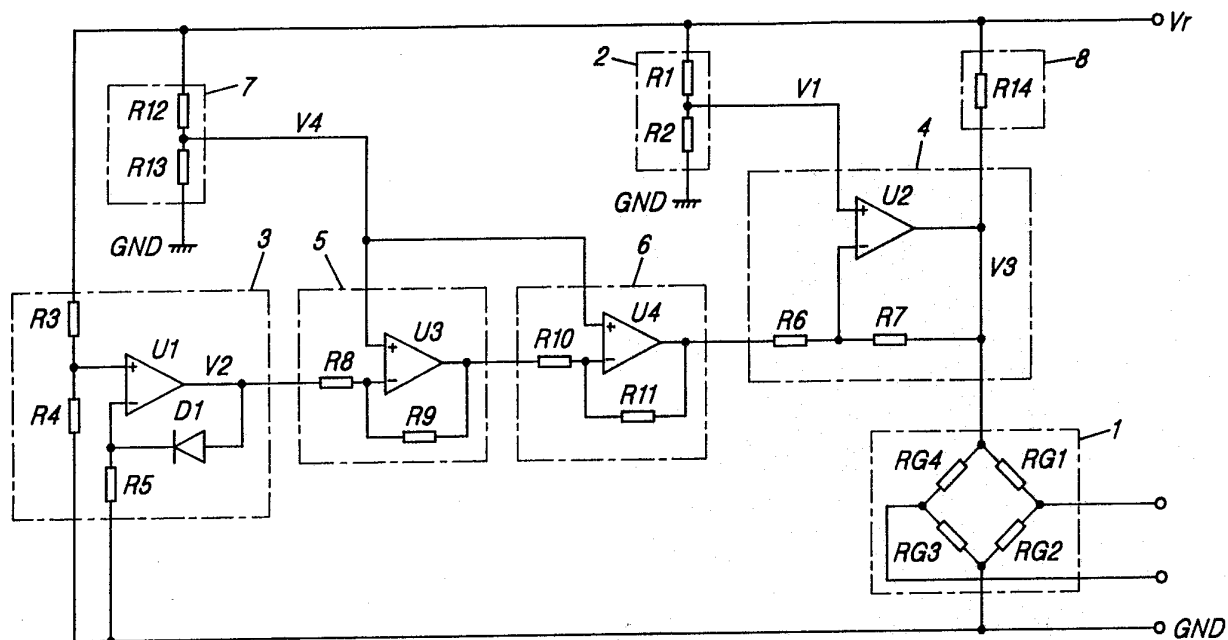




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification ⁵ : G05F 1/46, G01L 1/22</p>	<p>A1</p>	<p>(11) International Publication Number: WO 91/07713 (43) International Publication Date: 30 May 1991 (30.05.91)</p>
<p>(21) International Application Number: PCT/GB90/01744 (22) International Filing Date: 13 November 1990 (13.11.90)</p> <p>(30) Priority data: 8925578.0 13 November 1989 (13.11.89) GB 9016434.4 26 July 1990 (26.07.90) GB 9017573.8 10 August 1990 (10.08.90) GB</p> <p>(71) Applicant (for all designated States except US): NATIONAL RESEARCH DEVELOPMENT CORPORATION [GB/GB]; 101 Newington Causeway, London SE1 6BU (GB).</p> <p>(72) Inventor; and (75) Inventor/Applicant (for US only): BINNS, John, Philip, Lincoln [GB/GB]; Mead Lodge, Courtmead Road, Cuckfield, West Sussex RH17 5LR (GB).</p>		<p>(74) Agent: GASKIN, John, Shield; National Research Development Corporation, Patents Department, 101 Newington Causeway, London SE1 6BU (GB).</p> <p>(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE (European patent), DK (European patent), ES (European patent), FR (European patent), GB (European patent), GR (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent), US.</p> <p>Published With international search report.</p>

(54) Title: TRANSDUCER POWER SUPPLY



(57) Abstract

The invention provides a power supply circuit for applying a temperature-compensating supply voltage across a temperature-sensitive transducer (such as a strain gauge transducer), the circuit comprising a first operational amplifier, means for applying an output level determining voltage to one (preferably the negative) input of the amplifier, means for applying a temperature-dependent output slope determining voltage to the other (preferably the positive) input of the amplifier, and means for applying the resultant temperature-dependent output voltage of the amplifier to the transducer.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	ES	Spain	MG	Madagascar
AU	Australia	FI	Finland	ML	Mali
BB	Barbados	FR	France	MR	Mauritania
BE	Belgium	GA	Gabon	MW	Malawi
BF	Burkina Faso	GB	United Kingdom	NL	Netherlands
BG	Bulgaria	GR	Greece	NO	Norway
BJ	Benin	HU	Hungary	PL	Poland
BR	Brazil	IT	Italy	RO	Romania
CA	Canada	JP	Japan	SD	Sudan
CF	Central African Republic	KP	Democratic People's Republic of Korea	SE	Sweden
CG	Congo	KR	Republic of Korea	SN	Senegal
CH	Switzerland	LI	Liechtenstein	SU	Soviet Union
CI	Côte d'Ivoire	LK	Sri Lanka	TD	Chad
CM	Cameroon	LU	Luxembourg	TG	Togo
DE	Germany	MC	Monaco	US	United States of America
DK	Denmark				

- 1 -

TRANSDUCER POWER SUPPLY

This invention relates to power supply circuits for ratiometric transducers, such as strain gauge transducers of resistive-bridge or piezoresistive type, and more particularly to such power supply circuits providing a temperature-dependent supply voltage in order to compensate for temperature-dependent changes in the output sensitivity of such transducers. Circuits according to the invention are particularly useful when the supply voltage to the circuit is low, but are of general application.

10 Most strain gauge transducers have four terminals and can be represented as a resistor bridge circuit. In use a d.c. supply voltage is applied across two of the terminals and a much smaller differential output voltage may be measured across the other two terminals.

15 It is common in applications which use a diaphragm, such as pressure sensing, to incorporate the bridge circuit into the diaphragm by using a silicon diaphragm with diffused semiconductor strain gauge resistors. Some piezoresistive silicon sensors such as the known Sensym SPX series of pressure transducers function in the same way as a bridge though having a construction which is different.

20 Most of these transducers suffer a change in sensitivity as their temperature changes. For example, the known Motorola X-ducer series of pressure transducers ("X-ducer" is a trade mark of Motorola Inc.) will typically suffer a 5% change in full scale span over a 25°C temperature change. The normal method of span temperature compensation is to change the supply voltage so as to compensate for the change in sensitivity. For example, the X-ducer series has a sensitivity which drops with temperature.

30 It has been designed so that if the supply voltage applied across it is raised linearly at typically 0.19%/°C then the increase in sensitivity due to increased supply voltage exactly compensates for the decrease in sensitivity due to the rise in temperature.

- 2 -

The usual way of producing the required transducer supply voltage characteristic involves a technique called 'self temperature compensation'. One version of this method uses a constant current supply to the transducer. As the transducer's resistance increases with temperature so the voltage across it rises in the required manner. Another version uses a constant voltage supply with series resistors or thermistors. As the transducer's resistance rises so the voltage across it rises in the required manner. Both these methods can have combinations of components such as diodes, resistors and thermistors in series or parallel with the transducer and each other which can render improvements to the voltage characteristic obtained.

The problem with self temperature compensation is that the components used can take up to three quarters of the supply voltage available to the transducer. For example, if series resistors are used to compensate a Motorola X-ducer type pressure transducer they would normally be chosen to have a resistance three times that of the transducer itself. Thus if a 5v supply were applied to the network only 1.25v would appear across the transducer. This scheme is thus unworkable because the transducer output is then too low to amplify at reasonable cost. Moreover, it is found that these self temperature compensation networks never produce exactly the voltage required to compensate the transducer over a wide temperature range. In particular, both the transducer resistance and its temperature coefficient of resistance can vary widely from one transducer to another, making incorporation of any particular example into a standard network liable to generate errors in its temperature compensation.

Thus it can be seen that the only way to accurately temperature compensate, say, a strain gauge sensor, is to supply it with a compensation voltage that is not dependent upon the transducer resistance itself. This implies generating the voltage elsewhere in the circuit, with one or more operational amplifiers, and then applying it to the transducer. In general this approach has been rejected as being far too costly in the

- 3 -

past, but now that many operational amplifiers and resistors can be integrated on a single piece of silicon this approach could become more effective.

05 According to the present invention there is provided a power supply circuit for applying a temperature-compensating supply voltage across a temperature-sensitive transducer, the circuit comprising : a first operational amplifier; means for applying an output level determining voltage to one input of the amplifier; means for applying a temperature-dependent output
10 slope determining voltage to the other input of the amplifier; and means for applying the resultant temperature-dependent output voltage of the amplifier to the transducer.

