes with a ferromagnetic pinning element being arranged identical to a flux-guiding element on the first lateral side, and a second resistor R11, R12, R21, R22 can comprise resistor stripes with a ferromagnetic pinning element being temporarily during a pinning process arranged on the first lateral side of the stripe path opposite to a flux-guiding element being arranged later on, after the pinning process, on the second lateral side of the stripe path. Said configuration holds for resistors comprising different sets of resistors stripes having opposed sensitivity characteristic for Z-oriented magnetic field components. Favorably a number of resistor stripes of the first resistor and the second resistor is identical, thus half of the ohmic value of all resistors provide an opposed Z-magnetic sensitivity.

In a favorable embodiment of said first method, the ferromagnetic pinning element can be identical to the flux-guiding element, thus not being removed during the manufacturing process. Said embodiment proposes to remove pinning elements and deposit flux-guiding elements on the opposite side of pinning strips of the second resistors after pinning but to remain pinning elements of the first resistors as flux-guiding element, which saves manufacturing time and costs.

In a third inventive aspect a second manufacturing method is proposed, wherein in a first step for pinning TMR-elements of at least one resistor stripe having a positive resistor gradient for Z-oriented magnetic field components, said TMR-elements are pinned by an in-plane magnetic pinning field in an X/Y-plane, and in a subsequent step a ferromagnetic flux-guiding element is deposited adjacent to said resistor strip. In contrast to a first manufacturing method a processing magnetic field is applied as in-plane magnetic field, which holds for uniform pinning directions of all resistor strips being involved in the pinning process. Said second manufacturing method does not make use either of (temporarily) deposited ferromagnetic pinning elements or a Z-oriented processing magnetic field and provides a uniform over-all pinning direction of all TMR-elements in the resistor strips involved. Insofar a deposition and later removal of ferromagnetic pinning elements is unnecessary and all TMR-elements have an identical pinning direction so that a Z-sensitivity characteristic is dominated by an arrangement scheme of flux-guiding elements deposited later on.

In a favorable embodiment of said second method, a first and a second resistor stripe can be arranged on opposite lateral sides of said ferromagnetic flux-guiding element, each of said resistor strips belong to one of a pair of parallel aligned R11-R21 and R12-R22 resistors. By deposition of flux-guiding elements between resistor strips of parallel aligned resistors a reverse Z-sensitivity characteristic of said parallel aligned resistors is obtained which makes the sensor arrangement sensitive for Z-magnetic field components.

DRAWINGS

Further advantages are revealed by the present drawings and the associated descriptions of the drawings. The drawings show exemplary embodiments of the invention. The drawings, description and claims contain numerous features in combination. A person skilled in the art will expediently also consider the features individually and combine them into meaningful further combinations.

In the figures:

Figs. 1a-1f:	show circuit-diagrams of various Wheatstone-bridge configurations as embodiments of the invention;
Figs. 2a-2j:	show schematic layouts of resistor stripes and flux-guiding elements according to various embodiments of the invention;
Fig. 3:	show a schematic layout of a Z-component magnetic field sensor on an X/Y-plane according to a first embodiment of the invention;
Fig. 4:	show a schematic layout of a Z-component magnetic field sensor on an X/Y-plane according to a second embodiment of the invention;
Fig. 5:	show a schematic layout of a Z-component magnetic field sensor on an X/Y-plane according to a third embodiment of the invention;
Fig. 6:	show a schematic layout of a Z-component magnetic field sensor on an X/Y-plane according to a fourth embodiment of the invention;

Fig. 7: show a schematic layout of a 3D magnetic field sensor on an X/Y-plane according to a fifth embodiment of the invention;

Identical elements are denoted with the same reference signs in the figures. The figures merely show examples and should not be understood as being limiting.

Figs. 1a-1f show Wheatstone bridge arrangements V11 to V13, V21-V23 of embodiments of Z-component magnetic field sensors. Each Wheatstone bridge arrangement have a supply voltage terminal VCC (supply voltage) and GND (ground) and output signal terminals S+, S- having a voltage signal offset according to a magnitude of a Z-component field strength. Each resistor R11, R12, R21 and R22 of the Wheatstone bridge arrangement has an in-plane magnetic sensitive direction in the X/Y-plane depicted by a vectorial arrow and provided by an in-plane pinning direction of the TMR-elements of said resistor. Furthermore each resistor R11, R12, R21 and R22 has a Z-sensitivity direction depicted by a tip or a tail symbol of an vectorial arrow directed in a Z-direction outward or inward to the X/Y-plane and being provided by a flux-guiding element (not shown) adjacent to a resistor stripe in combination with the in-plane pinning direction of the resistor stripe(s) of each resistor.

All configurations show an identical Z-sensitivity characteristic in which pairs of parallel aligned resistors R11-R22 and R12-R21 have identical Z-magnetic sensitivity directions, which are opposite to each other. In these embodiments parallel aligned resistors R11-R22 show a Z-sensitivity direction being directed outward of the X/Y-plane (tip of vectorial arrow) while resistors R12-R21 show a Z-sensitivity direction being directed toward to the X/Y-plane (tail of vectorial arrow).

The configurations V11 to V13 of Figs. 1a to 1c show different configurations of in-plane pinning-directions, while Z-sensitivity directions are identical.

Fig 1a show a configuration V11 in which all four bridge resistors R11, R12, R21 and R22 have identical in-plane –Y sensitivity direction. In configuration V12 of **Fig. 1b** pairs of parallel aligned resistors R11-R21 and R12-R22 have identical sensitivity directions being opposite to each other. Configuration V13 of **Fig. 1c**

comprise two half-bridges R11-R12 and R21-R22 having identical Y-sensitivity directions, but the Y-directions of both half bridges are opposite to each other.

Configurations V21 to V23 of Figs. 1d to 1f show Wheatstone bridge directions in which either in-plane sensitivity directions within half-bridge resistors R11-R12 (V22, V23) and R21-R22 or between half-bridges (V21) are oriented perpendicular to each other.

In so far configuration V21 of **Fig. 1d** show a first half bridge R11-R12 in which an in-plane sensitivity direction is oriented in a Y-direction and is identical to each other in a –Y direction. A second half bridge R21-R22 show an X-direction aligned in-plane sensitivity being identical to each other in a +X direction.

Figs. 1e and 1f show configurations V22 and V23 in which in-plane sensitivity directions with each half bridge R11-R12 and R21-R22 are oriented perpendicular to each other.

Fig 1e show a configuration V22 with parallel aligned resistors R11-R21 having identical –Y sensitivity directions and R21-R22 having identical +X sensitivity directions.

V23 of **Fig. 1f** show diagonal aligned resistors R11-R22 having opposite in-plane directions in a Y-axis while diagonal aligned resistors R12-R21 having opposite in-plane directions in an X-axis.

All Wheatstone bridge directions are non-sensitive to in-plane X- and Y-field components of external magnetic field, but are highly sensitive to Z-oriented external magnetic field components. While configurations V11 to V23 show basic configurations it is straight forward that an axis configuration can be permutated. Furthermore since each resistor can comprise plural resistor strips, each resistor stripe have specific in-plane X/Y- and Z-sensitivity directions, enhanced embodiments comprising combinations of V11 to V23 configurations on a resistor level are also comprised in the invention. For instance a resistor can comprise a first set of resistor stripes having a Y sensitivity direction and a second set of resistor stripes having a +X sensitivity direction so that a depicted configuration can also applied within a single resistor layout thus providing a higher harmonic filtering of angular error components.

Figs. 2a to 2j show different embodiments of resistor stripes 100 to 118 with ferromagnetic flux guiding and/or pinning elements 22, 24, 26 having specific Z-component sensitivities. Each resistor stripe 100 to 110 comprises a plurality of TMR-elements 16 connected in series by electric conductive connection elements 18. Two connection elements 18 on different layers of an X/Y-substrate overlap a TMR-element 16 thus forming a stripe of TMR-elements 16. At both ends of said stripe contacting regions 20 provide an electric connection pad for wiring with other resistor stripes 100 to 110 for forming a resistor R11, R12, R21 or R22 of a Wheatstone bridge arrangement. Along a lateral side of each resistor stripe 100 to 110 an adjacent ferromagnetic flux-guiding element 24 is arranged or a ferromagnetic pinning element 22 is temporarily deposited and removed after completion of a pinning process. In the drawings a ferromagnetic flux-guiding element 24 is hatched by longitudinal hatching lines, a ferromagnetic pinning element 22 is hatched by transverse hatching lines. Combined ferromagnetic elements acting as well as pinning elements 22 and flux-guiding elements 24 are crosshatched.

Following sensor arrangements are composed of resistor strips 100 to 110 as shown in the embodiments of Fig. 2a to 2f. Each Fig. 2a to 2f also include a diagram of a resistor R showing its magnetic sensitivity in an in-plane +/-Y direction by vector arrows and a Z-direction by tip and tail representation of a vector arrow directing out of or toward the X/Y-plane.

Each ferromagnetic pinning element 22, ferromagnetic flux-guiding element 24 and combined ferromagnetic pinning and flux-guiding element has a length Δl and a width Δw. Each of said elements 22, 24 and 26 has a contour line 34 neighboring a resistor stripe 100 to 110 following a stripe path 30 of said resistor stripe 100 to 110. A lateral distance between said contour line 34 and the resistor stripe 100 to 110 is so close that no other structural or functional element can be placed between them. Typically a lateral distance can be close to zero or can be even negative, but preventing short-circuit of TMR-elements 16. Said distance can be adapted due to magnitude of field strength of a Z-magnetic field component to be measured.

Fig. 2a shows a first embodiment of a resistor stripe 100. The resistor stripe 100 comprises a straight line of 24 TMR elements 16 connected in series by electrical conductive elements 18 located on different substrate layers of the sensor. The resistor stripe 100 can be connected electrically at contacting regions 20. The TMR-elements 16 comprise multiple functional layers; at least a layer with ferromagnetic properties is pinned in a manufacturing step in an in-plane pinning direction thus providing a direction of magnetic sensitivity in said pinning direction. In this embodiment the TMR-elements 16 are pinned in a Y-direction. This is done by depositing a combined ferromagnetic pinning and flux-guiding element 26 adjacent to a stripe path 30 of the resistor stripe 100. At a so-called pinning-temperature a Z-directed processing field is applied so that a Y-directed stray field perpendicular to the contour line 34 of the ferromagnetic element 26 pins the TMR elements 16. After a pinning step the pinning element 22 serves as flux-guiding element 24 thus providing a combined pinning and flux-guiding element 26. In this was said pinning element has a specified Z-axis sensitivity dominated by a relative arrangement of a pinning element 22 in relation to a flux-guiding element 24. In this embodiment the sensitivity can be conserved as sensitive in a +Y direction.

