

Resistance measuring circuit, and thermal appliance, electrical thermometer and cold-generating appliance including such a measuring circuit.

The invention relates to a measuring circuit for measuring the resistance value of a resistor, which circuit comprises:

- a capacitor,
- a first resistor and a second resistor which can be coupled to the capacitor
- 5 for charging the capacitor, thereby forming a capacitor voltage,
- discharge means for discharging the capacitor,
- a first reference voltage source for generating a first reference voltage,
- first comparison means for comparing the capacitor voltage with the first reference voltage and for generating a first detection signal when the capacitor voltage passes
- 10 the first reference voltage,
- time measurement means for measuring a first time interval which, after discharging of the capacitor by the discharge means, terminates upon the occurrence of the first detection signal during charging of the capacitor *via* the first resistor, and for measuring a second time interval which, after discharging of the capacitor by the discharge means,
- 15 terminates upon the occurrence of the first detection signal during charging of the capacitor *via* at least the second resistor.

The invention also relates to a thermal appliance, an electrical thermometer and cold-generating appliance including such a measuring circuit.

- Such a measuring circuit is known from United States Patent No.
- 20 4,910,689. After it has been discharged the capacitor is charged *via* the first resistor and the time is measured which is required to charge the capacitor until the capacitor voltage has become equal to the first reference voltage. This measurement is the first measurement and the measured time is the first time interval. Subsequently, the second resistor is arranged in parallel with the first resistor and the capacitor is discharged again. After this, the capacitor
- 25 is charged again but now *via* the parallel-connected first resistor and second resistor, and again the time is measured which is needed to reach the first reference voltage. This measurement is the second measurement and the measured time is the second time interval. The ratio between the first and the second time interval is equal to the ratio between the resistance value of the first resistor and the resistance value of the parallel-connected first

resistor and second resistor. The resistance value of either the first or the second resistor is known, which is the reference resistance, so that the value of the other resistor, *i.e.* the unknown resistance to be measured, can be calculated from the ratio.

In the known measuring circuit the second resistor is arranged in parallel with the first resistor during the second measurement. The first resistor is connected permanently to the capacitor. However, it is also possible to charge the capacitor exclusively *via* the second resistor during the second measurement. The first resistor is then disconnected during the second measurement. The value of the unknown resistance can then again be derived from the ratio between the measured time intervals.

The unknown resistance may be a temperature-dependent resistance, for example a thermistor or an NTC (negative temperature coefficient) resistor. The measured resistance is then a measure of the temperature of the resistor. In that case the measuring circuit is very suitable for use in electrically heated appliances such as a flat-iron, coffee maker, electric kettle, deep fryer, roaster, cook-top, oven, grill, hot-plate, room-heating appliance, radiant heater, fan heater, hair dryer, hair curler, bread toaster, sandwich toaster, electric blanket and the like, electrical thermometers and cold-generating appliances such as an icemaker, food processor, refrigerator, deepfreezer, air conditioner and the like.

During discharging of the capacitor two currents will flow through the discharge means. Firstly, a discharge current which decreases to zero as a result of the short-circuit of the capacitor. Secondly, a substantially constant charging current whose magnitude at the beginning of the first measurement is mainly determined by the first resistance and at the beginning of the second measurement by the parallel-connected first and second resistance. Owing to the finite impedance of the discharge means the charging current produces a voltage drop across the discharge means, which voltage drop will be left across the capacitor as a residual voltage at the beginning of the first or the second measurement when the discharge path of the discharge means is opened. The residual voltage influences the time required to charge the capacitor to the first reference voltage and hence the lengths of the first and the second time intervals. During the second measurement the first and the second resistor are in parallel, so that the charging current at the beginning of the second measurement is larger than at the beginning of the first measurement. Consequently, the residual voltages across the capacitor also differ per measurement. Moreover, if the unknown resistor is an NTC resistor this difference in residual voltages also varies as a function of temperature. These residual voltages consequently result in an inaccurate measurement.

