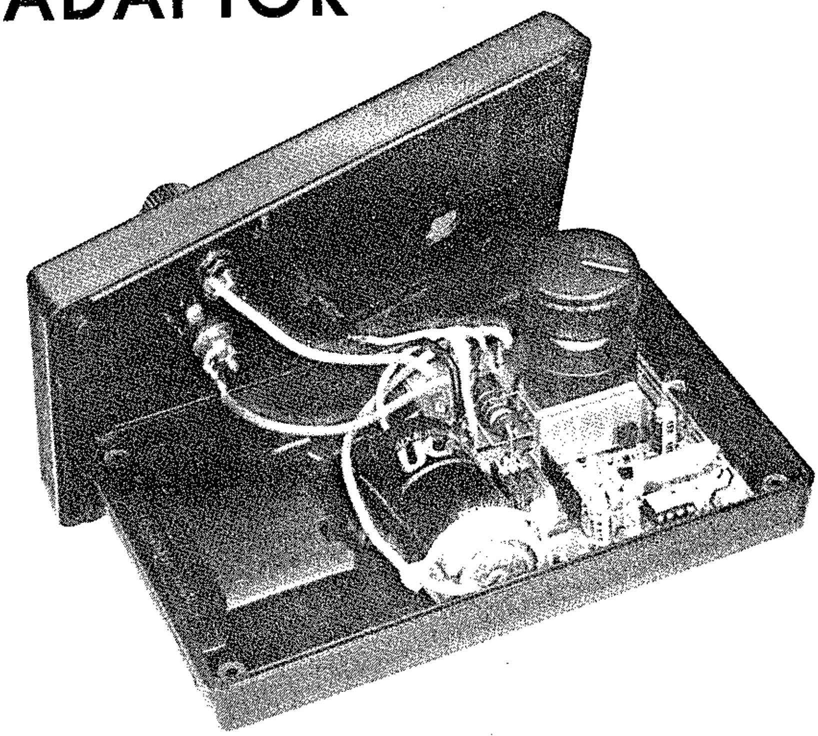
MILLI-OHM MEASUREMENT ADAPTOR

Prices of digital multimeters have come down to a level where they are affordable by almost any hobbyist. Although most multimeters offer a fair number of measurement ranges, including, on some of the latest models, frequency and capacitance, they are not really suited to measuring very small resistance values, say, in the milli-ohm range. The adaptor described here overcomes this problem.



Design by Ing. B.C. Zschocke

RESISTANCE values smaller than 10 Ω or so are notoriously difficult to measure because multimeters often lack a suitable range, or run into tolerances so high that measurement results are at best 'approximate'. Examples of low-value resistors are shunts used with moving-coil meters, and emitter resistors in transistor power amplifiers and power supplies. Typically, such resistors have values in the milli-ohm range, and are almost impossible to measure accurately with the aid of a normal multimeter.

Since low-value resistance measurements will not be required too often, most of you will be reluctant to buy a dedicated milli-ohm meter. Therefore, a simple circuit is described that functions as a mΩ-adaptor for use with any 3½-digit digital multimeter. The measurement ranges created by the adaptor are 20 Ω, 2 Ω and 0.2 Ω for full-scale deflection. The accuracy that can be achieved depends on the multimeter used and the tolerance of the reference resistor in the adaptor.

The resistor to be measured is connected to the multimeter (set to the 200 mV d.c. range) as well as to the adaptor. This creates a four-point resistance measurement.

The basics

The basic operation of the circuit is easily explained with reference to Fig. 1. As soon as the resistor to be measured, R_x, is connected into the circuit, opamp IC_1, power FET T_1 and resistor R_1 supply a reference voltage U_1. This means that a measurement current U_1/R_1 flows through the opamp and R_x. In the present circuit, a reference voltage of 100 mV is used, in combination with selectable reference resistors of 10 Ω, 1 Ω and 0.1 Ω. This results in measurement currents of 10 mA, 100 mA and 1 A. The multimeter is set to the 200-mV range, and connected in parallel with the test sockets on the adaptor.

