(12) UK Patent Application (19) GB (11) 2 170 012 A

(43) Application published 23 Jul 1986

(21) Application No **8601658**

(22) Date of filing **23 Jan 1986**

(30) Priority data

(31) **8501689** (32) **23 Jan 1985** (33) **GB**

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(51) INT CL[4]
G01R 35/00 19/00

(52) Domestic classification (Edition H):
G1U BC

(56) Documents cited
GB 1569390 **GB 0946163**
GB 1000959 **GB 0897780**
GB 0982772 **US 4337517**

(58) Field of search
G1U
Selected US specifications from IPC sub-class G01R

(54) Voltage measurement

(57) A precision measuring instrument, e.g. for low d.c. potentials has a low noise amplifier (4) and an A/D convertor (5) arranged to provide a digital output which is stored by a microcomputer (6), a stable reference potential source (1) and an inductive voltage divider (3) having one or more output taps corresponding to one or more accurately predetermined fractions of the reference potential, the microcomputer (1) controlling switches and being programmed to effect an automatic calibration and measurement cycle which includes momentary connection of the reference potential to the inductive voltage divider (3) to provide at the taps voltage pulses which are predetermined sub-multiples of the reference potential and which are applied to the amplifier (4) to provide calibration values which are stored in the microcomputer (6), and which further includes the momentary connection of a potential to be measured to the amplifier (4) to provide a measurement value in the microcomputer (6) from which an output reading can be computed by reference to the calibration values.

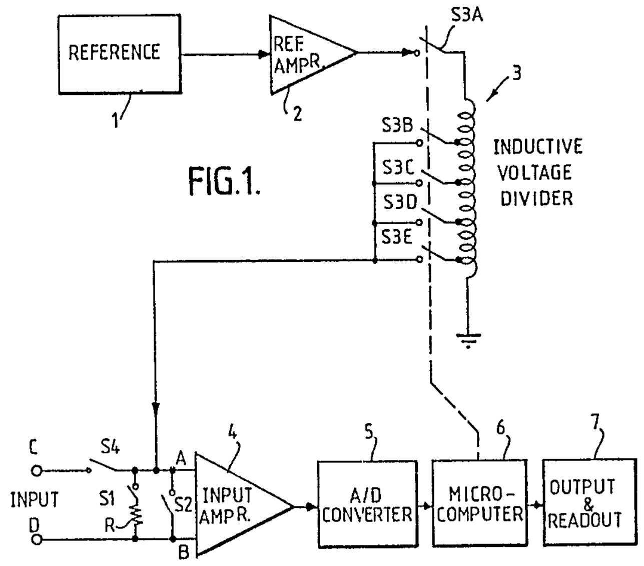

FIG.1.

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The drawing(s) originally filed was (were) informal and the print here reproduced is taken from a later filed formal copy.

