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GB 1574457

(58) Field of search
G1U

(54) Method for the measurement of capacitance

(57) In the method two reference capacitances (C_{R1}, C_{R2}) are connected in turn with a capacitance (C_M) to be measured, to a measurement oscillator (16) by a switching arrangement (13, 14, 15). Two external auxiliary reference sources (R_1, R_2) provide auxiliary reference signals (U_{R1}, U_{R2}) which are compared (19, 20) with the corresponding output signals (U_1) derived from the reference capacitances (C_{R1}, C_{R2}). Signals repesenting the difference between said output signals (U_1) and the signals (U_{R1}, U_{R2}) are formed to provide feedback signals (U_{c1}, U_{c2}) controlling the capacitance measuring circuit (16) in such a direction that the said differences approach zero or a preset corresponding value. Determination of the output signal (U_{out}) corresponding to the capacitance (C_M) to be measured is then performed by means of the measurement electronics (16) after the foregoing adjustment. The invention is useful in the telemetry of radiosondes in the measurement of atmospheric pressure, temperature and/or humidity.

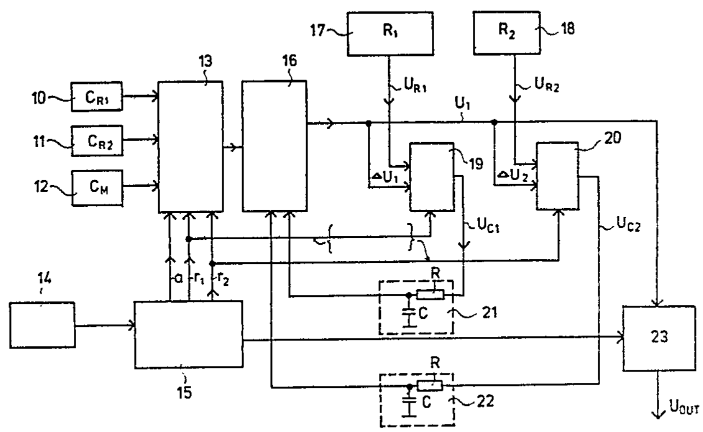

FIG. 3

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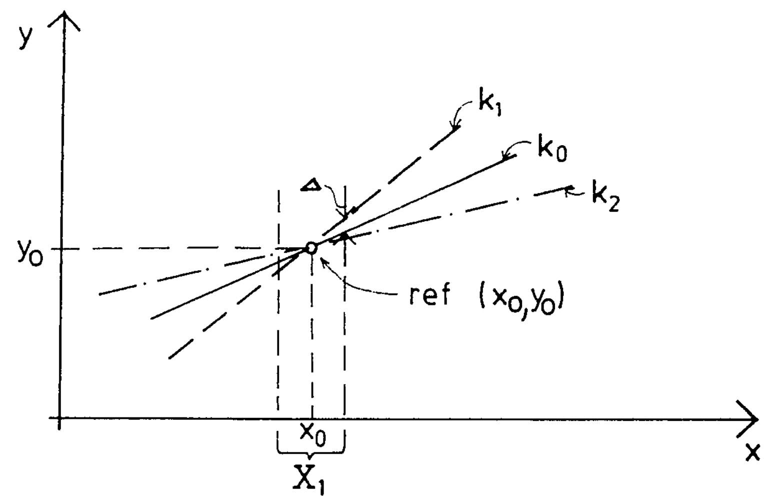
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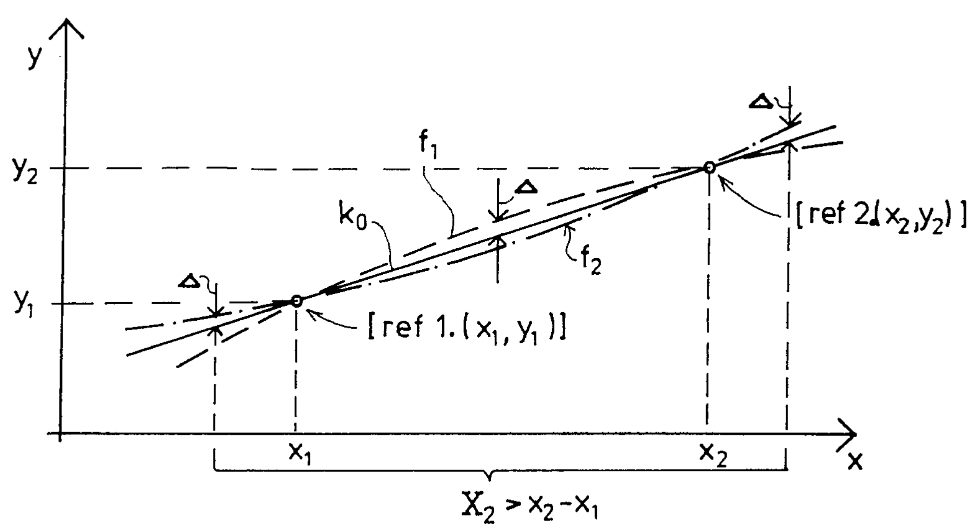
k1
k0
k2
Δ
y0
ref (x0,y0)
x0
X1
x

