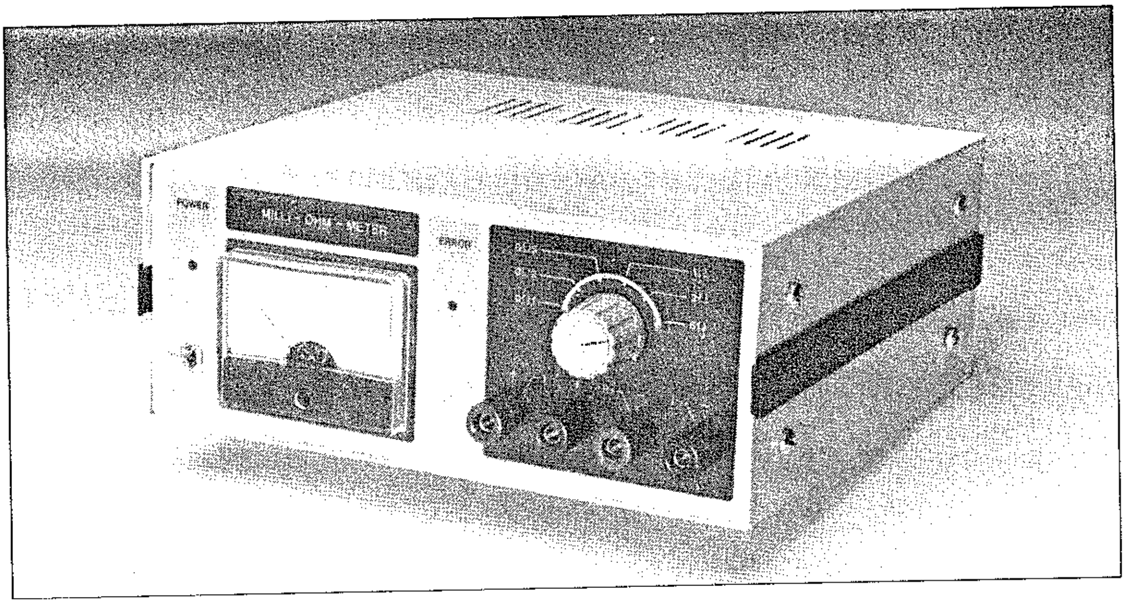
MILLIOHMMETER



As you are probably aware, measuring small resistance values is difficult, if not impossible, with conventional digital and analogue multimeters. While only a few of these instruments have a 1-Ω range with limited practical use, the meter presented here allows very small resistances in the range from 10 mΩ to 5 Ω to be measured reliably.

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That most multimeters have a lowest resistance range of 100 Ω or 1 kΩ is not surprising. The measurement of small resistances poses a number of special problems that do not occur in the kΩ ranges. Take, for instance, the measurement system which in many cases has to be changed just for the sake of the lowest range. There is, however, a more serious problem in the range up to 10 Ω: the contact resistance of the test lead plugs and the sockets on the instrument, and, of course, the resistance of the test leads themselves. A connection formed by a banana plug and a mating socket, both in new condition, represents a typical resistance smaller than 1 mΩ. This resistance rises to several milliohms as the contact surfaces start to oxidize. Although a few mΩ may not seem much to start worrying about, such values are significant since the instrument discussed here has a resolution of 2 mΩ. The resistance of the test leads is also a factor of some importance. A test lead with a length of 1 m and a cross-sectional area of 1 mm^2 has a typical resistance of 17 mΩ. For a similar lead with a cross-sectional area of 2.5 mm^2 this value becomes 7 mΩ. Relating these values to 1 Ω, the error factors are 1.7% and 0.7% respectively. In other words, our measurement starts to become unreliable when these parasitic resistances are not taken into account. Fortunately, there exists a measurement principle that eliminates the effects of these unwanted resistances. This principle is called four-point resistance measurement.

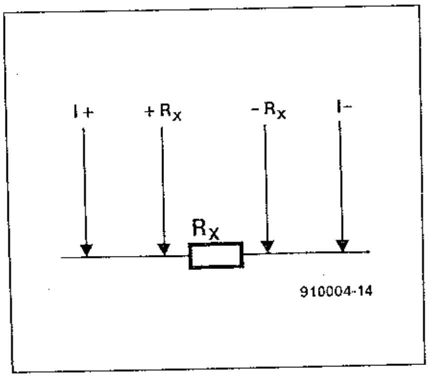

Fig. 1 Four-point resistance measurement principle

Two terminals, four wires?

