. . . IN CIRCUIT OHMMETER

By O.N. BISHOP

This instrument can be used for measuring the resistance of a component without the need to disconnect it from its circuit. This facility can save a lot of time in circuit checking, particularly when working with miniature components on circuit boards. It may also be used in the normal manner for checking unconnected components.

Like a conventional ohmmeter, it can be used for discovering short-circuits and checking continuity—again without removing components from the board.

Utilising a 50μA meter, it covers five ranges with full scale deflections of 500Ω, 5kΩ, 50kΩ, 500kΩ and 5MΩ respectively. Scaling is linear with an accuracy of $\pm$ 1 per cent. This means that the meter face does not have to be calibrated.

Other applications include go/no-go checks for semiconductors and capacitors.

HOW IT WORKS

The action of this ohmmeter depends on a special property of the operational amplifier, when connected as shown in Fig. 1. Here, the potential at the inverting input is automatically held at zero, with respect to negative potential. We sometimes say that the inverting input is a "virtual ground".

The non-inverting input (+) is at negative potential simply because it is wired to the negative rail. But the inverting input has a current (I_r) flowing to it. To keep the potential at zero, the amplifier detects this current and almost instantaneously adjusts its own output voltage (E_o) to cause a current (I_x) to flow in its feedback loop. This current is just sufficient to keep the potential of the inverting input at ground, or zero. In other words, the current I_x is equal in magnitude to I_r, but opposite in sign. It flows away from the inverting input. Mathematically we can say that

$$I_x = -I_r$$

The input, or reference current, comes from a reference cell, of voltage E_r and before reaching the inverting input flows through a reference resistor, R_r, so that

$$I_r = \frac{E_r}{R_r}$$

Similarly for the current in the feedback loop:

$$I_x = \frac{E_o}{R_x}$$

Since I_x is equal but opposite to I_r, we can combine these two equations and get

$$\frac{E_o}{R_x} = -\frac{E_r}{R_r}$$

which by rearrangement of terms gives:

$$R_x = -\frac{R_r}{E_r} \cdot E_o$$

This is the basis of resistance measurements by the ohmmeter. R_x is the unknown resistance which we want to measure. R_r and E_r are known and are constant. For different values of R_x we obtain different values of E_o, and E_o is linearly though inversely related to R_x. If we place a voltmeter between the output of the amplifier and the ground rail we can measure E_o, and use this value to derive the value for R_x. In practice we do not have to do any actual calculation; we simply calibrate the meter scale of the voltmeter to read "Ohms" instead of "Volts".

IN-CIRCUIT OPERATION

Fig. 2 shows R_x as part of a complex network of resistors. Some of the "resistors" in the diagram might be other components with some degree of electrical resistance, such as diodes, transistors, inductances or capacitors. To operate the ohmmeter in these circumstances the distant terminals of all resistors adjacent to R_x must be grounded. In the diagram, points C, D, E and F would need to be grounded.

Terminal A of R_x is at ground potential owing to the nature of the amplifier circuit, as explained above. Points C and D are also grounded. Since both ends of R_c and R_d are at ground potential, no current can flow through these resistors—they might just as well not be there. We can ignore them. Terminal B has a potential E_o provided by the output of the amplifier. Within very wide limits of load this potential is constant. So current flows from ground through R_f and R_e, but without affecting E_o. In this way the meter reads the resistance R_x, and is entirely unaffected by the network around.

The only circumstance in which this circuit will not ignore other resistors is when another resistor is wired in parallel with R_x. Then it is not possible to ground its distant terminal without also grounding either point A or B. The meter will indicate the parallel resistance of R_x and the second resistance, but not the resistance of R_x alone. If the second resistor should be a variable resistor there is no problem, for by grounding the wiper of the resistor we can treat it as two separate resistors.

CIRCUIT DETAILS

The practical circuit is shown in Fig. 3. The current I_r comes from B1, which also powers part of the amplifier IC1. The Zener diode D1 gives a regulated 5·1 volts and the resistors R2 and VR1 connected across D1 act as a potential divider. By adjustment of VR1 a voltage of 0·1 volts can be obtained at the wiper. This is E_r.