In the following embodiments of resistor strips 102 to 110 a dominant majority of features are identical to the features of resistor stripe 100. Thus only deviating and distinguishing features are to be described.

Fig. 2b shows a configuration of a resistor stripe 102 in which in a pinning step a ferromagnetic pinning element 22 is temporarily deposited in a positive Y displacement from resistor stripe 102. After completion of a pinning step the pinning element 22 is removed a ferromagnetic flux-guiding element 24 is deposited in a negative displacement of resistor stripe 102. A width of displacement from pinning element 22 to resistor stripe 102 and width of displacement from flux-guiding element 24 to resistor stripe 102 can be identical or can be different. Thus an opposite Z-sensitivity direction in contrast to resistor stripe 100 can be provided while a Y-sensitivity direction of resistor stripe 100 and 102 are identical.

Figs. 2c and 2d show similar configurations of resistor stripes 104 and 106. **Fig. 2c** shows a resistor stripe 104 having opposite Y-sensitivity directions but identical Z-sensitivity directions as resistor stripe 102 of **Fig. 2b**. The same hold with resistor stripe 106 of **Fig. 2d** having opposite Y-sensitivity directions but identical Z-sensitivity directions as resistor stripe 100 of **Fig. 2a**.

Figs 2e and Fig 2f show two resistor stripe embodiments 108 and 110 following a design configuration of resistor stripe 100 of Fig. 2a. Both resistor stripe 108, 110 have a +Z sensitivity direction and a +Y sensitivity configuration

While resistor stripe 100 arranges a series of TMR-elements 16 along a straight line of stripe path 30, a stripe path 30 of resistor stripe 108 and its adjacent combined pinning and flux-guiding element 26 shown in **Fig. 2e** is angled in an middle section by 60°. Insofar half of the TMR-elements 16 are pinned in a -30° angle of the Y-axis and another half of the TMR-elements 16 are pinned in a +30°angle of the Y-axis. Thus a 60° angled stripe path 30 provides a filtering of a 3rd harmonic angular error component.

Resistor stripe 110 and combined pinning and flux-guiding element 26 depicted in **Fig. 2f.** is curved following a half-circle outline thus providing multiple angled TMR-elements 16 for filtering multiple higher-order angle error components of in-plane magnetic fields.

Figs. 2g and 2h show resistor stripes 112, 114 having in-plane pinning direction thus are not pinned by a stray field of a pinning element 22 generated by a Z-oriented processing field. Resistor stripe 112 of **Fig. 2g** and resistor stripe 114 of **Fig. 2h** have an identical +Y directed pinning direction. A ferromagnetic element is deposited in a positive Y distance of resistor stripe 112 (Fig. 2g) and in a negative Y distance to resistor stripe 114 (Fig. 2h) causing opposing Z-axis sensitivity of resistor stripe 112 vs. resistor stripe 114. Using resistor stripes 112, 114 eliminates depositing of a specific pinning element 22 thus easing and speeding up manufacturing of said resistor stripes but requiring application of an in-plane pinning field in contrast to resistor stripes 100-110 requiring a Z-oriented processing field for generating pinning stray fields of pinning elements 22.

Figs 2i and 2j show two resistor stripes 116, 118 designed for in-plane magnetic sensitivity. Insofar both resistor stripes 116, 118 do not have an adjacent flux-guiding element 24, but a temporarily disposed pinning element 22, deposited before a pinning step and removed after a pinning step within a manufacturing process. A Y-sensitivity of resistor stripe 116 of Fig. 2i is opposed to a Y-sensitivity of resistor stripe 118 of Fig. 2j by a +Y vs. –Y displacement of pinning element 22w. Said resistor stripes 116, 118 are applicable for sensing in-plane X- or Y-components for a full 3-axis magnetic field sensor, as shown in Fig. 7.

Figs. 3 to 7 show various embodiments 10.1 to 10.5 of vectorial magnetic sensor arrangements on an X/Y-substrate. Each embodiment 10.1 to 10.5 comprise a Z-axis magnetic field sensor 14, embodiment 10.5 of Fig. 7 shows a full 3D vectorial magnetic field sensor 12.

Each sensor 12, 14 comprise an embodiment of a Wheatstone-bridge configuration V11-V13, V21-V23 and includes contact pads 28 for voltage supply VCC, GND and signal output S+, S-. Contact pads 28 for voltage supply VCC, GND are connected by voltage supply connection lines 36 with the Wheatstone bridge configuration, having identical resistance values, i.e. identical cross-sections and lengths. Contact pads 28 for signal output S+, S- are connected by voltage supply connection lines 36 with the Wheatstone bridge configuration, having identical resistance values, i.e. identical cross-sections and lengths.

Fig. 3 depicts a first embodiment 10.1 of a Z-axis magnetic sensor 14.1. The Z-sensor 10.1 comprises four bridge resistors R11, R12, R21 and R22 in a cross-like arrangement with vertical mirror symmetry (Y-axis symmetry plane) of the sensor layout on the X/Y plane. Each resistor R11, R12, R21 and R22 comprise a zigzag configuration of four resistor stripes 100, 102, following a Wheatstone-bridge configuration V11 as shown in Fig. 1a.

Resistors R11 and R22 are identically composed of a series connection of four resistor stripes 100 as shown in Fig. 2a and resistors R12 and R21 are identically composed of a series connection of four resistor stripes 102 as shown in Fig. 2b. Both sets of resistors R11-R22 and R12-R21 have opposing Z-axis sensitivity but identical Y-axis sensitivity which makes them highly sensitive for Z-axis magnetic fields but also holds for a non-sensitivity of external in-plane X- or Y-magnetic fields. During a manufacturing process, ferromagnetic pinning elements 22 are deposited on a +Y side of each resistor stripe 100, 102.

While said ferromagnetic pinning element 22 remains within the resistor stripe configuration 100 of resistors R11, R22 thus forming a combined pinning and flux-guiding element 26, said pinning element 22 is removed after a pinning step in a subsequent manufacturing step for resistor stripes 102 of resistors R12, R21 and is replaced by a ferromagnetic flux-guiding element 24 on a –Y side of resistor stripes 102, thus providing opposing Z-axis sensitivity of resistors R12,R21 in contrast to resistors R11, R22.

In **Fig. 4a** second embodiment 10.2 of a Z-axis magnetic sensor 14.2 is shown. The overall electrical design follows the first embodiment shown in Fig. 2a, i.e. following a Wheatstone bridge arrangement V11 shown in Fig. 1a. Insofar resistors R11 and R22 are identical and R12 and R21 are identical. Resistors R11 and R22 have an opposing Z-axis magnetic sensitivity in contrast to Resistors R12, R21. Each of resistors R11, R22 comprise a series connection of 30 resistor strips 100, as shown in Fig. 2a, and resistors R12 and R21 comprise a series connection of 30 resistor strips 102 as shown in Fig. 2b, in contrast to embodiment 10.1 wherein each resistor comprise 4 resistors 100, 102 respectively. All resistors R11-R22 have identical Y-axis in-plane sensitivity thus being non-sensitive to in-plane external magnetic field components. Insofar the second embodiment 10.2 shows an increased resistor dependence upon Z-axis magnetic field which makes it higher sensitive for Z-magnetic field variations as embodiment 10.1.

Due to an increased space of the Wheatstone-bridge arrangement on the substrate due to a high number of resistor stripes 100,102 contact pads 28 are arranged in an inner section of the sensor arrangement.

Fig. 5 shows a further, alternative embodiment 10.3 of a Z-axis magnetic field sensor 14.3. The Wheatstone bridge arrangement of sensor 10.3 follows a schematic V11 shown in Fig. 1a and is composed of resistor stripes 112, 114 as shown in Figs. 2g, 2h. In contrast to embodiments 10.1 and 10.2, wherein ferromagnetic pinning elements 22 have been at least temporarily deposited during a manufacturing step for pinning by a Z-oriented processing field, the resistor stripes 112, 114 are pinned by an in-plane processing field. Pairs of in series connected resistor stripes 112, 114 of resistor R11 and R21 following a zigzag-path share a same flux-guiding element 24. Said zigzag layout of resistor strips 112, 114 are nested within another in an interdigital form thus providing a space-saving arrangement of resistor pairs R11-on a sensor substrate. Since all resistor stripes 112, 114 are pinned for example in a +Y direction, flux-guiding elements 24 generate opposed Y-directed stray-fields of a Z-oriented external magnetic field exposing resistor stripes 112 of resistors R11, R22 and resistor stripes 114 of resistors R12, R21 in opposite directions. Thus all resistors R11-R22 show an identical Y-axis sensitivity on a basis of an identical in-plane pinning direction, but resistor pairs R11, R22 show an opposite magnetoresistive behavior in contrast to resistor pairs R12, R21 with respect to a Z-oriented external magnetic field. Thus Z-axis magnetic field sensor 14.3 is an alternative solution to other embodiments 14.1, 14.2 and 14.4, 12.

Fig. 6 displays a further embodiment 10.4 of a Z-axis magnetic field sensor 14.4 following a Whetstone-bridge arrangement V21 as depicted in Fig. 1d. The overall design of vectorial magnetic field sensor 10.4 is similar to the arrangement of sensor 10.1 shown in Fig. 3. In contrast to sensor 10.1 an in-plane orientation of resistors R21, R22 is rotated counter-clockwise upon 90°, thus an in-plane sensitivity of half-bridge resistors R21-R22 is oriented along an X-axis in an identical direction. Thus half-bridge R11-R12 have a common in-plane magnetic sensitivity direction in a Y-axis, while half-bridge R21-R22 show a common in-plane magnetic sensitivity direction along an X-axis. Z-axis sensitivity of sensor 10.4 is identical to sensitivity of sensor 10.1, but angled in-plane sensitivity directions increases non-sensitivity to arbitrary angled external in-plane magnetic field directions. Furthermore the 90° rotation makes the sensor more robust against pinning errors.