It is an object of the invention to improve the accuracy of the measuring circuit defined above and to this end the invention is characterised in that the measuring circuit further comprises:

- a second reference voltage source for supplying a second reference voltage which lies between the first reference voltage and the capacitor voltage immediately after discharging of the capacitor,
- second comparison means for comparing the capacitor voltage with the second reference voltage and for generating a second detection signal when the capacitor voltage passes the second reference voltage, and in that
- 10 - the first time interval and the second time interval start upon the occurrence of the second detection signal.

The time measurement is delayed until the capacitor voltage has increased sufficiently. This is signalled by the second detection signal and the time measurement is not started until then. As a result, the residual voltage across the capacitor no longer plays a
15 part.

A substantial reduction of the number of parts can be obtained with an embodiment which is characterised in that the first comparison means and the second comparison means are united in a single comparator, and in that the first reference voltage source and the second reference voltage source are united in a single reference voltage source
20 whose reference voltage is switchable from the second reference voltage to the first reference voltage after the occurrence of the second detection signal.

According to the invention a simple single reference voltage source with a switchable reference voltage is characterised in that the single reference voltage source comprises:

- 25 - a voltage divider with a series arrangement of a third resistor and a fourth resistor,
- a fifth resistor, and
- switching means for connecting the fifth resistor and the third resistor in parallel before the occurrence of the second detection signal and for connecting the fifth
30 resistor and the fourth resistor in parallel after the occurrence of the second detection signal.

These and other aspects of the invention will be described and elucidated with reference to the accompanying drawings, in which

Figure 1 shows a first circuit diagram of a measuring circuit in accordance with the invention,

Figure 2 shows some waveforms of signals appearing in a measuring circuit in accordance with the invention,

Figure 3 shows a second circuit diagram of a measuring circuit in accordance with the invention,

5 Figure 4 shows a third circuit diagram of a measuring circuit in accordance with the invention,

Figure 5 shows an electrical connection diagram of a flat-iron including a measuring circuit in accordance with the invention,

10 Figure 6 is a sectional view of a flat-iron including a measuring circuit in accordance with the invention, and

Figure 7 shows a circuit diagram of a flat-iron including a measuring circuit in accordance with the invention.

In these Figures like elements bear the same reference numerals.

Figure 1 shows a measuring circuit in accordance with the invention. A series arrangement of a first resistor 6 and a capacitor 8, which are connected to one another in a node 10, is connected between a positive supply terminal 2 and a negative supply terminal 4, which is assumed to be earthed. A discharge switch 12 is arranged in parallel with the capacitor 8 and can be opened and closed by means of a first switching signal S_1 . A series arrangement of a second resistor 14 and a parallel switch 16 is arranged in parallel with the first resistor 6. The parallel switch 16 can be opened and closed by means of a second switching signal S_2 , as a result of which the second resistor 14 is connected in parallel or is not connected in parallel with the first resistor 6. A first comparator 18 has one input connected to the node 10 and has another input connected to a first reference voltage source 20, which generates a first reference voltage U_{ref1} . The first comparator 18 supplies a first detection signal D_1 , whose value changes if the capacitor voltage U_c on the node 10 passes the first reference voltage U_{ref1} . A second comparator 22 also has one input connected to the node 10 and has another input connected to a second reference voltage source 24, which generates a second reference voltage U_{ref2} . The second comparator 22 supplies a second detection signal D_2 , whose value changes if the capacitor voltage U_c on the node 10 passes the second reference voltage U_{ref2} . The second reference voltage U_{ref2} has a value which lies between the first reference voltage U_{ref1} and the residual voltage U_{cr} across the capacitor 8 immediately after the capacitor 8 has discharged via the discharge switch 12.

The detection signals D_1 and D_2 are applied to inputs of a microcontroller (also referred to as microprocessor) 26, which under control of a program stored in a ROM

(read-only memory) 28 provides the timing of the measuring circuit and *inter alia* generates the switching signals S_1 and S_2 for controlling the discharge switch 12 and the parallel switch 16. The program of the microcontroller 26 has subroutines to count clock pulses (not shown) during time intervals defined by the detection signals D_1 and D_2 , subroutines to store the counts in a RAM (random-access memory) 30, subroutines to perform mathematical operations on the counts and, depending on the use of the measuring circuit, subroutines to apply results of mathematical operations to, for example, a display 32 or a digital-to-analog converter 34.

