(12) UK Patent Application (19) GB (11) 2 034 903 A

(21) Application No **7937007**
(22) Date of filing **25 Oct 1979**
(30) Priority data
(31) **954341**
(32) **25 Oct 1978**
(33) **United States of America (US)**
(43) Application published
11 Jun 1980
(51) **INT CL^3**
G01R 17/14
(52) Domestic classification
G1U JB9B
(56) Documents cited
GB 1012062
GB 863935
(58) Field of search
G1U

(71) Applicants
Burr-Brown Research Corporation, International Airport Industrial Park, P.O. Box 11400, Tucson, Arizona 85734, United States of America
(72) Inventor
Jerald G. Graeme
(74) Agents
Elkington and Fife

(54) Transducer bridge amplifier

(57) A transducer bridge amplifier system includes a first operational amplifier (19) having positive and negative inputs connected, respectively, to first and second output nodes (15, 5) of the bridge. The output of the operational amplifier is connected to a third node (7) of the transducer bridge. A transducer (3) of the transducer bridge is connected between the second node (5) and the third node (7). A second operational amplifier (21) has its positive input connected to earth and its negative input connected to the first node (15). A feedback resistor R_G is coupled between the output of the second amplifier (21) and the negative input of the second amplifier. An output signal produced by the second operational amplifier (21) has a linear response to transducer deviation and low sensitivity to offset voltages of the first and second operational amplifiers.

In Fig. 3 (not shown) amplifier 21 is connected as a voltage follower between nodes 15 and 11.

In Fig. 4, node 11 is fed by a constant current source 11B.