Fig. 7 show an embodiment 10.5 of a full 3D magnetic field sensor 12 for sensing a 3-axis magnetic field. Sensor 12 comprises three Wheatstone-bridge arrangements for sensing an X-, Y- and Z-component of an external magnetic field.

The Wheatstone-bridge for sensing a Z-axis component is located in the center of the sensor arrangement and follows a design principle of Z-axis magnetic field sensor arrangement 14.1 of Fig. 3.

Two pairs of bridge sensors Rx11-Rx12 and Rx21-Rx22 and two pairs of bridge sensors Ry11-Ry12 and Ry21-Ry22 are arranged on diagonal edges of the sensor design for providing symmetric Wheatstone bridge arrangements for sensing in-plane X- and Y-magnetic field components. Thereby each resistor comprises a zigzag-shaped series connection of resistor stripes 116, 118 as depicted in Figs. 2i, 2j. Pairs of resistors Rx11-Rx12, Rx21-Rx22, Ry11-Ry12, and Ry21-Ry22 forming respective half-bridges are nested within each other in an interdigital form thus providing a compact form of each half-bridge of the X- and Y-sensor arrangement.

A simultaneous pinning of all resistor stripes by a Z-oriented processing field can be applied in a manufacturing step thus providing uniform pinning conditions for all TMR elements 16 of all three Wheatstone bridge arrangements.

Contact pads 28 for supply voltage GND, VCC and of sensor signals Sx+/Sy-, Sy+/Sy- and Sz+/Sz- are arranged on an outer perimeter of the sensor arrangement. A magnetic shielding of the Z-sensor arrangement located in the center of the sensor arrangement is provided by a rectangular sequence of ferromagnetic shielding elements 32 surrounding the resistors Rz11, Rz12, Rz21, Rz22 constituting the Z-axis Wheatstone-bridge arrangement V11 of the 3-axis magnetic field sensor 10.5, 12. Said shielding elements 32 can also be applied for flux-guiding so the flux guiding elements 22, 24, 26 and 32 can used for pinning, flux-guiding and shielding and support field robustness and shielding against external parasitic fields.

Placing a flux-guiding element 22, 24, 26 on either side of a TMR-element 16 determine either pinning direction and/or direction of Z-axis sensitivity. In general a single Z-axis processing magnetic field provides all pinning directions of the sensor arrangement. The ferromagnetic elements 22, 24, 26 acts as an antenna for Z-oriented magnetic fields converting said magnetic fields into in-plane components in both lateral directions of the ferromagnetic elements either for pinning or for sensing.

Additional flux guide spheres for in-plane field components can be added for enhancing stray field robustness of the sensor. A flux guiding shield can reduce undesired, parasitic field components for a specific sensor direction thus enhancing an active sensor area and reducing a noise floor of a sensor output signal.

Reference Numerals

10	vectorial magnetic field sensor
12	3-axis magnetic field sensor
14	Z-axis magnetic field sensor
16	TMR-element
18	connection element
20	contacting region
22	ferromagnetic pinning element
24	ferromagnetic flux-guiding element
26	combined pinning and flux-guiding element
28	contact pad
30	stripe path
32	ferromagnetic shielding element
34	contourline of flux-guiding and/or pinning element
36	voltage supply connection line
38	sensor signal connection line
100	resistor stripe with positive in-plane -gradient and negative Z- gradient
102	resistor stripe with positive in-plane -gradient and positive Z- gradient
104	resistor stripe with negative in-plane -gradient and positive Z- gradient
106	resistor stripe with negative in-plane -gradient and negative Z-gradient
108	Resistor stripe with angled stripe path
110	Resistor stripe with curved stripe path
112	Resistor stripe with in-plane pinning
114	Resistor stripe with in-plane pinning
R11, R12, R21, R22	Magnetic sensitive resistor
Δl	length of ferrmomagnetic element
Δw	width of ferromagnetic element
V11, V12, V13	First, second and third Wheatstone bridge configuration of a z-sensor with parallel axis of magnetic sensitivity of both legs
V21,V22, V23	First, second and third wheatstone bridge configuration of a z-sensor with angled axis of magnetic sensitivity within a leg or between both legs
VCC, GND	Voltage supply
S+, S-	Sensor signal output

Claims

1. Vectorial magnetic field sensor (10, 12, 14) for measuring at least a Z-magnetic field component perpendicular to an X/Y-plane in which a Wheatstone-bridge configuration (V11, V12 V13, V21, V22, V23) of four magnetic sensitive resistors (R11, R12, R21, R22) is arranged, two of said resistors (R11, R12, R21, R22) form a half-bridge (R11-R12, R21-R22) of said Wheatstone-bridge configuration (V11, V12 V13, V21, V22, V23), Z-component magnetic sensitivity directions of each of said pair of resistors (R11, R12, R21, R22) of each half-bridge (R11-R12, R21-R22) are opposite to each other, and Z-component magnetic sensitivity directions of parallel aligned resistor (R11, R12, R21, R22) of both half-bridges (R11-R12, R21-R22) are opposite to each other, **characterized by** each resistor (R11, R12, R21, R22) comprises at least two or more resistor stripes (100, 102, 104, 106, 108, 110) connected in series, each resistor stripe (100, 102, 104, 106, 108, 110) consists of a series connection of a plurality of TMR-elements (16) aligned along a stripe path (30), an ferromagnetic flux-guiding element (24) is disposed adjacent to each resistor stripe (100, 102, 104, 106, 108, 110) in immediate vicinity, a contourline (34) of said flux-guiding element (24) follows said stripe path (30), and in-plane pinning directions (↑,↓) of TMR-elements (16) of pairwise diagonally arranged resistors (R11-R22, R12-R21) are perpendicular oriented either towards to, or away form said contourline (34), such that sensor signal terminals (S+, S-) of both half-bridges (R11-R12, R21-R22) of the Wheatstone-bridge configuration (V11, V12 V13, V21, V22, V23) are sensitive to a Z-magnetic field component.

2. Sensor (10, 12, 14) according to claim 1, **characterized by** in-plane pinning directions (↑,↓) of TMR-elements (16) of each resistor stripe (100, 102, 104, 106, 108, 110) being oriented in the X/Y plane.

3. Sensor (10, 12, 14) according to claim 1 or 2, **characterized by** each resistor stripe (100, 102, 104, 106, 108, 110) comprises at least 6 to 8, preferably 12 TMR-elements (16) or more.

4. Sensor (10, 12, 14) according to any of the preceding claims, **characterized by** said stripe path (30) is bended, curved or angled.

5. Sensor (10, 12, 14) according to any of the preceding claims, **characterized by** a lateral distance between the resistor stripe (100, 102, 104, 106, 108, 110) and the flux-guiding element (24) being less than a width (Δw) of said flux-guiding element (24).

6. Sensor (10, 12, 14) according to any of the preceding claims, **characterized by** resistor strips (100, 102, 104, 106, 108, 110) of different resistors (R11, R12, R21, R22) share the same flux-guiding element (24).

7. Sensor (10, 12, 14) according to any of the preceding claims, **characterized by** each resistor (R11, R12, R21, R22) comprises at least four resistor stripes (100, 102, 104, 106, 108, 110) arranged in a meandering form, preferably resistor stripes (100, 102, 104, 106, 108, 110) of a pair of resistors within a half bridge (R11-R12, R21-R22) or pairs of parallel aligned resistors (R11-R21, R12-R22) of both half bridges (R11-R12, R21-R22) are interdigitally arranged to each other.

8. Sensor (10, 12, 14) according to any of the preceding claims, **characterized by** a ferromagnetic shielding of the Wheatstone-bridge configuration (V11, V12 V13, V21, V22, V23) provided by ferromagnetic shielding elements (32) arranged along a perimeter of the Wheatstone-bridge configuration (V11, V12 V13, V21, V22, V23).

9. Sensor (10, 12, 14) according to any of the preceding claims, **characterized by** said flux-guiding element (24) having a length (Δl) to width (Δw) ratio of >5, preferably >10, in particular >20.

10. Sensor (10, 12, 14) according to any of the preceding claims, **characterized by** in-plane connection lines (36) connecting corresponding contact pads (28) for voltage supply (VCC, GND) having identical resistance values, and corresponding in-plane connection lines (38) connecting contact pads (28) for sensor signal terminals (S+, S-) having identical resistance values.

11. Sensor (10, 12, 14) according to any of the preceding claims, **characterized by** an arrangement of the resistors (R11, R12, R21, R22) in the X/Y-plane being point symmetrical to a barycenter of the Wheatstone bridge configuration (V11, V12 V13, V21, V22, V23) and/or mirror symmetrical to a symmetry line of the Wheatstone bridge configuration (V11, V12 V13, V21, V22, V23).

12. Sensor (10, 12, 14) according to any of the preceding claims, **characterized by** the Wheatstone-bridge configuration (V11, V12 V13, V21, V22, V23) being non-sensitive to in-plane magnetic field components, either by in-plane magnetic sensitivity directions being identical of resistors (R11, R12, R21, R22) of each half bridge (R11-R12, R21-R22) of a Wheatstone bridge configuration (V11, V13, V21), or by in-plane magnetic sensitivity directions being identical of parallel arranged resistors (R11-R21, R12-R22) of both half bridges (R11-R12, R21-R22) of a Wheatstone bridge configuration (V11, V12, V22), or by in-plane magnetic sensitivity directions being opposite of diagonal arranged resistors (R11-R22, R12-R21) of both half bridges (R11-R12, R21-R22) of a Wheatstone bridge configuration (V12, V13, V23).

13. Sensor (10, 12, 14) according to any of the preceding claims, **characterized by** in-plane magnetic sensitivity directions of resistors (R11, R12, R21, R22) of each half bridge (R11-R12, R21-R22) being angled in a Wheatstone bridge configuration (V22, V23), preferably being perpendicular to each other, and / or in-plane magnetic sensitivity directions of parallel arranged resistors of both half bridges (R11-R12, R21-R22) being angled in a Wheatstone bridge configuration (V21, V23), preferably being perpendicular to each other.

14. Method for manufacturing a sensor (10, 12, 14) according to one of the foregoing claims, wherein, in a first step for pinning said TMR-elements (16) of at least one resistor stripe (102, 104) having a positive resistor gradient for Z-oriented magnetic field components, a ferromagnetic pinning element (22) is deposited adjacent to a first lateral side of the stripe path (30) of said resistor stripe (100, 102, 104, 106, 108, 110) on the X/Y-plane, in a next step a Z-oriented magnetic pinning field is applied for pinning said TMR-elements (16) by an in-plane stray-field of the ferromagnetic pinning element (22), in a subsequent step the ferromagnetic pinning element (22) is removed from said X/Y-plane, and in a subsequent step a flux-guiding element (24) is deposited on a second lateral side of the stripe path (30) opposite to the first lateral side on the X/Y-plane.