Using four wires to connect a resistor with only two terminals to a meter system may seem strange at first. However, since these wires may be divided into two pairs with the same functions, this method allows us to eliminate the effects of parasitic resistances. The principle is illustrated in Fig. 1. The unknown resistor, *R*, is connected with four wires. The outer two cause a current flow through *R*. The present meter sends a constant current through *R* via terminals I+ and I–. The advantage of using a constant-current source is that it is not affected by the parasitic resistance. Hence, we know exactly how much current flows through *R*. To determine the value of *R*, all we have to do is

MAIN FEATURES

- **Ranges: 100 mΩ, 200 mΩ, 500 mΩ, 1 Ω, 2 Ω, 5 Ω**
- **Resolution: 2% of f.s.d. value**
- **Principle: 4-point measurement with pulsed constant current**
- **Measurement current: I_p = 1 A**
  I_{rms} = 10 mA
  pulse length approx. 1 ms
  repeat rate approx. 10 Hz.
- **error detection: too low test current**
- **current consumption: max. 70 mA**

measure the voltage across it as a result of the constant current. This voltage is fed to the instrument via wires +Rx and –Rx These wires are connected as close as possible to the resistor body, or to the terminals to which a resistor is to be connected later In this way only the voltage drop across the resistor is measured, without the additional voltage across all kinds of parasitic resistances The system also eliminates the resistance of the test leads, and the contact resistance at the plugs and sockets

Since the current flow into the voltage meter is negligible with respect to the constant current sent through the resistor under test, it may be concluded at this point that the four-point resistance measurement offers a reliable method of determining the value of small resistors at an accuracy that is not normally achievable with a multimeter

1 A, and no heat?

Good as the four-point measurement system may be as a basis for the design of a milliohmmeter, there are more aspects to such an instrument that need to be given thought. Among these factors is the heat dissipated by the resistor To make sure that a low-value resistor produces a voltage drop that is readily measured it must pass a relatively high current We can not make the current as high as we wish, however, since the maximum permissible dissipation of the resistor must be taken into account A 1-Ω resistor with a power rating of 0 25 W for instance, will not survive the constant current of 1 A supplied by the instrument The solution to this problem is found in the use of a pulsed constant-current source (see the block diagram in Fig 2). The resistor under test is fed with an effective current of only 10 mA since the 1-A current source is pulsed at a duty factor of 0 01 (1 ms on, 100 ms off) Even a 0 25-watt resistor will not mind such a low effective current Unfortunately, the use of a pulsed test current has one disadvantage in that resistors with a relatively high reactive component (stray inductance or capacitance) can not be measured reliably

The test current through the resistor is pulse-shaped because the constant-current source is switched on and off by a pulse generator The same generator controls a sample-and-hold circuit that stores the measured voltage during the 'off' period of the current This means that the output of the sample-and-hold supplies a constant voltage whose value is in direct proportion to the measured resistance. Depending on the selected range, this voltage is amplified or attenuated before it is fed to a moving-coil meter provided with an ohm scale

The circuit helps you avoid measurement errors by signalling over-range conditions This is achieved by monitoring the output current of the current source When a too large resistor is connected, or when the current wires, I+ and I–, are broken the current source will no longer be able to supply 1 A, so that the voltage measured across the resistor is no longer a direct measure for the resistance value However, the meter will still indicate 'something' because the measurement circuit and the resistor supply are separate circuits The fault condition is simple to recognize because the current source then pulls terminal I– to ground A detector circuit that measures the voltage between the I– terminal and ground is all that is required to signal over-range conditions When these occur the detector causes the ERROR LED to light