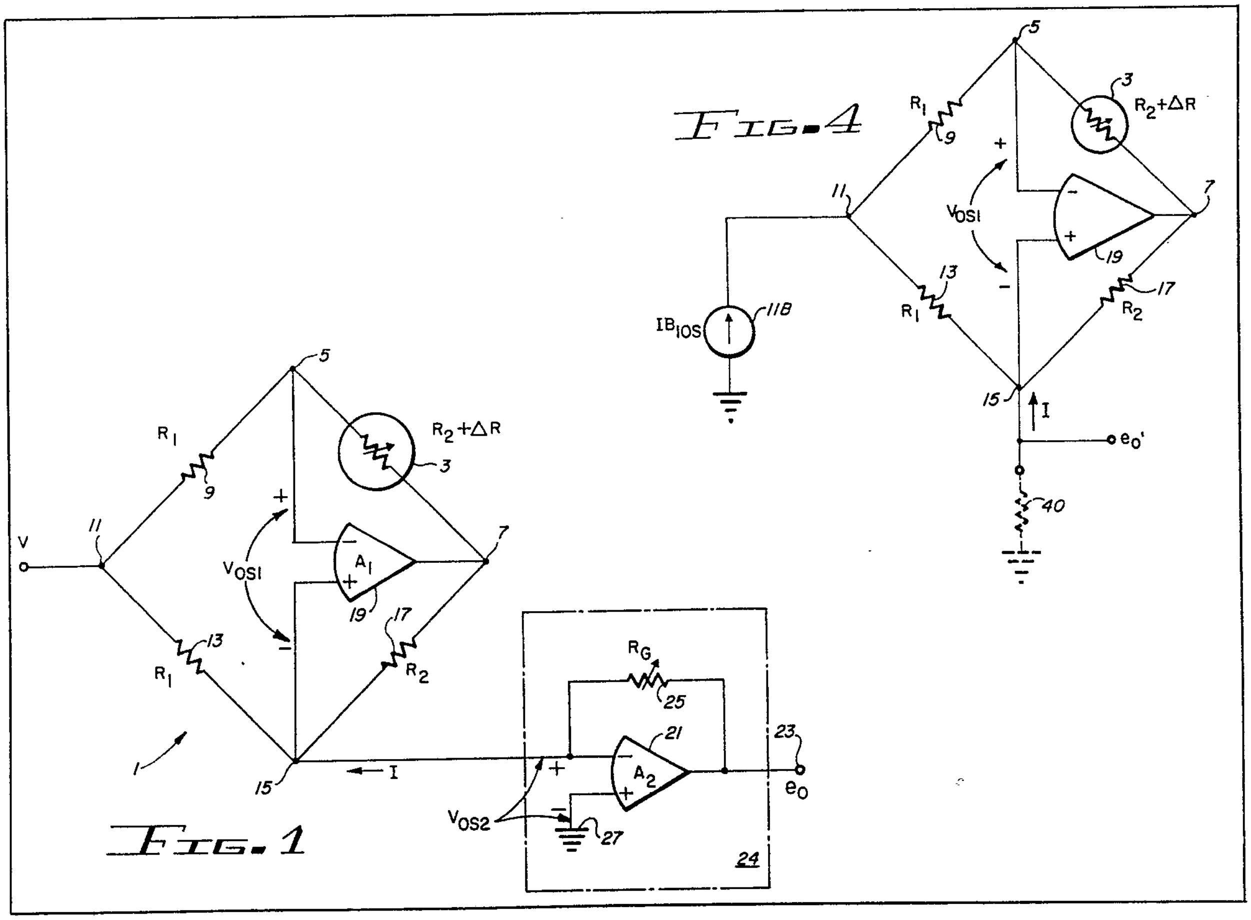
FIG. 4

FIG. 1

GB 2 034 903 A

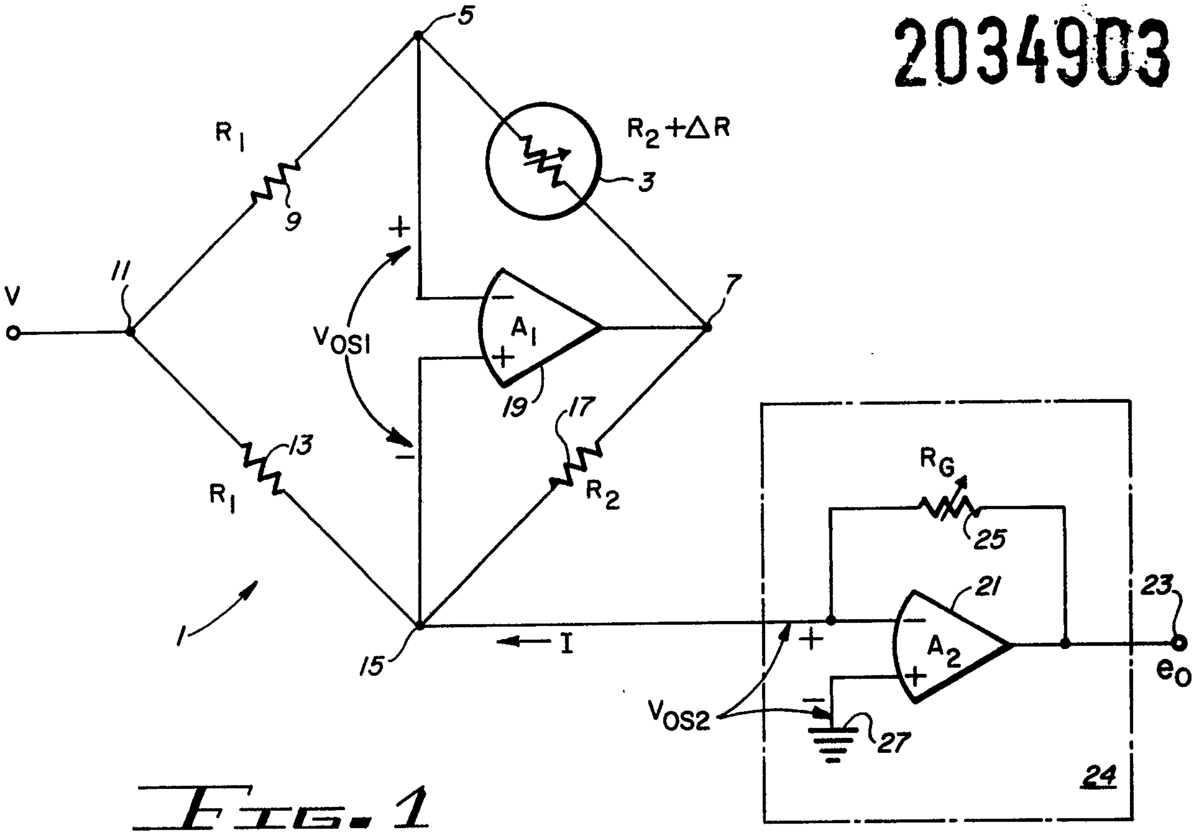
5
R_1
9
$R_2+\Delta R$
3
+
V_{OS1}
−
A_1
19
V
11
7
R_1
13
17
R_2
R_G
25
21
A_2
23
e_0
15
I
1
V_{OS2}
27
24

