INTRODUCTION TO METERS

MEASUREMENT OF CURRENT VOLTAGE AND RESISTANCE

INTRODUCTION

Although it is possible within limits to design meter movements with the f.s.d. required for a particular purpose, it is generally easier to build a standardised movement and add external circuitry to obtain the required range.

CURRENT MEASUREMENT

If the required f.s.d. current is to be higher than that of the movement, the excess current must bypass the movement via a parallel or shunt resistor.

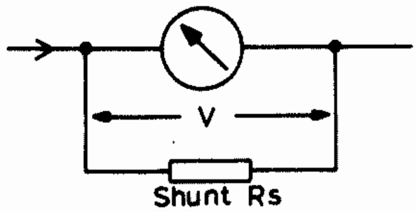

Fig. 1

If the resistance and f.s.d. of the movement are known, the shunt resistor can be calculated thus :-

1. Find the current I_s through the shunt resistor

   I_s = required f.s.d. - movement f.s.d.

2. Find the voltage V across the shunt and meter at f.s.d.

   V = movement resistance x movement f.s.d.

3. The shunt resistor $R_s = \frac{\text{volts across shunt}}{\text{current in shunt}} = \frac{V}{I_s}$

   See example overleaf.

Example :

A 10 mA f.s.d. meter is required and the movement available has a 50 μA f.s.d. and a resistance of 1500 Ω. Find the value of the shunt resistor.

1. $I_s = 10 \text{ mA} - 50\ \mu\text{A} = 9.95 \text{ mA}$

2. $V = 1500 \times 50\ \mu\text{A} = 75 \text{ mV}$

3. $R_s = \frac{V}{I_m} = \frac{75 \times 10^{-3}}{9.95 \times 10^{-3}} = 7.54\ \Omega$

Note that with sensitive movements with a low f.s.d., I_s is usually very nearly the same as the required f.s.d. If they are assumed equal, only small errors occur. In the above example :

$$I_s = 10 \text{ mA}, \quad R_s = \frac{75}{10} = \underline{7.5\ \Omega}$$

Most shunt resistances are low in value and are made from wire with a significant resistance and low temperature coefficient of resistivity. Very low resistances are usually formed from shaped metal sheets.

A multi-range meter can be arranged by switching in different values of shunt resistance, as in Figure 2. However, if the shunt circuit is broken momentarily when changing ranges, a large, possibly destructive current will flow through the movement. A re-arrangement of the circuit as in Figure 3 is commonly used to prevent this, but leaves unused shunts in series with the movement, thereby reducing its sensitivity.

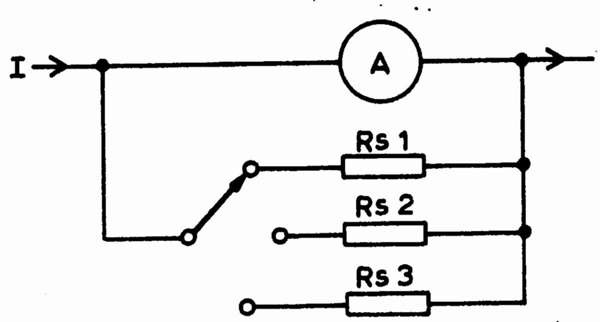

Fig. 2

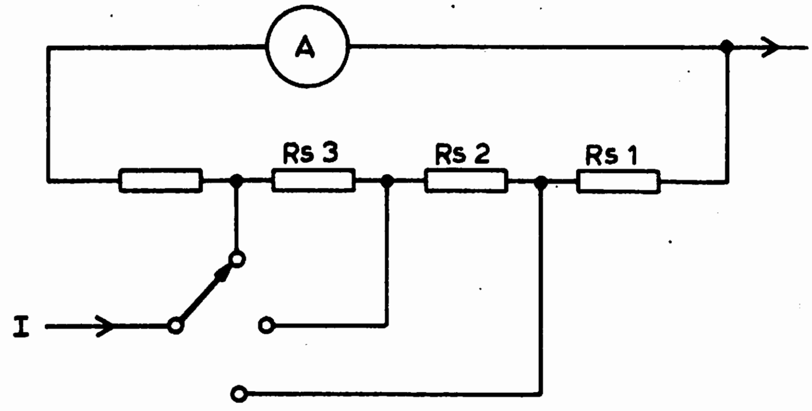

Fig. 3

VOLTAGE MEASUREMENT

A movement has a f.s.d. voltage given by Ohm's Law as :-

V_m = f.s.d. current x meter resistance

If a voltage f.s.d. higher than this is required, the current must be limited to the meter f.s.d. by a series resistor.

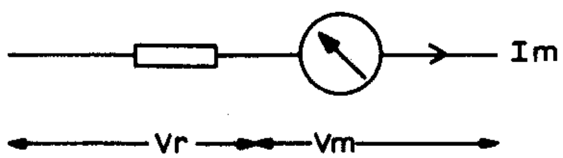

Fig. 4

Its value may be calculated as follows :-

1. At f.s.d. the volt drop across the resistor

   V_r = required f.s.d. voltage - meter f.s.d. voltage

2. The current in the resistor is meter current I_m

3. By Ohm's Law, value of resistor $= \frac{V_r}{I_m}$

Example :

A 10 V f.s.d. meter is required. Given a standard movement of 50 μA, 1500 Ω resistance, what series resistance is required?

