TRANSISTOR MILLIVOLTMETER

By F. G. RAYER

This instrument is of quite small size, and operates from a 4·5V battery, the current drawn being a little under 10mA. It has two main uses: measuring very small d.c. voltages; and measuring low, medium, or high voltages with extremely small current drain from the point tested.

METER RANGES

Readings are obtained on a 1mA moving coil meter, and sensitivity is adjustable. On the author's model, maximum sensitivity is 6mV (0·006V) for a full-scale reading of 1mA on the meter.

To allow easy reading on a 0–1mA scale, it is best to use ranges such as 0–100mV, 0–1V and 0–10V, then the original milliammeter scale need not be altered. A 1mA meter will usually be calibrated from 0 to 1mA at 0·1mA and smaller intervals. It is only necessary to ignore the decimal point, or mentally add one or more noughts, according to the range in use.

If a more sensitive meter movement is to hand, it can be shunted to obtain a full-scale range of 1mA. So a 0·5mA (500μA), 250μA, or 100μA meter can be utilised. The shunt may be calculated from:

$$\text{Shunt (ohms)} = \frac{\text{meter coil resistance (ohms)}}{(n-1)}$$

where n is the number of times the full-scale reading is to be multiplied.

Alternatively, a shunt can be made by trial and error, checking the full-scale reading against a testmeter as follows. Place the two meters in series, with a variable resistor (or potentiometer) and battery in circuit. Take care to have sufficient series resistance to avoid damage—a 50 kilohm potentiometer is suitable with a 100μA meter and 4·5V battery. With this voltage, a 20 kilohm or 25 kilohm potentiometer will do for a 250μA meter, while a 10 kilohm potentiometer is sufficient for a 0·5mA meter. Find a suitable length of resistance wire for the shunt by trials, wind it on insulating material, and solder it to tags on the meter terminals.

To avoid opening the meter, the ranges are best chosen to suit the existing scale. For a 100μA meter, they can be as for the 1mA instrument. For a 250μA meter, ranges such as 0–25mV, 0–250mV, 0–2·5V, etc., can be read at once. With a 0·5mA or 500μA meter, ranges of 0–50mV, 0–500mV, 0–5V and so on will suit the scale.

MULTIPLIER PRODS

Low, medium, and high voltages can be read using suitable voltage prods with series multiplier resistors.

The transistorised instrument has no particular advantage for testing batteries, power supplies, or other circuit voltages where the current drawn by an ordinary moving coil voltmeter is insignificant and causes no appreciable change in potential. But when the potential to be measured is obtained through a high series resistance, or will drop severely if an ordinary voltmeter is connected, then the transistorised meter gives a reading of much higher accuracy.

A conventional voltmeter or multirange testmeter incorporating a 1mA movement is said to be a "1,000 ohms per volt" (1kΩ/V) instrument. This means that on a 0–1V range its series resistance would be 1 kilohm, and it draws 1mA from a point having a potential of 1V. In the same way, a 10kΩ/V instrument has a series resistance of 10 kilohm for a 0–1V range, and draws 0·1mA when reading 1V on this range.

The transistorised meter can be used with an input resistance of 100kΩ/V, or even 1 megohm per volt, if wanted. Circuit point potentials can then be checked with negligible loading by the meter.

Ranges are obtained as described later. For transistorised equipment using supplies up to 9V, the 0–100mV, 0–1V, and 0–10V ranges are convenient.

CIRCUIT DESCRIPTION

Fig. 1 shows the circuit of the complete instrument.

With no voltage applied to the input terminals, the circuit is balanced, and no reading is obtained on the 1mA meter M1. Now assume a positive potential is applied to the blue input lead; the base of TR1 becomes more positive, so collector current falls. The voltage drop across R3 is thus reduced, making, in turn, TR3 base negative. The collector current of TR3 through R6 rises, and an increased voltage drop occurs across R6, so that TR5 base moves positive. The collector and emitter current of TR5 falls, reducing the voltage drop in R9, so that the junction point of R9 and VR2 is now more positive. At the same time transistors TR2, TR4, and TR6 have operated in the reverse manner, so that TR6 is passing a larger collector and emitter current, thus increasing the voltage drop in R10. Consequently a potential difference appears across the 1mA meter and VR2, and a reading appears on M1.