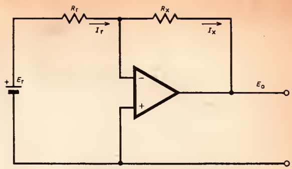


Fig. 1. Basic op. amp. circuit

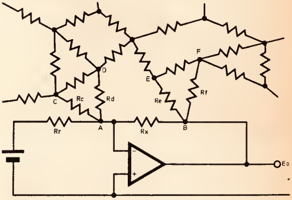


Fig. 2. In-circuit measurement

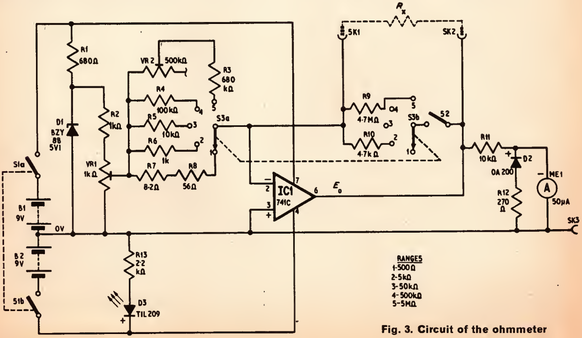


Fig. 3. Circuit of the ohmmeter

To provide a number of ranges any one of the resistors or resistor combinations R3/VR2, R4, R5, R6, or R7/8 can be switched into circuit, to act as R_r of Fig. 1. The output from the amplifier is fed out to the resistor to be measured through a terminal SK2 and back through SK1 to the inverting input of the amplifier. The voltmeter for output is a microammeter in series with resistor R11. So connected, the meter will give full-scale deflection for $E_o = -0{\cdot}5$ volts. Inserting these working values of E_i and maximum E_o in the equation, we can calculate that for any range the maximum resistance measurable is:

$$R_{x(max)} = -\frac{R_r}{0{\cdot}1}(-0{\cdot}5)$$
$$= 5R_r$$

So, when R6 is in circuit, f.s.d. of meter indicates R_x = 5kΩ; similarly, when R5 is in circuit, f.s.d. indicates 50kΩ and with R4, f.s.d. indicates 500kΩ. For a f.s.d. of 500Ω one might think that R7 and R8 should total 100Ω, but in practice they total only 64Ω. This is because such a low resistance draws a heavy current from the potential divider, and the potential (E_r) of the wiper falls. A corresponding reduction of R_r from theoretical 100V to practical 64V restores the balance of the equation, and gives f.s.d. at 500Ω. At the highest range, 5MΩ at f.s.d., the amplifier output does not reach the theoretical level, so the reference current has to be increased by using a reference resistor less than 1MΩ. This is provided by R3, with VR2 in series for adjustment to the correct total value.

CONTINUITY CHECKS

On all ranges short-circuiting of SK1 and SK2 puts R_x at zero, so E_o falls to zero. So this instrument can be used for checking continuity. When the terminals are unconnected, R_x is infinite and E_o is infinite too, at least theoretically, though the characteristics of the amplifier limit it to about −7 volts. Such a high voltage across a meter rated at 0·5 volts would damage the winding so D2 and R12 are wired in parallel to the meter to limit meter current to about 75μA. At low potentials the diode is non-conducting, but with increasing potentials the meter exceeds f.s.d. and the diode begins to conduct in its forward direction so that excess current is shunted through it.

The l.e.d. indicator is important for, unlike an ordinary ohmmeter which uses current only when actually connected to a resistor, this ohmmeter uses current as long as it is switched on. It draws about 7mA from B1 and, with the indicator l.e.d. in the B2 circuit, draws about 4·5mA from B2. These are low requirements, so small PP3 batteries can be used.

INTERNAL RESISTORS

By closing S2, one of two internal resistors (R9, R10) can be connected across the sockets, if the meter is also switched to range 2 (5kΩ f.s.d.) or range 5 (5MΩ f.s.d.). The purpose of these is threefold. They provide a simple check on battery condition and meter adjustment. They are used when checking capacitors or when measuring resistances greater than 5MΩ. The calculation for this is given later.

COMPONENTS . . .

Resistors

R1	680Ω
R2	1kΩ
R3	680kΩ
R4	100kΩ 2%
R5	10kΩ 2%
R6	1kΩ 2%
R7	8·2Ω
R8	56Ω
R9	4·7MΩ
R10	4·7kΩ
R11	10kΩ
R12	270Ω
R13	2·2kΩ

All 5% ¼ W carbon unless stated otherwise

Potentiometers

VR1	1k Ω
VR2	500k Ω
VR3	100 Ω (optional, see text)

Semiconductors

D1	BZY88 Zener 400mW, 5·1V
D2	OA200
D3	TIL209, l.e.d.