FIG.1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Δ
y2
f1
Δ
k0
[ref 2.(x2,y2)]
f2
Δ
y1
[ref 1.(x1, y1)]
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X2 > x2-x1

FIG.2

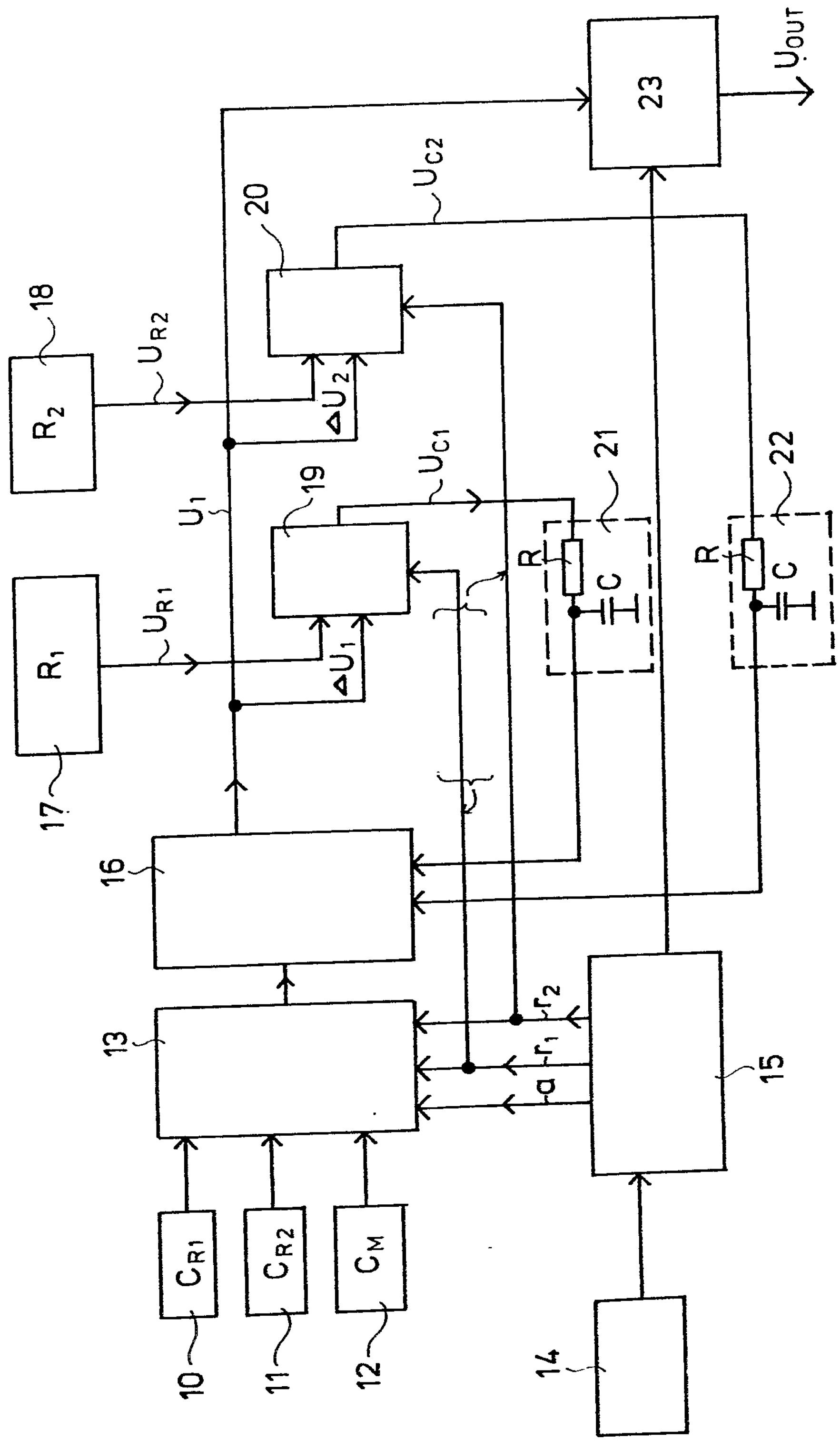
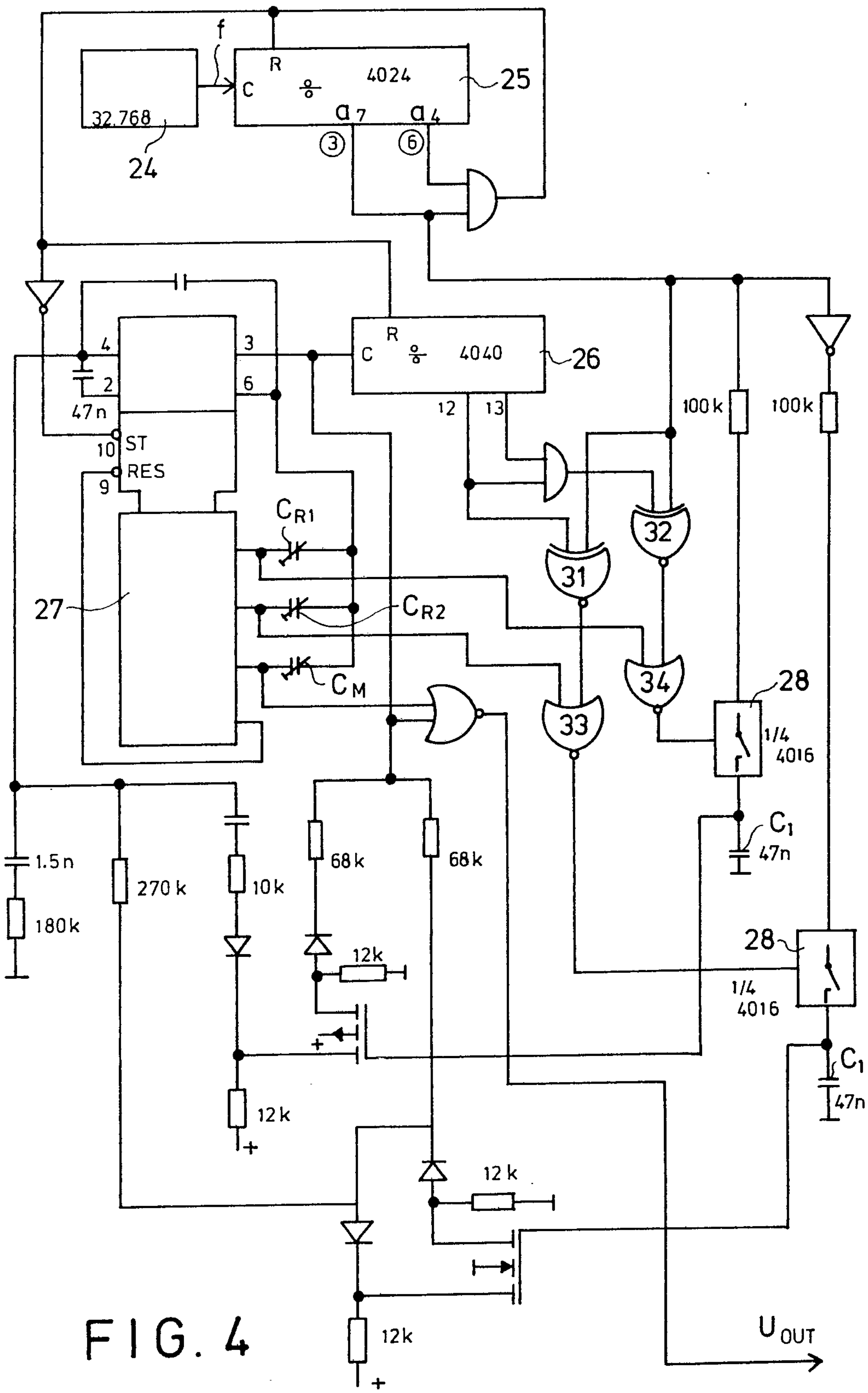