FIG. 1

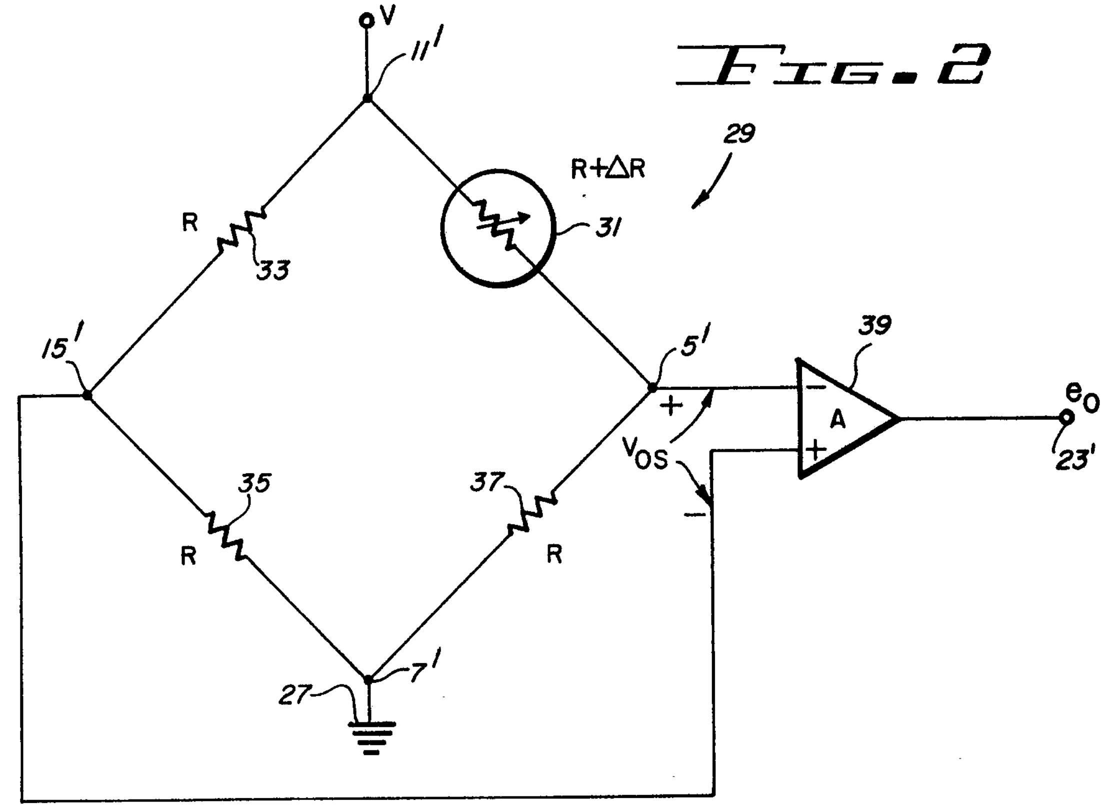
V
11'
29
$R+\Delta R$
R
33
31
15'
5'
39
A
e_0
+
V_{OS}
−
23'
35
R
37
R
27
7'

FIG. 2

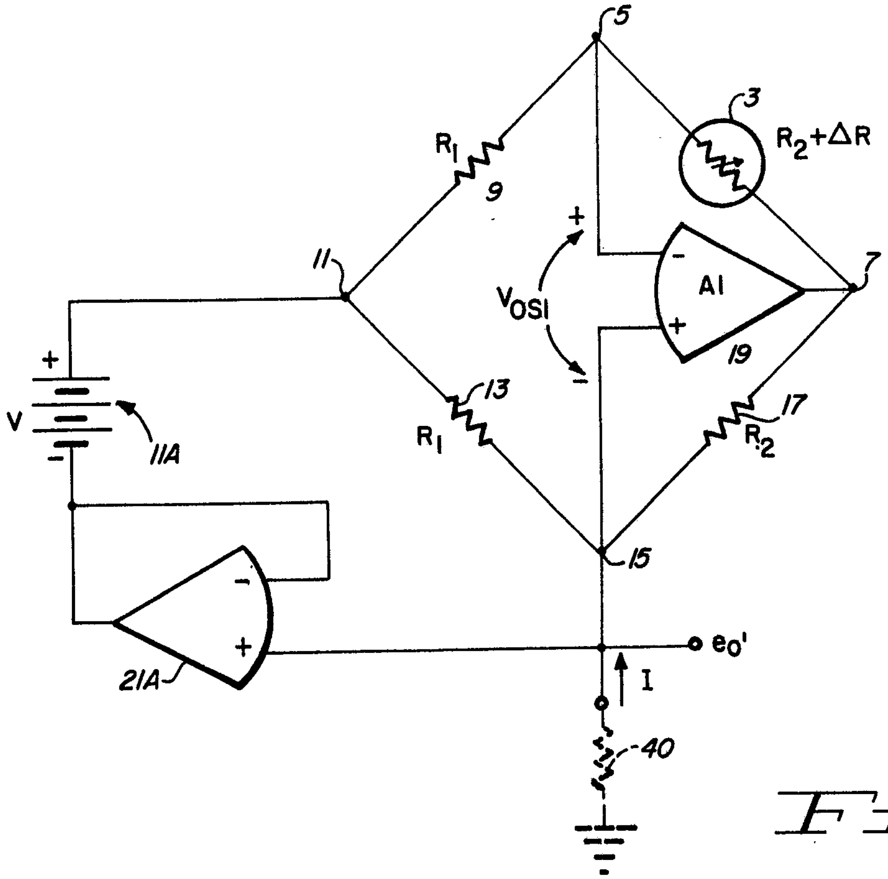
5
3
$R_2+\Delta R$
R_1
9
11
+
V_{OS1}
−
A1
+
19
7
+
V
−
11A
13
R_1
17
R_2
15
21A
e_0'
I
40