VR1 is a balancing control, to compensate for variations in the tolerances of resistors and transistors. This control is set so that the M1 reads zero with no input voltage.

VR2 allows sensitivity to be adjusted to suit the meter scale, or in some cases the range wanted. Increasing the value of VR2 reduces sensitivity.

CIRCUIT BOARD

Most of the circuit components are mounted on a piece of laminated plastics board, $\frac{1}{16}$in thick. Dimensions and drilling positions are indicated in Fig. 3. The corner fixing holes can be $\frac{1}{8}$in, and other holes $\frac{1}{16}$in.

The components are placed as in Fig. 2.

Assembly of components commences with the resistors.

(Note: To avoid unnecessary unbalance, R3, R4, R6, R7, R9 and R10 are 5 per cent tolerance, or 10 per cent resistors selected with a meter. Pairs of matching values are more important than the actual value.)

The resistor wire leads are bent a little clear of the body and passed through the holes. The board is then turned over and connections made as in Fig. 3.

The transistors are then fitted. Cut $\frac{1}{2}$in lengths of red sleeving for the collector wires, and similar lengths of yellow sleeving for the emitter leads. Base wires are bare, except for TR2. Connections are then easily identified. In Fig. 2 and Fig. 3, e, b, and c indicate emitter, base and collector respectively. Solder the transistors with usual care, removing the iron immediately the joint is made.

Snip off surplus wires. External connections should be made with thin coloured flex for easy identification. Blue is positive input, and grey negative. White leads from TR1 and TR2 emitters go to the outer tags of VR1, Fig. 2. A red lead runs from VR1 slider to R5. Black and red run from R10 and VR2, for the milliammeter. Take a further pair of black and red leads from C and R11 in Fig. 2, for the battery BY1. A 4·5V lamp battery will provide long service, and leads can be soldered directly to it. The on/off switch S1 is in the negative lead.

HOUSING THE INSTRUMENT

A wooden box was used for the prototype. The milliammeter M1 and other items are fixed to an insulated panel which is secured to the front of the box.

Of course, it is not essential to make the case, since various square and sloping front instrument cases of similar dimensions can be bought. A cheap plastic box is also satisfactory. Clear boxes can be painted inside.

The general assembly and covering is shown in Fig. 4. After testing, secure the circuit board with wood screws. A bracket cut from scrap metal helps keep the battery in place.

INITIAL TEST

An initial test should be made immediately after wiring. Proceed as follows. Connect a 1 kilohm resistor from blue to grey (across input) and adjust VR2 so that the whole element is in circuit (knob anticlockwise). Temporarily place a meter in one battery lead and switch on. Current should be around 7mA to 10mA. If much lower or higher, switch off at once and look for a wrong connection, short circuit, or wrong resistor value.

When VR2 is rotated towards minimum resistance, the 1mA meter will probably show some current. Adjust VR1 to restore the reading to zero.

If VR1 reaches its limit in one direction, without zero being obtained, the pairs of resistors R3 and R4, R6 and R7, or R9 and R10 may be unbalanced. If there is no obvious mistake such as an error in reading