The measuring circuit can measure the resistance value of the second resistor 14 if the resistance value of the first resistor 6 is known and *vice versa*. Thus, one of the two resistors functions as the known reference resistance and the other resistor is the unknown resistance to be measured. If the unknown resistance is an NTC (negative temperature coefficient) resistor the measured resistance will also be a measure of the temperature of this resistor. In that case it is also preferable to arrange the NTC resistor at the position of the second resistor 14. As will become apparent later on, the capacitor 8 is charged two times, one time *via* the first resistor 6 and one time *via* the first resistor 6 in parallel with the second resistor 14. By arranging the NTC resistor at the position of the second resistor 14 it is assured that the time constant for charging the capacitor 8 in the case of the parallel-connected resistors is smaller than in the case that the resistors are not in parallel. This simplifies the timing of the measuring circuit.

The operation of the measuring circuit will now be explained with reference to Figure 2, which shows some signal waveforms. The discharge switch 12 opens at the instant t_1 and subsequently a first measurement is effected. The capacitor voltage U_c at this instant is equal to the first residual voltage U_{cr1} , which is caused by the charging current through the discharge switch 12. The internal resistance of the discharge switch 12 is limited and can be a few hundreds of ohms in the case of transistor switches. The transistor switches are often incorporated in the microcontroller 26 and may exhibit a substantial spread in forward resistance. From the instant t_1 the capacitor voltage U_c increases from the first residual voltage U_{cr1} with a first time constant τ_1 , which is determined by the value R_1 of the first resistor 6 and the capacitance C of the capacitor 8 (Fig. 2 (a)). At the instant t_2 the capacitor voltage U_c reaches the value of the second reference voltage U_{ref2} and the value of the second detection signal D_2 changes (Fig. 2 (d)). At the same instant a first clock-pulse count CNT_1 is started by the microcontroller 26. At the instant t_3 the capacitor voltage U_c reaches the value of the first reference voltage U_{ref1} and the value of the first detection

signal D_1 changes (Fig. 2 (e)). The count CNT_1 now stops. The number of clock pulses CNT_1 is a measure of a first time interval $dt_1 = t_3 - t_2$ elapsing between passage of the second reference voltage U_{ref2} and the first reference voltage U_{ref1} . The clock pulse count CNT_1 is subsequently stored in the RAM 30. For the calculation of the first time interval dt_1 it is assumed that: U_{dd} = supply voltage on the positive supply terminal 2 relative to earth, $\tau_1 = R_1 * C$ en $t_1 = 0$. The capacitor voltage U_c then varies in accordance with:

$$U_c(t) = U_{cr1} + (U_{dd} - U_{cr1}) \left[1 - e^{-\frac{t}{\tau_1}} \right] \quad (1)$$

10 $U_c(t_2) = U_{ref2}$ at the instant t_2 and $U_c(t_3) = U_{ref1}$ at the instant t_3 . From equation (1) it now follows that:

$$dt_1 = t_3 - t_2 = -\tau_1 \ln \left[\frac{U_{dd} - U_{ref1}}{U_{dd} - U_{ref2}} \right] \quad (2)$$