R1
R2
UR1
UR2
U1
ΔU1
ΔU2
UC1
UC2
UOUT
CR1
CR2
CM
R
C
a
r1
r2
10
11
12
13
14
15
16
17
18
19
20
21
22
23

FIG. 3



f
R
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C
25
32.768
a7
a4
③
⑥
24
R
4040
C
26
4
3
2
6
47n
10
ST
RES
9
12
13
100k
100k
CR1
27
CR2
CM
31
32
33
34
28
1/4
4016
C1
47n
1.5n
180k
270k
10k
68k
68k
12k
12k
+
28
1/4
4016
C1
47n
12k
12k
+
UOUT

FIG. 4

SPECIFICATION

Method for the measurement of capacitance

The invention is concerned with a method for the measurement of capacitance, in particular of low capacitance, in which said method measurement electronics are used that include a measurement oscillator, whose output frequency is a function of the capacitance to be connected to the input terminals of the circuit determining the frequency of the said oscillator, and in which method two reference capacitances are used, whose electrical values are placed within the range of measurement and which are connected, being alternatingly exchanged with the capacitance or capacitances to be measured, to the measurement oscillator while making use of a switching arrangement.

One starting point for the present invention has been the prior-art technology that comes out, e.g, from the applicant's FI Patents 54,664 and 57,319 (corresponding US Patents 4,295,090 and 4,295,091). In the said patents, a method is suggested for the measurement of low capacitances, as well as an electronic change-over switch to be used in this connection, in particular for telemeter use in sondes.

In radiosondes, for the measurement of various parameters, in particular of atmospheric pressure, temperature and/or humidity, capacitive detectors are used, the magnitude of whose capacitance depends on the parameter being measured. The capacitances of these detectors are often relatively low, from a few pF to some dozens or, at the maximum, about 100 pF. The measurement of low capacitances in problematic, e.g., owing to stray capacitances, variations in supply voltage, and other disturbances.Moreover, the said detectors have to some extent varying properties, so that they have, e.g., an individual non-linearity and dependence on temperature.

In particular in telemeter applications, when, e.g., temperature, humidity or pressure or other, corresponding parameters are being measured by means of electric or mechano-electric detectors, it is known in prior art that, in connection with the measurement electronics, one or several references are provided which are stable and precisely known and by means of which it is possible to compensate individual properties of the measurement circuit and/or of the detector as well as their variations in time.

In connection with capacitive detectors, it is known in prior art to use a reference capacitance, which is, alternatingly with the measuring capacitance, connected to the measurement circuit, usually the input circuit determining the frequency of the RC- oscillator. By appropriately adjusting the measurement circuit or in some other way, the output variable of the measurement circuit, derived from the reference capacitance, can be brought to the correct level at each particular time.

It is known in prior art to use measurement circuits of one reference, in particular bridge connections, in which the measurement is, however, precise only when the electrical value of the reference is close to the value of the detector, e.g., when the bridge is in equilibrium. The more distant the value of the detector becomes from the reference, the larger will also the various errors be, e.g. errors caused by changes in the dynamics of the electronic measurement circuit. An advantage of connections with one reference is, however, the simplicity of the measurement circuit. The foundations of this prior-art method will be described in the following in more detail with reference to Figure 1.