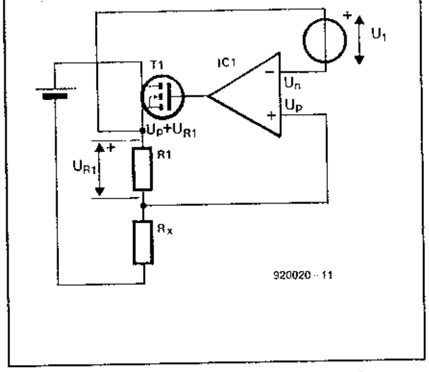


Fig. 1. Principle of four-point resistance measurement. The opamp is assumed ideal here.

When the multimeter has an accuracy of 0.1 mV, a resistance of

$$0.1\ \text{mV}/1\ \text{A} = 100\ \mu\Omega$$

can be measured in the highest current range. The simplicity of this type of measurement has one disadvantage: the measurement result can not be read directly from the multimeter, which gives a mV indication. Depending on the selection of the reference voltage and the reference resistor, the conversion boils down to a simple multiplication with 0.001 (or 1 for mΩ values), 0.01 or 0.1. For example, a meter indication of 167.8 mV in the 20-Ω range corresponds to a resistance of 16.78 Ω.

Practical circuit

The circuit diagram in Fig. 2 is the practical implementation of what has been discussed above concerning the principle of four-point resistance measurement. In fact, the circuit diagram is hardly more complex than Fig. 1: only the range resistor selection and the reference source are added.

A pseudo-zener diode Type TL431C is used as the reference source. The zener takes its unregulated input voltage from a 9-V (PP3) battery. The reference voltage at the − input of the opamp is set by a multiturn

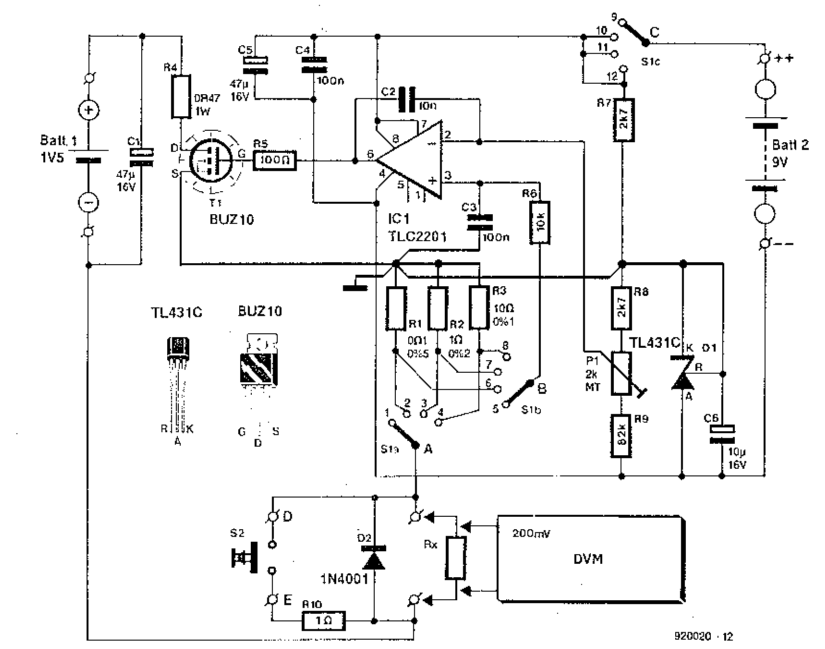


Fig. 2. Circuit diagram of the mΩ adaptor for digital multimeters.

MAIN SPECIFICATIONS

- **Suitable for all digital multimeters with a 200-mV d.c. range**
- **Added measurement ranges: 20 Ω, 2 Ω, 0.2 Ω**
- **Resolution: 10 mΩ, 1 mΩ, 0.1 mΩ**
- **Measurement error: 0.1%, 0.2%, 0.5% (depending on DMM tolerance)**
- **Four-point resistance measurement**

preset, P1 which forms part of a potential divider connected across the reference source. To eleminate the off-set voltage introduced by the opamp, the voltage at the – input is set to 100 mV minus the off-set voltage. All voltages in the circuit are referenced against the cathode of the TL431C.