1. V_m = 50 μA x 1500 = 75 mV

2. V_r = 10 - 0.075 = 9.925 V

3. series resistor $= \frac{9.925}{50\ \mu A}$ = 198.5 kΩ

For high voltage ranges, the volt drop across the meter becomes insignificant, and the series resistor or 'multiplier' can be calculated from :-

$$\text{series resistor} = \frac{\text{f.s.d. voltage required}}{\text{meter f.s.d. current}}$$

MEASUREMENT OF CURRENT VOLTAGE & RESISTANCE

A multi-range voltmeter can be produced by switching extra multipliers in series in turn, as in Fig. 5. The resistors then have less unusual values.

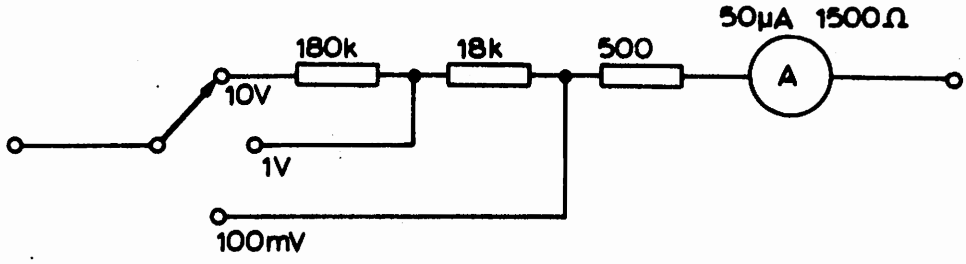

Fig. 5

SENSITIVITY

The current required to operate the meter can be significant when measuring voltages in high impedance circuits. The total load resistance of the meter depends on the voltage range selected. To aid quick calculation of this load resistance it is quoted in terms of resistance per volt of range selected. Thus a 20 kΩ/volt meter has a total resistance of 20 kΩ on the 1 volt range and 2 MΩ on the 100 volt range.

The units ohms/volt are the inverse of the meter f.s.d. current and give a measure of its sensitivity. A 50 μA movement gives 20 kΩ/volt, a 1 mA movement 1 kΩ/volt.

A.C. MEASUREMENTS

Although the moving iron meter will measure a.c., it has poor sensitivity and a non-linear scale. The moving coil movement is more sensitive, but indicates the mean level of a signal which is varying faster than its speed of response. If the a.c. is rectified the meter will indicate the mean value which differs from the r.m.s. value by a constant known as the form factor. Most a.c. meters assume a sinusoidal input and are calibrated in r.m.s. values on a separate scale (Fig. 6).

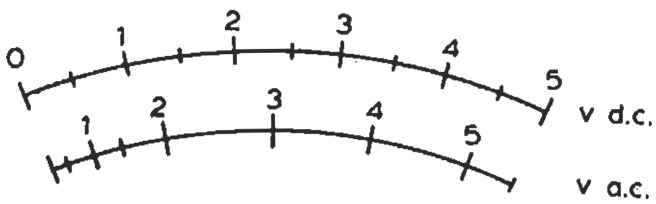

Fig. 6

When a silicon diode bridge rectifier is used, the forward resistance of the diodes varies with applied voltage, becoming very high below 0.6 V. This would give a scale cramped at the lower end. A large swamp resistor will minimise this effect, but only on the higher voltage ranges. To measure low a.c. voltages a step-up transformer is used; the impedance of the meter is then lowered by the square of the step-up ratio.

The same transformer, usually with a single tapped winding, can be used to provide a.c. ranges and a form factor correction to enable the same scale to be used for both a.c. and d.c. measurements.

A simplified circuit of a multimeter is given in Figure 7 below.