15. Method according to claim 14, wherein each half-bridge (R11-R12, R21-R22) comprises a first resistor (R11, R12, R21, R22) comprising resistor stripes (100, 106, 108, 110) with a ferromagnetic pinning element (22) being arranged identical to a flux-guiding element (24) on the first lateral side, and a second resistor (R11, R12, R21, R22) comprising resistor stripes (102, 104) with a ferromagnetic pinning element (22) being temporarily arranged on the first lateral side of the stripe path (30) opposite to a flux-guiding element (24) being arranged later on the second lateral side of the stripe path (30).

16. Method according to claim 15, wherein the ferromagnetic pinning element (22) is identical to the flux-guiding element (24), thus not being removed during the manufacturing process.

17. Method for manufacturing a sensor (10, 12, 14) according to one of the foregoing claims 1 to 13, wherein, in a first step for pinning TMR-elements (16) of at least one resistor stripe (100, 102, 104, 106, 108, 110) having a positive resistor gradient for Z-oriented magnetic field components, said TMR-elements (16) are pinned by an in-plane magnetic pinning field in an X/Y-plane, and in a subsequent step a ferromagnetic flux-guiding element (24) is deposited adjacent to said resistor stripe (100, 102, 104, 106, 108, 110).

18. Method according to claim 17, wherein a first and a second resistor stripe (100, 102, 104, 108 110) are arranged on opposite lateral sides of said ferromagnetic flux-guiding element (24), each of said resistor strips (100, 102, 104, 108, 110) belong to one of a pair of parallel aligned resistors (R11-R12, R21-R22).

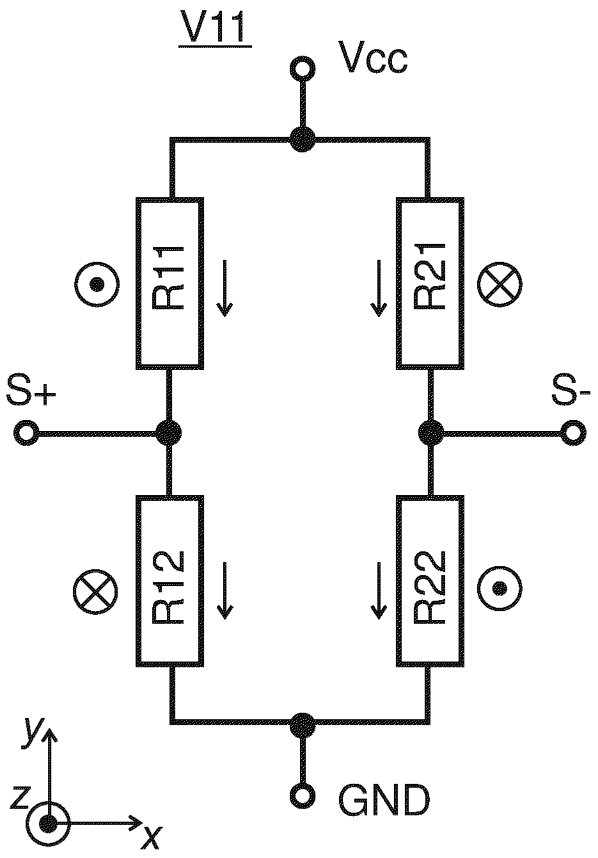


Fig. 1a

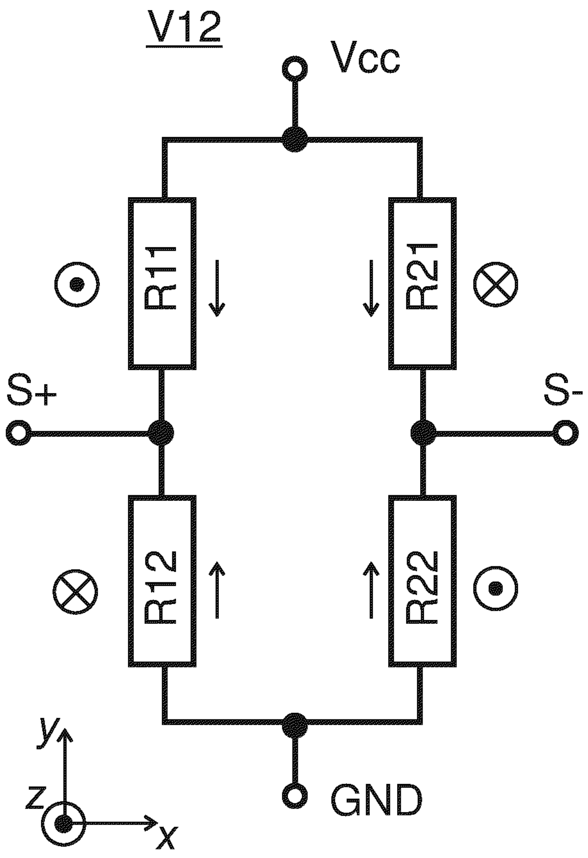


Fig. 1b

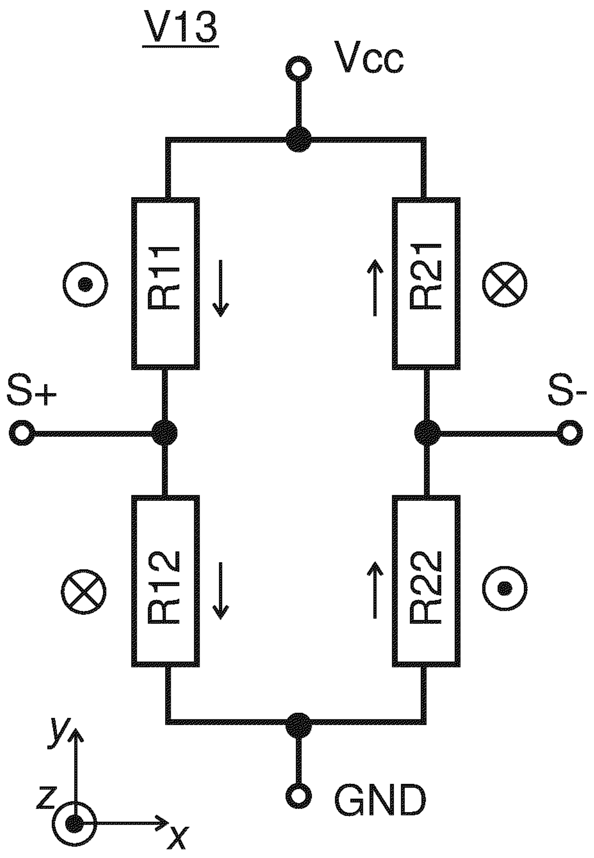
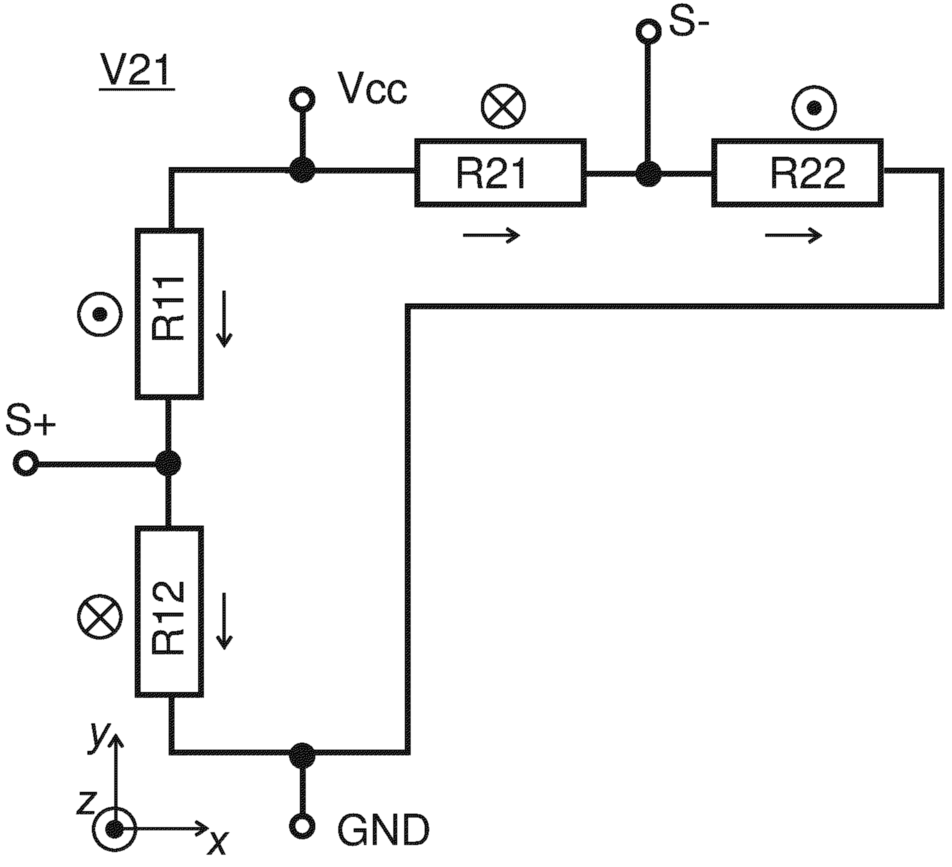