An advantage in measurement arrangements with two or more references is accuracy of the measurement even within wide ranges of measurement, but a drawback is the complexity of the measurement method and of the related computation. The foundations of measurement with two references will be described in the following in more detail with reference to Figure 2.

An objective of the present invention is a further development of the said measurement methods and circuits for low capacitances, e.g. about 0 to 100 pF, applied by the applicant and known in prior art, so that the said methods and circuits become more precise.

An objective of the present invention is to provide such a measurement method and measurement circuit with two references in which the complicated computation operations are avoided that were necessary in determining the results of capacitance measurements in prior art.

An objective of the invention is to provide such a measurement method and such "self-adjusting" measurement electronics in which the output variables corresponding to the reference detectors remain invariable even if the measurement electronics should creep, e.g., owing to variations in temperature or other circumstances.

In view of achieving the above objectives and those that will come out in the following, the invention is mainly characterized in

that in the method two external auxiliary references are used, the auxiliary reference signals obtained from them being compared with the corresponding output signals of the measurement electronics, derived from the said reference capacitances,

that signals representing the differences between the said output signals and the said signals coming from the external auxiliary references are formed, by means of which signals the feedback signals controlling the circuit are formed, the measurement electronics being controlled by means of the said feed-back signals in such a direction that the said differential signals or equivalent approach zero or a preset corresponding value, and

that determination of the output signal corresponding to the capacitance to be measured is performed by means of the measurement electronics adjusted correctly by means of the method steps defined above.

The objectives of the invention are achieved by in the measurement circuit fitting external auxiliary references corresponding to the output variables obtained in response to the capacitance references proper, which said auxiliary references are stable and independent from the measurement electronics and from its creep as well as from various interference sources. The variables obtained from these auxiliary references are compared with the output variables derived from the capacitance references proper, and on the basis of the said references, differential signals are formed, which are allowed, for one part, to act in the way of a constant term upon the measurement electronics and, for the other part, to act upon the steepness of the measurement electronics summingly during so many measurement cycles as a sort of an iteration process, so that the difference between the capacitance reference and the external reference becomes zero or sufficiently close to zero.

The comparison takes place preferably so that the differential signal derived from the first external auxiliary reference and from the first capacitance reference is made to act upon the measurement electronics in the way of a constant term, in other words, it is made to act upon the off-set of the measurement electronics. The differential signal derived from the second external auxiliary reference and from the second capacitance reference is, in the way described above, made to act upon the steepness of the measurement electronics, e.g. on its amplification. If a measurement circuit or a measurement method is concerned whose output variable is a variable frequency, one of the said differential signals is made to act upon the basic frequency of the measurement electronics and the other differential signal upon its dynamics, i.e. upon the change in frequency per a certain unit of change in capacitance.

In the following, the invention will be described in detail with reference to the figures in the accompanying drawing, wherein some of the background of the invention and some of its preferred embodiments are illustrated.

Figure 1 illustrates the characteristic curves (straight lines) of a single-reference measurement method in a system of xy-coordinates.

Figure 2 shows the characteristic curves of a two-reference measurement system, in a way corresponding to Figure 1.

Figure 3 shows a measurement method and circuit in accordance with the invention as a block diagram.

Figure 4 shows an exemplifying embodiment of the method and circuit in accordance with the invention as a wiring diagram.

Figure 1 illustrates a single-reference measurement method in a system of xy-coordinates.By means of a reference, which is, e.g., a capacitance whose electrical value is at the middle of the range X_1 of measurement, a point x_o,Y_o is fixed, through which the straight line k_o illustrating the measurement electronics runs.The coordinate x stands for the input variable, i.e. in the present case the magnitude of the capacitance to be measured, and y stands for the output variable, i.e. in the present case, e.g., a DC voltage or a variable frequency. However, owing to the creeping of the measurement electronics and to other circumstances, the straight line illustrating the properties of the system diverges from the basic straight line k_o between the example lines k_1 and k_2 depicted with dashed line and dot-dashed line.Thereby, within the permitted margins of error, the measurement range X_1 around x_o becomes relatively narrow.

