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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 November 2003 (27.11.2003)

PCT

(10) International Publication Number
WO 03/098162 A1

(51) International Patent Classification⁷: **G01F 1/00**, 17/00, G01K 15/00, G01F 1/12, G01D 1/00, G01F 1/68, G01N 25/00

(21) International Application Number: PCT/US03/11082

(22) International Filing Date: 11 April 2003 (11.04.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/380,237 13 May 2002 (13.05.2002) US
10/283,831 29 October 2002 (29.10.2002) US

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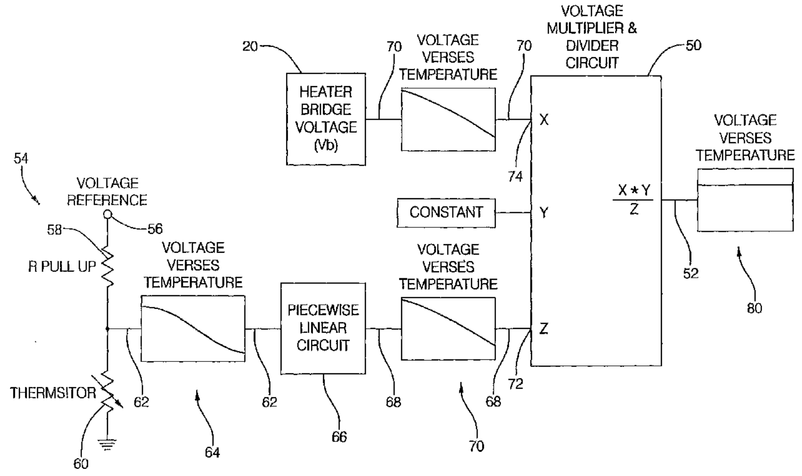
(81) Designated State *(national)*: JP.

(84) Designated States *(regional)*: European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR).

Published:
- *with international search report*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

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

(54) Title: OPTIMIZED CONVECTION BASED FLUID FLOW SENSOR CIRCUIT



(57) Abstract: A method and apparatus for measuring the amount of flow of a flowing medium. The method and apparatus include a bridge circuit (20) configured to develop a bridge voltage Vb such that the magnitude of the bridge voltage Vb is indicative of the amount of flow. The bridge circuit (20) is configured without having an ambient temperature sensor, thus the bridge voltage is uncompensated with respect to ambient temperature. A thermistor circuit (54) is configured to generate a temperature reference voltage (56) indicative of ambient temperature. A conditioning circuit (50) is configured to receive the uncompensated bridge voltage and the temperature reference voltage (56) to process the same and generate a compensated bridge voltage with respect to ambient temperature. The compensated bridge voltage is indicative of fluid flow.

WO 03/098162 A1

OPTIMIZED CONVECTION BASED FLUID FLOW SENSOR CIRCUIT

TECHNICAL FIELD

[0001] This invention relates to a flowmeter of the "hot wire" variety, and more particularly, to a circuit for temperature compensating such a flowmeter.

BACKGROUND OF THE INVENTION

[0002] Mass air flow meters used in automotive vehicles often are of the constant temperature anemometer type. In these meters, a sensing element is electrically heated to a constant temperature differential above the ambient air temperature. Heat is convectively removed from the element by the airflow and the current flowing in the element replaces the heat lost by convection. As the mass air flow varies, the current required to maintain the requisite temperature also varies such that the current is a known function of the mass air flow.

[0003] Typically, a "hot wire" type flowmeter includes a self-heated sensor resistor having a resistance RH which is a function of its temperature. In turn, the temperature of the heated resistor is determined at least in part by the difference between the heat generated within the heated resistor as a function of the voltage applied across the resistor and the heat transferred away from the heated resistor as a function of the amount of cooling fluid flow past the resistor. In addition, it is usual for a "hot wire" flowmeter to include an ambient temperature sensing resistor having a resistance RA determined by the ambient temperature of the flowing fluid.

[0004] Hot element anemometers frequently use a Wheatstone bridge configuration for the sensing elements. As shown in Figure 1, it is commonplace to employ a flow sensing resistor RH in one leg of a bridge 10 and an ambient temperature sensing resistor RA in another leg of bridge 10. In a bridge-type "hot wire" flowmeter, the self-heated resistor RH and the ambient temperature resistor RA are connected within a bridge circuit across which a voltage Vb is developed. In terms of fundamental structure, the bridge circuit includes a signal side for deriving a signal voltage V_{RL} which is a voltage divided function of the bridge voltage Vb as determined at least in part by the resistance RH of the sensor resistor in ratio to the resistance RL of a power dissipating resistor. The bridge circuit further includes a reference side for defining a reference voltage Vr which is a voltage divided function of the bridge voltage Vb as determined at least in part by the sum (RA+R1) of the resistance RA of the ambient resistor plus the resistance R1 of a ballast resistor in ratio to the resistance R2 of a calibration resistor.

[0005] It is common in a bridge-type flowmeter to drive the bridge circuit with an operational amplifier which compares the signal voltage V_{RL} with the reference voltage Vr. More specifically, the amplifier is responsive to the difference between the two voltages V_{RL} and Vr to alter the bridge voltage Vb thereby correspondingly altering the voltage applied across the self-heated resistor so as to change the heat generated within the resistor. As a result, the temperature of the heated resistor and its related resistance RH are modified such that the signal voltage V_{RL} is equalized with the reference voltage Vr. Under these circumstances, the bridge voltage Vb is indicative of the amount of fluid flow.

[0006] Resistor R2 in the lower arm of the bridge completing the bridge configuration with resistor R1 in series with the ambient sensing resistor RA is useful in bridge balance and calibration. The bridge values are selected so that the bridge will be balanced when the flow sensing resistor RH is at a prescribed temperature differential above the ambient temperature. As airflow changes tend to result in resistor RH changes, the bridge tends to unbalance and the amplifier makes a correction in the applied bridge voltage to restore the resistor temperature differential and thus the bridge balance. The applied bridge voltage Vb therefore varies with airflow and is useful as a measure of mass airflow.