Fig. 1c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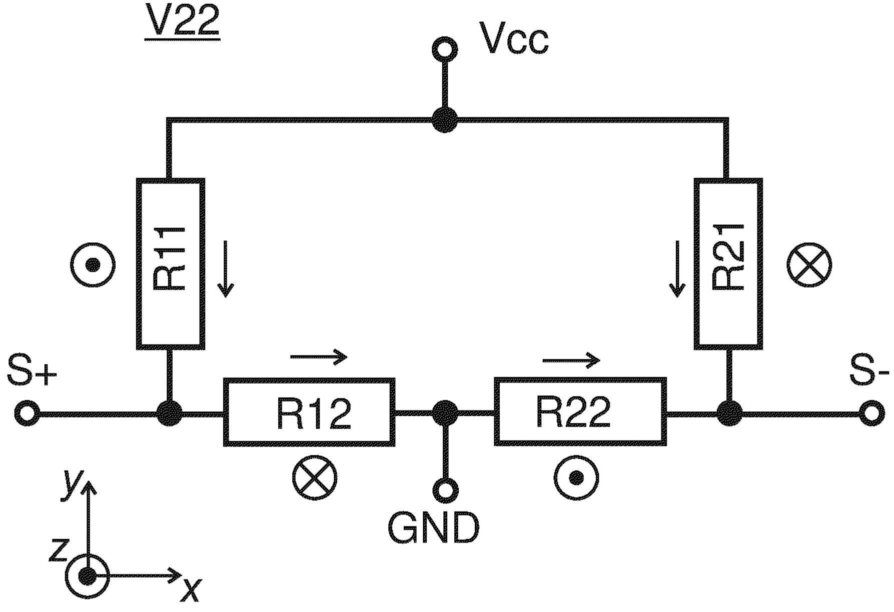
S-
R21
R22
R11
R12
S+
GND
y
z
x

Fig. 1d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S+
R12
R22
S-
GND
y
z
x