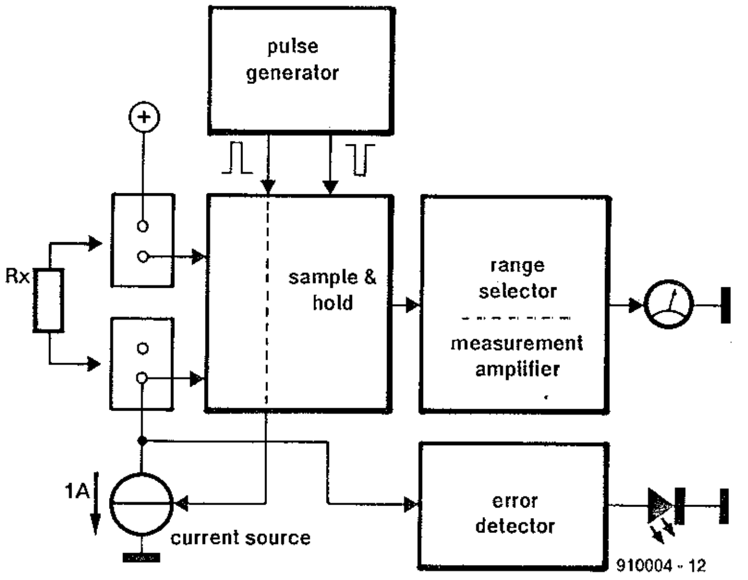

Fig 2 Block diagram of the milliohmmeter The resistor to be measured, R_x, is connected into a four-point network that supplies constant current pulses, and feeds the voltage developed across R_x to a sample-and-hold meter circuit.

Circuit description

Having explained the principle of operation of the milliohmmeter, we can start to look at the way the circuit is realized in practice Figure 3 shows the circuit diagram of the instrument The pulse generator is built around opamp IC_{2a} Resistors R_1, R_2 and R_3 cause the opamp to function as a Schmitt-trigger inverter, while components R_1 R_5 D_1 and C_1 provide the function of an oscillating pulse generator The operation of the generator is as follows: when the output of IC_{2a} is high capacitor C_2 is charged via diode D_1 and resistor R_4 until the voltage across it reaches the upper switching threshold of the Schmitt-trigger This takes about 1 ms Next the output of IC_{2a} goes low, so that C_2 is discharged to the lower switching threshold This takes about 100 ms The output of the opamp goes high again, and the cycle is repeated. Transistor T_1 inverts the output signal of the pulse generator

The current source in the instrument is built around opamp IC_4. This provides a drive signal to transistor T_2 that results in a voltage across emitter resistor R_{25} equal to the voltage at the +input of the opamp When this voltage is constant, the emitter current is constant too Since there is a fixed relation between the emitter current and the collector current of T_2, it follows that the collector current is also constant The magnitude of the collector current (which is the test current through the unknown resistor) depends on the value of R_{25} and the voltage at the +input of IC_4 That voltage is supplied by preset P_4, and is stabilized by a precision zener diode, D_2 The zener diode is powered by the pulse generator As a result, the voltage set by P_4 at the +input of IC_4 will vary between nought and the set peak value Hence the test current will also vary between nought and the set peak value of 1 A

The current sent through the resistor under test can not be drawn direct from voltage regulator IC_5 because the peak value (1 A) is about equal to the maximum current the 7810 is capable of supplying However since the peak current has a relatively short 'on' time, the necessary energy may be obtained from a large electrolytic capacitor in this case, C_5 It will be clear that the voltage across this capacitor is far from constant This is of little consequence, however, since these variations are compensated by the current source Resistor R_{30} between C_5 and the voltage regulator keeps the charge current within limits The relatively long 'off' time of the current pulses ensures sufficient time for the capacitor to be charged via this resistor

The test current sent through the unknown resistor via terminal I– gives rise to a voltage which is fed to the sample-and-hold circuit via the Rx terminals The sample-and-hold stores the measured voltage during the