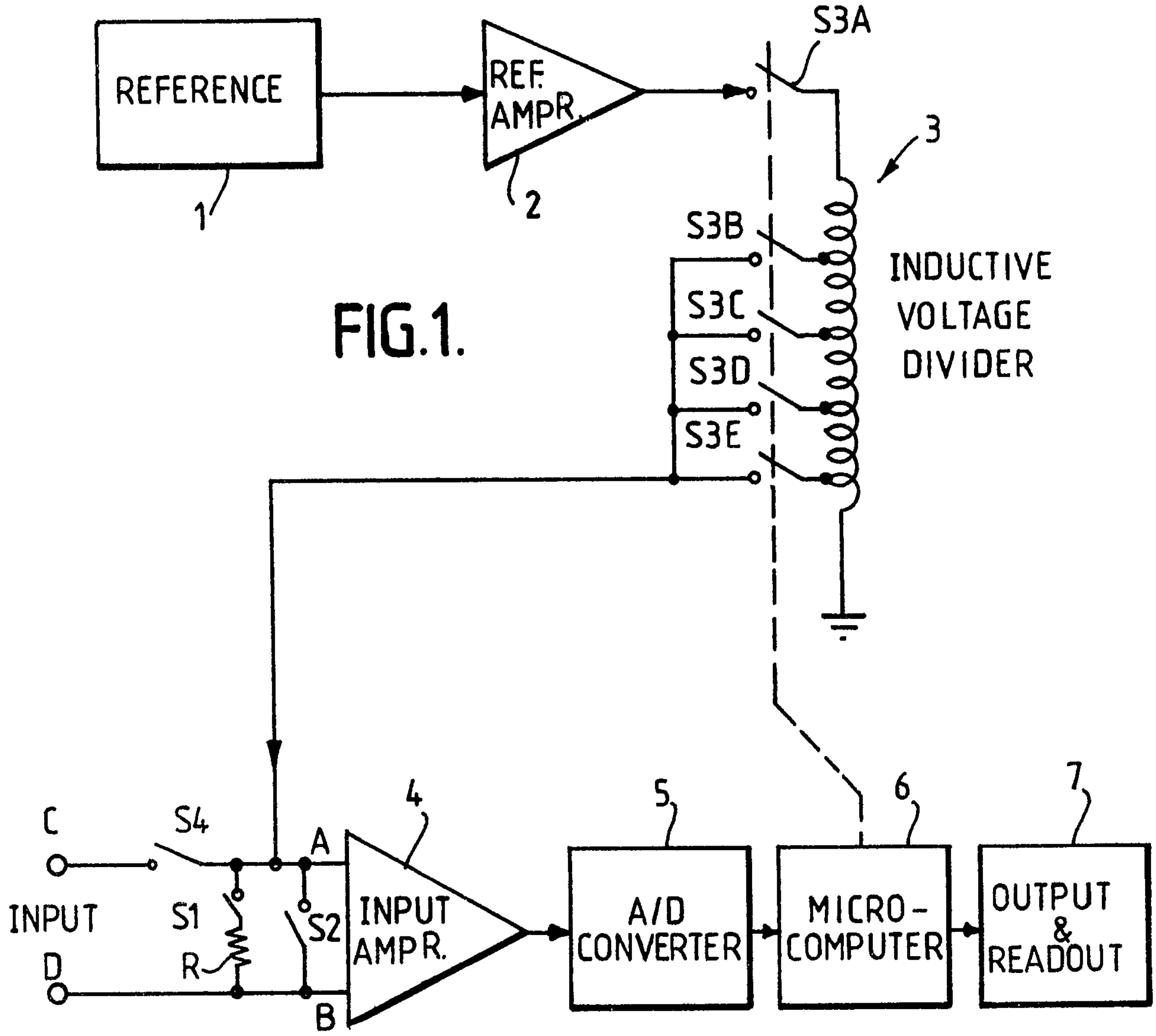
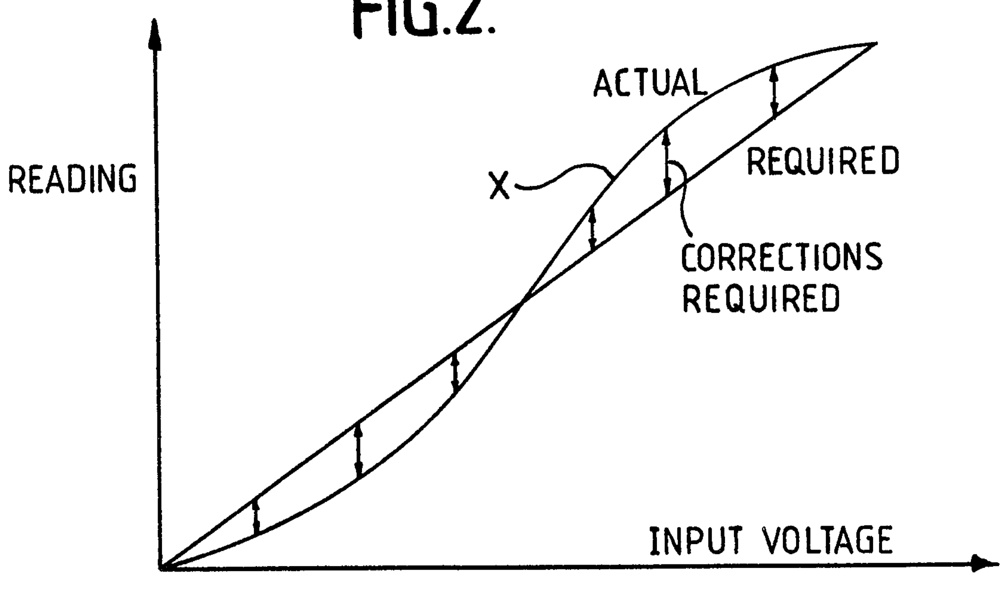

REFERENCE
1
REF. AMPR.
2
S3A
3
S3B
S3C
S3D
S3E
INDUCTIVE VOLTAGE DIVIDER
C
INPUT
D
S4
S1
R
S2
A
B
4
INPUT AMPR.
5
A/D CONVERTER
6
MICRO-COMPUTER
7
OUTPUT & READOUT

FIG.1.

