Online Radio & Electronics Course

Reading 15

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METERS

Though you will not be asked in the exam to describe the operation of a moving coil meter, I do believe it is a good idea to study it as it does reinforce some of the material we have already learnt.
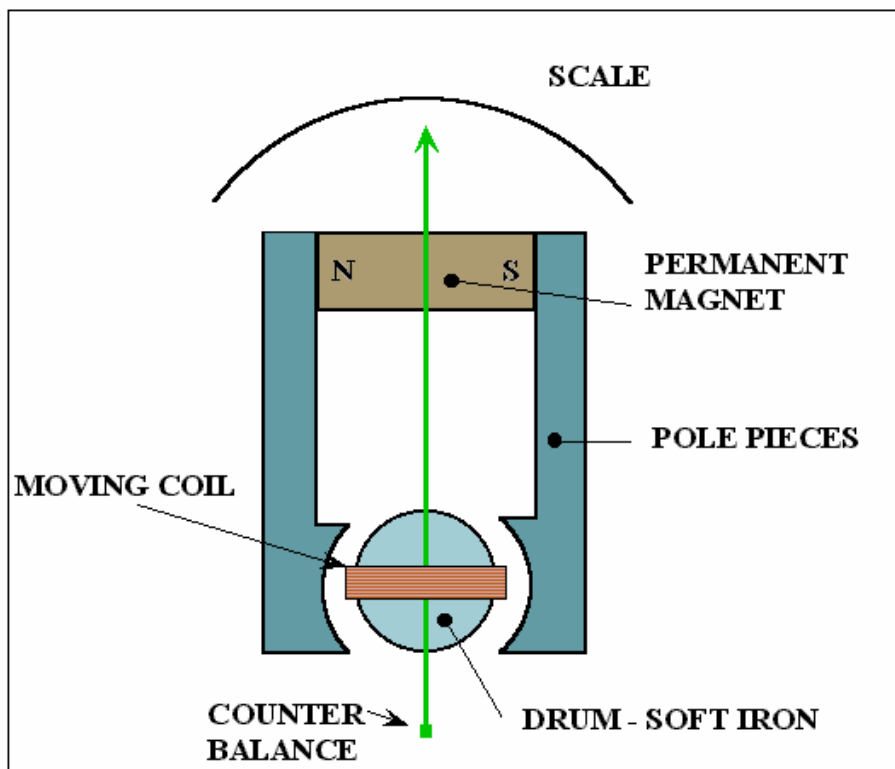

Figure 1.

A pictorial diagram of the moving coil meter is shown in figure 1. The moving coil is a coil wound and aluminium former. The coil is free to move clockwise and anticlockwise through about 130 degrees that in turn moves the pointer on the scale from left to right. The pointer is shown centred. Without any current flowing through the moving coil the pointer will actually be towards the left of the scale, pushed there by a small coil return spring not shown. The pointer will not go past the left end of the scale as there is a small pointer stop not shown. When current is passed through the moving coil a small magnetic field is created around it which interacts with the field created by the permanent magnet in such a way as to cause the moving coil and the pointer along with it to rotate clockwise. So we have a simple but very effective method of detecting current flow with the instrument. The important point is that the degree of deflection from left to right by the pointer is <u>directly proportional to the current</u> (must know). If a certain current X causes the pointer to move to 1/4 scale then a current of 2X will cause the pointers to move to half scale - this is a direct proportion.

The other important feature of the moving coil meter is that it is extremely sensitive to very small currents, typically in the order of microamperes, and therefore does not consume much power from the circuit in which it is placed. The moving coil meter is actually a microammeter. Typical current to enable full scale deflection ranges from 1uA to 30 mA. The moving coil does have some resistance of course. A movement with a smaller full-scale deflection current has a higher coil resistance and more turns of fine wire are needed to obtain the deflection.

We can make use of this meter by calibrating it and using it to measure current, voltage, and resistance. From now on I will draw the moving coil meter as a circle but it does help to remember what is inside.

The other point I would like to make is that many modern meters are digital. They do not use a moving coil. The digital circuitry performs an analogue to digital conversion of the applied current or voltage and displays the amount as a numerical readout. These meters are very accurate. However the moving coil meter (called an analogue meter) has advantages that will see it in use for a long time to come. The greatest advantage of the analogue meter is its ability to show changes in voltage or current. For example, if an analogue meter is placed across a charging capacitor, the pointer will slowly rise up the scale as the capacitor charges. I have an all bells and whistles digital meter. When I place it across a charging capacitor, because the voltage is changing, the digital display just "blinks" as it is unable to show a varying voltage adequately.