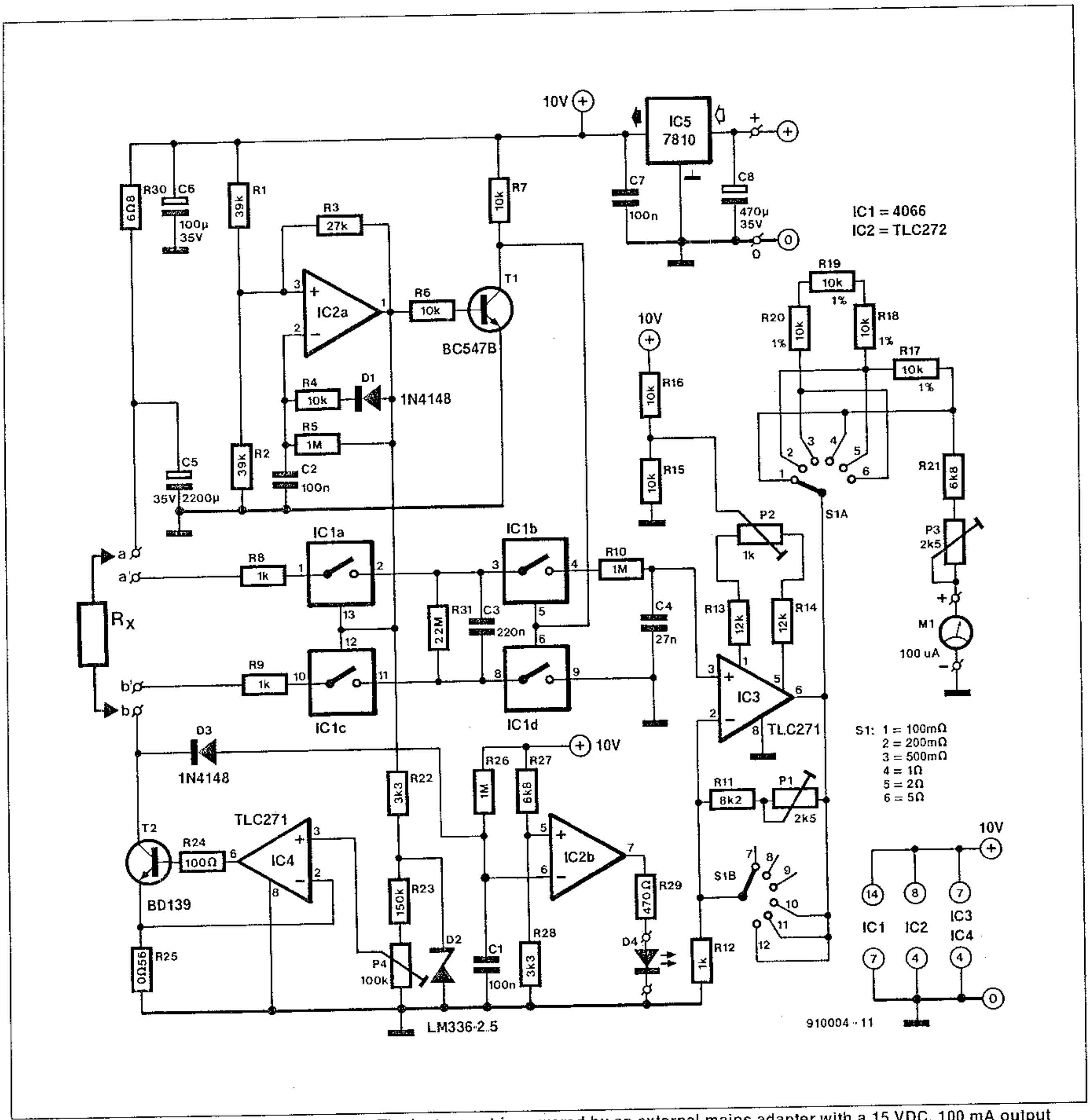

Fig 3. Circuit diagram of the milliohmmeter. The instrument is powered by an external mains adapter with a 15 VDC, 100 mA output

off' time of the test current. In addition, it converts this voltage from floating into one that can be measured with respect to ground. Four CMOS bilateral switches are used to achieve this. When the current source is on, switches IC1a and IC1c are closed, while IC1b and IC1d are open. Capacitor C3 is connected in parallel with Rx via resistors R8 and R9, and will be charged until the voltage across it equals that across Rx. The resistors and C3 form a low-pass filter to suppress interference. The moment the current source is switched off, switches IC1a and IC1c are opened, while IC1b and IC1d are closed. This results in C3 being connected to ground via IC1d. The switching can be done without the risk of a short-circuit occurring because the connection with the floating voltage across Rx is broken. Next, the voltage across C3 is fed to C4. This capacitor ensures that the measurement amplifier, IC3, is provided with an input voltage during the time C3 is connected to Rx.