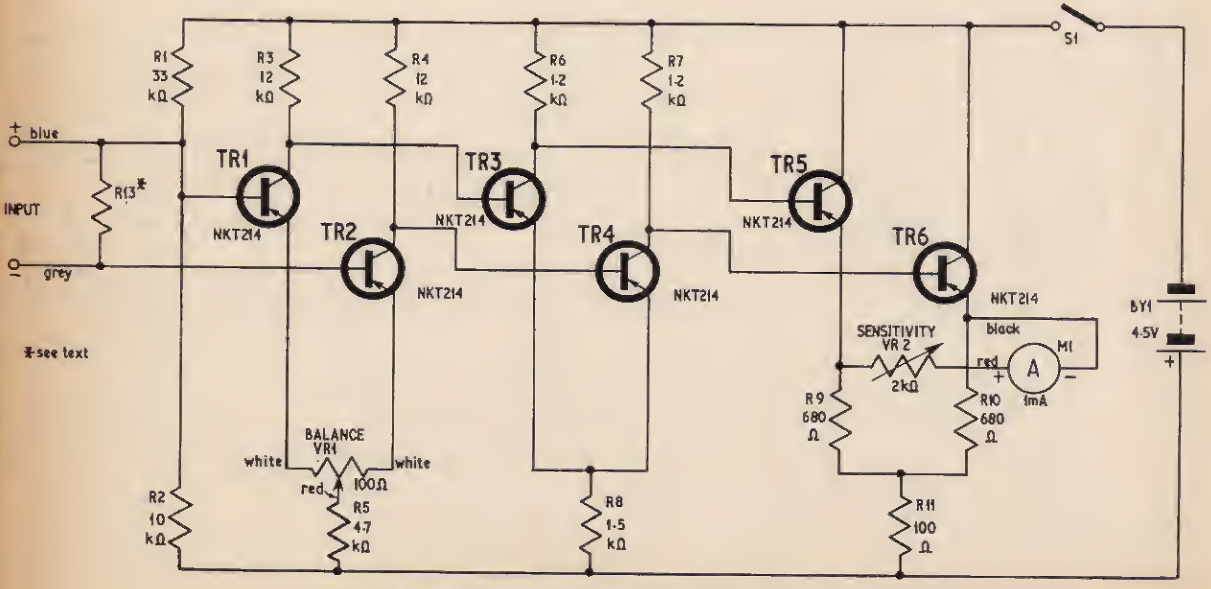

Fig. 1. Circuit diagram of the transistor millivoltmeter

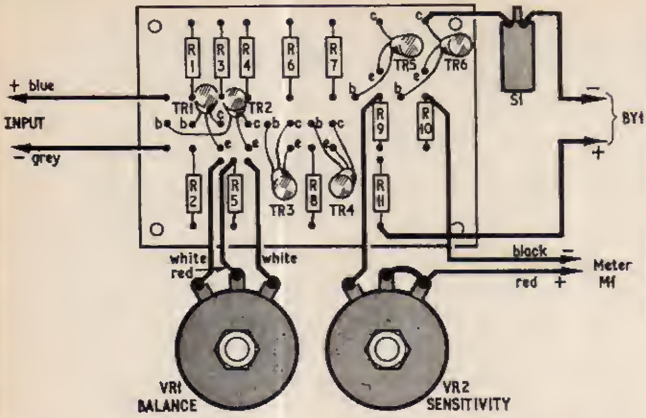

Fig. 2. Circuit board showing arrangement of components

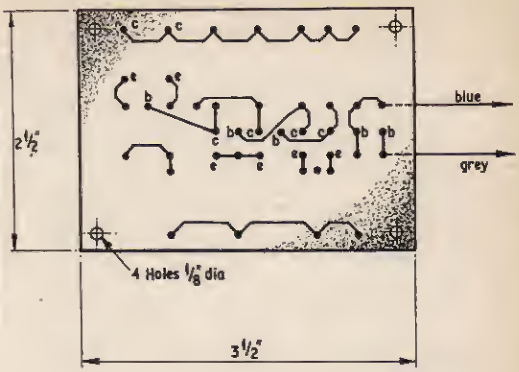

Fig. 3. Underside wiring of circuit board

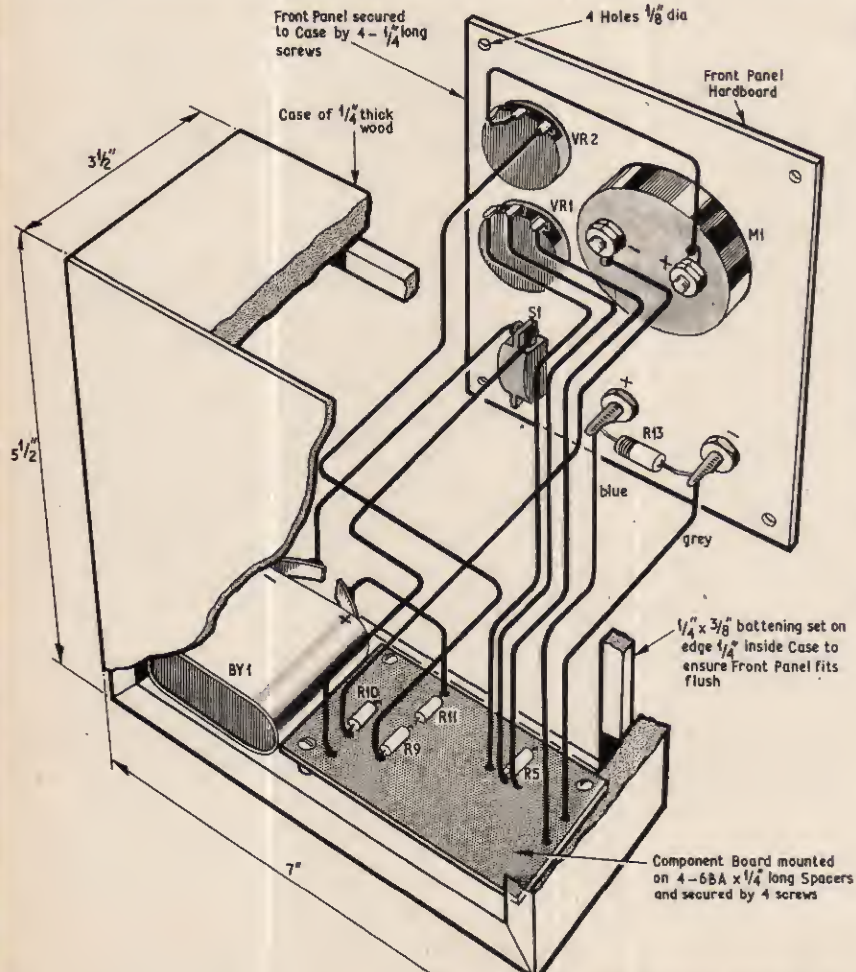

Fig. 4. General assembly and wiring of the millivoltmeter

COMPONENTS...

Resistors

R1	33kΩ
R2	10kΩ
R3	12kΩ 5%
R4	12kΩ 5%
R5	4·7kΩ
R6	1·2kΩ 5%
R7	1·2kΩ 5%
R8	1·5kΩ
R9	680Ω 5%
R10	680Ω 5%
R11	100Ω
R12, R13	See text

All ±10%, ¼W carbon, except where otherwise stated

Potentiometers

VR1	100Ω linear
VR2	2kΩ linear

Transistors

TR1–6 NKT214 (Newmarket) (6 off)

Miscellaneous

BY1	4·5V flat torch battery
M1	Moving coil meter, 1mA f.s.d.
S1	Single pole on/off toggle switch

Two terminals. Two knobs
Piece $\frac{1}{16}$in plastics laminate
Material for case (see Fig. 4)
Material for prod (see Fig. 6)

colour coding, it should only be necessary to change R3 or R4. Temporarily place a 100 kilohm, 68 kilohm or 47 kilohm resistor across R3 or R4. If this sufficiently corrects the error, it can be left. Alternatively, slightly reduce the value of the original resistor (or increase the value of the second of the pair).

If a high-resistance voltmeter is to hand (preferably one of 2kΩ/V to 10kΩ/V) it can be used to check the operation. When a small input voltage is applied as described later, there should be a small drop in the potential across R3, and a similar rise across R4. The voltage changes across R6 and R7 should also be similar, though opposite in direction. This also applies to R9 and R10.

CALIBRATION

The required range is obtained by means of two resistors. One is placed across the input points, see Fig. 1. For the ranges described, it can be 1 kilohm, permanently wired across the terminals on the panel. It is R13 in Fig. 5.

The second resistor is R12 (Fig. 5) and is in series with one test prod. This resistor could be included within the instrument for purely d.c. measurements. But with it included in the prod, the loading on points where audio or radio frequencies are present is negligible, so this arrangement is to be preferred.

Calibration of the 1mA meter is initially obtained with the aid of a d.c. voltmeter, service meter, or multirange meter. Nearly all such instruments can read 1V or 0·5V accurately. Some are suitable for much smaller voltages.

Connect a voltmeter or the service meter M2, a 1·5V battery BY2, and a 1 kilohm potentiometer (VR3) as in Fig. 5. Adjust VR3 until M2 indicates 1V.