MEASUREMENT OF CURRENT

Whether we are measuring amperes, milliamperes or microamperes, two important facts to remember are:

1. The current meter (ammeter) must be in series with the circuit in which the current is to be measured. The amount of deflection depends on the current through the meter. In a series circuit the current is the same in all parts of the circuit. Therefore the current to be measured must be made to flow through the meter as a series component in the circuit.

2. A DC meter must be connected with the correct polarity for the meter to read up-scale. Reversed polarity would make the meter read down-scale, forcing the meter pointer against the left-hand stop.

An ammeter should have a very low resistance when compared to the circuit in which it is placed. An arbitrary figure is 1/100th of the resistance of the circuit in which the ammeter is placed.

AMMETER SHUNTS

A meter shunt is a precision resistor connected across the meter movement for the purposes of shunting, or bypassing, a specific fraction of the circuit current around the meter movement. Shunts are usually inside the meter case. The schematic symbol for an ammeter usually does not show the shunt.

For example, we may have a 25 mA meter movement with a moving coil resistance of 1.2 ohms. We want the meter to be able to read 50 mA full scale. In other words, to double the range of the meter from 0-25 mA to 0-50mA.

To achieve this, a shunt resistance of 1.2 ohms (equal to the resistance of the moving coil) would do the job.

With a 1.2 ohm shunt, half of the total current will flow through the meter and half through the shunt since both form a parallel circuit consisting of two 1.2 ohms resistances. The use of the shunt in this instance has extended the full-scale deflection (FSD) of the meter from 0-25 mA to 0-50 mA.

Rm = 1.2 ohms

50 mA 25mA

Rs = 1.2 ohms

SINCE Rs & Rm are equal
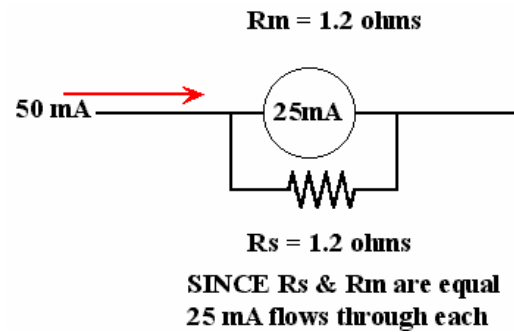25 mA flows through each

Figure 2.

Using the correct shunt, a moving coil meter can be used to measure any amount of current (FSD). The shunt, though it is a resistance, is very low in value. In typical ammeters the shunt is often a solid copper bar with a resistance in milliohms, particularly for high current ranges on the meter.

Note: It is common to hear a current meter called an ampmeter - this is wrong; the correct name for a current meter is an ammeter with no 'p'.

CALCULATING ANOTHER SHUNT

Figure 3 shows an ammeter. The moving coil has a resistance of 2000 ohms and is deflected full scale with 50 microamperes. We wish to modify the meter to measure 1 ampere full scale deflection. Calculate the value of the shunt resistor that would extend the range of the ammeter to 0-1 amperes.
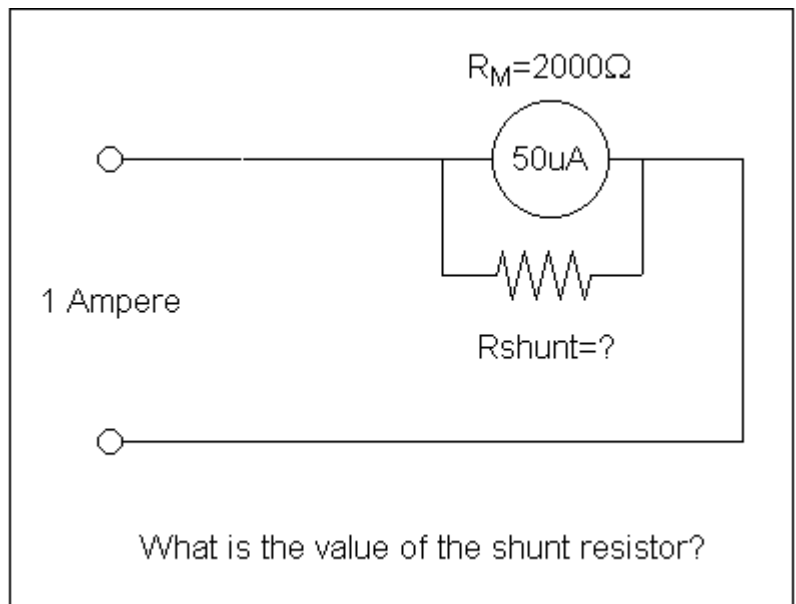
This is just an Ohms law problem. Assume that one ampere is flowing in the circuit. You know there is 50uA flowing through the meter movement. The current through the shunt is then:

R_M=2000Ω

50uA

1 Ampere

Rshunt=?

What is the value of the shunt resistor?

Figure 3.