Switch S1b selects between an amplification of one, and an amplification of 10, for opamp IC3. These amplification factors are used for the ranges 1 Ω, 2 Ω and 5 Ω (×1), and 100 mΩ, 200 mΩ and 500 mΩ (×10). The offset of IC3 is compensated by adjusting P2. The attenuater circuit that follows IC3 consists of a number of switchable potential dividers that drive moving-coil meter M1. The use of 1% resistors in the attenuator obviates any adjustments. The attenuator is followed by the moving-coil meter with its series resistors R21-P3.

The over-range detector is formed by comparator IC2b. Resistors R27 and R28 define the switching threshold of this comparator at about 3.3 V. The comparator compares this reference level to the voltage across capacitor C1, which is charged via R26 and can only be discharged when the current source is off. Then, the minimum voltage across C1 is about 0.6 V higher than the collector voltage of T2. When this voltage drops below 2.7 V as a result of a too high resistance between the I+ and the I− terminals, the voltage across C1 drops below the switching threshold of the comparator. Consequently, this toggles, so that LED D4 lights. Calculating the resistance value at which this happens, we find a value of about 7 Ω between the I terminals.

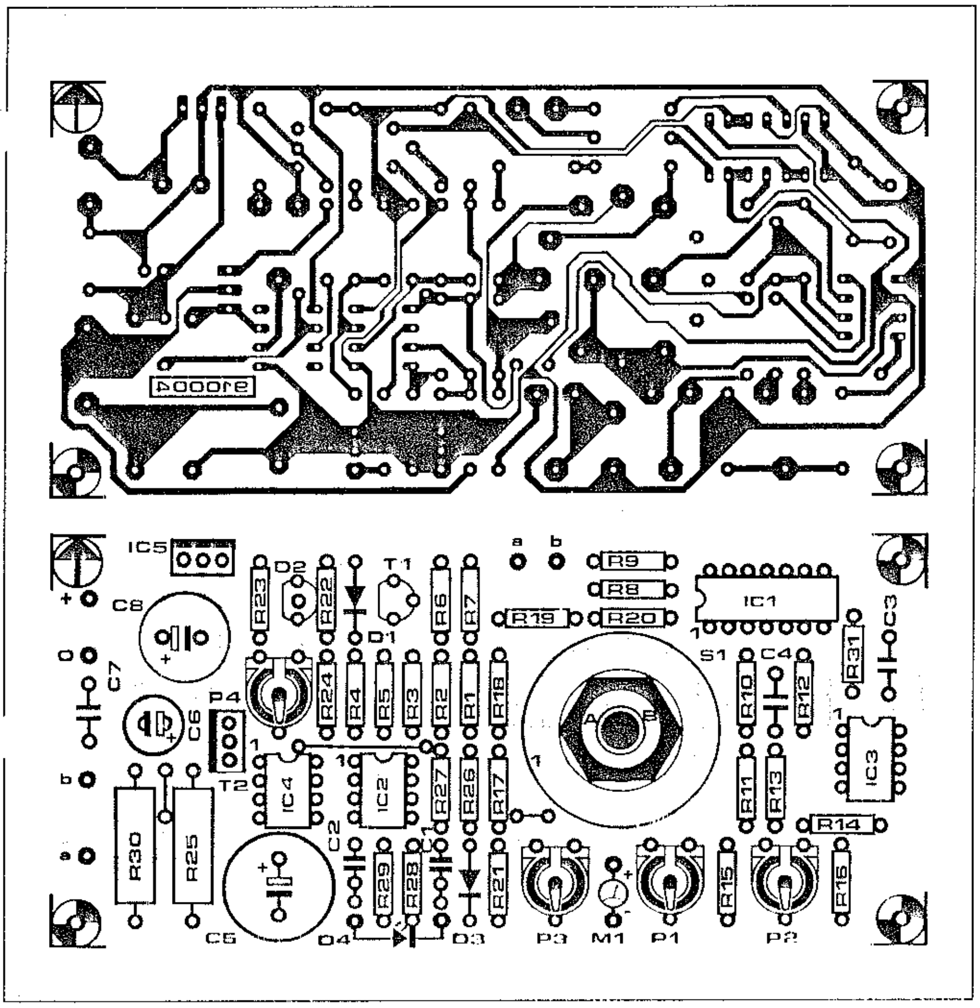

Fig. 4. Single-sided printed-circuit board for the milliohmmeter. Note that the range switches are fitted direct onto the PCB