[0007] The hot-wire type of sensor has several limitations. In particular, the RH and RA resistances are not consistent enough to have single value resistors to form the Wheatstone bridge described above. To compensate for the RH and RA resistance value variations, thick film resistors are laser trimmed to individually match corresponding RH and RA values. Furthermore, the Wheatstone bridge requires a costly ambient temperature sensor having a resistance vs. temperature characteristic similar to the heated sensor. Thus, it would be desirable to temperature compensate a hot wire anemometer without costly laser trimmed resistors and an ambient temperature sensor.

SUMMARY OF THE INVENTION

[0008] Disclosed herein is a method and apparatus for measuring the amount of flow of a flowing medium. The apparatus includes a bridge circuit across which a bridge voltage Vb is developed such that the magnitude of the bridge voltage Vb is indicative of the amount of flow. The bridge circuit has a signal side for deriving a signal voltage V_{RL} which is a voltage divided function of the bridge voltage Vb as determined at least in part by the resistance RH of a self-heated resistor in ratio to the resistance RL of a power resistor where the resistance RH is related to the temperature of the heated resistor as determined at least in part by the difference between the heat generated within the heated resistor as a function of the voltage applied across the heated resistor and the heat transferred away from the heated resistor as a function of the amount of fluid flow. The bridge circuit also has a reference side for defining a reference voltage Vr which is a voltage divided function of the bridge voltage Vb as determined at least in part by a resistance Rp of a potentiometer. The bridge circuit further includes an amplifier responsive to the difference between the signal voltage V_{RL} and the reference voltage Vr for altering the bridge voltage Vb to maintain the heat generated within the self-heated resistor thereby maintaining its temperature and related resistance RH so as to equalize the signal voltage V_{RL} and the reference voltage Vr.

[0009] The method for temperature compensation of a constant temperature anemometer described above further includes generating a temperature reference voltage indicative of ambient temperature from a thermistor circuit; receiving the uncompensated bridge voltage and the temperature reference voltage in a conditioning circuit configured to process the uncompensated bridge voltage and the temperature reference voltage; and generating a compensated bridge voltage with respect to ambient temperature. The compensated bridge voltage indicative of fluid flow across resistor RH in an ambient temperature range.

[0010] The above described and other features are exemplified by the following figures and detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Referring now to the Figures wherein like elements are numbered alike.

[0012] Figure 1 is a schematic diagram of a conventional airflow meter circuit.

[0013] Figure 2 is a schematic diagram of an exemplary embodiment of an airflow meter circuit.

[0014] Figure 3 is a graph illustrating how a bridge voltage in the circuit of Figure 2 changes with ambient temperature with a heated sensor heated at a constant 250°C.

[0015] Figure 4 is a schematic diagram of a frequency output air meter employing the circuit of Figure 2 and a thermistor circuit to correct bridge voltage for ambient temperature changes.

[0016] Figure 5 is a schematic diagram of a voltage output flow meter employing the circuit of Figure 2 and a thermistor circuit to correct bridge voltage for ambient temperature changes.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0017] Referring to Figure 2, a circuit schematic of an exemplary embodiment of a flowmeter 12 is illustrated for measuring the amount of fluid flow through a conduit (not shown). An arrow 14 indicates the direction of flow from left to right. As one example, the fluid may be air and the conduit may be part of an intake passage of an internal combustion engine (not otherwise shown). In the latter event, the flowmeter 12 measures the mass airflow through the conduit into the engine.

[0018] Flowmeter 12 is of the "hot wire" variety, i.e., it includes a self-heated sensor resistor 16 having a resistance RH which is a function of its temperature (T_{RH}). Preferably, the heated resistor 16 is mounted within the conduit so as to be exposed to the fluid flow therethrough. The temperature of the heated resistor 16 (and its related resistance RH) is determined, at least in part, by the difference between the heat generated within resistor 16 as a function of the voltage applied thereacross and the heat transferred away from resistor 16 as a function of the cooling fluid flow thereover.

[0019] Flowmeter 12 also includes a resistive element 18 electrically coupled in parallel with resistor 16. The resistive element 18 has a resistance determined by a desired constant temperature of resistor 16.

[0020] In addition, flowmeter 12 includes a bridge circuit 20 within which the self-heating resistor 16 and the resistive element 18 are connected. In operation, a voltage Vb is developed across the bridge circuit 20 where the magnitude of the bridge voltage Vb is indicative of the amount of fluid flow across resistor 16 and through the conduit.

[0021] More specifically, the bridge circuit 20 includes a signal side 22 for deriving a signal voltage V_{RH} which is a voltage divided function of the bridge voltage Vb as determined in part by the resistance RH of the heated resistor 16 in ratio to the resistance RL of a power dissipating resistor 24. The signal voltage V_{RL} is tapped from between the resistors 16 and 24.

[0022] As a further matter, the bridge circuit 20 includes a reference side 30 for defining a reference voltage Vr which is a voltage divided function of the bridge voltage Vb as determined using a digital programmable potentiometer for resistive element 18 to compensate for part to part variation in the heated resistor 16. To achieve identical temperature behavior between different flow meters, the temperature of the heated resistor 16 should be the same. It will be recognized that the temperature of the heated resistor 16 is set by the voltage divider on reference side 30. In an exemplary embodiment, the voltage divider needed on reference side 30 is constructed using a digital programmable potentiometer to configure resistive element 18 thus eliminating the need for laser trimmed resistors R1 and R2 shown with respect to Figure 1. The reference voltage Vr is then tapped from resistive element 18.

[0023] In addition, the flowmeter 12 includes an operational amplifier 32 for driving the bridge circuit 20. More particularly, amplifier 32 is responsive to the difference between the signal voltage V_{RL} and the reference voltage Vr to alter the bridge voltage Vb thereby correspondingly altering the voltage applied across the self-heated resistor 16 so as to change the heat generated therein. As a result, the temperature of the heated resistor 16 and its related resistance RH are modified such that the signal voltage V_{RL} equals the reference voltage Vr (i.e., the difference between the two voltages V_{RL} and Vr is zero).