15 Preferably the output level determining voltage and the output slope determining voltage are applied respectively to the positive and to the negative inputs of the amplifier.

20 Preferably, also, the output slope determining voltage is, or is derived from, the output of a differential amplifier having a temperature-sensitive feedback element (which may be a semiconductor diode or a temperature-sensitive resistor) connected between its output and its negative input.

25 These and other features of circuits according to the invention will be more fully disclosed and explained by reference to certain preferred embodiments of transducer power supply circuits according to the invention as described below with reference to the accompanying drawings, in which :-

Figure 1 shows a first circuit according to the invention, connected to supply a bridge-circuit transducer;

30 Figure 2, A and B, shows temperature-dependent output voltages of operational amplifiers comprised by the circuit shown in Figure 1;

Figure 3 shows a second circuit according to the invention, similarly connected to supply a bridge-circuit transducer;

35 Figure 4 (A, B and D) shows temperature-dependent output voltages of operational amplifiers comprised by the circuit shown in Figure 3;

- 4 -

Figure 5 shows a third circuit, closely similar to that shown in Figure 1 or Figure 3, but differently connected to supply a bridge-circuit transducer and appropriately modified;

05 Figure 6 shows a fourth circuit, combining the circuits of Figure 1 or 3, and Figure 5, connected to supply a bridge-circuit transducer;

Figure 7, A to D, shows temperature-dependent output voltages of operational amplifiers comprised by the circuit shown in Figure 6, and

10 Figures 8, 9 and 10 show embodiments of simplified circuits according to the invention.

Referring first to Figure 1, the transducer circuit 1 is represented as four resistors (RG1 to RG4) in a Wheatstone bridge configuration. The span temperature compensation circuit
15 comprises level setting voltage generating circuit 2 and temperature dependent voltage generating circuit 3 feeding into the positive and negative inputs respectively of an inverting amplifier 4 which supplies the output to the transducer 1. The level setting voltage generating circuit 2 comprises resistors R1
20 and R2 connected in series between a regulated supply Vr and ground (GND). The node between resistors R1 and R2 is the output.

The temperature dependent voltage generating circuit 3 comprises resistors R3 and R4 in series between the regulated supply Vr and ground (GND), with the node therebetween connected
25 to the non-inverting (+) input of an operational amplifier U1. The output of amplifier U1 is connected via a diode D1 to its inverting (-) input. The inverting (-) input is also connected via a resistor R5 to ground (GND). The amplifier U1 supplies the required temperature dependent voltage V2 at its output.

30 The amplifier 4 comprises an operational amplifier U2 with its output connected via a feedback resistor R7 to its inverting (-) input. The temperature-dependent output voltage of circuit 3 is connected via an input resistor R6 of the amplifier 4 to the inverting (-) input of amplifier U2. The level setting output of
35 the circuit 2 is connected to the non-inverting (+) input of

- 5 -

amplifier U2. The output of amplifier U2 provides the required temperature compensated voltage V3 which is applied to the transducer 1.

The operation of this circuit is as follows: Suppose the
05 transducer 1 requires a voltage supply (V3) of 3.0v at 20°C with
a linear slope of 4.5mv/°C. The voltage level is set to 3.0v by
adjusting the resistor ratio R1/R2 in the level setting circuit 2
so that its output (V1) is 3.0v and by adjusting the ratio R3/R4
in the temperature dependent voltage generating circuit 3 so that
10 its output (V2) is the same at 20°C. This circuit 3 is an
operational amplifier in a non-inverting configuration with a
temperature dependent component (diode D1) in the feedback
circuit which therefore has a constant current through it. This
will give a straight line voltage output (V2) of approximately
15 -2mv/°C as shown in Figure 2A. In the inverting output stage 4,
the resistor ratio R7/R6 is set to 2.25, to give a gain of -2.25
on the slope of the temperature dependent voltage (V2), and this
gives the required temperature compensated voltage (V3), as shown
in Figure 2B, for application to the transducer 1.

20 The circuit shown in Figure 1 has a drawback. If, for
example, it incorporates amplifiers of low cost known type LM124,
and functions over a wide temperature range, it will require a
supply voltage of at least 5v if the common mode input range of
the output amplifier U2 is not to be exceeded, and probably
25 requires 5.5v in order to be able to supply a typical current of
5 to 10 mA to the transducer. This is disadvantageous because
the industry standard T.T.L. supply voltage can drop as low as
4.5v.

An embodiment of the invention with enhancements for low
30 voltage operation is shown in Figure 3, in which the transducer
circuit 1, the level setting voltage generating circuit 2, the
temperature dependent voltage generating circuit 3, and the
output amplifier 4 in inverting configuration, are as described
with reference to Figure 1. The circuit shown in Figure 3
35 comprises, additionally, inverting gain stages 5 and 6 with an

- 6 -

associated false ground generating circuit 7, and a pull-up circuit 8.

The inverting gain stage 5 comprises an operational amplifier U3 with its output connected to its inverting (-) input via a feedback resistor R9. The output voltage V2 of the amplifier U1 of circuit 3 is connected via an input resistor R8 to the inverting (-) input of the amplifier U3. The output of the false ground generating circuit 7 is connected to the non-inverting (+) input of amplifier U3.

The inverting gain stage 6 comprises an operational amplifier U4 with its output connected to its inverting (-) input via a resistor R11. The output of amplifier U3 is connected to the inverting (-) input of amplifier U4 via an input resistor R10. The output of the false ground generating circuit 7 is connected to the non-inverting (+) input of amplifier U4. The output of amplifier U4 is connected to the inverting (-) input of amplifier U2 via the input resistor R6.

The false ground generating circuit 7 comprises resistors R12 and R13 in series between regulated supply Vr and ground (GND). The node therebetween is the output and is connected to the non-inverting (+) inputs of amplifiers U3 and U4.

The pull-up circuit 8 comprises a resistor R14 connected between the regulated supply voltage Vr and the output of the amplifier U2.

To provide the same temperature-dependent voltage V3 as described above in the case of Figure 1, this circuit operates as follows:

The temperature dependent voltage generating circuit 3 generates a voltage (V2) with a slope of about $-2\text{mv}/^\circ\text{C}$ but the resistor ratio R3/R4 is set in this case so as to give an output voltage of only 1.2v at 20°C , as shown in Figure 4A. The resistor ratio R12/R13 in the false ground generating circuit 7 is also set so as to give a false ground voltage (V4) of 1.2v. This means that the input common mode voltage of inverting amplifier stages 5 and 6 is only 1.2v. The gain of stage 5 is

- 7 -

set by the resistor ratio $R8/R9$ at -2.25 . The output voltage, as shown in Figure 4B, has a slope of $+4.5\text{mv}/^\circ\text{C}$ and is applied to the inverting amplifier stage 6 which (its resistors $R10$ and $R11$ being made equal) has a gain of -1 and inverts the signal relative to false ground to give a falling output as shown in Figure 4C. This is so that the final output voltage ($V3$) will be a rising output as required. If a falling output were required then this stage would be omitted.

The output of inverting amplifier stage 6 is fed into the negative side of the output stage 4. This stage, in this instance, has its resistors $R6$ and $R7$ equal and gives a gain of -1 and thus an output voltage with a slope of $+4.5\text{mv}/^\circ\text{C}$ as required. The output level requirement of 3.0v at 20°C is met by adjusting the level setting voltage ($V1$) to 2.1v . This output is shown in Figure 4D.

It will be noted that the input common mode voltage (at 2.1v) is lower than before and implies a supply voltage of no more than 4.1v if LM124 operational amplifiers are used. Similarly, although the output stage 4 is unable to source current at the required output voltage whilst its supply is at only 4.1v , this requirement is met by the pull-up circuit 8, shown as a resistor $R14$, which is chosen to supply more current than the bridge requires at any temperature. The output stage 4 is then able to determine the voltage $V3$ as required, by sinking the excess current.

As shown in Figures 1 and 3, the transducer 1 has one supply voltage terminal connected to ground and the temperature-dependent voltage $V3$ is applied to its other supply voltage terminal. In the essentially similar arrangement shown Figure 5, one supply voltage terminal of the transducer bridge 1 is again held at fixed voltage, but by being connected to the regulated voltage Vr rather than to ground. Accordingly the temperature-compensated $V3$ which is to be applied to the other supply voltage terminal of the bridge 1 is required, in this case, to be close to ground potential. This is achieved by voltage supply

- 8 -

circuitry comprising circuit units 2, 3 and 4 which are the same as in Figure 1, except for appropriate changes in the values of the resistors R1, R2 etc., and the provision in the output stage 4 of an additional inverting amplifier U5 to reverse the direction of slope of the voltage V3. Corresponding to the pull-up resistor R14 which is shown in the circuit of Figure 3 and which may be similarly provided in the circuit shown in Figure 1, the circuit shown in Figure 5 may have a pull-down resistor R' connected between ground and the bridge supply voltage terminal to which the voltage V3 is applied.