FIG. 3

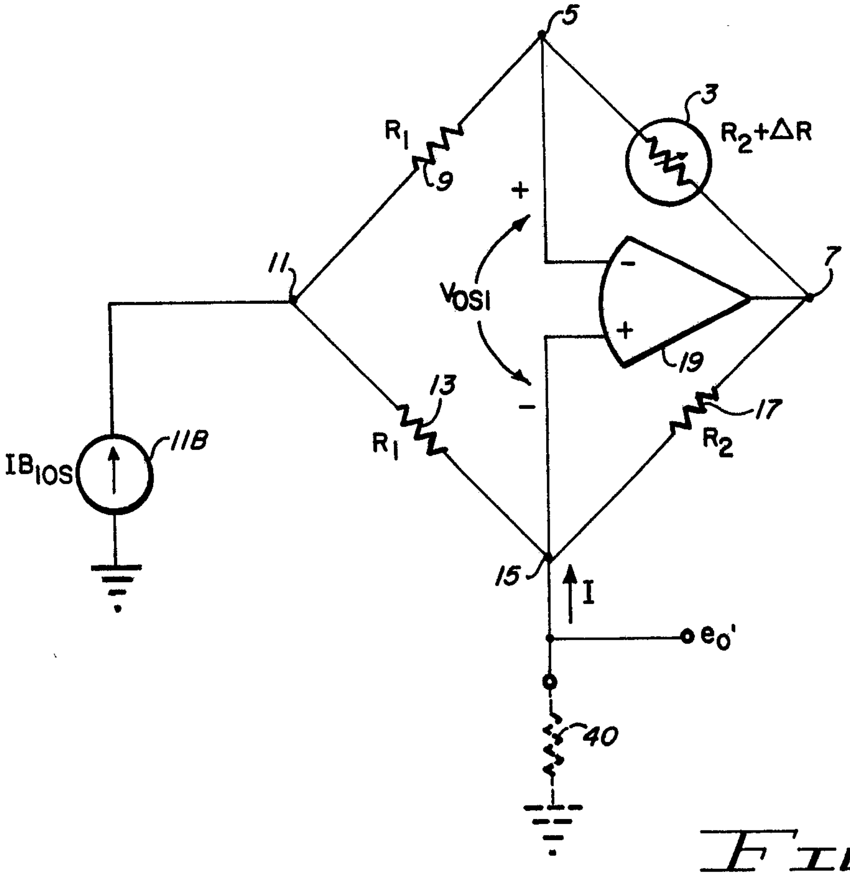
5
3
$R_2+\Delta R$
R_1
9
+
11
V_{OS1}
−
+
19
7
13
17
R_1
R_2
IB_{1OS}
11B
−
15
I
e_0'
40

FIG. 4

SPECIFICATION

Linear low drift bridge amplifier

This invention relates to a bridge amplifier circuit. Transducer bridges are widely used to sense deviations or variations in resistance in many types of transducers. One of the most common applications for transducer bridges is in sensing transducer deviation of strain gauges. Another typical application is for sensing photoresistive transducers which are responsive to varying light intensities. Numerous transducer bridges and bridge amplifier circuits (also referred to herein as bridge monitor circuits) are well known. Unfortunately, most of the known bridge amplifier circuits have linear output response only for a very small transducer deviation. Consequently, the known bridges and bridge amplifier circuits require expensive, specialized compensation networks in order to provide more linear operation. This results in undue circuit complexity, cost, and loss of reliability.