[0024] Referring now to Figure 3, a graph depicted generally at 40 shows how the bridge voltage Vb changes with respect to ambient temperature when resistor 16 is maintained at 250°C. . In the exemplary flowmeter depicted in Figure 2, it is desirable that the bridge voltage Vb be temperature compensated over the ambient temperature range. This means that for any given amount of flow, the change in bridge voltage Vb is controlled in a prescribed fashion as the ambient temperature changes. For instance, it may be desirable that the bridge voltage Vb change in a predetermined manner over the ambient temperature range so as to cancel or compensate for some inverse temperature responsive change that would be otherwise be induced in the bridge voltage Vb. In an exemplary embodiment illustrated in Figures 4 and 5 the bridge voltage Vb is fed through a subsequent voltage conditioning circuit 50 that produces an output 52 which is a temperature responsive function of the bridge voltage.

[0025] Referring to Figures 4 and 5, a low cost thermistor circuit 54 is employed to create a correction voltage for use with conditioning circuit 50. Thermistor circuit is a voltage divider having a voltage reference 56 applied thereto. Thermistor circuit 54 includes a pull up resistor 58 and a thermistor 60. A reference voltage signal 62 is tapped from between the resistors 58 and 60. Reference voltage signal 62 is shown over a wide ambient temperature range at 64 such that the voltage vs. temperature characteristic may not match the voltage vs. temperature characteristic illustrated at 70. In such case, a piecewise linear circuit 66 may be required to achieve the desired accuracy. Piecewise linear circuit 66 outputs a corrected reference voltage output signal 68 that substantially duplicates the voltage vs. temperature characteristic illustrated at 70. Corrected reference voltage signal 68 is then input to conditioning circuit 50 along with a heater bridge voltage signal 72 (i.e., Vb) determined in bridge circuit 20 of Figure 2.

[0026] It has been found that low cost thermistors provide more than 1.0°C accuracy over an entire ambient temperature range of about –40°C to about 125°C. Moreover, many applications using flowmeter 12 may also require an air temperature signal. By tapping reference voltage signal 62 from thermistor 60, this thermistor signal may optionally provide an air temperature output signal in parallel with reference voltage signal 62 indicative of the ambient air temperature.

[0027] In the flowmeter 12, since it is desirable that the bridge voltage Vb be temperature compensated over the ambient temperature range of the flowing fluid, this means that for any given amount of flow, the change in bridge voltage Vb is controlled in a prescribed fashion as the ambient temperature T_{amb} of the fluid changes by employing conditioning circuit 50.

[0028] The present disclosure is directed to an approach for temperature compensating the bridge voltage Vb over the ambient temperature range of the flowing fluid. The inventive approach is based on holding the temperature of the heated resistor 16 constant and processing the bridge voltage to correct for ambient temperature changes using conditioning circuit 50. In this manner, a costly ambient air sensor in the Wheatstone bridge of Figure 1 can be eliminated. In order to temperature compensate the constant temperature heated resistor 16 in flowmeter 12, the bridge voltage Vb is modified by the inverse of a heater bridge voltage equation shown below.

$$\left[\frac{(T_{RH}-T_{amb})\bullet P_{CONVECTIVE}(T_{amb})\bullet[RH(T_{RH})+RL]^2}{RH(T_{RH})}\right]^{1/2}$$

Where: Vb is the flow bridge voltage.
T_{RH} = Heated Resistor Temperature
T_{amb} = Ambient Air Temperature
$P_{CONVECTIVE}(T_{amb})$ = Convective heat transfer from the Heated Resistor
$RH(T_{RH})$ = Resistance of RH when heated to T_{RH}
RL = Resistance of RL

[0029] More specifically with reference to Figure 4, for a frequency output air meter generally shown, conditioning circuit 50 is a voltage controlled oscillator circuit to correct the temperature uncompensated bridge voltage Vb for ambient temperature changes. Corrected reference voltage signal 68 is applied to a reference voltage input 72 of the voltage controlled oscillator circuit and bridge voltage signal 70 is applied to a heater bridge voltage input 74 of the voltage controlled oscillator circuit. The voltage controlled oscillator circuit generates output 52 that is indicative of a frequency output. The frequency output is indicative of a compensated bridge voltage over the ambient temperature range indicated generally as graph 76. Graph 76 indicates a compensated bridge voltage Vb as a frequency output over the ambient temperature range and processed by the voltage controlled oscillator circuit as follows:

$$\text{Frequency Output} = \frac{UncompensatedBridgeVoltage(Vb)}{Corrected\,\mathrm{Re}\,ferenceVoltage}\bullet\text{Constant}$$

[0030] In other words, conditioning circuit 50 processes the compensated bridge voltage by multiplying the bridge voltage input Vb by a constant and an inverse of the above described bridge voltage equation:

$$\left[\frac{(T_{RH}-T_{amb})\bullet P_{CONVECTIVE}(T_{amb})\bullet[RH(T_{RH})+RL]^2}{RH(T_{RH})}\right]^{1/2}$$

[0031] Referring now to Figure 5, in another embodiment using a voltage output meter generally shown, conditioning circuit 50 is an analog multiplier-divider bridge voltage compensation circuit to correct the temperature uncompensated voltage Vb for ambient temperature changes. Corrected reference voltage signal 68 is applied to reference voltage input 72 (Z) of the analog multiplier-divider bridge voltage compensation circuit and uncompensated bridge voltage signal 70 is applied to input 74 (X) of the analog multiplier-divider bridge voltage compensation circuit. The constant is applied to input (Y). The analog multiplier-divider bridge voltage compensation circuit generates output 52 that is indicative of a voltage output. The voltage output is indicative of a compensated bridge voltage over the ambient temperature range indicated generally as graph 80. Graph 80 indicates a compensated bridge voltage Vb as a voltage output over the ambient temperature range and processed by the voltage controlled oscillator circuit as follows:

$$\text{Voltage Output} = \frac{UncompensatedBridgeVoltage(Vb)}{Corrected\,\mathrm{Re}\,ferenceVoltage} \bullet \text{Constant}$$

or,

$$= \frac{X}{Z} \bullet Y$$

$$\text{Where } Z = \left[\frac{(T_{RH} - T_{amb}) \bullet P_{CONVECTIVE}(T_{amb}) \bullet [RH(T_{RH}) + RL]^2}{RH(T_{RH})} \right]^{1/2}$$