Integrated circuit

IC1 741C op. amp.

Miscellaneous

ME1	Microammeter, 50μA f.s.d. SEW SD830 or similar
S1	Push-switch or toggle switch, DPST
S2	Push-switch or toggle switch, SPST
S3	Rotary wave-change switch, 2-pole, 6-way
SK1–3	Terminals, yellow, green, black

Veroboard, 0·1 in matrix, 24 holes×24 strips (half a 5″×2½″ board)
Veropins; knob for S3, battery connectors.
1% or 2% resistors for calibration (470Ω, 4·7kΩ, 47kΩ, 470kΩ, 4·7MΩ.)

OHMMETER WIRING DETAILS

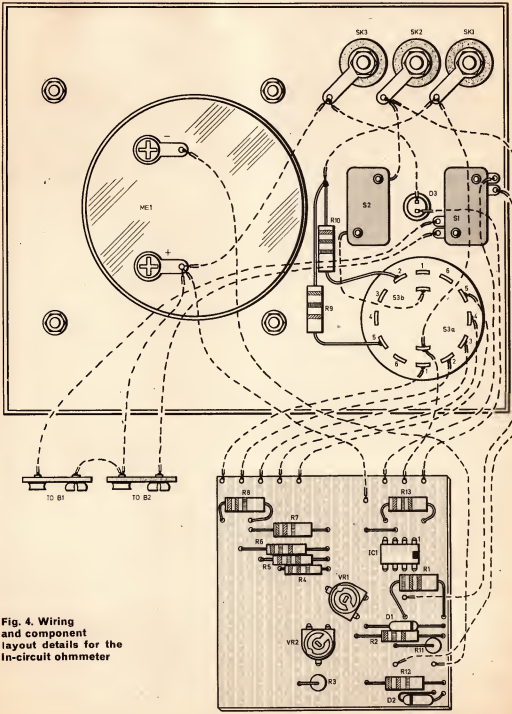
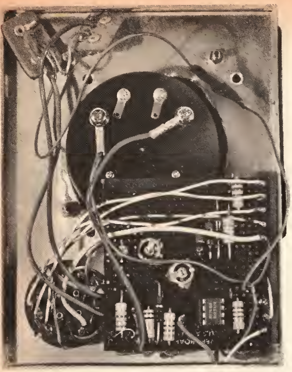


Fig. 4. Wiring and component layout details for the In-circuit ohmmeter



CONSTRUCTION

This presents few problems. Details of layout of circuit board are given in Fig. 4, and are not critical.

The lid of a 10·5cm × 13·5cm × 4cm box was drilled for meter, terminals, switches and l.e.d., and the connections between these were completed before wiring to the circuit board. Fairly long leads were routed to these components, ready for making connections to the Veropins on the circuit board. For convenience the circuit board, with components ready mounted on it, was stuck to the back of the meter case, using contact adhesive; connections to the board then being made.

Apart from marking switch positions for S3, no panel labelling was thought to be necessary. The switch positions were indicated by coloured discs stuck in position on the panel. In order from low to high range these discs were brown, red, orange, yellow and green. This corresponds to the resistor colour code, being the third colour of a resistor corresponding to f.s.d. on each range. Coloured self-adhesive spots sold as colour-slide spots were used for red, yellow and green, and the other discs were punched from coloured card.

SETTING UP

Make sure S2 is open, then connect a 4·7kΩ resistor across terminals SK1 and SK2. If possible, use a 1% or 2% resistor but, if not, try with several 5% resistors. Switch to the 5kΩ range and switch on the batteries. The needle may rest anywhere on the scale, or even swing violently beyond 50. Adjust VR1 until the needle comes to 47 (corresponding to 4.7kΩ on this range). It can now be seen why a precision resistor is not required for R11. Any inaccuracy in R11 is compensated for by adjusting VR1. The value of E_r is only nominally 0·1V and f.s.d. is only nominally 0·5V, but the ratio between them remains the same (1 : 5) and the equation still applies.