One known bridge amplifier produces an output voltage which is directly proportional to the transducer deviation even for large fractional changes in the transducer resistance. This bridge amplifier circuit is disclosed in Fig. 6—10 of "Operational Amplifiers; Designs and Applications", by Jerald G. Graeme (the present inventor), G. Tobey; and L. Huelsman, McGraw-Hill, 1971. Unfortunately, the above mentioned linear bridge amplifier circuit has extremely low gain, so that a second stage amplifier is required, and it requires modification of the bridge configuration, so present commercially available bridges cannot be used.

The above mentioned linear wide-deviation bridge amplifier, when utilized with a subsequent amplifying stage to obtain the amount of gain necessary for most applications, has a high sensitivity to the input offset voltages of both of the operational amplifiers required therein, and consequently also has high sensitivity to thermal drift of the input offset voltage of such operational amplifiers. Compensation for the input offset voltages is expensive, and does not effectively avoid the effects of thermal drift of the input offset voltages. Chopper-stabilized operational amplifiers are required in the known bridge amplifier circuits in order to obtain low thermal drift response. There is clearly an unmet need for a low cost, linear, drift insensitive bridge amplifier.

One prior patent, United States Patent No. 3,651, 696, discloses a non-linear bridge circuit designed to produce a linear output response to temperature variations in a platinum resistance thermometer. Platinum resistance thermometers have a highly non-linear temperature-to-transducer deviation relationship. The circuit described in patent No. 3,651,696, provides circuitry to produce a non-linear response of the bridge amplifier output to transducer resistance deviation of the platinum resistor in order to obtain a linear output response with respect to temperature. The structure of the bridge amplifier is similar in certain respects to that of the present invention, but it should be clearly noted that amplifier of U.S. Patent No. 3,651,696 produces a non-linear, rather than a linear output response to deviations in transducer resistance, and also lacks the desired reduced drift sensitivity.

According to the invention there is provided a bridge amplifier circuit for linearly amplifying a transducer deviation signal produced by variations in resistance of a transducer of a transducer bridge, the transducer bridge including first, second, third, and fourth nodes, the transducer being connected between said second and third nodes, first resistance means being connected between the second and fourth nodes, second resistance means being connected between the fourth node and the first node, third resistance means being connected between the first node and the third node, a power supplying conductor being connected to the fourth node, the bridge amplifier circuit comprising:

(a) Amplifier means having a positive input, a negative input, and an output coupled to the first, second, and third nodes, respectively, for producing an increased or decreased current through the third resistance means in response to a positive variation in the transducer resistance or a negative variation in the transducer resistance, respectively, the increased or decreased current in the third resistance means acting to maintain the transducer bridge in a balanced voltage condition; and

(b) constant current maintaining means for maintaining constant current in said first and second resistance means, whereby current flowing into or out of the bridge amplifier circuit through the first node is linearly related to the variations in resistance of the transducer.

Thus, in a preferred embodiment of the invention there is provided a transducer bridge amplifier circuitry which produces a linear output response to large as well as small deviations in transducer resistance. The transducer bridge amplifier circuitry also has very low sensitivity to input offset voltages of operational amplifiers contained in the transducer bridge amplifier circuitry. The transducer bridge amplifier circuitry includes a first operational amplifier having positive and negative inputs connected to first and second nodes of the transducer bridge, the first and second nodes being output nodes of the transducer bridge. The output of the first operational amplifier is connected to a third node of the transducer bridge, the third node being coupled to the second node by means of a transducer of the transducer bridge, thereby providing negative feedback for the first operational amplifier. The first node of the transducer bridge is connected to a circuit which provides a low impedance or virtual earth. In the described embodiment of the invention, the source of low impedance or virtual earth voltage includes a second operational amplifier having a positive input connected to an earth voltage conductor and a negative input connected to the first node. The output of the second operational amplifier is connected to the negative input thereof by means of a feedback resistor. The voltage produced at the output of the second operational amplifier is directly proportional to deviations in resistance of the transducer for a large range of such deviations. The output signal of the second operational amplifier contains a term dependent upon the input offset voltage of the first operational amplifier. However, the latter term is multiplied by a comparatively low gain factor, so that the transducer bridge amplifier circuitry is comparatively insensitive to the input offset voltage of the first operational amplifier and is consequently comparatively insensitive to thermal drift of the input offset voltage of the first operational amplifier.