Fig. 1e

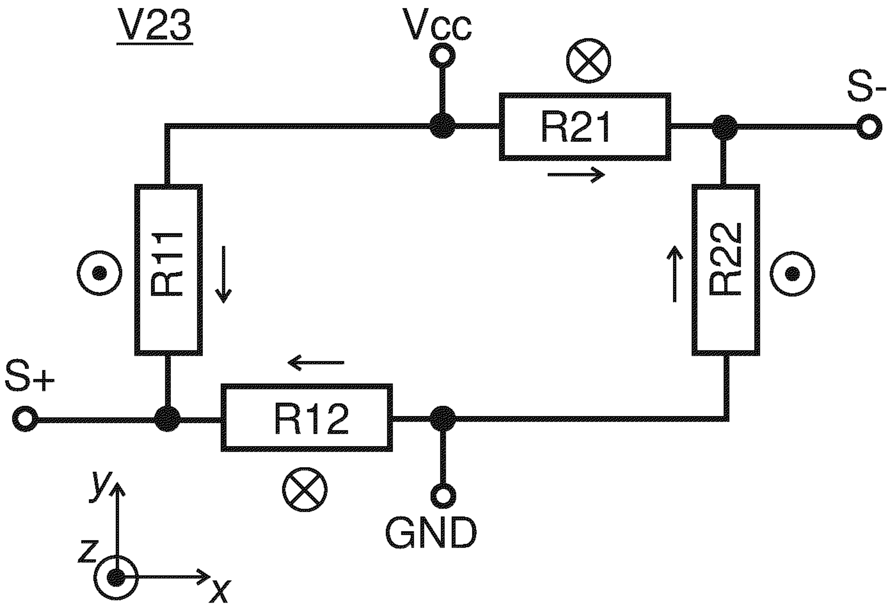


Fig. 1f

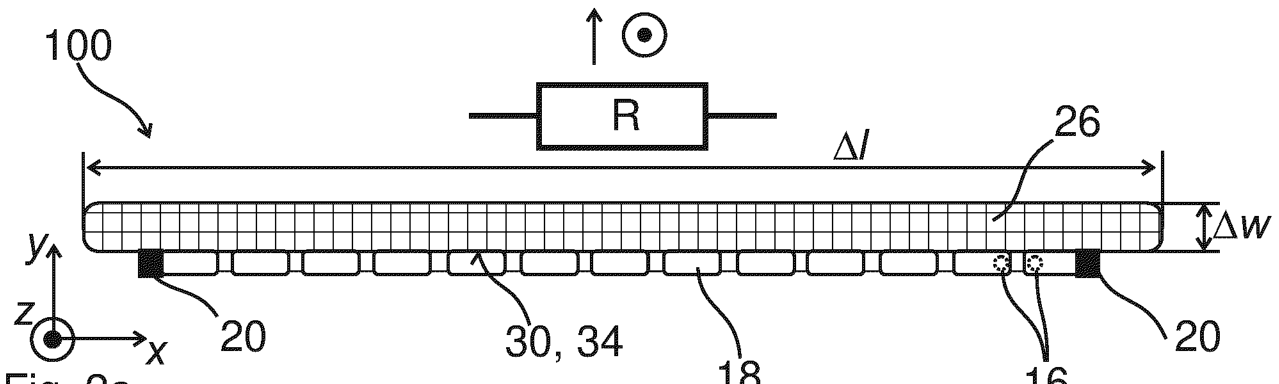


Fig. 2a

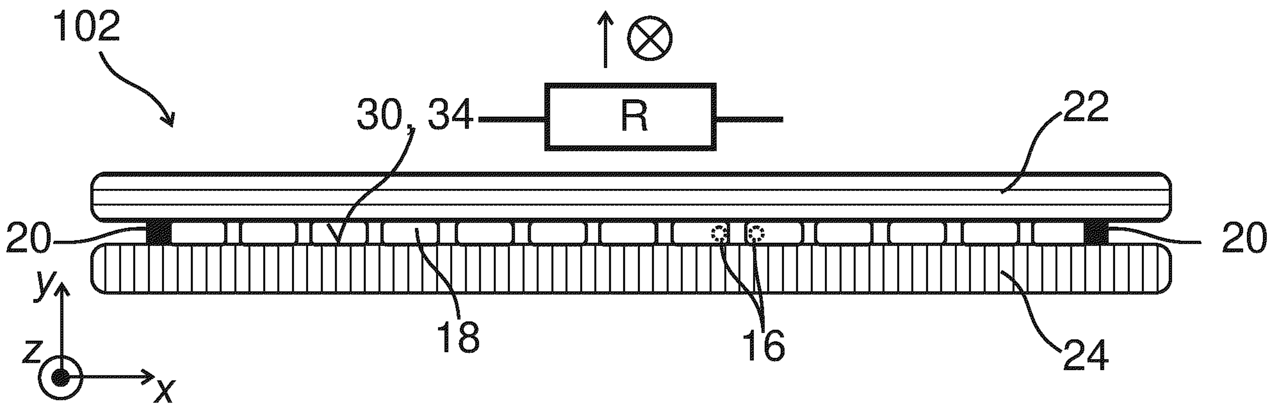


Fig. 2b

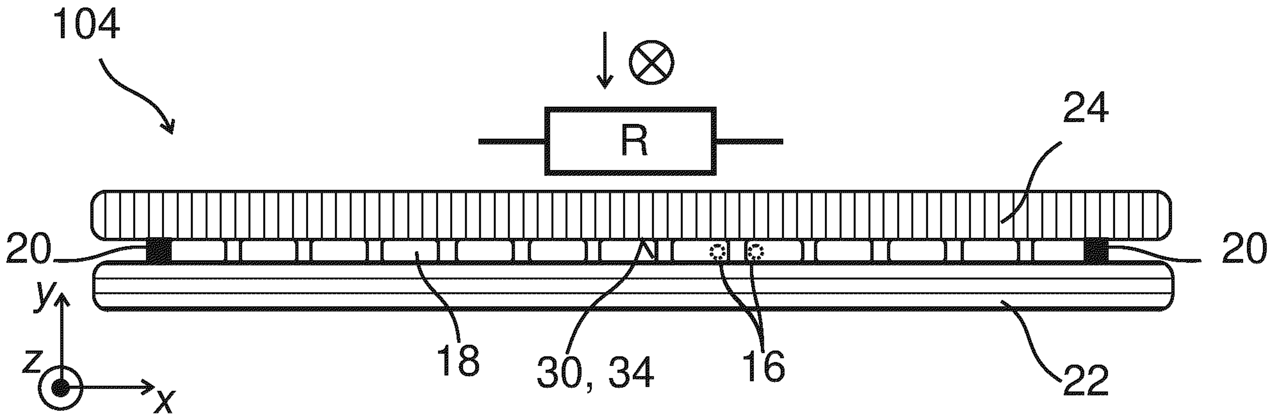


Fig. 2c

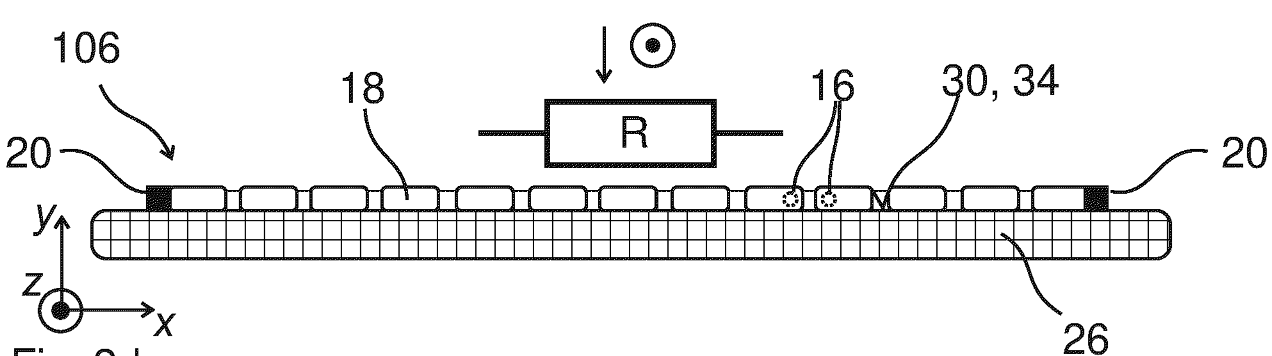


Fig. 2d

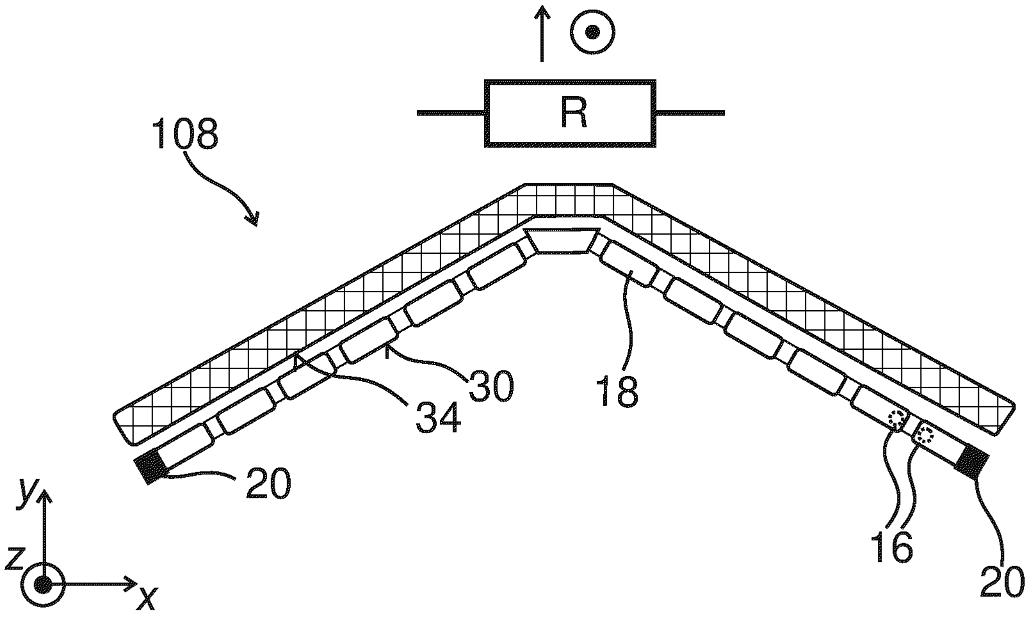


Fig. 2e

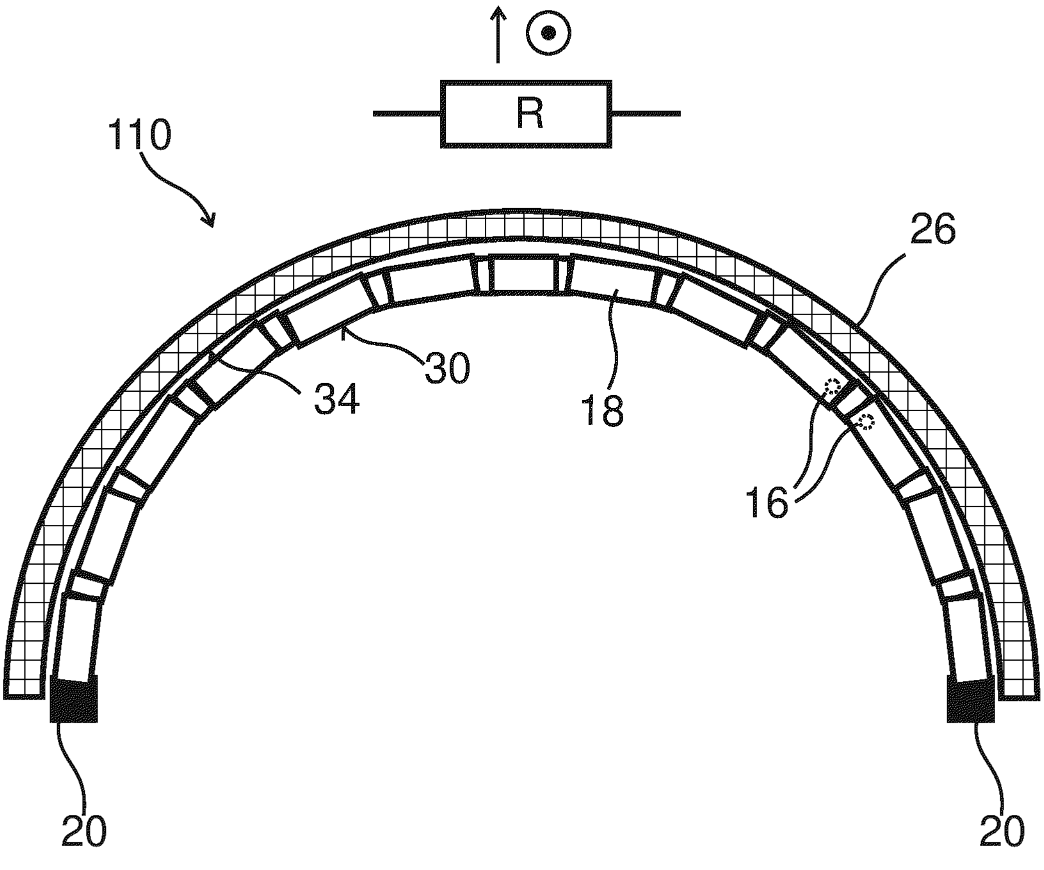


Fig. 2f

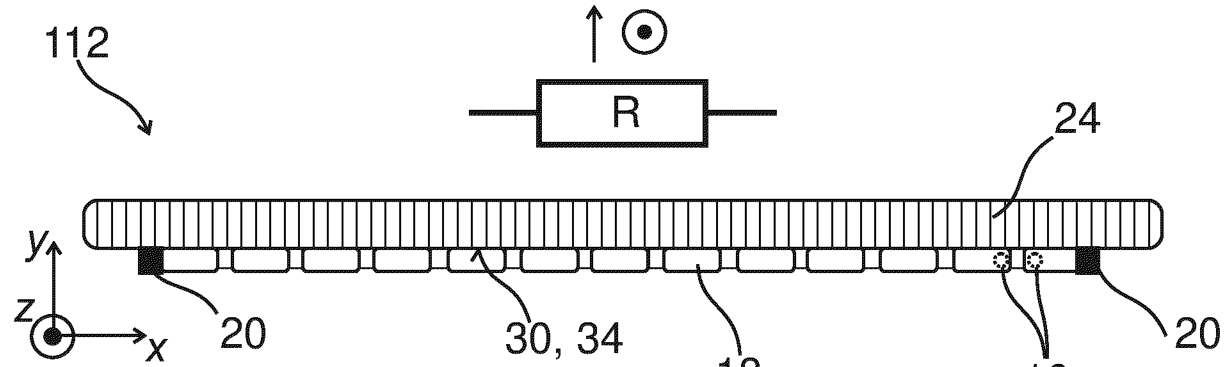


Fig. 2g

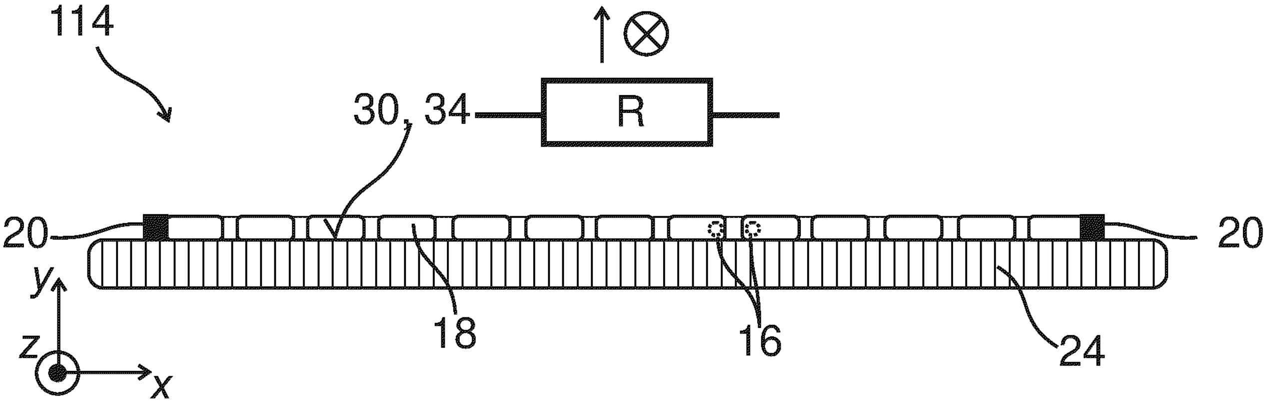


Fig. 2h