Figure 6 shows a voltage supply circuit which is essentially a combination of the circuits shown in Figures 1 and 5, in that the temperature-compensating variations in the voltage which it provides are applied, preferably equally, to both the supply voltage terminals of the transducer bridge 1 which it supplies. As shown in Figure 6, the bridge circuit 1 has temperature-compensated voltages V3 and V5, respectively, applied to its supply voltage terminals, the voltages V3 and V5 being provided as the outputs of operational amplifiers U2 and U5 comprised by parallel output stages 4 and 11 of the compensated voltage supply circuit. Level-setting voltage generating circuits 2 and 10 respectively provide steady voltages to the positive inputs of the amplifiers U2 and U5. The temperature-dependent voltage generating circuit 3 is like that shown in Figures 1 and 3 except that its temperature-sensitive component, instead of being a diode, is shown as a platinum resistor Rt (though it might equally well be a diode as in Figures 1 and 3); and its output voltage V2 is applied to the output stage 4 not directly but through an inverting gain stage 5 including an amplifier U3 and provided with an associated false-ground generating circuit 7. The temperature-dependent component of the voltage V2 is applied to the output stage 11 not directly but via the amplifiers U3 and U2, as is further described below. The supply voltage terminals of the bridge circuit 1 to which the voltages V3 and V5 are applied are connected respectively to the regulated voltage Vr and to ground by pull-up and pull-down circuits 8 and 9,

- 9 -

respectively, constituted by resistors R14 and R15 which correspond to the resistors R14 and R' in Figures 3 and 6 respectively.

The circuit shown in Figure 6 operates as follows:

05 Transducer 1 is a foil-based transducer of 350Ω resistance which requires a voltage supply (V3-V5) of 9.0v at 20°C with a linear slope of $5.7\text{ mv}/^\circ\text{C}$. With a supply voltage V_r of 10v this is achieved by setting voltage V3 to 9.5v with a slope of $+2.85\text{mv}/^\circ\text{C}$ and voltage V5 to 0.5v with a slope of $-2.85\text{mv}/^\circ\text{C}$.
10 The method of achieving this will be described with additional references to Figure 7.

Temperature-dependent voltage generating circuit 3 has a platinum resistor R_t with a resistance of 100Ω at 20°C and a slope of $0.385\Omega/^\circ\text{C}$. The resistor ratio R_3/R_4 is set to give a
15 voltage of 2.75v at the non-inverting (+) input of operational amplifier U1. Resistor R_5 is set to $1\text{K}\Omega$ to give an output voltage V2 of 3.0v at 20°C with a slope of $1.06\text{mv}/^\circ\text{C}$ as shown in Figure 7A. This voltage is fed into the negative input of
20 inverting gain stage 5. The resistor ratio R_{12}/R_{13} is set to give a false ground V4 of 3.0v, and this voltage is fed into the positive input of amplifier U3 of inverting gain stage 5.

Inverting gain stage 5 has resistor ratio R_9/R_8 set to 2.69 to give a gain of -2.69 and hence an output voltage with a slope of $-2.85\text{mv}/^\circ\text{C}$ as illustrated in Figure 7B.

25 The output of inverting amplifier stage 5 is fed into the negative side of output stage 4. This stage gives a gain of -1 and thus a slope of $+2.85\text{mv}/^\circ\text{C}$ as required. The output level requirement of 9.5v at 20°C is met by adjusting the level setting voltage V1 to 6.25v. This output (V3) is shown in Figure 7C.

30 The output voltage V3 is also fed into the negative side of output stage 11. This stage also has a gain of -1, giving a slope of $-2.85\text{mv}/^\circ\text{C}$ as required. The output level requirement of 0.5v at 20°C is met by adjusting the level setting voltage V6 to 5.0v. This output (V5) is shown in Figure 7D. It will be
35 appreciated that the negative input of the output stage

- 10 -

11, instead of being supplied with the voltage V3, may alternatively be supplied with the voltage V2 from amplifier U1 or, in principle, with a voltage from any part of the circuit which has the required sign of slope of voltage against
05 temperature.

It will be noted that although output stage 4 is unable to source current at the required output voltage whilst its supply is at only 10v, this requirement is met by the pull-up resistor R14 which is chosen to supply more current than the transducer 1
10 requires at any temperature and then the output stage 4 is able to determine the voltage by sinking the excess current. Similarly, although output stage 11 is unable to sink much current at the required output voltage of about 0.5v, this requirement is met by the pull-down resistor R17 which is chosen
15 to sink more current than the bridge sources at any temperature and then the output stage 11 can control the voltage by sourcing the excess current required.

This circuit with dual output stages 4 and 11 has advantages over the use of a single output stage in certain applications.
20 It is common for bridge transducers to be packaged separately from the associated power supply and amplification electronics. The output voltage from this type of transducer is a small differential voltage resting on a large common mode voltage. Normally this common mode voltage would be half-way between the
25 two voltages on the supply terminals. This type of transducer would thus be connected to an amplifier circuit which requires a common mode voltage to be approximately half-way between the supply voltages. The use of dual output stages in the temperature compensation circuit allows compatibility with
30 external amplifier circuits to be maintained, i.e. the transducer common mode voltage can be set half way between the supply rails whereas the use of a single output amplifier would not allow this. Additionally, any change in the common mode voltage during operation could cause common mode errors in the associated
35 amplifier. The use of a single output stage means that the

- 11 -

common mode voltage would change with temperature whereas the use of two output stages means that although the voltage across the transducer changes with temperature the common mode output voltage need not.

05 Another feature of this circuit, as described above, is the use of a temperature sensitive resistor instead of a diode in the temperature dependent voltage generating circuit 3. The voltage across the resistor is proportional to the current through it whereas the voltage across the diode is highly insensitive to the
10 current through it. Hence, the use of the resistor allows the construction of a circuit which is ratiometric. This is advantageous because it enables the construction of a very accurate transducer which incorporates both the electronic circuit and a bridge circuit but which mimics all the features of
15 the stand-alone bridge transducer i.e. it is ratiometric and it has a common mode voltage which does not change with temperature and is half way between the voltage rails.

In all the embodiments of the invention described above, the amplifier U2 (or U5) has an output level determining voltage
20 applied to its positive input and an output slope determining voltage applied to its negative input. If the amplifier has a gain of 1, however, a satisfactory circuit can also be achieved by applying the output level determining voltage to the negative input and the output slope determining voltage to the positive
25 input. There is a potential drawback to this modification, but it can be overcome: in the original circuit shown in Figure 1, for example, the output level determining voltage generating circuit 2 is a pair of resistors whose output is fed into the positive input of the inverting amplifier 4, which is the high
30 impedance input, whereas in the alternative circuit, the output of the circuit 2 would be fed into the negative side of the inverting amplifier circuit 4 which has a relatively low impedance determined by the value of resistor R6. Thus it might be necessary to incorporate an output buffer into the output
35 level determining voltage generating circuit 2. This buffer

- 12 -

would normally be an operational amplifier, and the alternative circuit would thus require one more operational amplifier than the preferred circuit configuration; but it may well be, since operational amplifiers are packaged four to a chip, that there is
05 a spare amplifier available and so the alternative circuit need not be more expensive.

It will be understood that the pull-up and pull-down circuits 8 and 9, shown as resistances, can be any component or combination of components that will supply or sink most or all of
10 the current required by the transducer 1. Typical examples would be a current circuit or one or more diodes in series with a resistor.

It will also be understood that the diode D1 or temperature sensitive resistor R_t of the temperature-dependent voltage
15 generating circuits 3 as above described may be replaced by another temperature sensitive component or a network incorporating at least one temperature sensitive component, and that this component or network could replace one or more of the components in the circuit in order to achieve various different
20 temperature-dependent voltage characteristics. Also, some known voltage regulators and voltage reference supply circuits supply a straight line temperature-dependent voltage as an auxiliary output, and if a straight line characteristic is satisfactory then these may be used to replace the temperature dependent
25 voltage generating circuit 3.

In some circumstances it may be arranged that the output voltage V_2 of the temperature-dependent voltage generating
circuits 3 are suitable for direct application to the transducer 1, and examples are described below with reference to Figures 8
30 to 10.

Referring to Figure 8, a transducer circuit 1 is again represented as four resistors (R_{G1} to R_{G4}) in a Wheatstone Bridge configuration. In this circuit, however, the temperature-dependent voltage generating circuit 3 itself constitutes the
35 output stage of the supply circuit for the transducer 1.