In a corresponding way, Figure 2 illustrates a two-reference measurement method, which is the starting point of the present invention, in a way corresponding to Figure 1.In the method, two references are applied, viz. references 1. and 2., which fix two points in the system of xy-coordinates, viz. points x_1,Y_1 and x_2,Y_2, the straight line k_o placed through the said points being the linear basic operation line of the system. In practice, owing to changes in temperature or to other circumstances, the characteristic curves of the system vary at both sides of the straight line k_o between the curves f_1 and f_2. Thereby, within the margins of error, it is possible to accomplish a range of measurement X_2, which is larger than x_2-x_1. Thereby as compared with the single-reference measurement method, a range of measurement X_2 can be accomplished that is at least by one order larger.

Since it is possible, by means of the invention to be described in more detail in the following, to eliminate the complicated computation operations occurring in prior art in connection with a measurement circuit of two references, by means of the present invention an advantageous measurement method and measurement circuit are accomplished, which can be carried into effect quite simply and an exemplifying embodiment of which will be described in the following with reference to Figures 3 and 4.

According to Figure 3, the system comprises a capacitance (C_M) 12 to be measured and two reference capacitances 10 and 11 (C_{R1} and C_{R2}). The values between the reference capacitances 10 and 11 correspond to the points x_1 and x_2 shown in Figure 2, between which said points, and even outside them, the measurement range X_2 extends. The measurement circuit includes an electronic change-over switch 13, its control circuit 15, which is controlled by a clock 14.Being controlled by the control signals a,r_1,r_2 from the control circuit 15, the change-over switch 13 connects the capacitance C_M to be measured and the reference capacitances C_{R1} and C_{R2} alternatingly to the measurement electronics 16.

In a way in itself known, the measurement electronics 16 includes, e.g., a RC oscillator, the capacitance to be measured, which is as a rule within the range of 0 to 100 pF, and the reference capacitances being alternatingly connected to the input circuit that determines the frequency of the said oscillator. The measurement electronics 16 may also include distributors and other known switching arrangements, so that from the measurement electronics, an output variable is obtained, e.g. a DC voltage or a frequency which varies substantially linearly on the basis of the electrical value of the capacitance C_M.

It is assumed that the output variable of the measurement electronics 16 is a voltage U_1. This voltage U_1 is passed to the first comparison circuit 19 and to the second comparison circuit 20. According to the present invention, in the measurement circuit and method, two external auxiliary reference circuits 17 and 18 are used.From these reference circuits 17,18, e.g., DC voltages U_{R1} and U_{R2} are obtained, which are passed each of them to its own comparison circuit 19 or 20.The differential voltages U_1 and U_2 of the said external auxiliary reference voltages U_{R1} and U_{R2} are and of the output voltage U_1 of the measurement electronics are input voltages of the comparison circuits 19 and 20. The comparison circuits 19 and 20 are controlled by means of the control pulse sequences R_1 and R_2 obtained from the control circuit 15 of the change-over switch 13, so that from the comparison circuits 19 and 20, output voltages U_{c1} and U_{c2} are obtained, by means of which the measurement electronics 16 are controlled via the RC circuits 21 and 22 (low pass filters).

The invention is preferably accomplished so that the first control signal U_{c1} acts, in the way of a constant term, upon the measurement electronics 16, i.e. upon the so-called off-set of the measurement electronics. The second control signal U_{c2} again acts upon the steepness of the measurement electronics, e.g. upon its amplification.

The control signals U_{c1} and U_{c2} affect the measurement electronics in such a direction that the said differential voltages U_1 and U_2 are reduced step-wise, and this feedback effect is repeated, e.g. as controlled by the control circuit 15 of the change-over switch, for the duration of so many measurement cycles that the said differential voltages U_1 and U_2 can be made to approach zero stepwise. After the said differential voltages U_1 and U_2 have been brought sufficiently close to the zero point, the measurement electronics 16 has been adjusted "correctly". Thereby, controlled by the control circuit 15 of the change-over switch 13, the change-over switch 13 connects the capacitance 12 to be measured to the measurement electronics.