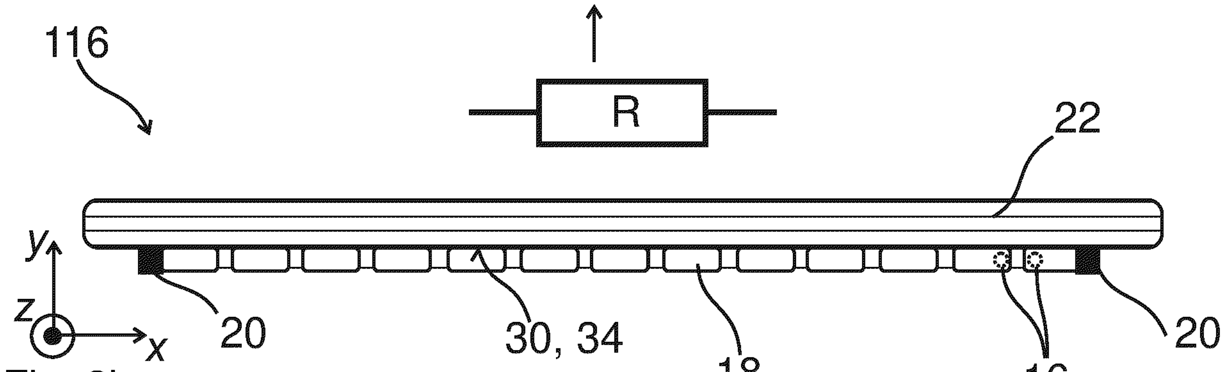


Fig. 2i

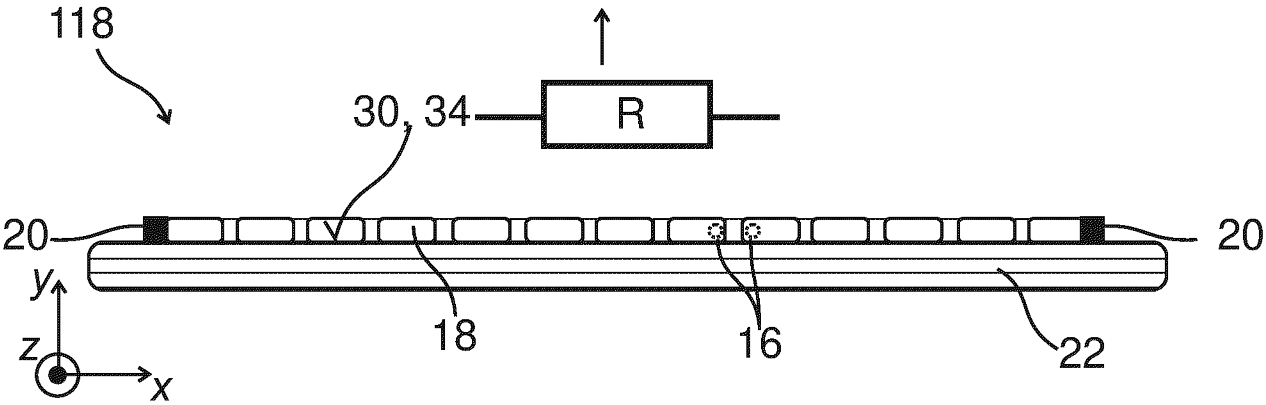
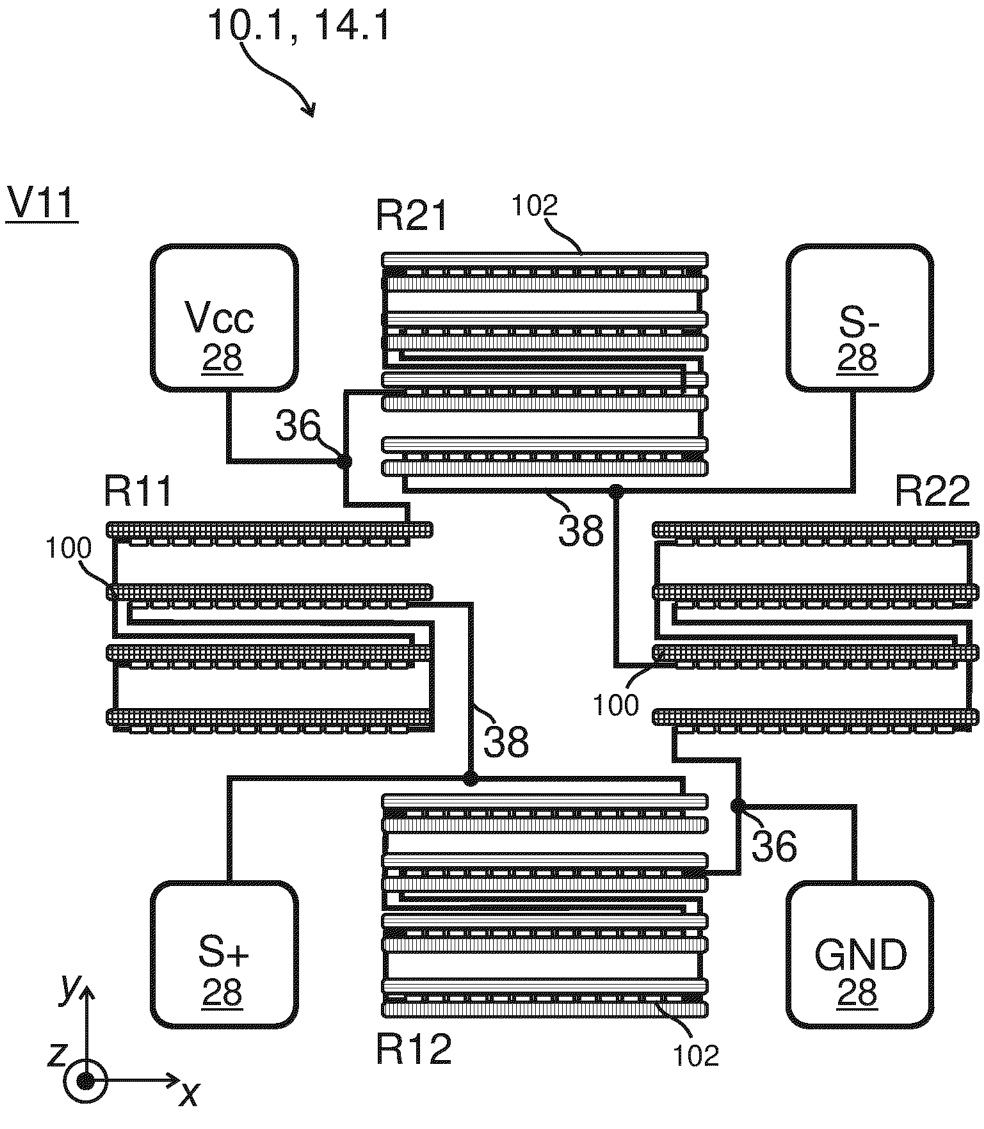


Fig. 2j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28
R12
102
y
z
x

Fig. 3

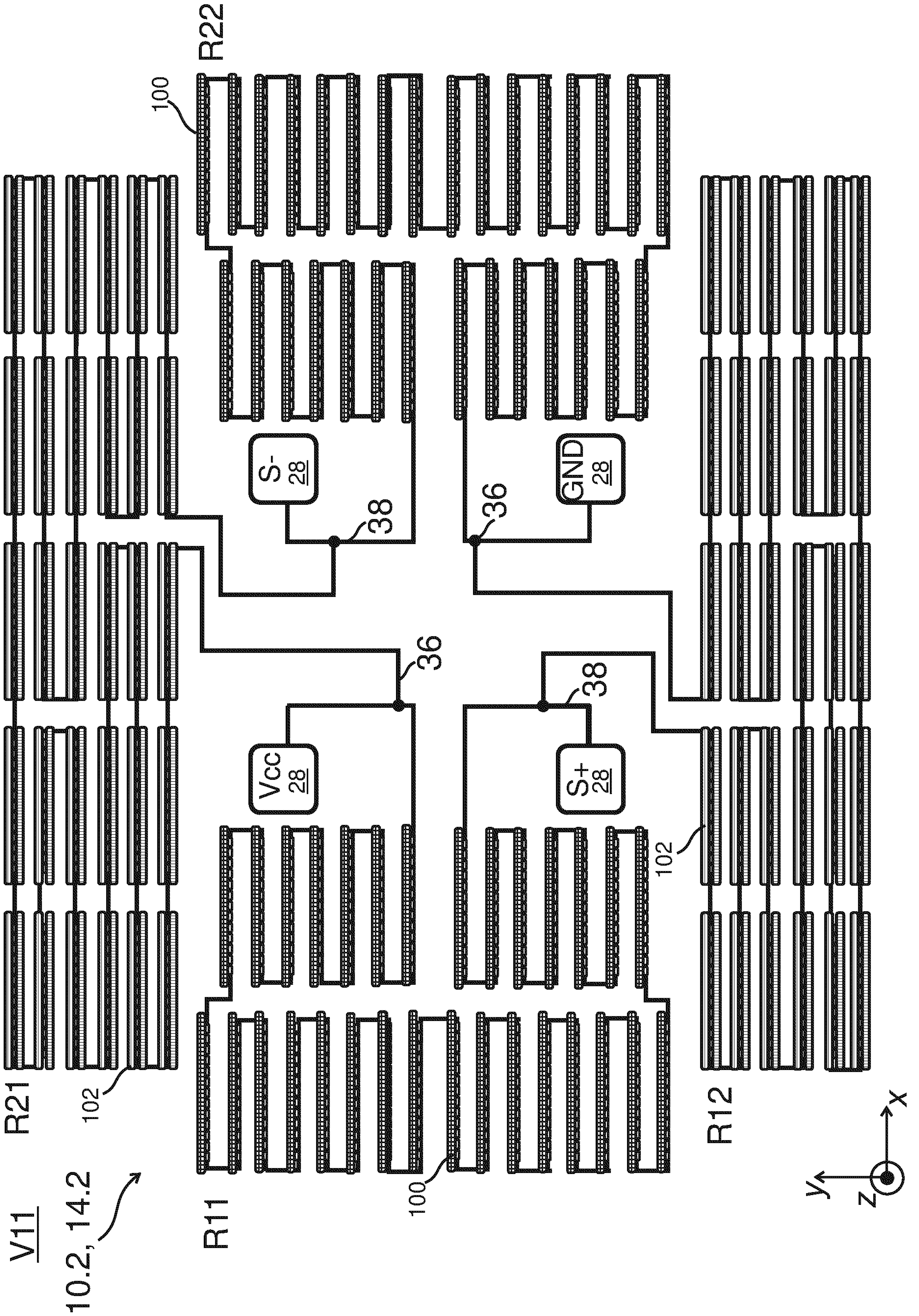
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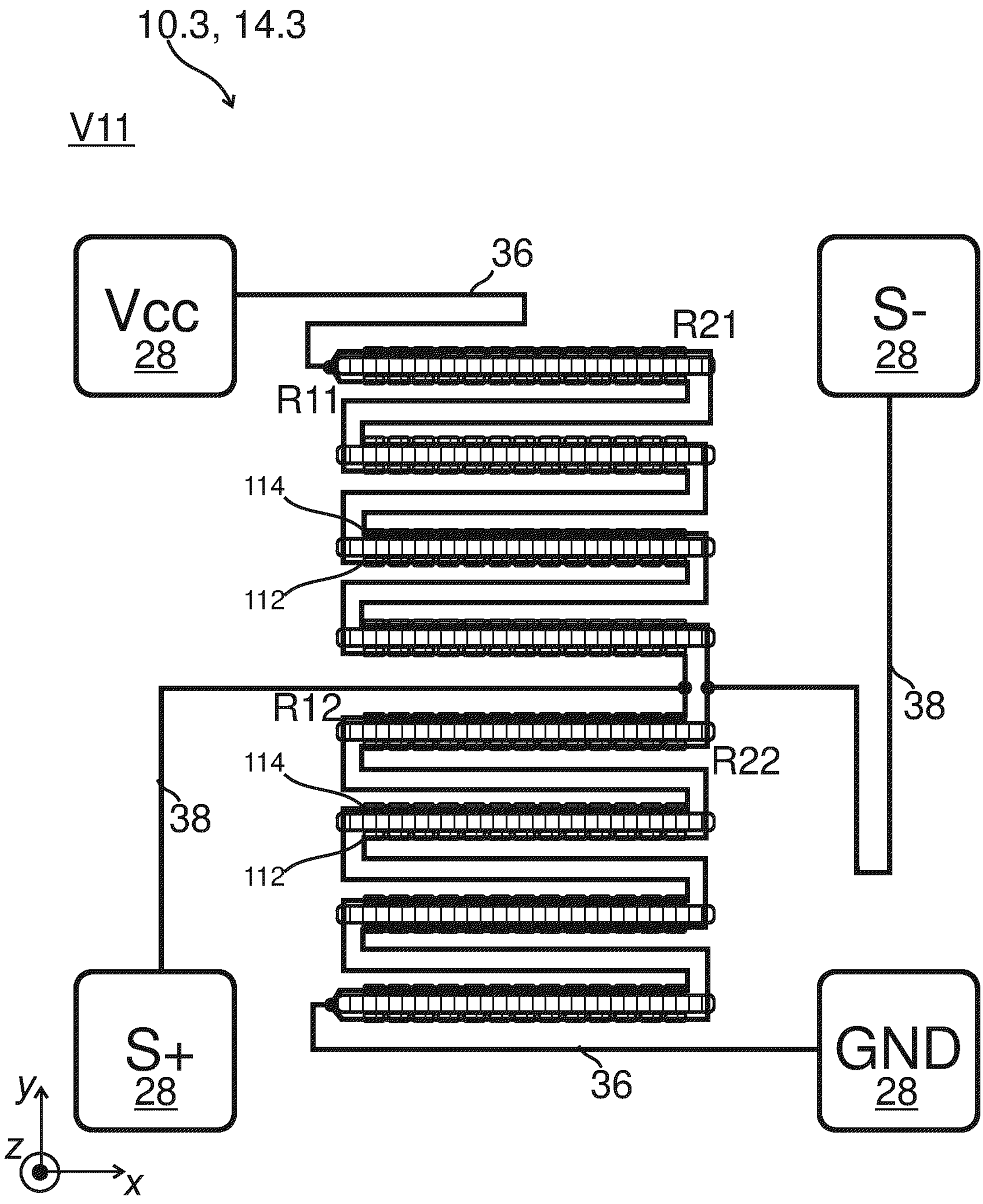
Fig. 4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y
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x