- 13 -

The temperature dependent voltage generating circuit 3 comprises, as in the earlier described embodiments, resistors R3 and R4 in series between a regulated supply voltage Vr and ground (GND), with the node therebetween connected to the non-inverting (+) input to an operational amplifier U1. The output of operational amplifier U1 is connected via a temperature dependent feedback element, in this instance a temperature-sensitive resistor Rt as in Figure 6, to its inverting (-) input. The inverting (-) input is also connected via a resistor R5 to ground (GND). The desired temperature dependent voltage, V2, is provided at the output of amplifier U1, which is connected to the positive supply side of transducer 1. The optional pull-up device 8, if included, connects this side of the transducer 1 to the regulated supply voltage Vr. The negative supply side of transducer 1 is connected to ground (GND).

A particular example of the circuit shown in Figure 8 operates as follows:

Transducer 1 requires a temperature compensated voltage supply (V2) of 3.0V at 20°C, with a linear slope of 4.5 mV/°C. Temperature dependent voltage generating circuit 3 is an operational amplifier in non-inverting amplifier configuration with the temperature dependent component (resistor Rt) in the feedback circuit which therefore has a constant current through it. Resistor Rt has a resistance of 1077Ω at 20°C and a temperature coefficient of 3.85 Ω/°C. In order to provide for a voltage change of 4.5 mV/°C it requires a constant current of 1.169 mA. At 20°C this constant current implies a potential difference of 1.26V across resistor Rt. The output voltage (V2) requirement of 3.0V at 20°C is met by dropping an additional 1.74V across resistor R5. This is achieved by setting the resistor ratio R3:R4 to give a voltage of 1.74V at the non-inverting (+) input of operational amplifier U1. With 1.74V across it, a resistance value of 1030Ω is selected for resistor R5 to give the required constant current of 1.169 mA through it (and therefore through resistor Rt).

- 14 -

In certain circumstances, for example when the regulated voltage V_r is relatively low, it may be that the operational amplifier U1 is unable to source enough current to maintain the supply voltage (V_2) required by the transducer 1. This requirement can be met by including the optional pull-up device 8, usually a resistor, which is chosen to supply more current than the transducer 1 requires at any temperature so that the operational amplifier U1 then determines the voltage by sinking the excess current.

As shown in Figure 9 the positive supply side of transducer circuit 1 is connected to ground (GND) and the output voltage V_2 of the temperature-dependent voltage generating circuit 3 as described above with reference to Figure 8 is connected to the negative supply side of the transducer 1 which, optionally, is connected to ground (GND) by a pull-down device 9 which will usually be a resistor. Assuming again that the transducer 1 requires a voltage across it of 3.0V at 20°C, with a linear increase with temperature of 4.5 mV/°C, then, if the regulated supply voltage V_r is 5.0V, this is achieved by setting the temperature dependent voltage V_2 to 2.0V at 20°C with a slope of -4.5 mV/°C. The circuit element shown as R_t is in this instance required to have a negative temperature coefficient of resistance. Assuming for purposes of explanation that it is again a resistance having a value of 1077 Ω at 20°C and a temperature coefficient, now, of -3.85 Ω /°C, it requires a constant current of 1.169 mA in order for the resistor R_t to provide for a voltage change of -4.5 mV/°C. At 20°C this constant current implies a potential difference of 1.26V across resistor R_t . The output voltage (V_2) requirement of 2.0V at 20°C is met by dropping an additional 0.74V across resistor R_5 . With the constant current of 1.169 mA flowing through it this gives a required resistance value of 633 Ω for R_5 .

In certain circumstances, for example when temperature dependent voltage V_2 is too close to ground (GND), it may be that the operational amplifier U1 is unable to sink enough current to

- 15 -

maintain the temperature dependent voltage V2 required by the transducer 1. This requirement can be met by including the optional pull-down device 9, usually a resistor, which is chosen to sink more current than the transducer sources at any temperature so that the amplifier U1 then determines the voltage by sourcing the extra current required.

Analogously with the circuit shown in Figure 6, a circuit combining features of Figures 8 and 9 may be provided as illustrated in Figure 10. As in Figure 8, the amplifier U1 of the temperature dependent voltage generating circuit 3 in Figure 10 supplies a temperature-dependent voltage V2 to the positive supply side of transducer 1 which, optionally, is connected by the pull-up device 8 to the regulated voltage supply Vr. The output of operational amplifier U1 is also connected to the inverting input side of inverting amplifier circuit 11 which, as in the circuit shown in Figure 6, comprises an operational amplifier U5 with its inverting input connected via a resistor (R6) to the output of operational amplifier U1 and its output connected to its inverting input via a resistor (R7). The positive input of operational amplifier U5 is connected to the output of level setting voltage generating circuit 10. The output of operational amplifier U5 is connected to the negative supply side of transducer 1 which, optionally, is connected by the pull-down device 9 to ground (GND). The level setting voltage generating circuit 10 comprises, in this case, a pair of resistors connected in series between the regulated voltage supply Vr and ground (GND), and from the node between these resistors is taken an output voltage V6 which is applied to the positive input of the amplifier U5.

Assuming as before that the regulated supply voltage Vr is 5.0V and that the transducer 1 requires a voltage across it of 3.0V at 20°C which linearly increases with temperature at 4.5 mV/°C, the circuit shown in Figure 10 enables this to be achieved by setting the voltage V2 on the positive supply side of the transducer to 4.0V at 20°C with a slope of +2.25 mV/°C and

- 16 -

the voltage V3 on the negative supply side of the transducer 1 to 1.0V with a slope of $-2.25 \text{ mV}/^\circ\text{C}$. To that end, resistor Rt has a resistance of 1077Ω at 20°C and a temperature coefficient of $3.85 \Omega/^\circ\text{C}$. In order for the resistor Rt to provide for a voltage
05 change of $2.25 \text{ mV}/^\circ\text{C}$ it requires a constant current of 0.584 mA. At 20°C this constant current implies a potential difference of 0.630V across resistor Rt. The requirement of 4.0V at 20°C for the output voltage V2 is met by dropping an additional 3.37V across resistor R5. This is done by setting the resistor ratio
10 R3:R4 to give 3.37V at the non-inverting (+) input of operational amplifier U1. The constant current requirement of 0.584 mA through resistor R5 which has a voltage of 3.37V across it determines its required resistance at 5770Ω . The slope requirement of $-2.25 \text{ mV}/^\circ\text{C}$ for the output voltage V3 can be met
15 by applying a slope gain of -1 to the $+2.25 \text{ mV}/^\circ\text{C}$ slope of the temperature dependent voltage V2. This is done by setting $R6 = R7$ in inverting amplifier circuit 11. The level requirement of 1.0V at 20°C for the output voltage V3 is met by adjusting the resistor ratio in the level setting voltage generating circuit 10
20 to give an output voltage V6 of 2.5V.

It will be seen that, in the circuit illustrated in Figure 10, the output of the temperature dependent voltage generating circuit 3 is applied to the positive supply side of the transducer and the output of inverting amplifier circuit 11 is
25 applied to the negative supply side. It will be understood, however, that an equivalent circuit, equally in accordance with the invention, might have the temperature dependent voltage generating circuit 3 connected to the negative supply side and the inverting amplifier circuit 11 connected to the positive
30 supply side, with optional pull-up and pull-down devices as necessary.

It will be appreciated that although the circuits described above employ in each case the minimum number of components necessary for a circuit functioning in the intended manner,
35 circuits within the scope of the invention may nevertheless

- 17 -

contain additional components such, for example, as extra amplifiers in various configurations, of which the functions reduce logically to those of the circuits illustrated.

Circuits in accordance with the invention, as described
05 above, may be made on a printed circuit board or on a thick film hybrid, though most if not all of such a circuit may alternatively be placed on a single piece of silicon. The temperature dependent component in the circuit will normally be located physically close to the transducer itself and if the
10 transducer is based on silicon then the temperature dependent circuit component may itself also be diffused into the silicon.

Any of the above-described circuits according to the invention will usually be part of a larger sensor signal conditioning circuit, which may also include sensor output
15 amplification, offset compensation, and temperature coefficient of offset compensation (with the temperature dependent voltage for this latter function being derived, preferably, from the output of one of the amplifiers in the circuit according to the invention, as is described and claimed in our co-pending UK
20 Patent Application No. 8925579.8.