FIG.2.


READING
ACTUAL
X
REQUIRED
CORRECTIONS REQUIRED
INPUT VOLTAGE

SPECIFICATION

Method and apparatus for voltage measurement

This invention relates to the measurement of voltages.

The object of the invention is to provide a high precision system for measuring voltages. In particular, but without being so limited, the invention seeks to provide a system capable of measuring low d.c. potentials in the microvolt range with an accuracy of 1 part per 10 million or better, so that with for example an input voltage of 100 uV, the resolution approaches 10 picovolts.

Although voltmeters with an accuracy of 1 part per million can be constructed using modern analogue to digital conversion techniques coupled with automatic calibration, the components used in such instruments limit the accuracy obtainable in practice, so that, even using modern digital filtering techniques, the best resolution obtainable with reliability is of the order of a few tens of nanovolts. Thermal drift of the calibrated zero of the measuring equipment, and hence of the reference against which the measurement is made, also give rise to problems in measuring very low voltage levels.

The problems referred to above are exacerbated when both high accuracy and high resolution are required in a low level d.c. voltmeter.

The present invention avoids the problems associated with existing low level d.c. voltmeters by utilising a measurement and calibration technique which requires only short term stability of the critical components in the measuring circuit, that is to say, high stability over, for example, a period of the order of a few hundreds of milliseconds.

According to the present invention in one aspect there is provided a method of measuring voltages in which a measuring system is calibrated by applying to an input thereof a calibration voltage derived from a voltage divider coupled to a reference voltage source. By dividing the reference voltage down to a lower calibration voltage and using this to calibrate the measuring system, the effect of inaccuracies in the measuring system, due, say, to temperature variation and ageing can be largely overcome. The accuracy of the method is mainly dependent on the accuracy of the reference source and the voltage divider. Preferably, the divider is an inductive divider and the reference source is pulsed so that, for example, a single reference voltage pulse is applied to the divider, which may be an auto-transformer, to provide an accurate stepped down voltage pulse which is applied to the input of the measuring system. In a preferred form the measuring system is able to produce and store a calibration value which can be used in the measurement of an unknown input voltage applied to the said input. With a short time interval separating the respective applications of the unknown voltage and the calibration voltage to the measuring system, only very short term variations in the measuring system can affect the accuracy of the reading, which means in practice that the main components determining the accuracy of the method are the source of the reference voltage pulse and the inductive divider.

The measuring system preferably comprises a low noise amplifier coupled to an analogue to digital converter to provide a digital output. A suitable ultra low level voltage amplifier is described in the Applicants' British Patent Application No. 2 118 391A. The digitised output is preferably stored in a microcomputer which also stores one or more calibrated values.

In the preferred method the microcomputer controls an automatic switching sequence which includes momentary connection of the reference potential to the inductive voltage divider to effect an automatic calibration before effecting a momentary connection of the potential to be measured to the amplifier.

The invention also provides, in another aspect, precision voltage measuring apparatus including calibration means having a reference voltage generator coupled to a voltage divider, and a measuring system having an input connectible to a tap of the voltage divider to receive a calibration voltage from the latter. Preferably, the divider is an inductive divider, and the reference voltage generator comprises a d.c. reference potential source and a first switching device operable to couple the reference source momentarily to the voltage divider to pulsed calibration voltage. The apparatus also preferably includes a second switching device for connecting the said input of the measuring system alternatively to the voltage divider tap or to a measuring input.

The measuring system advantageously has the low noise amplifier, analogue to digital converter, and microcomputer referred to above, the microcomputer controlling thé switching devices and being programmed to effect an automatic calibration and measurement cycle which includes momentary connection of the reference potential to the inductive voltage divider to provide at the said tap or one of several taps a voltage pulse which is a predetermined fraction of the reference potential and which is applied to the amplifier to provide a calibration value which is stored in the microcomputer, and which further includes a momentary connection of a potential to be measured to the calibrated amplifier.