Now the voltage across R13 depends on the ratio of the resistors R12 and R13. If R12 is 99 kilohm and R13 is 1 kilohm, then 1V across points 1 and 3 will provide 0·01V, or 10mV across points 2 and 3. Rotate VR2 (Fig. 1) until the milliammeter M1 shows full-scale. The instrument range is now 0–1V across points 1 and 3.

If R12 is reduced to 9 kilohm, then 100mV across 1 and 3 provide 10mV across 2 and 3. So the instrument now has a 0–100mV range.

When R12 is 99 kilohm and R2 is 1 kilohm, the input resistance from 1 to 3 is 100 kilohm (ignoring the transistors) and 1V applied across points 1 and 3 gives a full-scale reading. So the instrument is working with a 100kΩ/V input resistance.

MAKING THE PRODS

A prod is readily made as in Fig. 6, using the body of an old ball point pen, or any suitable insulated tube. One wire end of the resistor R12 projects about ¼in and acts as the "probe". A thin flexible lead is soldered to the other resistor wire. The resistor is pushed in the tube, and sealing wax used to close the ends.

Mark each prod with its resistance value or voltage range. For a very high value, two or more resistors are employed in series.

When R13 is 1 kilohm, the prod resistors (R12) for various ranges are as follows:

0–10mV	zero
0–100mV	9kΩ
0–1V	99kΩ
0–10V	1MΩ

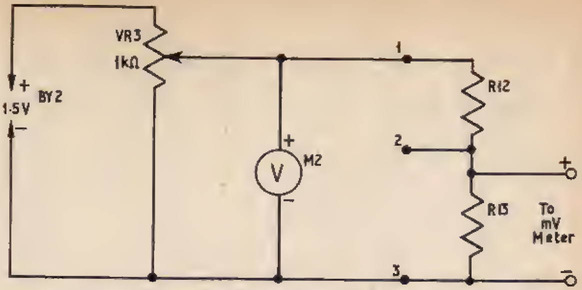

Fig. 5. Calibration circuit. BY2, VR3 and M2 are external components for setting up purposes only; R12 and R13 are incorporated in the prod and the millivoltmeter respectively

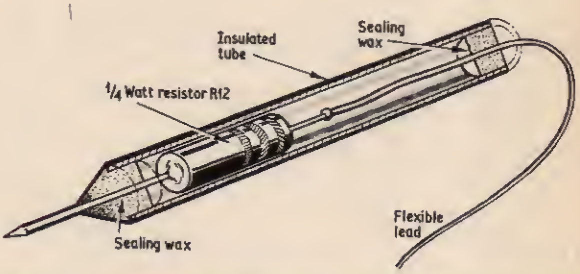

Fig. 6. Construction details of the voltage multiplier prod

GENERAL POINTS

To secure maximum versatility, the following points are worth noting.

When resistors R12 and R13 (Fig. 5) provide a voltage range across points 1 and 3, and this voltage can be checked with a service meter (M2), these resistors need not be close-tolerance. Compensation for the actual values is obtained by adjusting VR2 until the M1 meter reading agrees with the service voltmeter reading at some convenient point.

When resistors R12 and R13 form a potential divider in which the voltage from 2 to 3 needs to be known, then both resistors should be close-tolerance components.

Because sensitivity is adjustable, calibration must be made in advance from a multirange or other voltmeter.

When one test point is "earthed" at radio or audio frequency, the negative test prod is taken to this, if d.c. voltages to be found are positive relative to the earth line. If voltages to be checked are negative relative to "earth", then include the prod in the negative lead.

If a d.c. voltage test is required between two points both of which have r.f. or a.f. present, then a prod made as in Fig. 6 can be placed in each test lead. The *total* value is as for a single prod for the same range; for example, two 0·5 megohm prods are required for 0–10V.

For a higher input resistance, R13 can be 10 kilohm. Sensitivity is then 1 megohm per volt. R1 can then be 90 kilohm for 0–100mV, 1 megohm for 0–1V, and 10 megohm for 0–10V.

Extremely high value resistors between points 2 and 3 are not recommended, as drift upsets calibration. ★