- 18 -

CLAIMS

- 05 1. A power supply circuit for applying a temperature-compensating supply voltage across a temperature-sensitive transducer, the circuit comprising: a first operational amplifier; means for applying an output level determining voltage to one input of the amplifier; means for applying a temperature-dependent output slope determining voltage to the other input of the amplifier; and means for applying the resultant temperature-dependent output voltage of the amplifier to the transducer.
- 10 2. A circuit as claimed in Claim 1, wherein the output level determining voltage is applied to the positive input of the amplifier and the output slope determining voltage is applied to the negative input of the amplifier.
- 15 3. A circuit as claimed in Claim 1, wherein the output level determining voltage is applied through a high-impedance buffering amplifier to the negative input of the first amplifier and the output slope determining voltage is applied to the positive input of the first amplifier.
- 20 4. A circuit as claimed in any of Claims 1 to 3, wherein the output slope determining voltage is, or is derived from, the output of an operational amplifier having a temperature-sensitive feedback element connected between its output and its negative input.
- 25 5. A circuit as claimed in Claim 4, wherein the output of the operational amplifier with a temperature-sensitive feedback element is applied via one or more inverting amplifiers to the said other input of the first amplifier.
- 30 6. A circuit as claimed in Claim 2, wherein the means for applying a temperature-dependent output slope determining voltage to the negative input of the first amplifier comprises a temperature-sensitive feedback element connected between the output and the negative input of the first amplifier.
- 35 7. A circuit as claimed in Claim 4 or Claim 6, wherein the temperature-sensitive feedback element is a semiconductor diode.

- 19 -

8. A circuit as claimed in Claim 4 or Claim 6, wherein the temperature-sensitive feedback element is a temperature-sensitive resistor.

05 9. A circuit as claimed in any of Claims 1 to 8, wherein the output level determining voltage is derived from a resistive voltage divider circuit.

10 10. A circuit as claimed in any of Claims 1 to 9, wherein the temperature-dependent output voltage of the first amplifier is applied to a first supply terminal of the transducer and a second supply terminal thereof is connected to a point of fixed voltage.

15 11. A circuit as claimed in any of Claims 1 to 9, wherein the temperature-dependent output voltage of the first amplifier, derived from the said means for applying a temperature-dependent output slope determining voltage, is applied to a first supply terminal of the transducer and there is also applied, to a second supply terminal of the transducer, a further temperature-dependent voltage derived from the same said means for applying a temperature-dependent output slope determining voltage.

20 12. A circuit as claimed in Claim 11 wherein the temperature-dependent output voltage of the first amplifier is applied to a first supply terminal of the transducer and also, via an inverting amplifier provided with independent voltage level setting means, to the second supply terminal of the transducer.

25 13. A circuit as claimed in any of Claims 10 to 12, wherein the or each supply terminal of the transducer to which a temperature-dependent voltage is applied is connected by a pull-up or pull-down current-conducting circuit to a respective point of fixed voltage.

30 14. A circuit as claimed in any preceding claim, wherein the transducer is a strain gauge and the circuit provides span temperature compensation therefor.

15. A circuit as claimed in Claim 14, wherein the strain gauge is a pressure sensor.

- 20 -

16. A power supply circuit for applying a temperature-compensating supply voltage across a temperature-sensitive transducer, substantially as described herein with reference to any of the accompanying drawings.