In the accompanying drawings:

Fig. 1 is a partial circuit schematic of an embodiment of the present invention;

Fig. 2 is a circuit schematic diagram useful in pointing out the problems of the prior art overcome by the circuit of Fig. 1;

Fig. 3 is a circuit schematic of another embodiment of the invention; and

Fig. 4 is a circuit schematic of yet another embodiment of the invention.

The differences between the bridge amplifier circuit of the present invention and a typical bridge amplifier of the prior art can best be understood by a brief analysis of the typical prior art transducer bridge and bridge amplifier shown in Fig. 2. It should be noted that primed reference numerals are used to indicate nodes of the transducer bridge of Fig. 2 corresponding to the nodes of the transducer bridge of Fig. 1, described below.

It is to be noted that transducer bridges produce very low output signals that require exceptionally high-performance bridge monitoring amplifiers to achieve accurate indications of transducer signals. A principle limitation in the accuracy of prior bridge monitor amplifiers is due to the thermal drift of the input offset voltage of the amplifier circuits utilized therein. Accuracy is further limited by the inherent non-linearity of most known transducer bridge monitor circuitry with respect to transducer deviation.

It can be shown that the output e_o appearing at node 23′ in Fig. 2 is described by the expression

$$e_o = \frac{A}{4} \cdot \frac{\Delta RV/R}{1 + \Delta R/(2R)} - AV_{os} \qquad (1)$$

where ΔR is a transducer deviation, A is the amplifier gain of amplifier 39 (which is a differential amplifier) and V_{os} is the input offset voltage of differential amplifier 39. It should be noted that the transducer deviation ΔR appears in the denominator of equation (1), thereby resulting in a non-linear response for e_o. For the small transducer deviations, ΔR is negligible, so the above expression becomes

$$e_o = \frac{A}{4} \cdot \frac{\Delta RV}{R} - AV_{os} \qquad (2)$$

Note that the term

$$\frac{\Delta RV}{R}$$

is defined as the transducer deviation signal.

It can be seen from equation (2) that the transducer deviation signal

$$\frac{\Delta RV}{R}$$

is amplified by only one quarter of the gain A, while the offset voltage V_{os} is multiplied by the full amount of gain A. The non-linearity and sensitivity to amplifier input offset voltages are serious shortcomings typical of known bridge amplifiers. It should be noted that although the initial value of V_{os} can be compensated by well known biasing circuitry connected to the inputs of amplifier 39, thermal drift of V_{os} introduces new error which cannot be conveniently compensated.

Referring now to Fig. 1, a presently preferred embodiment of the invention is comprised circuitry 1, which includes a transducer bridge and bridge amplifier circuitry functioning as a bridge monitor connected to the transducer bridge. The transducer bridge includes a transducer 3 connected between nodes 5 and 7, a resistor 9 connected between nodes 5 and 11, a resistor 13 connected between node 11 and output node 15, and resistor 17 connected between nodes 15 and 7. A supply voltage V is connected to node 11.

The bridge amplifier circuitry includes an operational amplifier 19 which has a positive input connected to node 15 and a negative input connected to node 5. Operational amplifier 19 also has an output connected to node 7.

The bridge amplifier circuitry further includes a second operational amplifier 21 having a positive input connected to earth conductor 27 and a negative input connected to node 15. The output of operational amplifier 21 is connected to a node 23. A feedback resistor 25 is connected between node 15 and output node 23.

Transducer 3 has a resistance given by the expression R2 + ΔR where ΔR represents the transducer deviation. In a typical application, R2 may have a value in the range from 150 ohms to approximately 1 kilohm and ΔR may typically have a value which is approximately 10% of R2. Resistors 9 and 13 each have resistances R_1, which in a typical application, may be approximately 5 kilohms if supply voltage V is approximately 5 volts. Resistor 17 has a value R_2, which, in a typical application, would be selected to have a resistance equal to the "un-deviated" or neutral resistance of transducer 3. The gain of operational amplifier 19 is equal to A_1. Operational amplifier 19 has an input offset voltage designated by V_{OS1}, having a polarity as indicated in Fig. 1. Operational amplifier 21 has a value of gain designated by A_2 and has an input offset voltage designated by V_{OS2}, the polarity of V_{OS2} being indicated in Fig. 1. The value of resistor 25 is designated by R_G, which may typically have a value of approximetely 20 kilohms.