I_{shunt} = 1amp - 50uA = 0.99995 amperes.

We now know the current through the shunt. What is the voltage across it? We know the resistance of and the current through the meter, and since the meter and the shunt are in parallel they will have the same voltage. So, if we calculate the voltage across the meter we will know the voltage across the shunt:

E_{shunt} = I_m x R_m = 50uA x 2000 ohms = 0.1 volts.

Now calculate the resistance of the shunt:

R_{shunt} = E_{shunt} / I_{shunt} = 0.1 / 0.99995 = 0.100005 Ohms.

This shunt, which is just over a 1/10th of an ohm, would be a solid bar inside the meter. The manufacturer (or the builder) would use a reference current and adjust the resistance of the shunt as accurately as possible.

VOLTMETER

Although a meter movement responds only to current moving in the coil, it is commonly used for measuring voltage by the addition of a high resistance in series with the movement. Such a high series resistance is called a multiplier.

The multiplier must be higher than the coil resistance in order to limit the current flow through the coil. The combination of a meter movement with its added multiplier then forms a voltmeter.

Since a voltmeter has a high resistance, it must be connected in parallel to measure the potential difference between any two points in a circuit. Otherwise, the high resistance multiplier would add so much series resistance to the circuit the current would be reduced to a very low value.

The circuit is not opened to connect a voltmeter in parallel. Because of this convenience (not having to break the circuit), it is common to make voltmeter tests in trouble shooting rather than ammeter tests. If you need to know the current through a resistor, it is far easier to measure the voltage across it and then work out the current using Ohm's law.

Figure 4 shows how a 1mA meter movement is connected with a multiplier to enable it to be used as a voltmeter with an FSD of 10 volts. In other words, a voltmeter with a 10V range.

With the 10V applied by the battery there must be a total of 10,000 ohms of resistance to limit the current to 1mA for full-scale deflection (FSD) of the meter movement. Since the movement has a resistance of 50 ohms, 9950 is added in series, resulting in a total resistance of 10KΩ. Current through the meter is then: I = 10 / 10,000 = 1 mA.
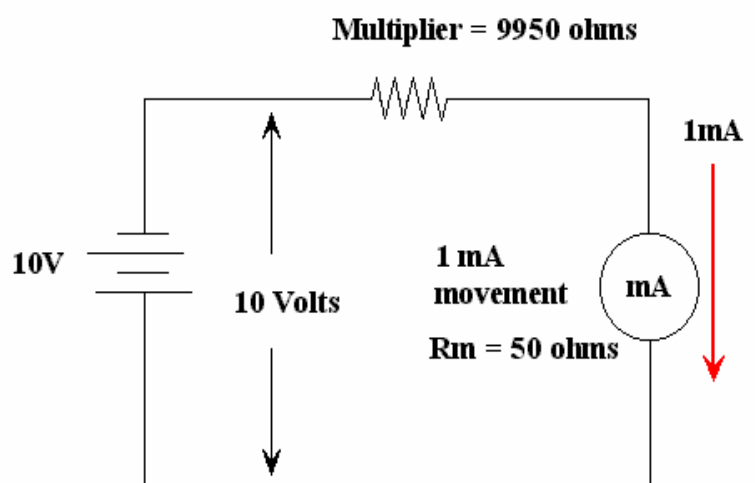

Figure 4.

With 1mA in the movement, the FSD can be calibrated as 10V on the meter scale. Of course since deflection is directly proportional to current the meter can be calibrated proportionately from 0-10 Volts. For example half scale would be 5 volts, 1/4 scale 2.5 volts etc.

Of course the battery is taken away, and the circuit consisting of the meter movement and the multiplier is our voltmeter. Different multipliers can be switched in for different voltage ranges.

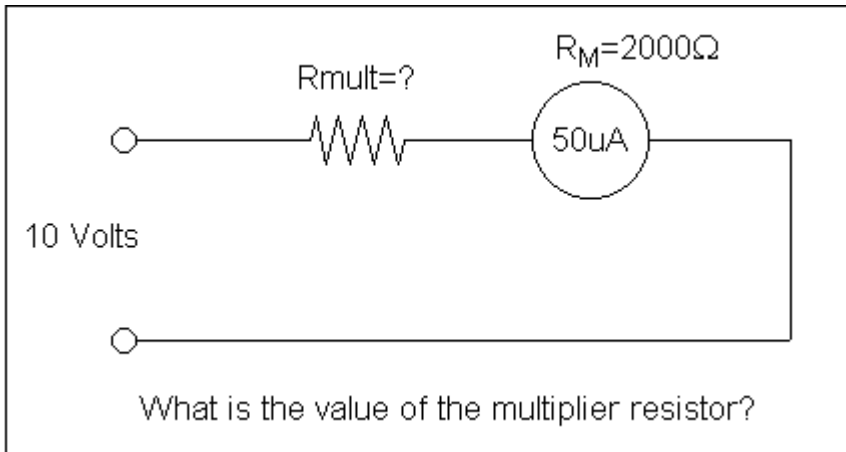Let's calculate another shunt to make sure we understand this.