The opamp adapts the gate drive of FET T1 until the voltage drop across the selected reference resistor (R1, R2 or R3) equals the reference voltage. When this is achieved, the current through Rx is either 1 A, 100 mA or 1 mA.

An *R-C* network, R6-C3, and a capacitor, C2, ensure a high d.c. amplification of the opamp, while keeping the a.c. amplification as small as possible to prevent instability.

There are good reasons for using a less than common opamp in this circuit. The TLC2201 from Texas Instruments offers a large drive margin right up to about 0.1 V below the supply voltage, while its off-set voltage remains stable despite changes in the ambient temperature and the supply voltage. Also, its input bias current is very small thanks to the use of input FETs. The large drive margin is essential here to ensure sufficient gate drive for the FET at a relatively low supply voltage (battery operation).

Given the relatively high measurement currents, the contact resistance of the range switch must be taken into account. That is why the opamp input, pin 3, is connected to the selected measurement resistor via R6 and an extra deck on switch S1, rather than directly to the pole of S1a (point 'A').

The functions of the rest of the components in the circuit are easily explained. Resistor R4 reduces the power dissipation in the FET. It can be made smaller when high contact resistances are to be compensated in the measurement circuit. Push-button S2 and resistor R10 are included to check the correct function of the adaptor and the multimeter ('battery test'). The 1.5-V battery marked 'Batt 1' in the circuit diagram may be a 'mono' (IEC R20) or 'baby' (IEC R14) type, or a 'mignon'-size (IEC R6) NiCd battery. The internal resistance of all these three battery types is sufficiently small. The battery marked 'Batt 2' is a 9-V PP3 (IEC 6F22) power pack.

Diode D2 protects the circuit against back e.m.f. produced when inductances are measured. A protection against external voltages is **not** provided. Also, be careful when measuring the resistance of transformer windings—the voltage induced in the primary winding may be dangerous!

Construction and adjustment

The adaptor is built on a small single-sided printed circuit board, of which the artwork is shown in Fig. 3. Because of the relatively high measurement current, it is recommended to use fairly thick wires (e.g., 0.75 mm² multi-strand wire). Do not use solder terminals—instead, solder the wires directly to the board, the battery holder and the terminal posts on the front panel. The terminal posts (or 'wander sockets' as they are sometimes called) are types with a horizontal through hole in the threaded shaft. These holes are used to clamp down the wires of the resistor to be measured, while the probes of the multimeter are inserted into the vertical cylinders in the terminals.

To adjust the adaptor, set it to the highest measurement range (reference resistor R3, switch S1a to position '4'). Short-circuit the measurement posts. Connect the multimeter probes directly across reference resistor R3, and adjust preset P1 until the DMM indicates 100 mV. It is recommended to repeat this adjustment from time to time.

In principle, the adaptor may also be adjusted in any of the two other ranges. However, adjustment in the 20-Ω range will provide the highest accuracy because the measurement resistor in this range has the smallest tolerance (0.1%). In any case, fit new batteries before adjusting the adaptor.

A few remarks on the battery voltages: the BUZ10 (T1) starts to conduct at gate voltages between 2.1 V and 4 V. A drain current of 1 A requires a gate-source voltage of 4.5 V or more. In practice, this means that the battery voltage of Batt 2 must not drop below 7 V. Theoretically, the lowest voltage of Batt 1 is

$$I_{max}\,(R4+R1+R_{max}) =$$
$$1\,(0.47+0.1+0.2) = 0.77\ V$$

Again in practice, the minimum battery voltage will higher at about 1 V to allow for the drain-source voltage ($U_{d\text{-}s}$) of T1, wire losses,