COMPONENTS LIST

Resistors:

2	39kΩ	R1;R2
1	27kΩ	R3
5	10kΩ	R4;R6;R7; R15;R16
3	1MΩ	R5;R10;R26
3	1kΩ	R8;R9;R12
1	8kΩ2	R11
2	12kΩ	R13;R14
4	10kΩ 1%	R17 – R20
2	6kΩ8	R21;R27
2	3kΩ3	R22;R28
1	150kΩ	R23
1	100Ω	R24
1	0Ω56	R25
1	470Ω	R29
1	6Ω8	R30
1	22MΩ	R31
2	2kΩ5 preset H	P1;P3
1	1kΩ preset H	P2
1	100kΩ preset H	P4

Capacitors:

3	100nF	C1;C2;C7
1	220nF	C3
1	27nF	C4
1	2200µF 35V radial	C5
1	100µF 35V radial	C6
1	470µF 35 V radial	C8

Semiconductors:

2	1N4148	D1;D3
1	LM336 2 5V	D2
1	LED	D4
1	BC547B	T1
1	BD139	T2
1	4066	IC1
1	TLC272	IC2
2	TLC271	IC3;IC4
1	7810	IC5

Miscellaneous:

1	100µA moving-coil meter	M1
1	2-pole 6-way rotary switch for PCB mounting	S1
1	metal enclosure, e g , Telet LC850 (supplier: C-I Electronics) Approx dimensions: 80×200×180 mm	
1	printed-circuit board 910004	
1	front-panel foil 910004-F	

Construction

When the PCB shown in Fig 4 is to be fitted into the enclosure mentioned in the parts list the corner near IC1 will have to be cut off Next, fit the parts on to the PCB, starting with the three wire links. Zener diode D2 comes in two different enclosures: a metal type and a plastic type If you have a metal version, pay attention to the correct polarization (see Fig 6) The plastic version presents no problems since its orientation is printed on the component overlay

As with previous test instruments in this series (see the list at the end of this article), the milliohmmeter is powered by a mains adapter In this case, an adapter with a rating of 15 VDC at about 100 mA is recommended

The prototype of the milliohmmeter is shown in Fig 7 The completed PCB is fitted vertically at a suitable distance behind the front panel Use short pieces of solid wire to connect the banana sockets to the relevant points on the PCB The range selection switch is a type for PCB-mounting that obviates any wiring The front panel is not fitted as yet

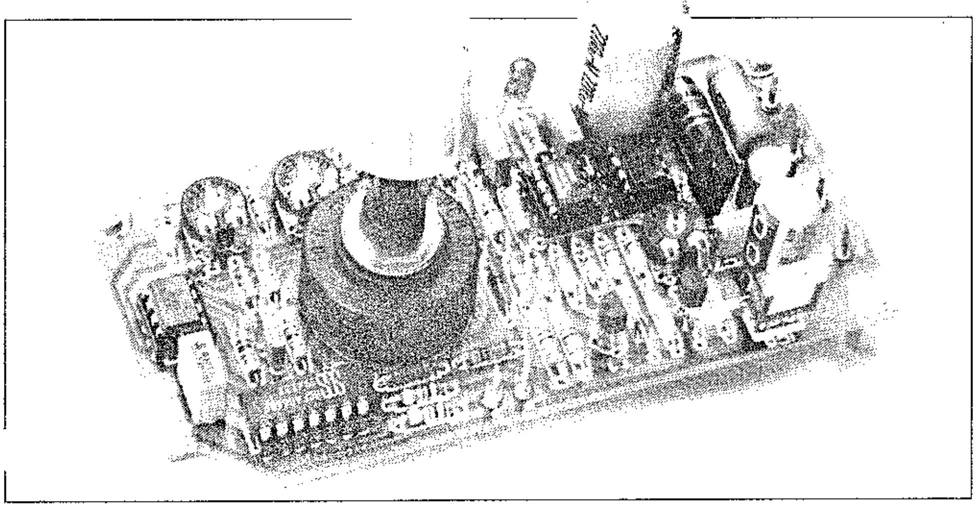

Fig. 5. Completed circuit board, ready for fitting into the enclosure. Note that the left-hand bottom corner of the PCB is cut off diagonally.