[0032] Referring again to Figures 1 and 2, it will be recognized by one skilled in the pertinent art that in order to achieve similar temperature behavior, the temperature of heated resistor 16 must be the same on every air meter. To achieve similar temperature behavior, the temperature of the heated resistor 16 is set by the voltage divider in reference side 30. More specifically, this voltage divider needs to be adjustable to account for part-to-part variation between different heated resistors 16. By using a voltage divider on reference side 30 configured with a digital programmable potentiometer, employment of laser trimmed resistors can be eliminated. For example, the resistances of resistors R1 and R2 of the prior art voltage divider are variable resistances which are adjusted to the values calculated in accordance with the previously described aspects of the invention. In the prior art, the resistors R1 and R2 are provided in the form of thick-film or thin-film resistors which are fabricated on a substrate and interconnected by conductive leads. The resistances of resistors R1 and R2 are individually trimmed to the desired values by a laser trimming apparatus which necessitates a laser for trimming resistors R1 and R2 (e.g., vaporizing a slit in the resistor), a pair of probes for monitoring the resistances during the laser trimming process, and a control unit for controlling the laser to trim resistors R1 and R2 to the desired values of resistance. This extensive process of laser trimming is eliminated with a digital programmable potentiometer Rp in place of laser trimmed resistors R1 and R2.

[0033] Furthermore, the need for an expensive ambient temperature sensor is eliminated by the above described flow meter. By eliminating the ambient temperature sensor, lead frames also eliminated. Moreover, by employing a thermistor circuit to generate a correction voltage, power dissipation decreases with increasing temperature and an optional air temperature signal is available. In addition, elimination of laser trimmed resistors eliminates a requirement for a costly ceramic board material used in conjunction with the laser trimmed resistors.

[0034] While the invention has been described with reference to an exemplary embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

CLAIMS

1. An apparatus for measuring the amount of flow of a flowing medium comprising:

a bridge circuit (20) across which a bridge voltage Vb is developed such that the magnitude of the bridge voltage Vb is indicative of the amount of flow,

the bridge circuit (20) including a signal side (22) for deriving a signal voltage V_{RL} which is a voltage divided function of the bridge voltage Vb as determined at least in part by the resistance RH of a self-heated resistor (16) in ratio to the resistance RL of a power resistor (24) where the resistance RH is related to the temperature of the heated resistor (16) as determined at least in part by the difference between the heat generated within the heated resistor (16) as a function of the voltage applied across the heated resistor (16) and the heat transferred away from the heated resistor (16) as a function of the amount of fluid flow,

the bridge circuit (20) also including a reference side (30) for defining a reference voltage Vr which is a voltage divided function of the bridge voltage Vb as determined at least in part by a resistance Rp of a potentiometer (18),

and an amplifier (32) responsive to the difference between the signal voltage V_{RL} and the reference voltage Vr for altering the bridge voltage Vb to maintain the heat generated within the self-heated resistor (16) thereby maintaining its temperature and related resistance RH so as to equalize the signal voltage V_{RL} and the reference voltage Vr.

2. The apparatus of claim 1, wherein said potentiometer is a digital programmable potentiometer.

3. The apparatus of claim 1, wherein the bridge voltage is further processed to correct for ambient air temperature changes.

4. The apparatus of claim 3 further comprising:

a thermistor circuit (54) configured to generate a temperature reference voltage (56) to correct the bridge voltage with respect to ambient air changes.

5. The apparatus of claim 4, wherein the temperature reference voltage (56) is tapped from between a pull up resistive element (58) electrically connected to a voltage reference source and a thermistor element (60) electrically connected to ground.

6. The apparatus of claim 5, wherein the temperature reference voltage (56) is indicative of ambient air temperature.

7. The apparatus of claim 5, wherein the temperature reference voltage (56) and the bridge voltage are input into a conditioning circuit (50) to generate a compensated bridge voltage with respect to ambient air temperature.

8. The apparatus of claim 7, wherein the conditioning circuit (50) processes the compensated bridge voltage by multiplying the bridge voltage input by a constant and an inverse of the following equation:

$$\left[\frac{(T_{RH}-T_{amb})\bullet P_{CONVECTIVE}(T_{amb})\bullet[RH(T_{RH})+RL]^2}{RH(T_{RH})}\right]^{1/2}$$

Where: Vb is the bridge voltage input
T_{RH} = Heated Resistor Temperature
T_{amb} = Ambient Air Temperature
$P_{CONVECTIVE}(T_{amb})$ = Convective heat transfer from the Heated Resistor
$RH(T_{RH})$ = Resistance of RH when heated to T_{RH}
RL = Resistance of RL.

9. The apparatus of claim 8, wherein said temperature reference voltage (56) is processed with a linear piecewise circuit (66) prior to processing with the conditioning circuit (50) for ambient temperature ranges greater than about 50°C.

10. The apparatus of claim 8, wherein the conditioning circuit (50) is one of a voltage controlled oscillator circuit and an analog multiplier-divider circuit.

11. The apparatus of claim 10, wherein said voltage controlled oscillator circuit outputs a frequency output indicative of a compensated bridge voltage with respect to ambient temperature.

12. The apparatus of claim 10, wherein said analog multiplier-divider circuit outputs a voltage output indicative of a compensated bridge voltage with respect to ambient temperature.

13. The apparatus of claim 5, wherein said thermistor element (60) is one of a thermistor and a temperature dependent resistive element.