Table 1. DMM indication to value conversion

Measurement range (adaptor)	Indication (DMM)	Resistance (Rx)	Conversion
0.2 Ω	200mV	200 mΩ	readout × 1 mΩ/mV
2.0 Ω	200mV	2 Ω	readout × 0.01 Ω/mV
20 Ω	200mV	20 Ω	readout × 0.1 Ω/mV

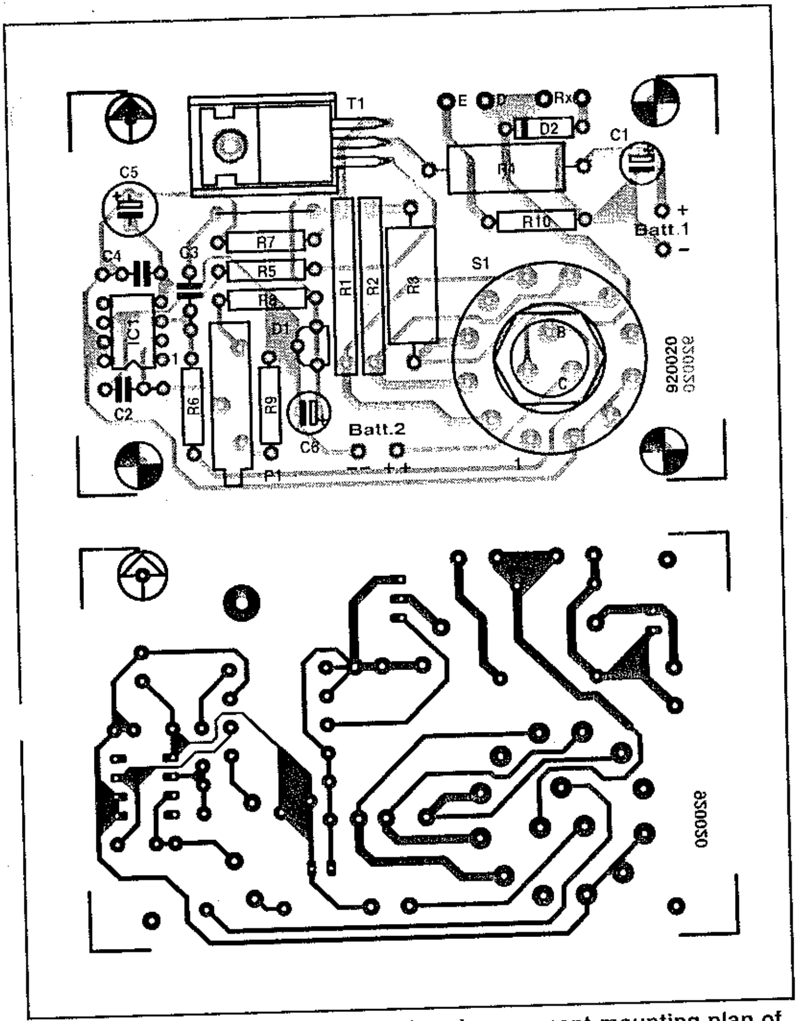


Fig. 3. Track layout (mirror image) and component mounting plan of the adaptor PCB.