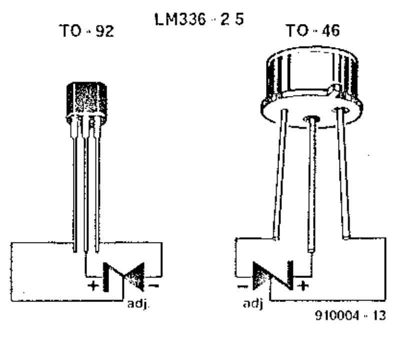

Fig. 6. The LM336-2V5 precision zener diode comes in two different enclosures.

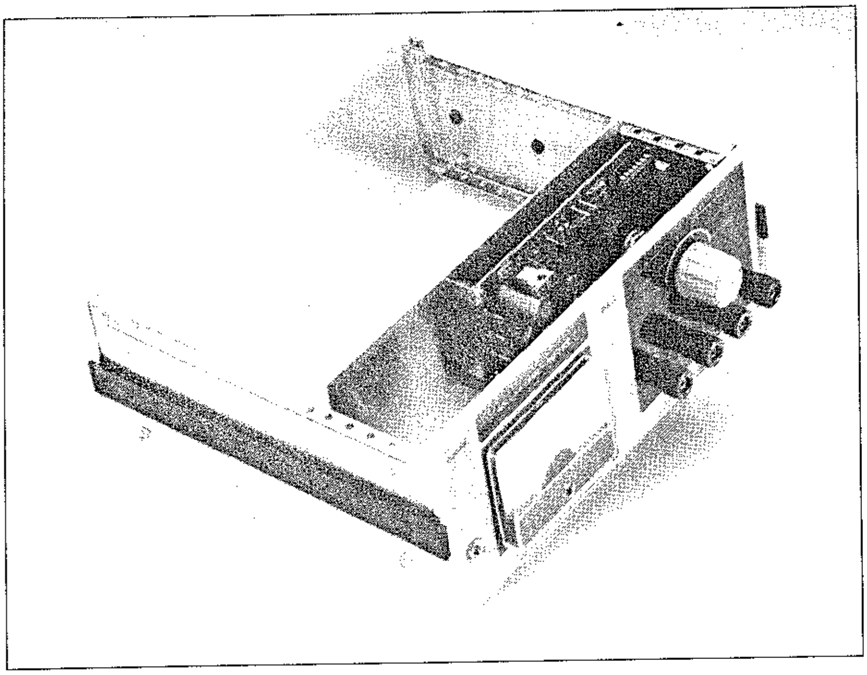

Fig. 7 Internal view of the instrument

Adjustment

To adjust the instrument you require two 1% resistors: one of 1 Ω and one of 0.5 Ω (preferred value) or smaller. Where these resistors are not available, two pieces of 0.5-Ω/m resistance wire may also be used with good results. The 1-Ω resistor then has a length of 2 m, and the 0.5-Ω resistor a length of 1 m. In the first case, an error of 1 cm corresponds to a resistance error of 0.5% — in the second case, to a resistance error of 1%. Resistance wire with a different specification may also be used, although the required values of 1 Ω and 0.5 Ω will be a little more difficult to calculate.

The indicated length of the resistance wire applies to where it is connected to the +Rx and −Rx terminals. This means that the wires must be made slightly longer than 2 m or 1 m to allow the ends to be connected to terminals I+ and I−. Having prepared the calibration resistors, put them aside for the moment.

First, null the moving-coil meter mechanically by adjusting the screw on the front. Switch on the instrument and turn the range switch to select the 100-mΩ range. Connect the +Rx and −Rx terminals, and adjust P2 for maximum meter deflection. Next, re-adjust P2 until the meter just indicates zero. Do not turn P2 any further, since this may cause an unwanted, negative, off-set. Remove the connection between the test terminals. The meter may start to deflect slowly. This is no cause for alarm, however, since it indicates that C4 is charged by the input off-set current. This effect disappears as soon as a resistor is connected to the Rx terminals.