After the instant t_3 , at a suitable instant t_4 , the capacitor 8 is discharged in response to a change of value of the first switching signal S_1 (Fig. 2 (b)). Slightly later at an instant t_5 the parallel switch 16 is also closed under command of the second switching signal S_2 (Fig. 2 (c)). The values of the detection signals D_1 and D_2 change as a result of the discharging process. The first resistor 6 and the second resistor 14 are now in parallel and a larger current flows through the discharge switch 12, so that the second residual voltage U_{cr2} is also higher than the first residual voltage U_{cr1} . At the instant t_6 the discharge switch 12 opens again and a second measurement is now carried out. From the instant t_6 the capacitor voltage U_c increases from the second residual voltage U_{cr2} with a second time constant τ_2 , which is determined by the value R_p of the first resistor 6 in parallel with the second resistor 14 and the capacitance C of the capacitor 8 (Fig. 2 (a)). At an instant t_7 the capacitor voltage U_c again reaches the second reference voltage U_{ref2} and the value of the second detection signal D_2 changes again (Fig. 2 (d)). At the same instant a second clock-pulse count CNT_2 is started by the microcontroller 26. At an instant t_8 the capacitor voltage U_c reaches the first reference voltage U_{ref1} and the value of the first detection signal D_1 changes again (Fig. 2 (e)). The count CNT_2 now stops. The clock pulse count CNT_2 is a measure of a second time

- interval $dt_2 = t_8 - t_7$ elapsing between passage of the second reference voltage U_{ref2} and the first reference voltage U_{ref1} . The clock pulse count CNT_2 is subsequently stored in the RAM 30. For the calculation of the second time interval dt_2 it is further assumed that: R_2 = the resistance value of the second resistor 14, $\tau_2 = R_p * C$, $R_p = R_1 * R_2 / (R_1 + R_2)$ and $t_6 = 0$.
- 5 The capacitor voltage U_c then varies in accordance with a formula comparable to formula (1). $U_c(t_7) = U_{ref2}$ at the instant t_7 and $U_c(t_8) = U_{ref1}$ at the instant t_8 . From equation (1) it now follows that:

$$dt_2 = t_8 - t_7 = -\tau_2 \ln \left[\frac{U_{dd} - U_{ref1}}{U_{dd} - U_{ref2}} \right] \quad (3)$$

- 10 The resistance value R_2 for a given value of R_1 can now be calculated from the ratio between dt_1 and dt_2 . It appears that the ratio is equal to R_1/R_p and therefore only depends on the values of R_1 and R_2 . The microcontroller 26 now performs a simple operation upon the counts CNT_1 and CNT_2 in order to calculate the value R_2 of the second resistor 14. If the second resistor 14 is an NTC resistor the value thus found is compared with a table in the
- 15 ROM 28 and is converted to a signal whose value is representative of the temperature of the relevant NTC resistor. If the circuit is used in an electronic thermometer this temperature signal is shown on the display 32 in a suitable manner.

- As is indicated in Fig. 2 (a), the discharging process of the capacitor 8 can be prolonged as required. Thus, the timing of the switching signals S_1 and S_2 can be
- 20 chosen so as to ensure that the capacitor 8 is not discharged prematurely for any value of the time constant τ_2 . If the second resistor is an NTC resistor its resistance value can vary from some hundreds of kilo-ohms at low temperature to some hundreds of ohms at high temperature. Arranging the NTC resistor at the position of the second resistor 14 now ensures that the time constant for charging the capacitor 8 in the case of parallel-connected
- 25 resistors is smaller than in the case that the resistors are not connected in parallel. Instead of a microcontroller with a RAM and a ROM it is, of course, also possible to use separate timers, counters, registers and the like for controlling the discharge switch 12 and the parallel switch 16 and for carrying out the mathematical operations. The discharge switch 12 and the parallel switch 16 can be constructed as relays with relay contacts or as transistor
- 30 switches. The discharge switch 12 is, for example, an NMOS or NPN transistor and the parallel switch 16 a PMOS or PNP transistor.

Figure 3 shows a simplified measuring circuit. The first reference voltage source 20 and the second reference voltage source 24 can be replaced by a single controllable voltage source 36 whose voltage is switched *via* an interface circuit 38 under control of a third switching signal S_3 . Fig. 2 (f) shows the timing of this third switching signal S_3 .

- 5 Briefly after the capacitor voltage U_c has passed the second reference voltage U_{ref_2} (t_2 , t_7) the reference voltage is switched from U_{ref_2} to U_{ref_1} . Now only one comparator 40 is needed, which has one input connected to the node 10 and another input to the controllable voltage source 36.