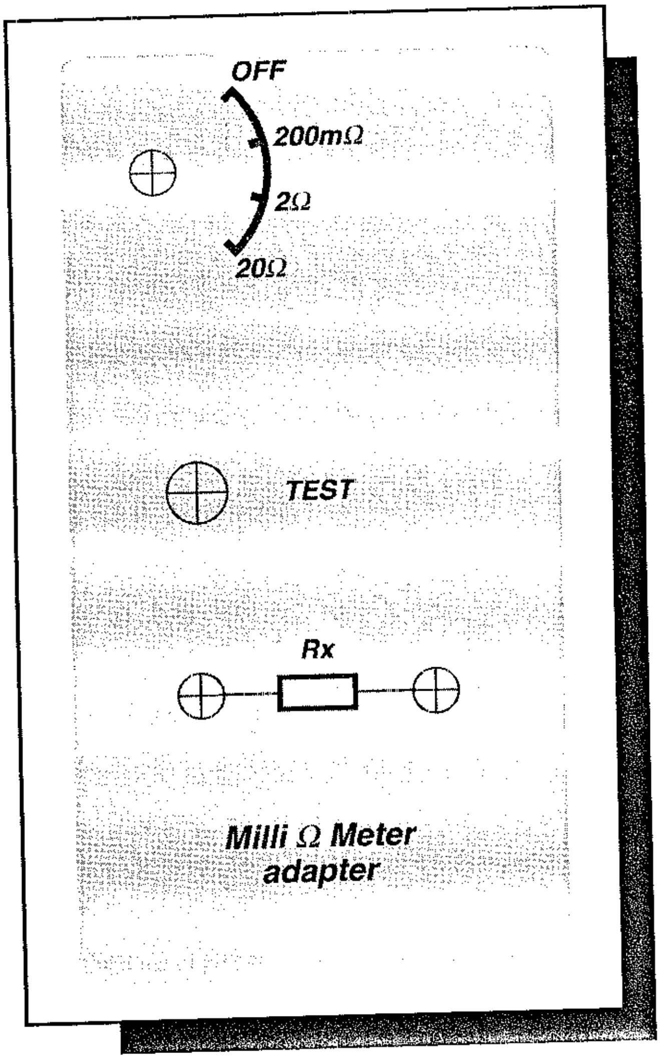


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Fig. 4. Suggested front panel design.

and copper track losses.

When long test wires are used between the adaptor and the resistor to be measured, or when high contact resistances are to be taken into account, resistor R1 should be made smaller, e.g., 0.22 Ω.

Practical use

The unknown resistor and the DMM are connected to the terminal posts on the front panel of the milli-ohm adaptor. The reading on the DMM is converted into a resistance value as shown in Table 1.

As already mentioned, care should be taken when measuring inductive components such as large chokes and transformer windings. When an inductive component is disconnected from the adaptor, it may produce an induced voltage. In the interest of safety, keep to the following order: (1) connect the unknown inductor to the adaptor; (2) connect the multimeter; (3) switch on the adaptor with S1. The opposite order applies when the measurement is finished: (1) turn off the adaptor; (2) disconnect the multimeter; (3) disconnect the inductor. Large inductances, for example, power transformers, are best short-circuited before disconnecting.

Fortunately, the above connection and disconnection order need not be observed when purely resistive components are measured.

Extensions

It is, of course, possible to extend the present adaptor into a dedicated milli-ohm meter: all that is required to do so is a separate power supply and a conventional DVM module. The inputs of the DVM are then connected directly between the pole of S1b and the ground. In this way, the DVM measures the ratio of the unknown resistance to the reference resistance, independent (within limits, of course) of the measurement current, which makes adjustment unnecessary. The accuracy of the instrument thus depends on the accuracy of the DVM module and that of the reference resistor. ■

COMPONENTS LIST

Resistors:

1	0Ω1 0.5%	R1
1	1Ω 0.2%	R2
1	10Ω 0.1%	R3
1	0Ω47 1W	R4
1	100Ω	R5
1	10kΩ	R6
2	2kΩ7	R7;R8
1	82kΩ	R9
1	1Ω	R10
1	2kΩ multiturn preset	P1

Capacitors:

2	47µF 16V radial	C1;C5
1	10nF	C2
2	100nF	C3;C4
1	10µF 16V radial	

Semiconductors:

1	TL431C	D1
1	1N4001	D2
1	BUZ10	T1
1	TLC2201	IC1

Miscellaneous:

1	3-pole 4-way PCB mount rotary switch	S1
1	SPST push-button	S2
1	9V battery with clip	Batt.1
1	1.5V battery with holder	Batt 2
1	Heat-sink for T1	
1	ABS enclosure size approx 145×90×30mm	
1	Terminal post black	
1	Terminal post red	
1	Printed circuit board	920020