14. A method for temperature compensation of a constant temperature anemometer for measuring the amount of flow of a flowing medium, the method comprising:

configuring a bridge circuit (20) to develop a bridge voltage Vb such that the magnitude of the bridge voltage Vb is indicative of the amount of flow,

generating an bridge voltage from the bridge circuit (20), the bridge voltage is uncompensated with respect to ambient temperature;

generating a temperature reference voltage (56) indicative of ambient temperature from a thermistor circuit (54);

receiving the uncompensated bridge voltage and the temperature reference voltage (56) in a conditioning circuit (50) configured to process the uncompensated bridge voltage and the temperature reference voltage (56); and

generating a compensated bridge voltage with respect to ambient temperature, the compensated bridge voltage indicative of fluid flow across resistor RH in an ambient temperature range.

15. The method of claim 14, wherein configuring the bridge circuit (20) further comprises:

including a signal side (22) for deriving a signal voltage V_{RL} which is a voltage divided function of the bridge voltage Vb as determined at least in part by the resistance RH of a self-heated resistor (16) in ratio to the resistance RL of a power resistor where the resistance RH is related to the temperature of the heated resistor as determined at least in part by the difference between the heat generated within the heated resistor as a function of the voltage applied across the heated resistor and the heat transferred away from the heated resistor as a function of the amount of fluid flow;

including a reference side (30) for defining a reference voltage Vr which is a voltage divided function of the bridge voltage Vb as determined at least in part by a resistance Rp of a potentiometer (18); and

including an amplifier (32) responsive to the difference between the signal voltage V_{RL} and the reference voltage Vr for altering the bridge voltage Vb to maintain the heat generated within the self-heated resistor (16) thereby maintaining its temperature and related resistance RH so as to equalize the signal voltage V_{RL} and the reference voltage Vr.

16. The method of claim 15, wherein said potentiometer (18) is a digital programmable potentiometer.

17. The method of claim 14, wherein the bridge voltage is further processed to correct for ambient air temperature changes.

18. The method of claim 14, wherein the temperature reference voltage (56) is tapped from between a pull up resistive element (58) electrically connected to a voltage reference source and a thermistor element (60) electrically connected to ground.

19. The method of claim 14, wherein the conditioning circuit (50) processes the compensated bridge voltage by multiplying the bridge voltage input by a constant and an inverse of the following equation:

$$\left[\frac{(T_{RH}-T_{amb})\bullet P_{CONVECTIVE}(T_{amb})\bullet[RH(T_{RH})+RL]^2}{RH(T_{RH})}\right]^{1/2}$$

Where: Vb is the bridge voltage input
T_{RH} = Heated Resistor Temperature
T_{amb} = Ambient Air Temperature
$P_{CONVECTIVE}(T_{amb})$ = Convective heat transfer from the Heated Resistor
$RH(T_{RH})$ = Resistance of RH when heated to T_{RH}
RL = Resistance of RL.

20. The method of claim 14, wherein said temperature reference voltage (56) is processed with a linear piecewise circuit (66) prior to processing with the conditioning circuit (50) for ambient temperature ranges greater than about 50°C.

21. The method of claim 14, wherein the conditioning circuit (50) is one of a voltage controlled oscillator circuit and an analog multiplier-divider circuit.

22. The method of claim 21, wherein said voltage controlled oscillator circuit outputs a frequency output indicative of a compensated bridge voltage with respect to ambient temperature.

23. The method of claim 21, wherein said analog multiplier-divider circuit outputs a voltage output indicative of a compensated bridge voltage with respect to ambient temperature.