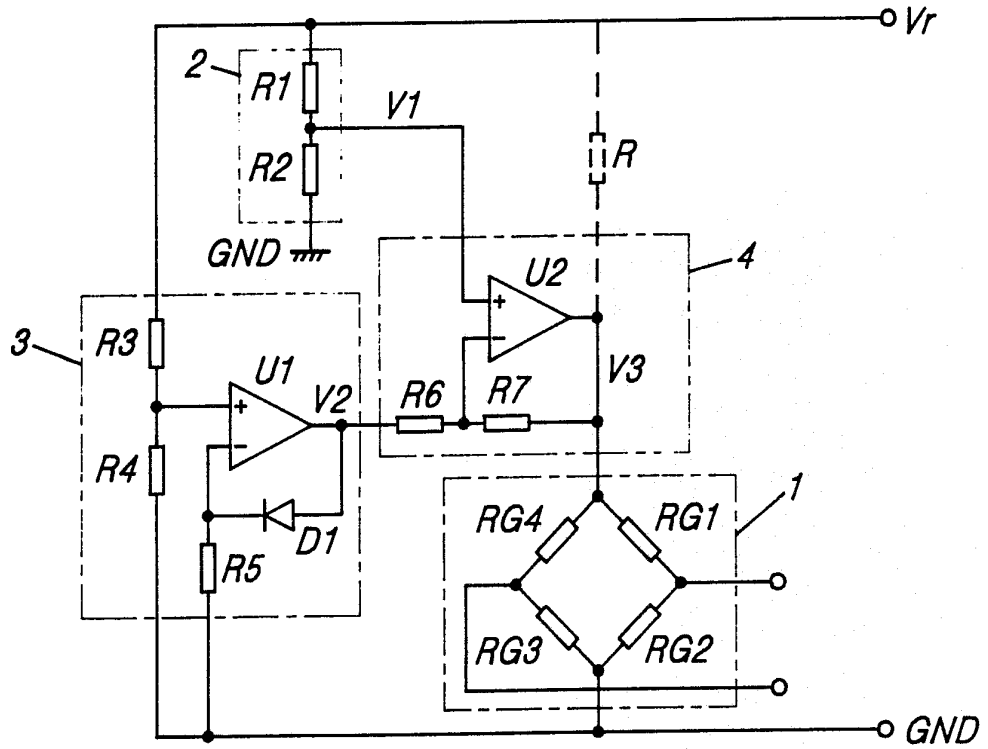


Fig. 1

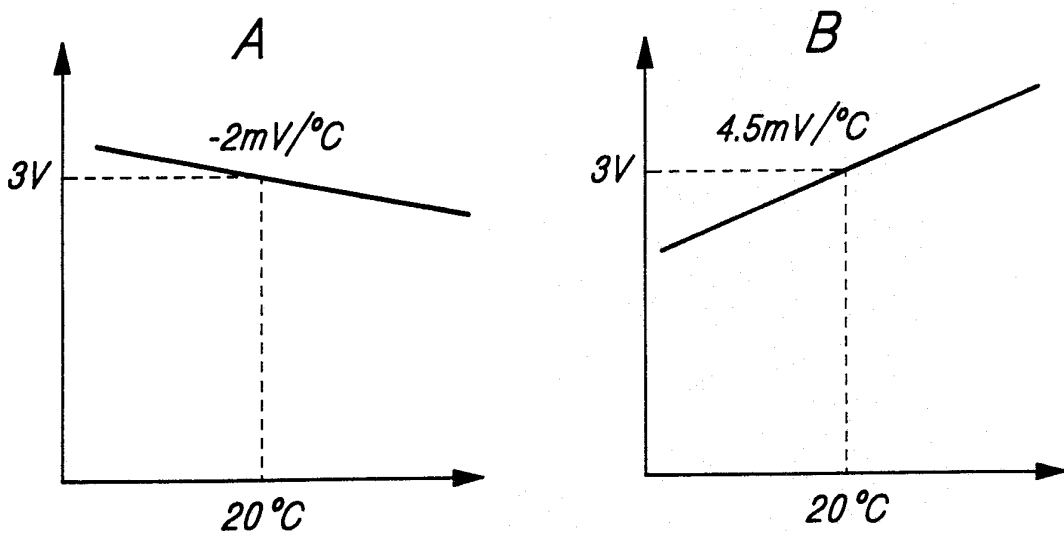


Fig. 2

2/8

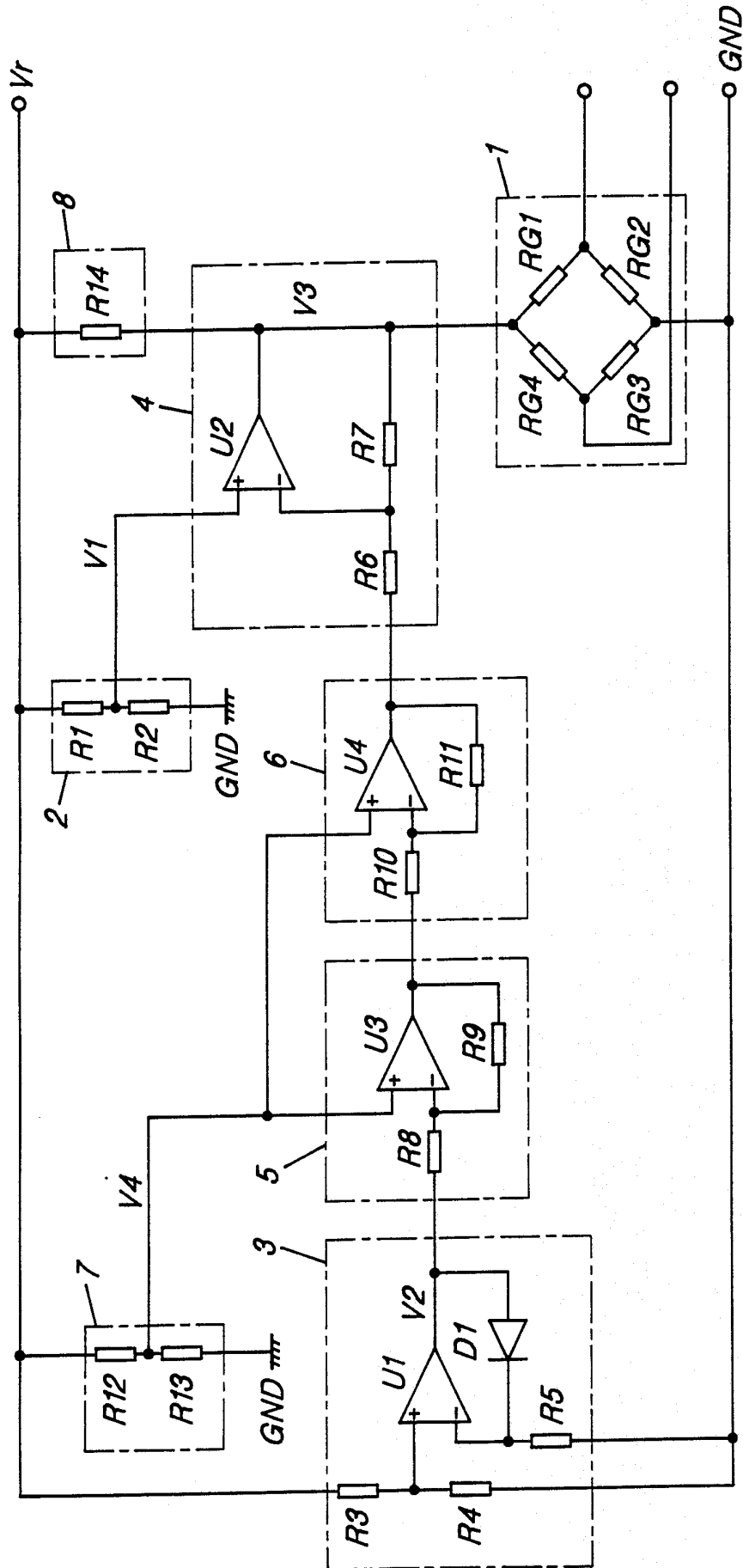


Fig.3

3/8

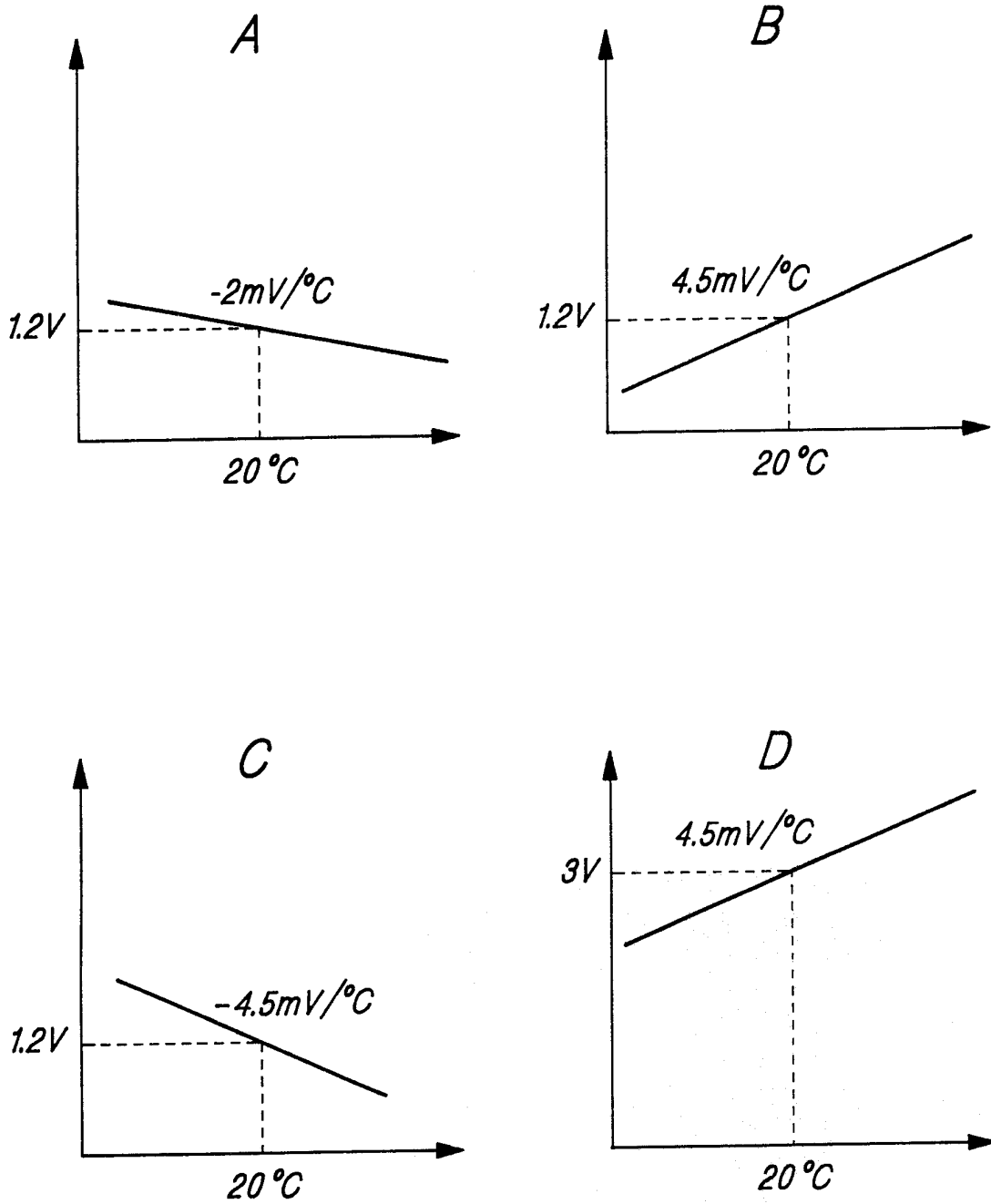


Fig. 4

4/8

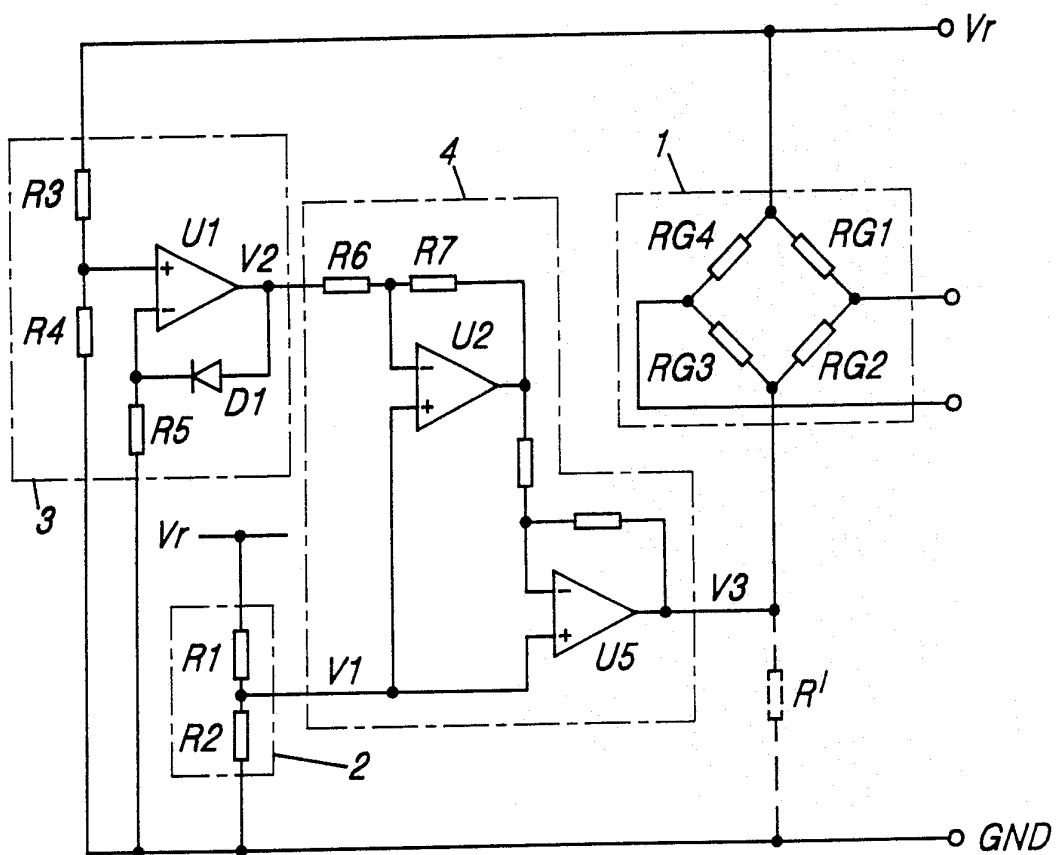


Fig.5

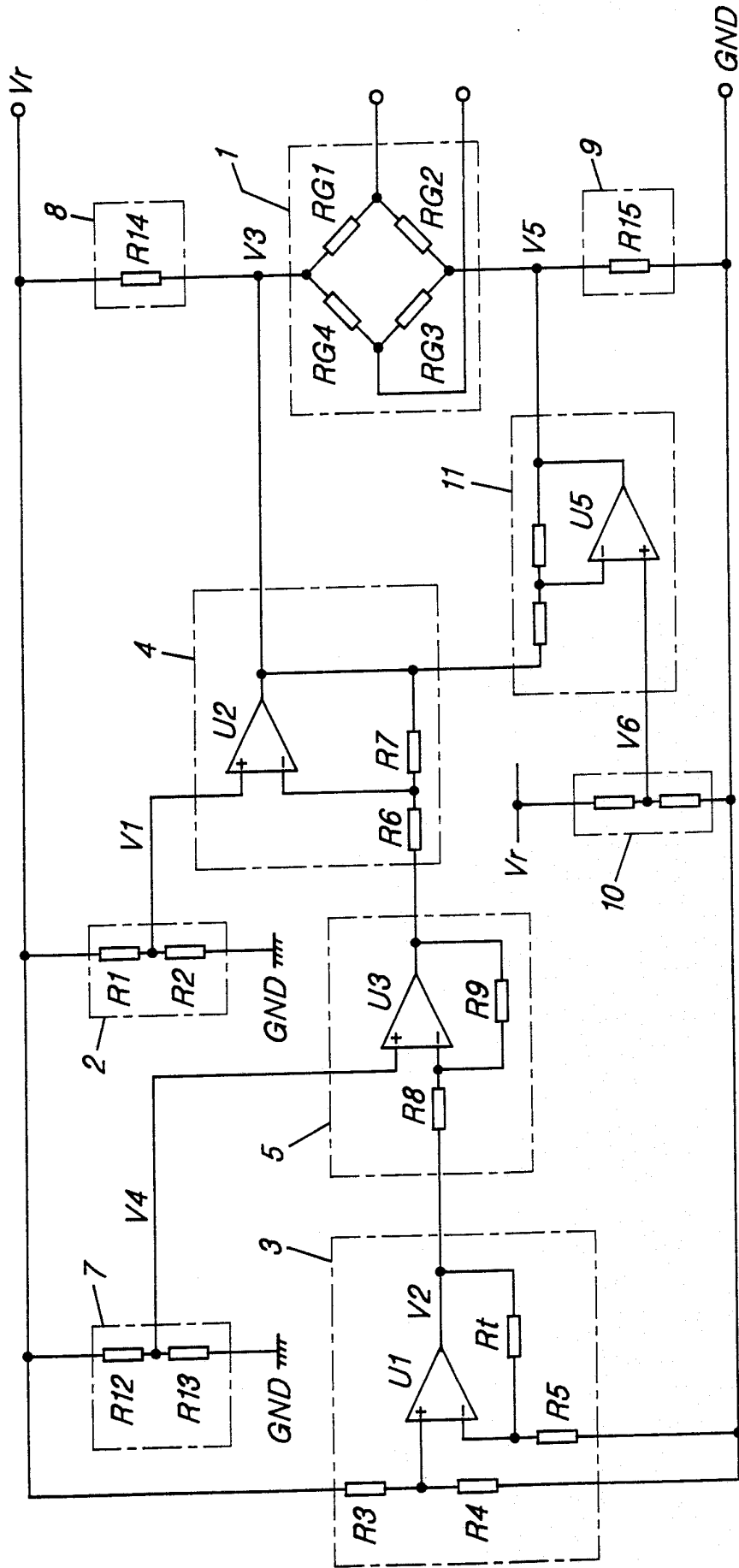


Fig. 6

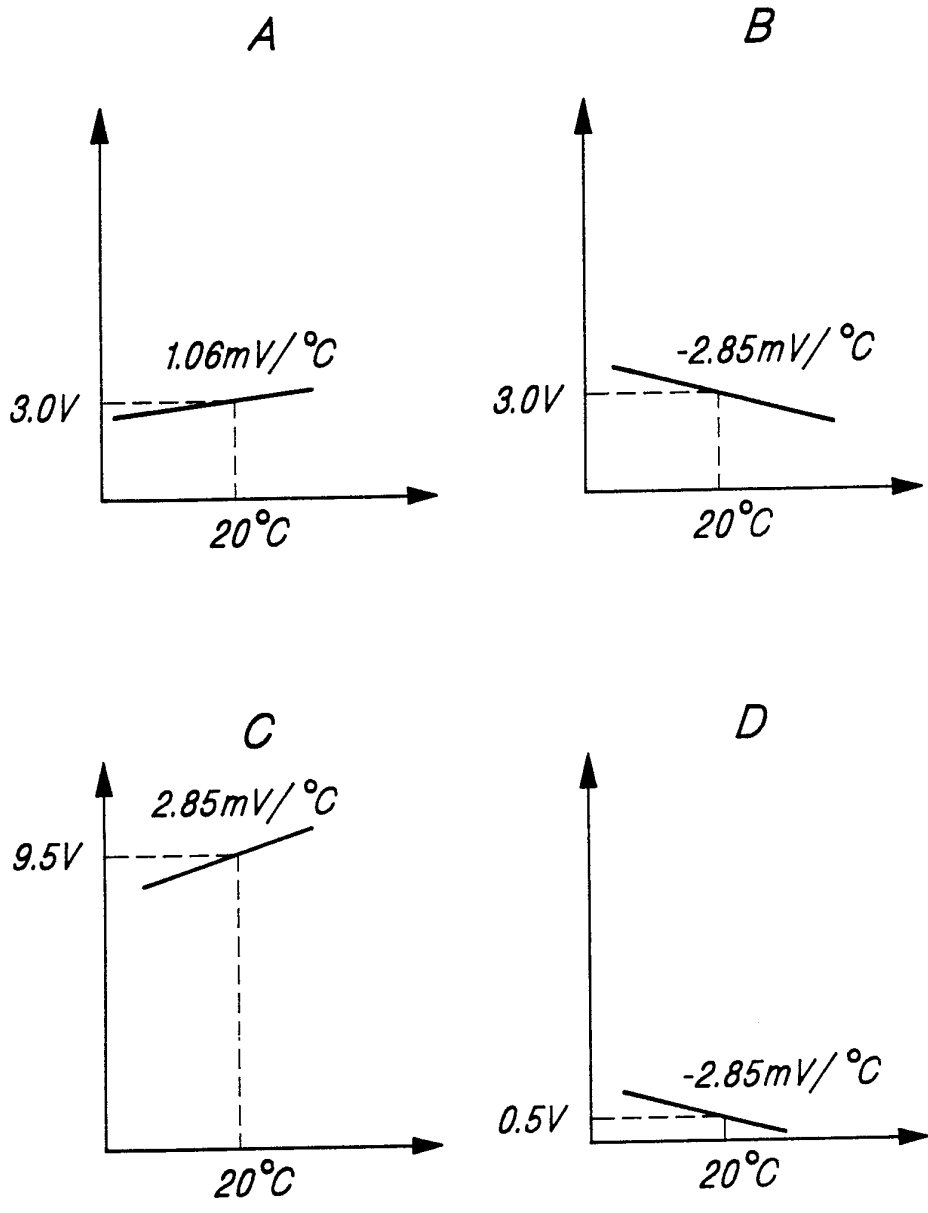


Fig.7

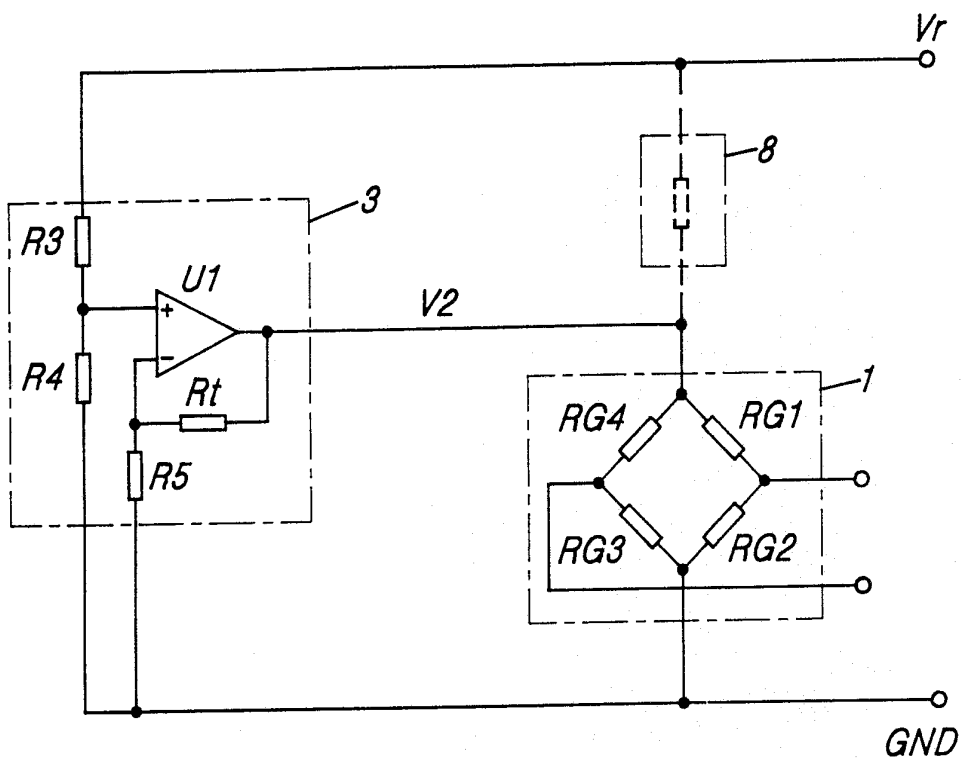


Fig. 8

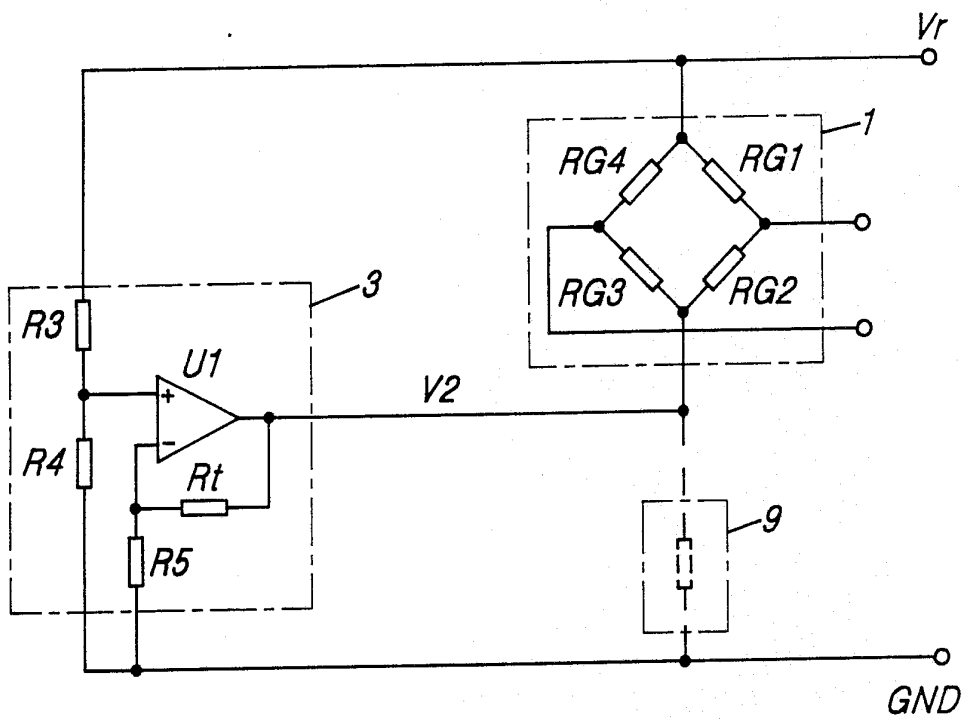


Fig. 9

8/8

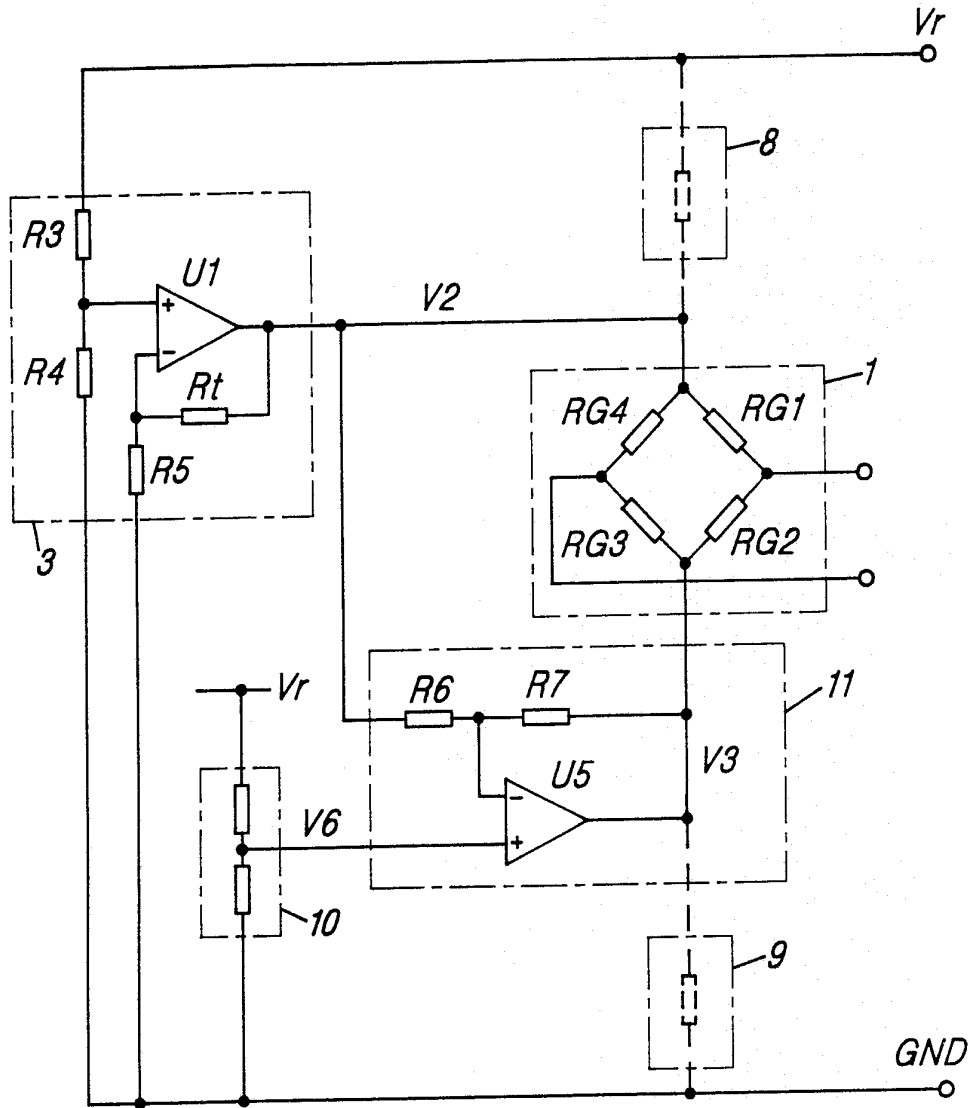
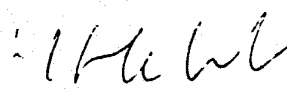


Fig. 10

INTERNATIONAL SEARCH REPORT

PCT/GB 90/01744

International Application No

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶		
According to International Patent Classification (IPC) or to both National Classification and IPC: Int.Cl. 5 G05F1/46 ; G01L1/22		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
Int.Cl. 5	G01L ; G05F	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹		
Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	US,A,4798093 (R. KENOUN) 17 January 1989 see column 2, lines 41 - 58 see column 4, line 21 - column 6, line 15 see figure 1	1, 2, 4, 6, 8-10 14, 15
Y	---	3, 5
Y	ELECTRONIC ENGINEERING. vol. 51, no. 617, January 1979, LONDON GB page 14 N. Allen-Rowlandson: "Voltage reference has adjustable tempo" see the whole document	3, 5
P,X	EP,A,0392746 (LUCAS INDUSTRIES) 17 October 1990 see page 2, line 52 - page 6, line 32; figures 1-3	1, 2, 9, 11, 14, 15
<p>¹⁰ Special categories of cited documents</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"I" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"I" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
01 FEBRUARY 1991	FEB 13 1991	
International Searching Authority	Signature of Authorized Officer	
EUROPEAN PATENT OFFICE	HELOT H.V. 	

ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.

GB 9001744

SA 41739

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on

The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information. 01/02/91

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-4798093	17-01-89	None	
EP-A-0392746	17-10-90	None	