The invention will now be described, by way of example only, with reference to the accompanying purely diagrammatic drawings, in which:

Figure 1 is a block schematic diagram of a precision measuring system for low level d.c. potentials, according to one embodiment of the invention, and

Figure 2 is a graphical representation of a typical calibration of the measuring system associated with the apparatus shown in Figure 1.

The measuring apparatus illustrated in Figure 1 includes a stable reference potential source 1, which may, for example, be a bank of certified zener diodes contained in a reference oven of a predetermined temperature, or a certified standard cell contained within or connected externally to the instrument. The reference source 1 is connected through a reference amplifier to a calibration switch S3A. The reference amplifier 2 has a very high input impedance, a low input offset current, a low output impedance and a gain of unity.

The calibration switch S3A, which is normally open, is connected to an inductive voltage divider 3 which consists of an accurately wound inductance provided at predetermined turn intervals with a series of taps each of which is associated with a normally open selectively operable calibration switch. The divider is linear in the sense that the output voltage from each tap is a linear function of the input voltage. For such taps associated calibration switches S3B, S3C, S3D, and S3E are provided as shown in the illustrated example. The inductance of the divider 3 is sufficiently high not to significantly load the output of the reference amplifier, but also sufficiently low that the resistances of the connections to the taps are not significant.

The output taps of the inductive voltage divider 3 are connected through the respective calibration switches S3B-S3E to one input A of a very low noise input amplifier 4, the other input B of which is normally earthed. The input amplifier 4 has a high input impedance, a low offset current, and low drift.

Two further calibration switches are associated with the input amplifier 4: a calibration switch S1 is connected in series with a resistor across the two inputs A, B of the amplifier 4, and a second calibration switch S2 is connected directly across the two inputs A and B, the two switches S1, S2, like the calibration switches S3, being normally open.

Two input terminals C, D for the potential to be measured are connected to the inputs A, B, respectively of the input amplifier 4, a normally open switch S4 being interposed between the input terminal C and the amplifier input A.

The output of the amplifier 4 is connected through a high-resolution analogue to digital converter 5 with short term stability to a central microcomputer 6. The microcomputer 6 is connected to an output and readout stage 7.

The central microcomputer 6, as well as storing the outputs of the amplifier 4, also controls the operation of the switches S1-S4 in a programmed sequence of calibration and measurement.

A full calibration cycle of the measuring system is effected automatically at infrequent intervals, for example every 20 seconds. The automatic switching sequence for calibration and measurement is as follows:-

(i) switch S1 is closed and the computer 6 then automatically adjusts the input current zero of the amplifier 4, following which swich S1 is automatically reopened;

(ii) switch S2 is closed, effectively short circuiting the two inputs A and B of the amplifier 4, the computer 6 automatically adjusts the input voltage zero of the amplifier 4, following which switch S2 is reopened;

(iii) the switches S3 are closed selectively, that is, switch S3A and one of the switches S3B-S3E are closed momentarily, for example for a period of a few hundreds of milliseconds. The effect of the brief closure of the switch S3A is to apply a voltage pulse to the inductive voltage divider 3 from the reference source 1, this voltage pulse being subdivided accurately into predetermined submultiples at each of the taps of the voltage divider 3 and, according to which of the switches S3B-S3E is closed, the submultiple reference voltage, for example 30% or 60% of the applied source voltage, is applied as a pulse to the input A of the input amplifier 4, switches S1, S2 and S4 being open. The resultant reading at the output 7 of the instrument is stored against the submultiple reference voltage and a further calibration is then effected with the other switches S3B-S3E closed in turn, to establish a sequence of calibration values, stored in the computer 6, giving accurate correlations between the readings at the output 7 and the voltages at the amplifier input A. The actual calibration curve produced by the sequence of calibration measurements may be as shown in Figure 2, where the straight line indicates the ideal relationship between the readout at the output 7, represented on the ordinate, and the input voltage of the amplifier 4, represented on the abscissa. For each calibration measurement a correction is computed between this ideal straight line calibration and the actual calibration curve, represented by X in Figure 2. After the calibration sequence the switches S3 will remain open, and the microcomputer 6 will have stored a sequence of calibration readings corresponding, in effect, to the calibration curve X shown in Figure 2.