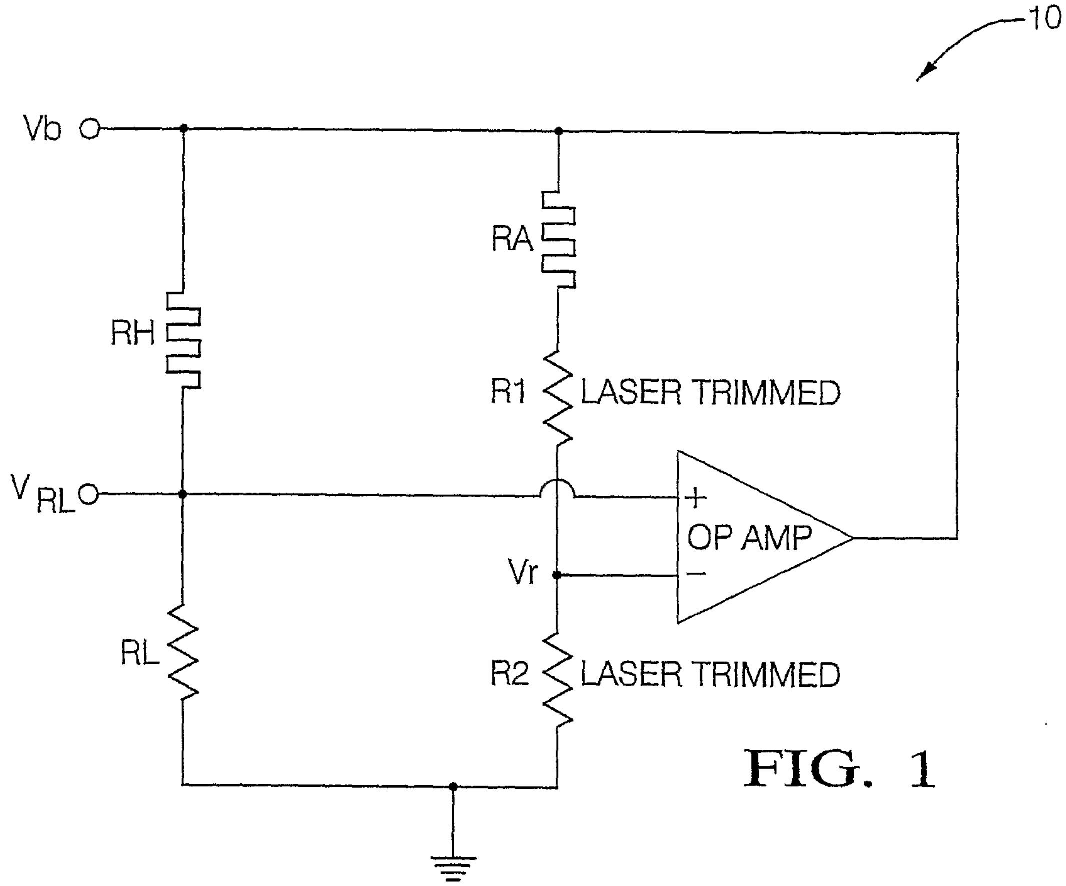

10
Vb
RA
RH
R1
LASER TRIMMED
V_RL
+
OP AMP
−
Vr
RL
R2
LASER TRIMMED

FIG. 1

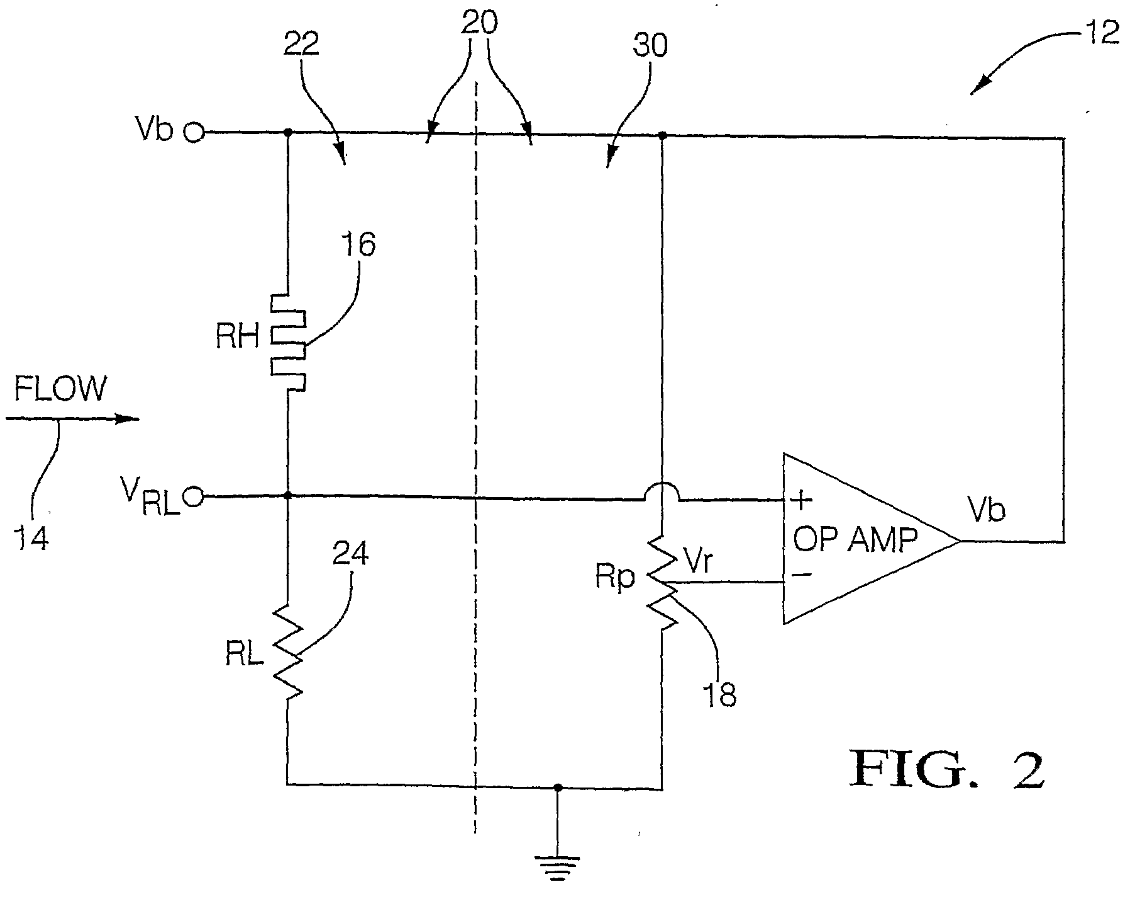

22
20
30
12
Vb
16
RH
FLOW
V_RL
14
24
+
OP AMP
−
Vb
Vr
Rp
RL
18

FIG. 2

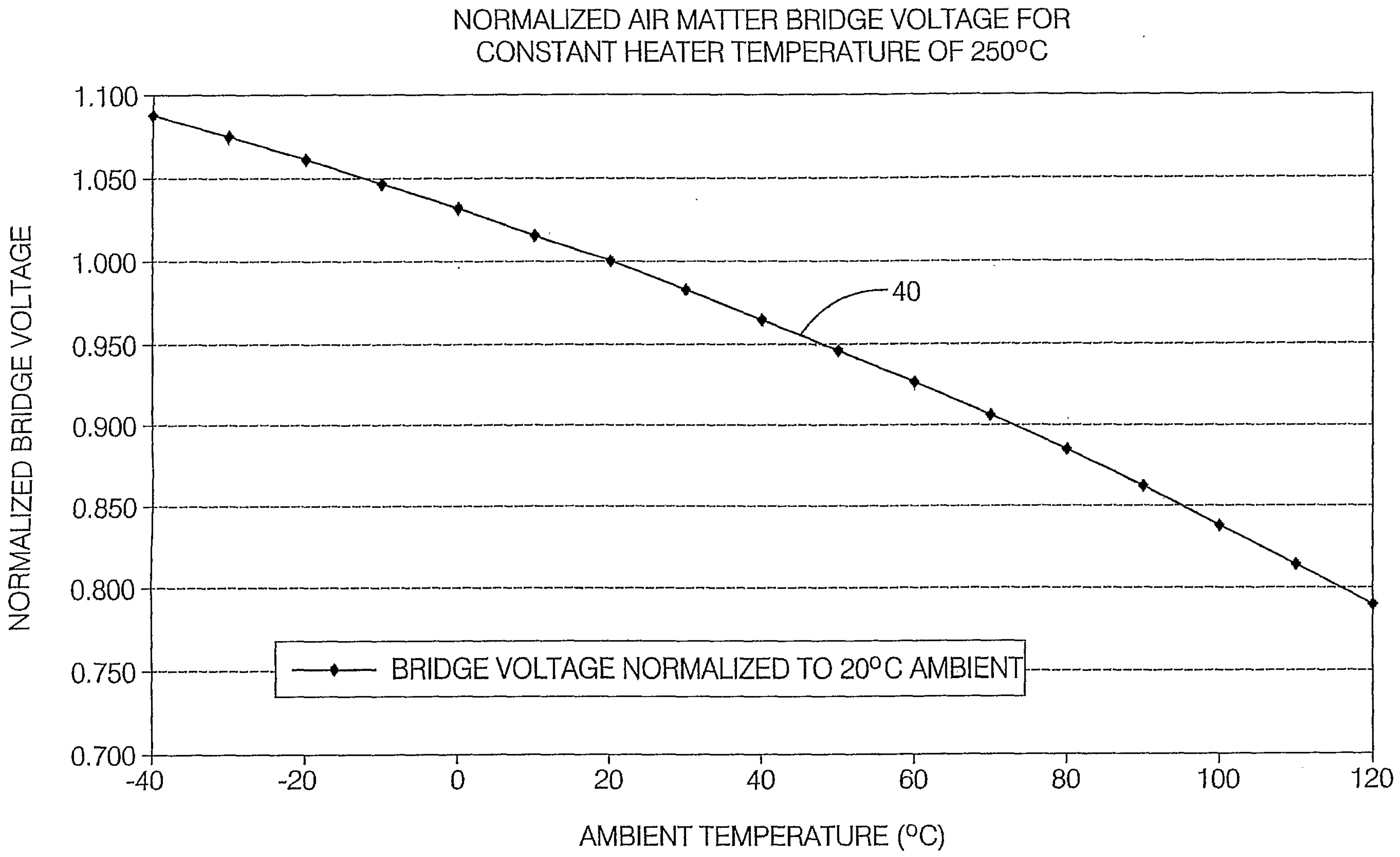

NORMALIZED AIR MATTER BRIDGE VOLTAGE FOR
CONSTANT HEATER TEMPERATURE OF 250°C
NORMALIZED BRIDGE VOLTAGE
1.100
1.050
1.000
0.950
0.900
0.850
0.800
0.750
0.700
-40
-20
0
20
40
60
80
100
120
AMBIENT TEMPERATURE (°C)
40
BRIDGE VOLTAGE NORMALIZED TO 20°C AMBIENT