Next, P4 must be adjusted. If you do not have access to an oscilloscope, set the preset to the centre of its travel (this does not affect the accuracy of the instrument). If you do have an oscilloscope, connect the 1-Ω resistor between the I terminals of the instrument. Do not connect the resistor to the Rx terminals as yet. Connect the oscilloscope as close as possible to the resistor body or, when you use resistance wire, at the distance you have previously calculated to produce a resistance of 1 Ω. Adjust P4 until the peak value of the measured voltage is 1 V. This sets a peak current of 1 A. Remove the scope connections and connect the 1-Ω resistor to the Rx terminals. Switch to the 1-Ω range and adjust P3 for full-scale deflection of the meter.

Finally, connect the 0.5-Ω resistor, and switch the instrument to the 0.5-Ω range. Adjust P1 until the meter indicates 0.5 Ω.

This concludes the adjustment of the milliohmmeter. At this point, you may fit the front panel and apply the ready-made two-colour self-adhesive foil that gives the instrument a professional look. ■

Other test instruments in this series are:

- RF inductance meter *Elektor Electronics* October 1989
- LF/HF signal tracer *Elektor Electronics* December 1989
- Simple AC millivoltmeter *Elektor Electronics* January 1990
- Q meter *Elektor Electronics* April 1990
- Budget sweep/function generator *Elektor Electronics* May 1990
- High-current h_FE tester *Elektor Electronics* September 1990
- 400-W laboratory power supply *Elektor Electronics* October 1990 and November 1990

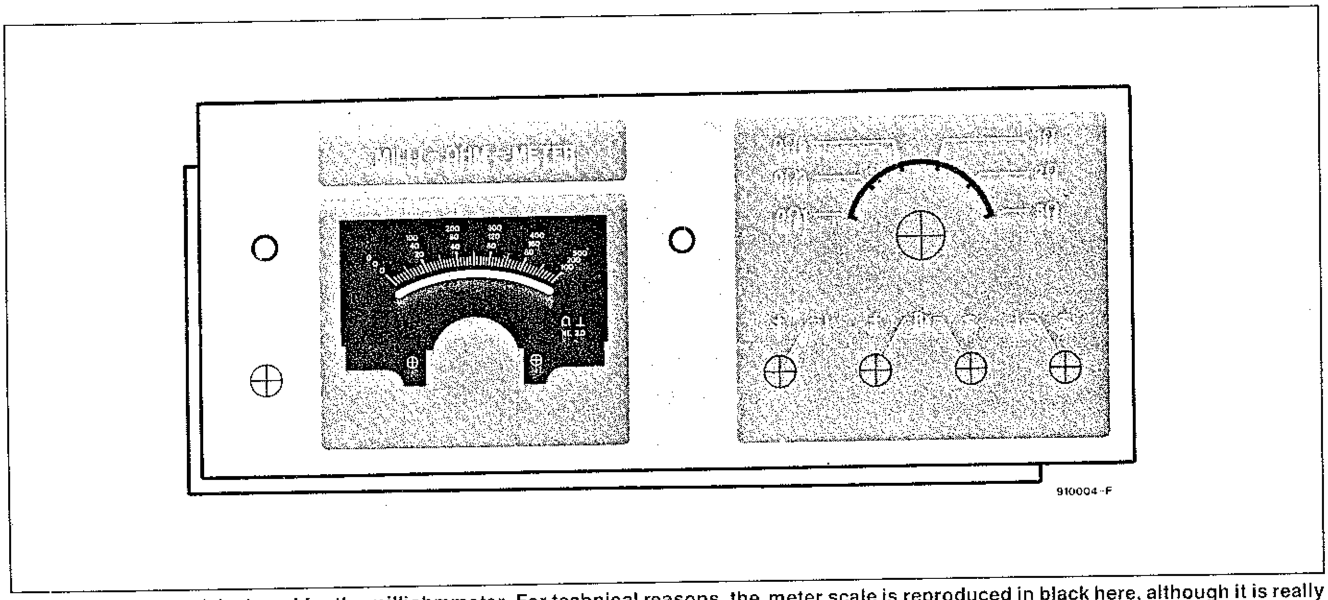

Fig. 8 Front-panel designed for the milliohmmeter. For technical reasons, the meter scale is reproduced in black here, although it is really white. The scale can be cut out of the self-adhesive foil, to replace the one that comes with the moving-coil meter.