Fig. 5

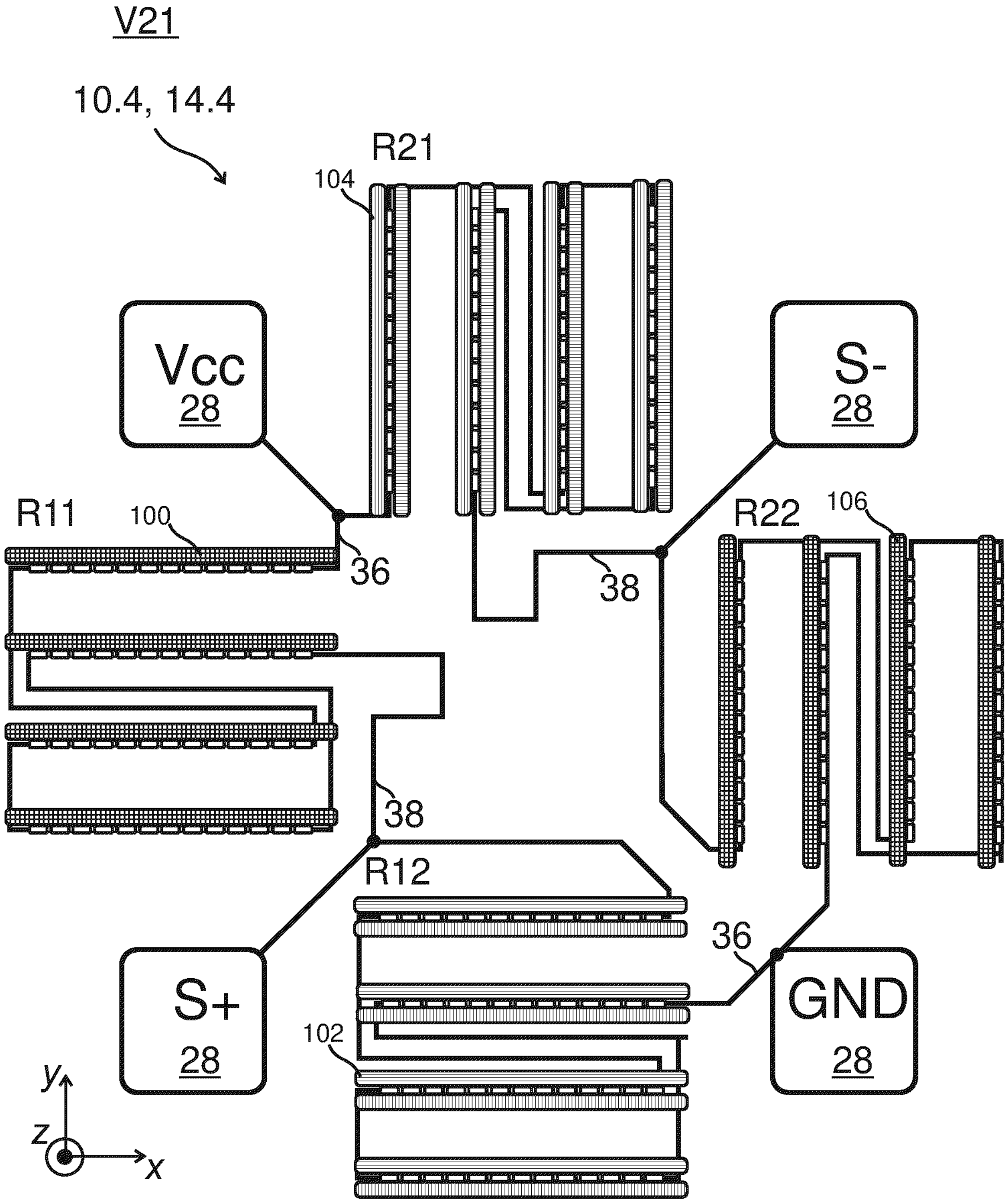
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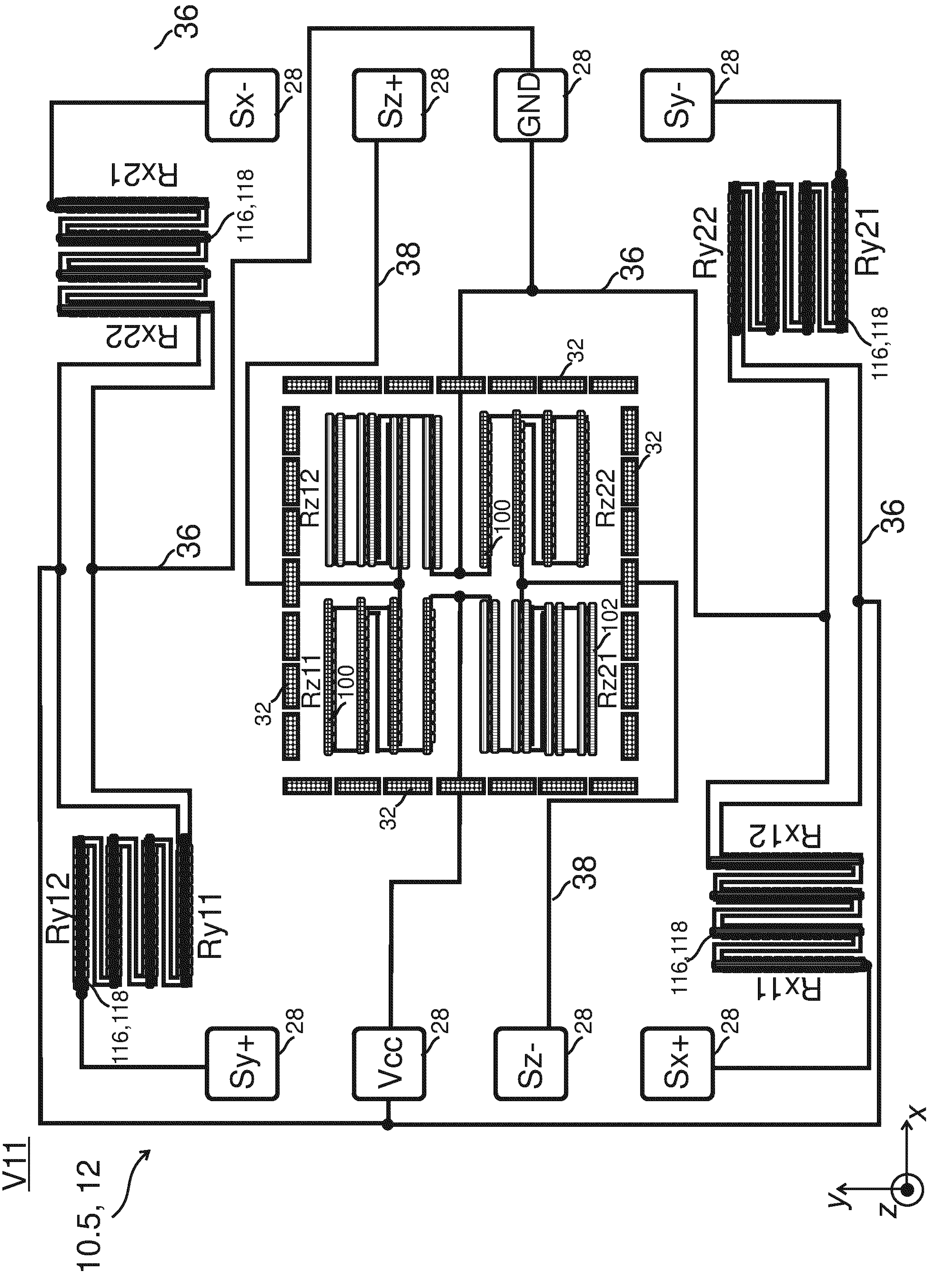
Fig. 6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y
z

Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2022/062668

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R33/00 G01R33/09 G01R33/02
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)
G01R

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 2017/059668 A1 (CHANG CHING-RAY [TW] ET AL) 2 March 2017 (2017-03-02)	1-14,17, 18
A	paragraphs [0018] - [0040]; figures 1-8 -----	15,16
Y	US 2017/328963 A1 (SCHMITT JOCHEN [DE] ET AL) 16 November 2017 (2017-11-16)	1-14,17, 18
A	paragraphs [0058] - [0060]; figures 1-9 -----	15,16
Y	US 2022/091198 A1 (PAUL JOHANNES [DE] ET AL) 24 March 2022 (2022-03-24)	1-14,17, 18
A	paragraph [0072]; figures 1-7 -----	15,16
A	EP 3 124 989 A1 (MULTIDIMENSION TECHNOLOGY CO LTD [CN]) 1 February 2017 (2017-02-01) the whole document -----	1-18

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

☒ See patent family annex.

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

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Date of the actual completion of the international search 12 December 2022	Date of mailing of the international search report 20/12/2022
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Philipp, Peter

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2022/062668

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