(iv) switch S4 is finally closed momentarily and the applied voltage to be measured is then compared in the computer 6 with the stored calibration, producing a readout at the output 7 which will be an accurate measurement of the applied input voltage, to a high degree of resolution. The gain of the amplifier 4, and digital filtering of the applied input voltage, will be adjusted as required.

In a typical instrument constructed to operate in accordance with the invention as described, the total scale length of the instrument would comprise at least 64 digits, or two million, and the lowest range of measurement would correspond to an input d.c. potential of 200 microvolts full scale.

In addition to the automatic full calibration and linearisation of the instrument as described above at infrequent intervals, a single calibration would be effected, by closure of the switch S3A and one of the tap switches S3B-S3E, before each reading, for example corresponding to a full scale reading.

The extremely high accuracy and resolution of the system as described derives from the fact that measurement is made against a very stable reference voltage which is subdivided using a high precision inductive voltage divider, and this subdivided reference voltage is utilised for a very short period of time, e.g. 1 microsecond to 1 second, during which it is for all practical purposes invariant. Moreover, the inductive voltage divider can be made with a voltage accuracy which is very accurate.

While the invention is primarily intended for the measuring of low voltages, it can be used for high precision measurement of higher voltages of the order of 10 to 1000 volts.

CLAIMS

1. A method of measuring low voltages, in which a measuring system is calibrated by applying to an input thereof a calibration voltage derived from a voltage divider coupled to a reference voltage source.

2. A method according to claim 1, wherein the divider is an inductive divider and the reference source is pulsed.

3. A method according to claim 2, wherein a d.c. reference voltage is applied momentarily to an auto-transformer to produce a calibration voltage pulse having a voltage level which is a predetermined fraction of the reference voltage, and wherein the calibration pulse is applied to the input of the measuring system which produces and stores a calibration value, following which the voltage to be measured is applied to the said input to provide a measurement value which is then processed to provide an output reading dependent on the calibration value.

4. A method according to claim 3, in which the calibration voltage and the voltage to be measured are converted to digital form in the measuring system.

5. A method according to claim 4, wherein the measuring system includes an input amplifier , an analogue to digital converter, and a microcomputer and wherein, under the control of the microcomputer, the calibration voltage is applied to the input amplifier for a first predetermined time interval, the resulting digital output is stored as a calibration value, the voltage to be measured is applied to the input amplifier for a second predetermined time interval, the resulting digital measurement output is stored as a measurement value, and wherein a reading corresponding to the measurement value is computed in the microcomputer by reference to the calibration value.

6. A method according to claim 5, wherein the inductive divider has a plurality of taps, and the microcomputer causes a plurality of calibration voltages from different respective taps to be applied to the input amplifier to provide a plurality of stored calibration values.

7. A precision measuring instrument for measuring low voltages, wherein the instrument includes calibration means having a reference voltage generator coupled to a voltage divider, and a measuring system having an input connectible to a tap of the voltage divider to receive a calibration voltage from the latter.

8. An instrument according to claim 7, wherein the reference voltage generator comprises a d.c. reference source and a first switching device operable to couple the reference source momentarily to the voltage divider, wherein the divider is an inductive divider, and wherein the instrument includes a second switching device for connecting the input of the measuring system alternatively to the voltage divider tap or to a measuring input.

9. An instrument according to claim 8, wherein the measuring system comprises an amplifier coupled to an analogue to digital converter which is, in turn, coupled to a microcomputer, the microcomputer being programmed to operate the first and second switching devices, to store a calibration value corresponding to the calibration voltage, and to compute an output reading from a measurement value derived from a voltage applied to the measuring input by reference to the calibration value.

10. An instrument according to claim 9, wherein the voltage divider has a plurality of taps, each of which is connectible to the input of the measuring system, and wherein the microcomputer is programmed to connect each tap successively to the measuring system input to provide a plurality of calibration values over a predetermined voltage range.

11. A voltage measurement method in which a measuring system is calibrated by applying to an input thereof a calibration voltage derived from a transformer fed with a pulsed reference voltage.

12. Voltage measuring apparatus including calibration means having a reference voltage generator coupled to a voltage divider, and a measuring system having an input connectible to a tap of the voltage divider to receive a calibration voltage from the latter.

13. A method of measuring low voltages substantially as herein described with reference to the drawings.

14. A voltage measuring instrument constructed and arranged substantially as herein described and shown in the drawings.

Printed in the UK for HMSO, D8818935, 6/86, 7102.
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