FIG. 3

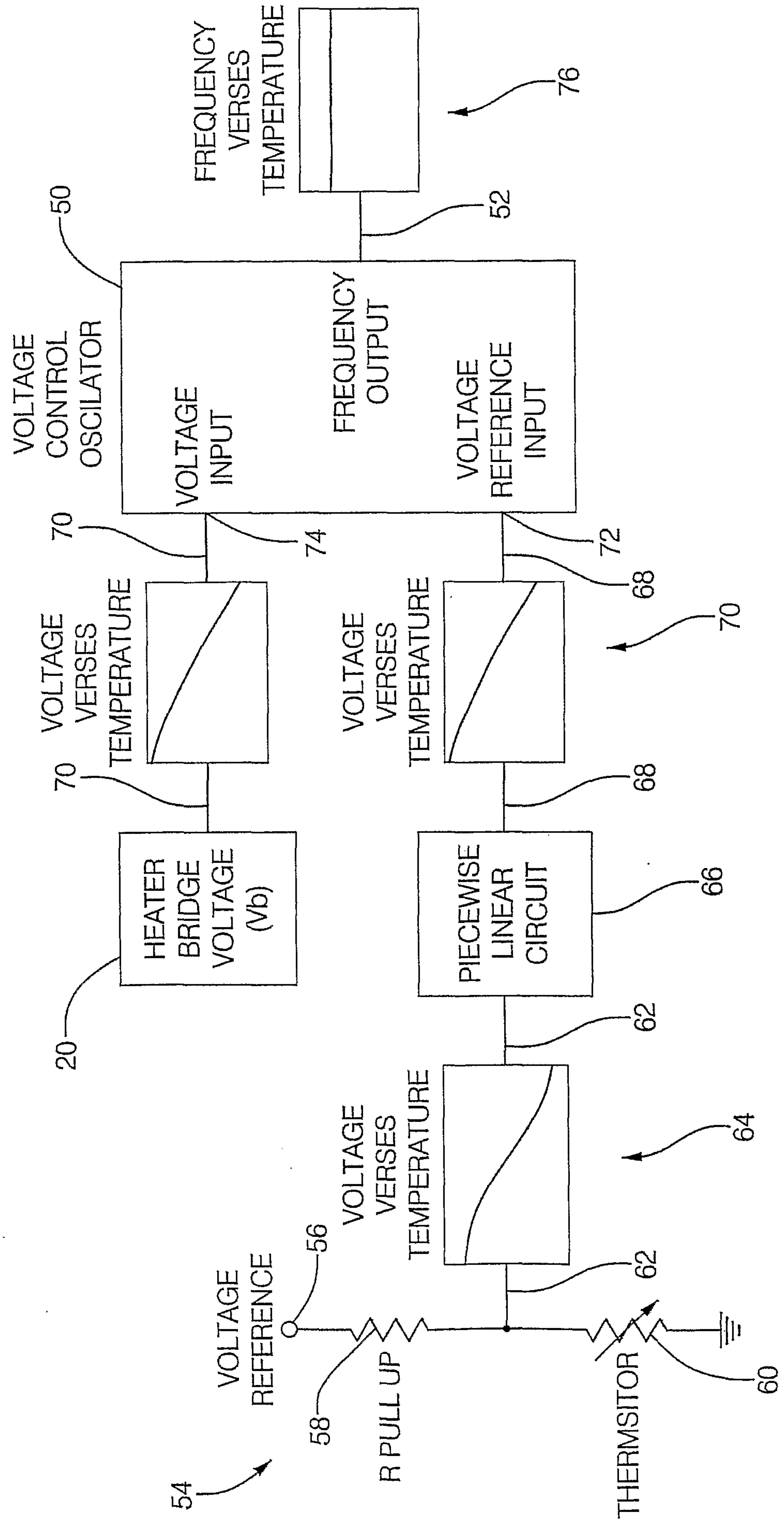
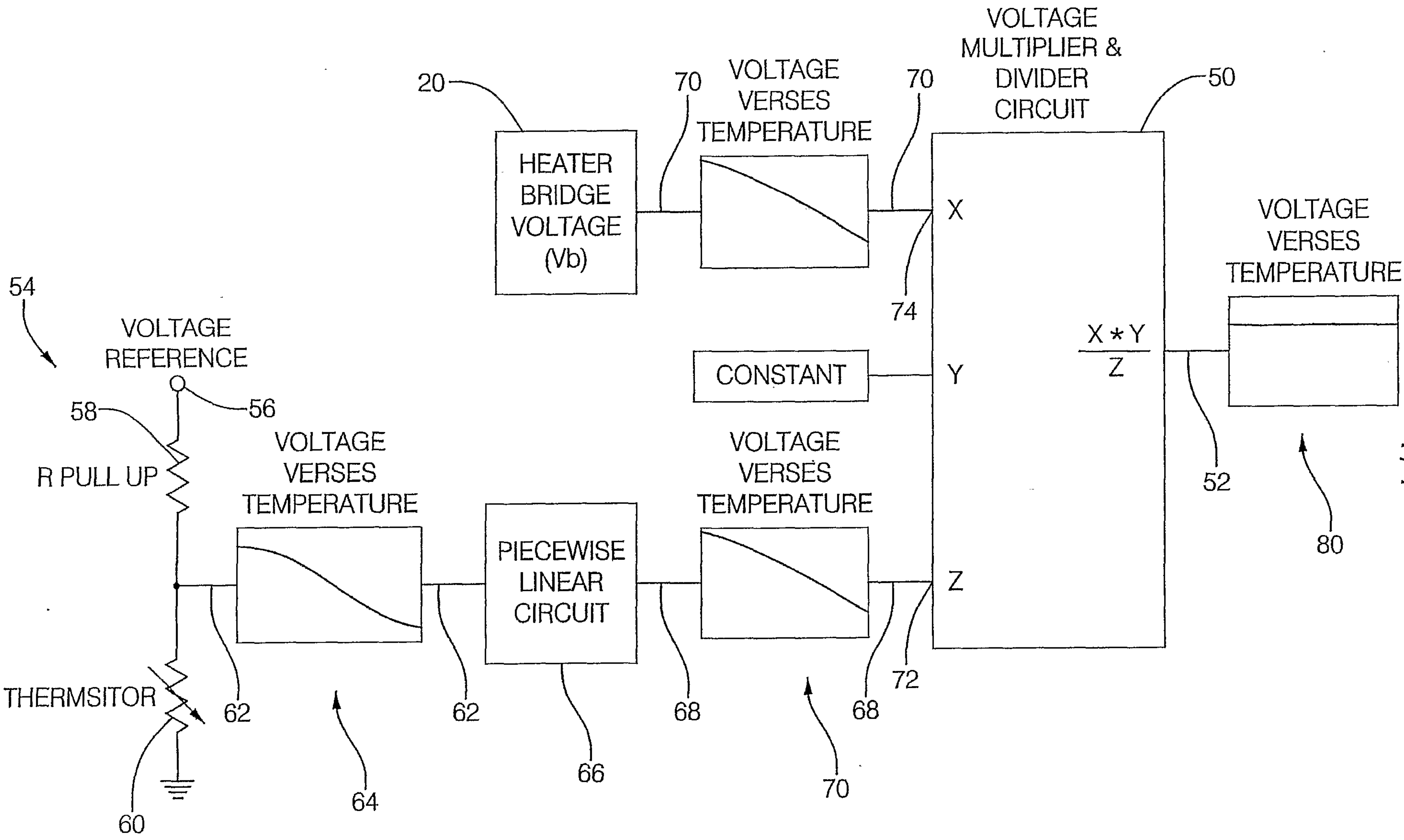

VOLTAGE REFERENCE
56
54
R PULL UP
58
THERMSITOR
60
62
VOLTAGE VERSES TEMPERATURE
64
62
PIECEWISE LINEAR CIRCUIT
66
68
VOLTAGE VERSES TEMPERATURE
70
68
HEATER BRIDGE VOLTAGE (Vb)
20
70
VOLTAGE VERSES TEMPERATURE
70
74
72
VOLTAGE CONTROL OSCILATOR
50
VOLTAGE INPUT
FREQUENCY OUTPUT
VOLTAGE REFERENCE INPUT
52
FREQUENCY VERSES TEMPERATURE
76

FIG. 4


54
VOLTAGE REFERENCE
56
58
R PULL UP
THERMSITOR
60
62
VOLTAGE VERSES TEMPERATURE
64
62
PIECEWISE LINEAR CIRCUIT
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68
VOLTAGE VERSES TEMPERATURE
70
68
72
20
HEATER BRIDGE VOLTAGE (Vb)
70
VOLTAGE VERSES TEMPERATURE
70
74
CONSTANT
VOLTAGE MULTIPLIER & DIVIDER CIRCUIT
50
X
Y
Z
X * Y / Z
52
VOLTAGE VERSES TEMPERATURE
80

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US03/11082

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G01F 1/00,17/00; G01K 15/00;G01F 1/12;G01D 1/00; G01F 1/68; G01N 25/00
US CL : 702/45, 53, 55, 99, 100, 127; 73/204.17, 204.18, 204.19, 204.25, 204.27; 374/1,3
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)
U.S. : 702/45, 53, 55, 99, 100, 127; 73/204.17, 204.18, 204.19, 204.25, 204.27; 374/1,3

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)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,987,549 A (GEE) 22 January 1991 (22.01.1991), see entire document.	1-23
Y	US 3,905,229 A (TOGO et al) 16 September 1975 (16.09.75), see entire document	1-23
Y	US 6,094,982 A (SUZUKI) 01 August 2000 (01.08.2000), see entire document.	1-23

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier application or patent published on or after the international filing date		
"L"	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)	"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
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search 12 June 2003 (12.06.2003)	Date of mailing of the international search report 09 OCT 2003
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