At the same time, by means of the control circuit 15 of the change-over switch 13, a holding element 23 or another, corresponding component is controlled so that the output signal U_1 of the measurement electronics 16 is connected,as such or as appropriately scaled, so as to make the outlet signal U_{out}.

Figure 4 shows a wiring diagram of an embodiment of a practical wiring system, which constitutes the measurement electronics for little capacitive detectors (0 to 100 pF). The measurement frequency is about 100 kHz, which frequency has not been processes as such, but it has been divided by means of circuits 25 and 26 to a sufficient extent to a lower frequency in order that the delays in gates etc. and the changes in them should not affect the measurement result. In respect of the construction and operation of the multicap circuit 27, which is an essential part in the wiring system and which is a patented special circuit expressly for the measurement by capacitive detectors, reference is made to the said FI Patents 57,664 and 57,319 (corresponding US Patents 4,295,090 and 4,295,091). The variable that is being examined is time. The auxiliary reference consists of a time that is obtained from the crystal oscillator 24 and further from the pin 3 of the distributor microcircuit 25 (4024). The zeroing takes place a little later (pins 3 and 6 are ones). A second auxiliary reference is not needed, because a different distribution number has been taken from the other distributor microcircuit 26 (4040) by means of the references C_{R1} and C_{R2}.

The comparison of the time differences is carried out by the gates 31 and 32. The gates 33 and 34 take care that the correction currents may act upon the voltages of the capacitors C_1 of 47 nF only when the references C_{R1} and C_{R2} are being measured. The output signal U_{out} is, in the wiring of Figure 4, a frequency burst, whose frequency contains the information on the electrical magnitude of the detector capacitance C_M to be measured. The output may also be connected in the same way as has been done in respect of the references C_{R1} and C_{R2}, whereby a pulse is obtained whose width (duration of half cycle) contains the information on the electrical value of the detector capacitance.

From the wiring in Figure 4, it is possible to calculate the number of pulses in the frequency burst or, with little modifications, a burst is obtained from which the number of pulses corresponding to the value of one of the references C_{R1}; C_{R2} has been deducted.The latter alternative embodiments do not require a crystal oscillator, because the pulse numbers are abstract numbers.

In the following, the patent claims will be given, whereby the various details of the invention may show variation within the scope of the inventive idea defined in the said claims and differ from what has been stated above.

CLAIMS

1. A method for the measurement of capacitance, in particular of a low capacitance, in which measurement electronics include a measurement oscillator, whose output frequency is a function of a capacitance connected to the input terminals of a circuit determining the frequency of the oscillator, and in which method two reference capacitances (C_{R1},C_{R2}) are used, whose electrical values (x_1,x_2) are in a desired range (X_2) of measurement and which are connected to the measurement oscillator by means of a switching arrangement for connecting the reference capacitances and the capacitances to be measured to the input circuit, wherein two auxiliary reference signals (U_{R1},U_{R2}) are provided by external auxiliary references (R_1,R_2), the signals being compared with the corresponding output signals (Ui_1) of the measurement electronics, derived from the said reference capacitances (C_{R1},C_{R2}),

signals (U_1,Ui_2) representing the differences between the said output signals (U_1) and the said reference signals (U_{R1},U_{R2}) are used to provide feedback signals ($U_{c1,c2}$) for controlling the circuit, the measurement electronics being adjusted by means of the feedback signals so that the said differential signals (U_1,U_2) or equivalent approach zero or a preset corresponding value, and

the determination of the output signal (U_1,U_{out}) corresponding to the capacitance (C_M) to be measured is performed by means of the measurement electronics when adjusted to a desired level.

2. A method as claimed in claim 1, wherein the differential signals (U_1,U_2) are formed during several and so many measurement cycles that the differential signals (U_1,U_2) can be made stepwise to approach zero or to become close enough to zero, whereupon the determination of the corresponding output variable (U_1,U_{out}) of the capacitance (C_M) to be measured is performed.