- 10 In the measuring circuit shown in Figure 1 the second resistor 14 is arranged in parallel with the first resistor 6 during the second measurement. The first resistor 6 is permanently connected to the capacitor 8. However, alternatively the capacitor 8 can be charged exclusively *via* the second resistor 14 during the second measurement. The first resistor 6 is then disconnected during the second measurement. The parallel switch 16 then becomes a change-over switch, which connects the first resistor 6 to the capacitor 8 during
15 the first measurement and which connects the second resistor 14 to the capacitor 8 during the second measurement. This configuration again enables the value of the unknown resistance to be calculated from the measured time intervals. Such a change-over switch instead of the parallel switch 16 can also be used in the following embodiments and examples.

- Figure 4 shows a measuring circuit which has been simplified even
20 further. In the present case the controllable voltage source 36 and the interface circuit 38 are constructed with a third resistor 42 between the negative supply terminal 4 and a node 44, a fourth resistor 46 between the node 44 and the positive supply terminal 2, and a fifth resistor 48 having one end connected to the node 44, its other end being connectible to the positive supply terminal 2 or to the negative supply terminal 4 under control of the third switching
25 signal S_3 *via* a change-over switch 4. The inputs of the comparator 40 are connected to the nodes 10 and 44. The comparatively low reference voltage U_{ref_2} is obtained by arranging the fifth resistor 48 in parallel with the third resistor 42. The comparatively high reference voltage U_{ref_1} is obtained by arranging the fifth resistor 48 in parallel with the fourth resistor 46.

- 30 Figure 5 shows the measuring circuit used in a thermal appliance, for example a flat-iron. The electronic parts are mounted on a printed circuit board 52. The second resistor 14 is an NTC resistor in thermal contact with the soleplate 54, which is heated by an electric heating element 56. The second resistor 14 is connected to a terminal 58 and a terminal 60, and the electric heating element 56 is connected to a terminal 62 and a

terminal 64 of the printed circuit board 52. Figure 6 is a sectional view of the iron and Figure 7 shows the circuit diagram of the printed circuit board 52. The temperature of the soleplate 54 can be set by means of selector switches 66 connected to input ports of the microcontroller 26. The electric heating element 56 is turned on and turned off by means of a relay 68, which is energised by the microcontroller 26 via a control transistor 70. The measured temperature of the soleplate 54 is compared with the temperature set by means of the selector switches 66. If the temperature is too low the relay 68 is energised, as a result of which the electric heating element 56 is powered from the a.c. mains and heats the soleplate 54. When the desired temperature is reached the relay is de-energised and the power supply to the electric heating element 56 is interrupted.

The circuit shown in Figure 7 is also suitable for use in other thermal appliances having a heating element, with or without temperature control, such as coffee makers, electric kettles, deep fryers, roasters, cook-tops, ovens, grills, hot-plates, room-heating appliances, radiant heaters, fan heaters, hair dryers, hair curlers, bread toasters, sandwich toasters, electric blankets and the like.

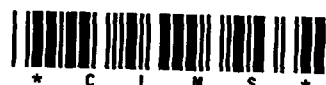
If instead of the electric heating element 56 a cooling unit 72 is used the circuit shown in Figure 7 can also be used in cold-generating appliances such as icemakers, food processors, refrigerators, deepfreezers, air conditioners and the like.

Claims:

1. A measuring circuit for measuring the resistance value of a resistor, which circuit comprises:

- a capacitor (8),
- a first resistor (6) and a second resistor which can be coupled to the capacitor (8) for charging the capacitor (8), thereby forming a capacitor voltage (U_c),
- discharge means (12) for discharging the capacitor (8),
- a first reference voltage source (20) for generating a first reference voltage (U_{ref1}),
- first comparison means (18) for comparing the capacitor voltage (U_c) with the first reference voltage (U_{ref1}) and for generating a first detection signal (D_1) when the capacitor voltage (U_c) passes the first reference voltage (U_{ref1}),
- time measurement means (26-30) for measuring a first time interval which, after discharging of the capacitor (8) by the discharge means (12), terminates upon the occurrence of the first detection signal (D_1) during charging of the capacitor (8) via the first resistor (6), and for measuring a second time interval which, after discharging of the capacitor (8) by the discharge means (12), terminates upon the occurrence of the first detection signal (D_1) during charging of the capacitor (8) via at least the second resistor (14), characterised in that the measuring circuit further comprises:
 - a second reference voltage source (24) for supplying a second reference voltage (U_{ref2}) which lies between the first reference voltage (U_{ref1}) and the capacitor voltage immediately after discharging of the capacitor (8),
 - second comparison means (22) for comparing the capacitor voltage (U_c) with the second reference voltage (U_{ref2}) and for generating a second detection signal (D_2) when the capacitor voltage (U_c) passes the second reference voltage (U_{ref2}), and in that
 - the first time interval and the second time interval start upon the occurrence of the second detection signal (D_2).

2. A measuring circuit as claimed in Claim 1, characterised in that the first comparison means (18) and the second comparison means (22) are united in a single comparator (40), and in that the first reference voltage source (20) and the second reference



voltage source (24) are united in a single reference voltage source (36) whose reference voltage is switchable from the second reference voltage (U_{ref2}) to the first reference voltage (U_{ref1}) after the occurrence of the second detection signal (D_2).

3. A measuring circuit as claimed in Claim 1 or 2, characterised in that the
5 single reference voltage source (36) comprises:

- a voltage divider with a series arrangement of a third resistor (42) and a fourth resistor (46),
- a fifth resistor (48), and
- switching means (50) for connecting the fifth resistor (48) and the third
10 resistor (42) in parallel before the occurrence of the second detection signal (D_2) and for connecting the fifth resistor (48) and the fourth resistor (46) in parallel after the occurrence of the second detection signal (D_2).

4. A measuring circuit as claimed in Claim 1, 2 or 3, characterised in that the second resistor (14) is a temperature-dependent resistor (NTC).

15 5. A measuring circuit as claimed in Claim 1, 2, 3 or 4, characterised in that the discharge means (12) and the switching means (16; 50) are transistors.

6. A thermal appliance, characterised in that it comprises:

- an electric heating element (56),
- a temperature-sensitive resistor (14),
- 20 - means (26-30, 70, 68) for controlling the power supply to the electric heating element (56) in response to the resistance value of the temperature-sensitive resistor (14), and
- a measuring circuit as claimed in Claim 1, 2, 3, 4 or 5, either the first resistor (6) or the second resistor (14) being the temperature-sensitive resistor.

25 7. A thermal appliance as claimed in Claim 6, characterised in that the thermal appliance is an appliance of the group including: a flat-iron, coffee maker, electric kettle, deep fryer, roaster, cook-top, oven, grill, hot-plate, room-heating appliance, radiant heater, fan heater, hair dryer, hair curler, bread toaster, sandwich toaster, electric blanket.

8. An electrical thermometer, characterised in that it comprises:

- 30 - a temperature-sensitive resistor (14),
- a measuring circuit as claimed in Claim 1, 2, 3, 4 or 5, either the first resistor (6) or the second resistor (14) being the temperature-sensitive resistor (14),
- a device (26-30) for supplying an electric signal which is representative of the resistance value of the temperature-sensitive resistor (14), and



- a indicator device (32) for indicating a temperature in response to the electric signal.

9. A cold-generating appliance, characterised in that it comprises:

- a cooling unit (72),

5 - a temperature-sensitive resistor (14),

- means (26-30, 70, 68) for controlling the cooling unit in response to the resistance value of the temperature-sensitive resistor (14), and

- a measuring circuit as claimed in Claim 1, 2, 3, 4 or 5, either the first resistor (6) or the second resistor (14) being the temperature-sensitive resistor (14).

10 10. A cold-generating appliance as claimed in Claim 9, characterised in that the appliance is an appliance of the group including: an icemaker, food processor, refrigerator, deepfreezer, air conditioner.