The operation of circuitry 1 is such that operational amplifier 19 forces the transducer bridge circuitry to supply current 1 to operational amplifier 21 when the transducer bridge is unbalanced. Part of the current 1 is supplied from the bias voltage V through resistor 13. Another part of current 1 is supplied to node 15 from the output of amplifier 19 through resistor 17. When the transducer bridge circuitry is balanced, the two components of current in resistor 13 and resistor 17, respectively, are equal and opposite, so that the current 1 will be equal to zero. When the transducer bridge circuitry is unbalanced due to transducer deviation ΔR the two currents through resistors 13 and 17 are unequal, and their difference is equal to 1.

The operation of the transducer bridge and bridge amplifier circuitry of Fig. 1 can best be understood by means of the following analysis, which develops the equation for the current 1 and the expression for the output voltage e_0 appearing on node 23.

First, it should be noted that amplifier 21 and feedback reistor 25, as connected in Fig. 1, function as a current-to-voltage converter which converts current 1 into output voltage e_0. Since the positive input of amplifier 21 is at earth potential or zero volts, the negative input of amplifier 21 is also at zero volts, since the voltage difference between the positive and negative inputs of an operational amplifier is ordinarily negligible. Thus, node 15 is at a virtual earth potential. Similarly, the voltage differences between the positive and negative inputs of operational amplifier 19 is also negligible. Therefore, for purposes of a DC analysis, node 5 is also at zero volts. Thus, the current flowing through resistor 9 from node 11 to node 5 is equal to V/R_1. Since the current flowing into the negative input of operational amplifier 19 is negligible, the current flowing from node 5 through transducer 3 to node 7 is also equal to V/R_1. The voltage between nodes 5 and 7 is thus given by the expression

$$\frac{V(R2 + \Delta R)}{R1}$$

Consequently, the voltage of node 7 is equal to

$$\frac{-V(R2 + \Delta R)}{R1}$$

Consequently, the current flowing through resistor 17 from node 15 to node 7 is given by the expression

$$\frac{V(R2 + \Delta R)}{R1R2}$$

Consequently, the current 1 is given by the expression

$$1 = \frac{\Delta RV}{R1R2} \tag{3}$$

neglecting the effects of V_{OS1}, the input offset voltage of operational amplifier 19.

The component of current 1 due to V_{OSI} is equal to

$$\frac{-V_{OSI.}}{Ri}$$

Consequently, the final expression for the current 1 is given by the equation

$$1 = \frac{\Delta RV}{R1R2} \quad \frac{-V_{OS1}}{R1} \tag{4}$$

It should be noted that the current 1 has a linear response to the transducer deviation ΔR. In order that this condition be met, it is necessary that node 15 of Fig. 1 must be returned to a low impedance point such as a virtual earth voltage so that the current 1 does not cause node 15 to vary significantly from zero volts. The disclosed current-to-voltage converter (designated by reference numeral 24) includes operational 21 and resistor 25, and provides an output equal to the product of current 1 and the value of resistor 25. Assuming the input current of operational amplifier 21 to be zero, the output voltage e_o is then given by the equation

$$\text{(5)} \quad e_o = \frac{R_g}{R1} \left(\frac{\Delta RV}{R2} \cdot -V_{OSI} \right) + V_{OS2}$$

where V_{OS2} is the input offset voltage of operational amplifier 21.

It is readily seen that e_o retains the same linear relationship with ΔR as does current 1. It should also be noted that the transducer deviation signal (previously defined) is equal to

$$\frac{\Delta RV}{R2}$$

and is multiplied by the same gain term $R_G/R1$ as the bridge amplifier offset voltage V_{OS1}. This is a great improvement over the previously described prior art bridge amplifiers, wherein the transducer signal is multiplied by only one quarter of the gain by which the bridge amplifier offset voltage is multiplied. Thus, the bridge amplifier circuitry of Fig. 1 achieves a 4:1 reduction in sensitivity to bridge amplifier offset voltage and thermal drift thereof. The input offset voltage V_{os2} of amplifier 21 is not amplified, and is therefore negligible.

The bridge amplifier circuitry of Fig. 1 can be readily constructed to obtain very high accuracy performance utilizing an inexpensive operational amplifier, such as the Burr-Brown 3510 precision operational amplifier for amplifier 19 and a very low cost operational amplifier, such as the Fairchild 741, amplifier 21.

Node 15 of the embodiment of the invention shown in Fig. 1 must be returned to a low impedance point, such as a virtual earth voltage, so that the current 1 does not create voltage swings at output node 15 which would alter voltages across the four bridge elements. It can be readily seen that connecting node 15 to a high impedance, rather than to the virtual earth provided by operational amplifier 21 and feedback resistor 25, would result in a voltage swing at node 15 due to incremental variations in current 1 (which variations in turn are due to transducer deviation ΔR). Such voltage variations at output node 15 would alter the voltages across resistors 9 and 13. This in turn would produce corresponding variations of currents flowing through transducer 3 and resistor 17. It can be shown by analysis that output current 1 would be non-linearly related to transducer deviation ΔR if a large impedance were connected between output node 15 and earth because of the above variations in currents through resistors 9 and 13.