3. A method as claimed in claim 2, wherein

that a constant term or off-set of the measurement electronics is controlled by means of a control signal (U_{c1}) formed in a comparator or equivalent on the basis of one said differential signal (U_1),

that the steepness of the measurement electronics, e.g. the amplification of the measurement electronics, is controlled by means of a control signal (U_{c2}) obtained, e.g., from a comparator on the basis of the other differential signal (U_2), and

that the said adjustment is carried out summingly during so many measurement cycles as an iteration process that the variables illustrating the difference between the capacitance references (C_{R1},C_{R2}) and the external references (R_1,R_2) can be made equal to zero or equal to a predetermined value.

4. A method as claimed in any of the claims 1 to 3, wherein the capacitance (C_M) to be measured and both of the reference capacitances (C_{R1},C_{R2}) are alternately connected by means of an electronic change-over switch, to the measurement electronics and in which method the said change-over switch is controlled by means of a change-over-switch control circuit, which is controlled by a clock, characterized in that the control signals (R_1,R_2) of the control circuit of the change-over switch, which connect the reference capacitances (C_{R1},C_{R2}), are used one (R_1) for controlling one comparator and the other one (R_2) for controlling the other comparator.

5. A method as claimed in any of the claims 1 to 4, wherein as the measurement frequency, a basic frequency of the order of about 100 kHz is used, which said basic frequency is lowered by means of distributors to such a low level that the delays in gates etc. and changes in them do not have an interfering effect on the measurement result.

6. A method as claimed in any of the claims 1 to 5, characterized in that the output signal (U_{out}) of the circuit is a DC voltage.

7. A method as claimed in any of the claims 1 to 5, wherein the output signal of the circuit applying the method is a frequency burst whose frequency contains information on the magnitude of the capacitance (C_M) of the detector to be measured.

8. A method as claimed in claim 7, wherein the number of pulses in the frequency burst is computed, the result of the said computation being used as the measure of the capacitance (C_M) to be measured.

9. A method as claimed in claim 8, wherein the number of pulses corresponding to the value of one of the references is deducted from the number of pulses in the said frequency burst, and the result of computation obtained in this way is utilized in the determination of the capacitance to be measured.

10. A method of measuring a capitance, substantially as hereinbefore described with reference to Figures 3 and 4 of the accompanying drawings.

11. Use of any method as claimed in claim 1 or of a circuit operating as per said method in telemetry of radiosondes for the measurement of atmospheric pressure, temperature and/or humidity.

12. Apparatus for measuring capacitance, comprising means for measuring capacitance, said means providing an output signal proportional to the capacitance being measured, first and second capacitances of predetermined value, means for connecting the first and second reference capacitances to the capacitance measuring means, means for providing an output signal corresponding to an expected output of the capacitance measuring means; means for comparing the actual output signal of the capacitance measuring means and the expected output signal, feedback means for feeding a difference signal representative of the difference between said actual and expected signals back to said capacitance measuring means to adjust the proportionality of the output signal to the capacitance, and means for connecting to the adjusted capacitance measuring means a capacitance to be measured.

13. Apparatus as claimed in claim 12, wherein a first difference signal obtained from the first reference capacitance adjusts the absolute value of the output signal relative to the input capacitance and a second difference signal obtained from the second reference capacitance adjusts the slope.

14. Apparatus for measuring capacitance, substantially as hereinbefore described with reference to the accompanying drawings.

15. A method of measuring capacitance, in which first and second reference capacitances spanning or adjacent a range to be measured are used to provide respective output signals from a capacitance measuring device, the respective output signals are compared to predetermined expected output signals and difference signals are obtained indicating the difference between the expected and actual output signals, and the difference signals are used to adjust the response of the capacitance measuring means to bring the actual and expected output signals closer together prior to measuring a capacitance to be determined.

16. A method as claimed in claim 14, wherein the first and second reference capacitances are cycled through in an iterative process.

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