Now check the 50kΩ and 500kΩ ranges, using 47kΩ and 470kΩ external resistors. These should give correct readings (47 on the scale in each case) without further adjustment of VR1. If not, check wiring—particularly correct connections on the rotary switch, and also that R10 really was out of circuit when you set the 5kΩ range!

Now put a 4·7MΩ resistor across the terminals and switch to the 5MΩ range. Adjust VR2 until the meter reads 47. Finally switch to the 500Ω range, with a 470Ω resistor across the terminals; the needle should read 47. If it reads low, reduce the value of R8; if it reads high, increase R8. Some constructors may prefer to use a 100Ω preset in place of R7 and R8 and adjust this to get the correct reading.

Check the internal resistors by closing S2. The needle should read 47 on the 5kΩ and 5MΩ ranges, with no resistors connected externally to the terminals. Battery condition can also be assessed by this.

USING THE METER

Individual components are connected across SK1 and SK2. Components in circuit are tested by first disconnecting any power supply from the circuit and discharging any capacitors. Then the device under test is connected to SK1 and SK2. The distant terminals of any devices which are joined to the device under test are grounded by connecting them to SK3. A number of leads with crocodile clips will be found useful for this.

When measuring resistances, be sure to have S2 open, or there will be false readings on the 5kΩ and 5MΩ ranges.

The internal resistor of the 5MΩ range can be made use of for measuring resistances higher than 5MΩ. The formula for such resistances in series is:

$$\frac{1}{R} = \frac{1}{R_x} + \frac{1}{4{\cdot}7}$$

Where R is the resistance measured as shown on the scale, R_x is the unknown external resistor, and all values are expressed in megohms. This equation can be rearranged to give:

$$R_x = \frac{4{\cdot}7 \times R}{4{\cdot}7 - R}$$

So if R is measured, R_x can be calculated. If scale reading is 46 (normally equivalent to 4.6MΩ on this range), this would indicate a value of $R_x = (4{\cdot}7 \times 4{\cdot}6)/(4{\cdot}7 - 4{\cdot}6) = 21{\cdot}62/0{\cdot}1 = 216$MΩ. So by using the internal resistor one can estimate very high resistances, though with reduced accuracy, for with high resistances the difference between 4·7 and R is only a few scale-divisions, which cannot be estimated to a high percentage accuracy. Still, one is no worse off than when measuring high resistances at the crowded end of the scale of an ordinary ohmmeter.

Diodes and transistors can be tested for shorts and open-circuit—often a sufficient means of confirming that a component is useless. Switch to the 5MΩ range for these tests. Terminal SK1 is positive to SK2, and by connecting a diode first one way round then the other it can soon be found if it passes negligible reverse current (equivalent to high resistance—often in excess of f.s.d.). Similarly an *npn* transistor will conduct from base to emitter and

from base to collector, but not in reverse or from collector to emitter. A *pnp* transistor will conduct only from emitter or collector to base. When connected for conduction, the meter will indicate some resistance less than f.s.d. When otherwise connected, a greater resistance (usually greater than f.s.d.) will be shown.

CAPACITORS

To test capacitors, switch to either the 5kΩ range (for capacitors of 1µF or more) or the 5MΩ range (for capacitors less than 1µF). Close switch S2. Without the capacitor in place, the needle should read 47. When a capacitor is connected across SK1 and SK2, the needle kicks sharply toward zero, then steadily returns to 47. The higher the capacitance the greater the swing, and the longer time taken to return to 47. It is important to discharge the capacitor before testing and re-testing. With electrolytic capacitors observe correct polarity (positive to SK1). Take care not to charge the capacitor unknowingly; if you touch one terminal of the capacitor with one hand, and have the other hand in contact with a lead from the instrument, a current can pass through your body sufficient to charge the capacitor appreciably, and give a false reading—possibly *no* kick, which would be taken to indicate a useless open-circuit capacitor.

It is worth remembering this point too when measuring high resistances. The resistance of the human body from hand to hand is about 1–2MΩ. If this is shunted across a high resistor under test a very false reading will be obtained.

Readers may observe that the time taken for the needle to fully return to its starting point (47) is proportional to the capacitance of the capacitor. This could be the basis of a simple and rough way of estimating capacitance. Similar capacitance testing can be done with an ordinary ohmmeter, but usually a barely perceptible kick is obtained below 10,000pF. With this ohmmeter a useful check can be made on capacitors as low as 30pF. ★