Two other circuit techniques which preserve the linear response of output current 1 with respect to transducer deviation ΔR and the low sensitivity of output current 1 with respect to input offset voltage drift of operational amplifier 19 are shown in the circuits of Figs. 3 and 4. These two techniques retain the precise linear relationship of current 1 to transducer deviation ΔR and also precisely retain the low sensitivity or current 1 to input offset voltage and drift thereof previously described for the circuit of Fig. 1.

Referring now to Fig. 3, it is seen that the bridge resistors, the transducer, and amplifier 19 are connected in the same manner as in Fig. 1. However, output node 15, rather than node 23 of Fig. 1, is used as the bridge amplifier output. Node 15 is connected to the positive input of amplifier 21A. The output and negative input of operational amplifier 21A are connected to the negative terminal of voltage source 11A; the positive terminal of voltage source 11A is connected to node 11. It can be readily seen that if a large load resistance 40 is connected between node 15 and earth, so that variations in current 1 cause corresponding variations in the voltage at node 15, operational amplifier 21 A causes such voltage variations to be applied to the negative terminal of voltage source 11A. Consequently, the voltage variations at node 15 are added to voltage V at node 11. Thus, it can be seen that incremental voltage creations at node 15 do not produce corresponding variations in current through resistors 9, 13, 17 and tranducer 3. It can be shown by analysis that the current 1 is linearly related to transducer deviation and has low sensitivity to input offset voltage drift in precisely the same manner as the corresponding current 1 in the circuit of Fig. 1. If a voltage output (rather than a current output) is desired for the transducer bridge of Fig. 3, an inexpensive differential amplifier can be connected to node 15 to produce an output voltage which is linearly proportional to transducer deviation and comparatively insensitive to input offset voltage and drift.

Fig. 4 shows a third embodiment of the invention which uses a constant current source 11B to provide a constant bias current into node 11. This causes the current in bridge resistors 9, 13 and 17 and in transducer 3 to be independent of incremental voltage variations across load resistance 40. Such incremental voltage changes at node 15 cannot alter the output of biasing current source 11B because of the nearly infinite output resistance of current source 11B. Therefore, the current supplied to bridge resistors 9 and 13 cannot be altered by voltage variations at node 15. Consequently, the current in transducer 3 and also output current 1 remain unaffected by voltage variations at node 15. The linear relationship between output current 1 and transducer deviation ΔR is the same as for the circuits of Figs. 1 and 3. The sensitivity of output current 1 to input offset voltage drift is also structurally identical to that of the circuits of Figs. 1 and 3.

CLAIMS

1. A bridge amplifier circuit for linearly amplifying a transducer deviation signal produced by variations in resistance of a transducer of a transducer bridge, the transducer bridge including first, second, third, and fourth nodes, the transducer being connected between said second and third nodes, first resistance means being connected between the second and fourth nodes, second resistance means being connected between the fourth node and the first node, third resistance means being connected between the first node and the third node, a power supplying conductor being connected to the fourth node, the bridge amplifier circuit comprising:

(a) amplifier means having a positive input, a negative input, and an output coupled to the first, second and third nodes, respectively, for producing an increased or decreased current through the third resistance means in response to a positive variation in the transducer resistance or a negative variation in the transducer resistance, respectively, the increased or decreased current in the third resistance means acting to maintain the transducer bridge in a balanced voltage condition; and

(b) constant current maintaining means for maintaining constant current in said first and second resistance means, whereby current flowing into or out of the bridge amplifier circuit through the first node is linearly related to the variations in resistance of the transducer.

2. A circuit according to Claim 1, wherein the amplifier means includes a first operational amplifier.

3. A circuit according to either preceding claims, wherein the first resistance means and the second resistance means are resistors having equal resistances and wherein the third resistance means has a resistance equal to an undeviated resistance value of the transducer.

4. A circuit according to Claim 2, comprising a low impedance means which includes a further amplifier means has a negative input coupled to the first node, a positive input coupled to an earth voltage conductor, and an output coupled to the negative input of the further amplifier means by a feedback element.

5. A bridge amplifier circuit, substantially as herein described with reference to Figs. 1, 3 or 4 of the accompanying drawings.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1980. Published by the Patent Office,
25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.