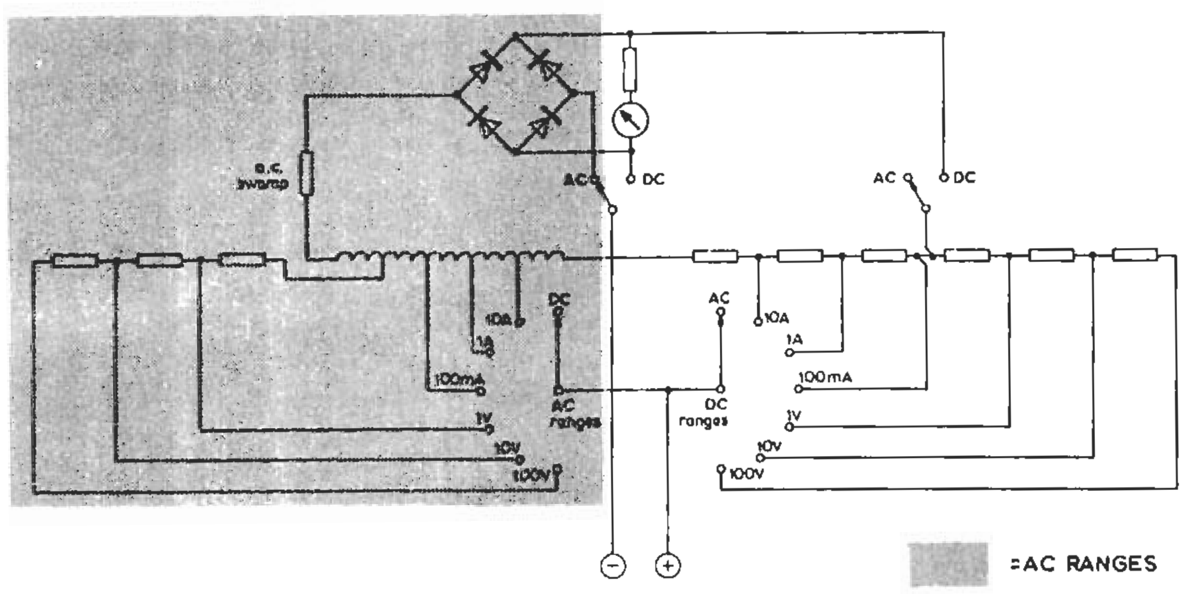

Fig. 7

MEASUREMENT OF CURRENT VOLTAGE & RESISTANCE

MEASUREMENT OF RESISTANCE

If a source of e.m.f. is used to drive a current through an unknown resistance, the value of current will give a measure of resistance. In practical terms, a battery is put in series with the resistance and a meter. The meter must be calibrated to give f.s.d. for zero ohms by using an adjustable series resistance set to give f.s.d. with the terminals shorted.

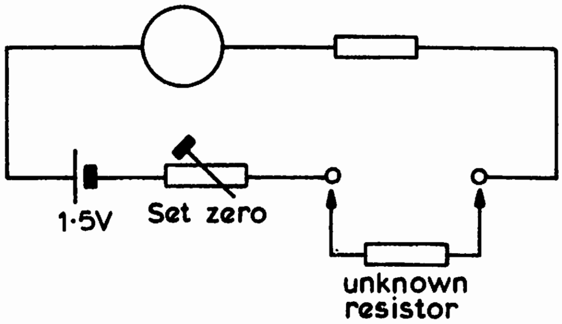

Fig. 8

Since the current is inversely proportional to resistance, the scale is non-linear and becomes very cramped at high resistance/low current readings. Further resistance ranges can be obtained by using higher e.m.f.s. A typical multi-range meter uses a 1.5 V and 15 V battery.

MEASUREMENT OF INSULATION RESISTANCE

Insulation resistance can be of the order 5 MΩ to 1000 MΩ. Such high values give unmeasureably small currents with a simple ohm-meter. Much higher voltages between 250 and 1000 volts are required, which also check the dielectric strength of the insulator, i.e. its resistance to electrical breakdown.

A specialised instrument, commonly called a 'megger', has a hand operated generator producing the high voltage. The movement driving the pointer is similar to a moving coil system, but has two coils fixed together and mounted on the same pivot at right angles to each other (Fig. 9). Coil A carries the current through the insulation and is driven clockwise. Coil B is driven anti-clockwise in proportion to the voltage across the insulation. The equilibrium position where the two forces are equal gives a deflection proportional to volts and inversely proportional to current thus indicating resistance.

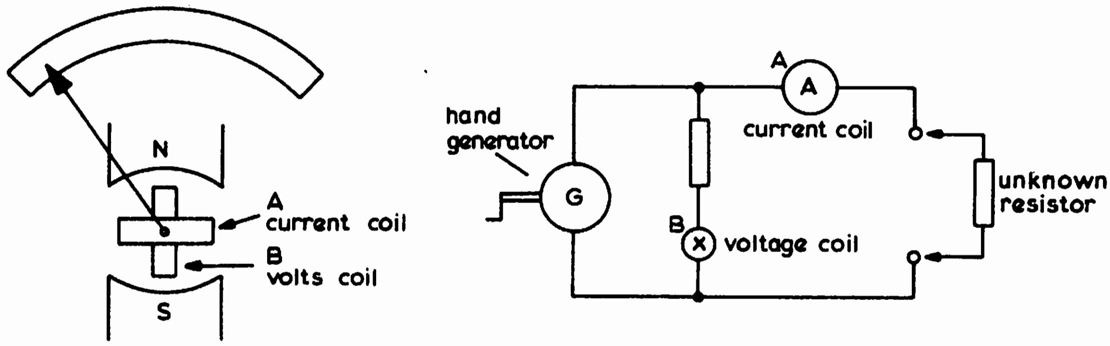

Fig. 9

The e.m.f. is limited to a constant value by a slipping clutch mechanism on the generator. More recent instruments have an electronic high voltage generator powered by mains or battery.

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