Figure 5.

The circuit of figure 5 is a voltmeter. It has a very sensitive meter movement (50uA). What is the value of the multiplier resistor required to allow this meter to measure from 0-10 volts?

We know that at FSD the current in the circuit and through the multiplier will be 50uA. We can work out the voltage across the meter movement and subtract this from the applied voltage (10V) to get the voltage across the multiplier.

Voltage across meter = I_{meter} x R_{meter} = 50uA x 2000 ohms = 0.1 volts

$R_{multiplier}$ = $E_{multiplier}$ / $I_{multiplier}$

$R_{multiplier}$ = (10-0.1 volts) / 50uA = 9.9 volts / 50uA = 198,000 ohms

VOLTMETER RESISTANCE

The high resistance of a voltmeter with a multiplier is essentially the value of the multiplier resistance. Since the multiplier is changed for each range, the voltmeter resistance changes. To indicate the resistance of a voltmeter independently of the range, voltmeters are generally rated in ohms of resistance needed for 1V of deflection. This value is the ohms-per-volt rating of the voltmeter.
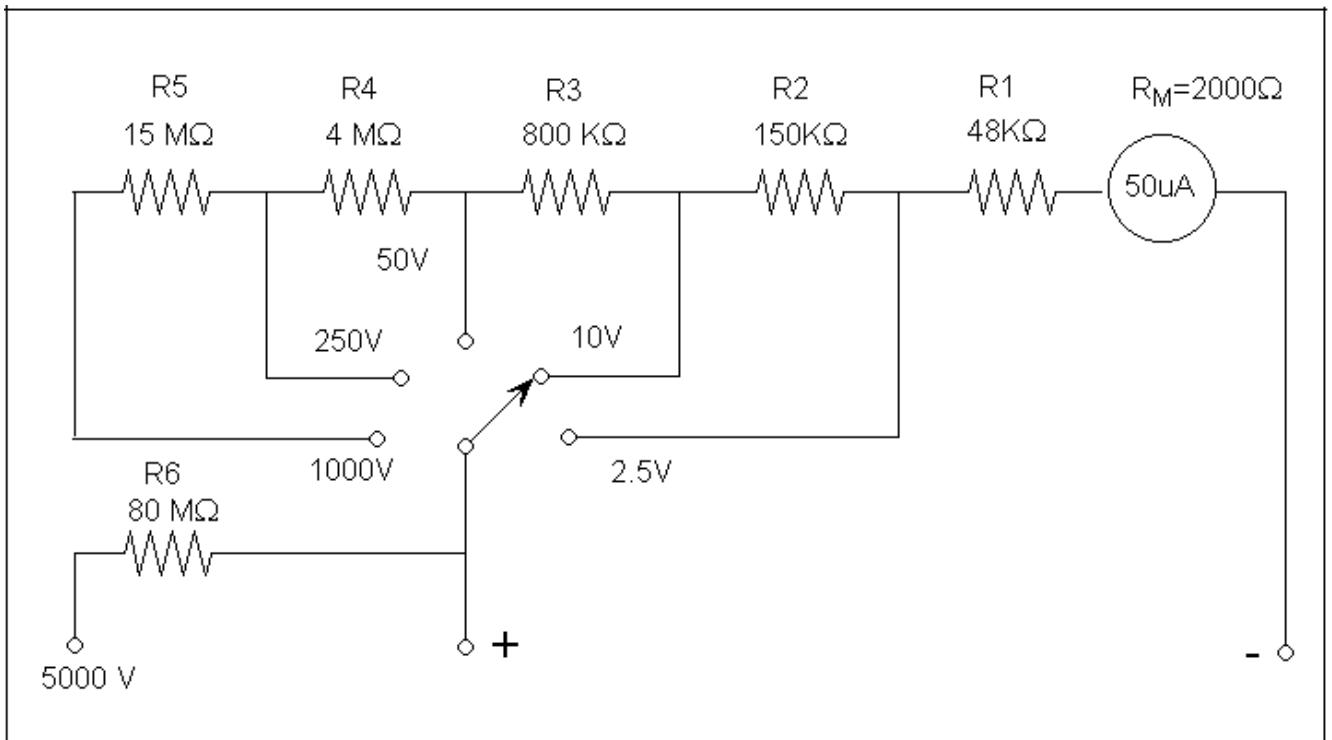
Figure 6 is an actual circuit of a multirange voltmeter.

Figure 6 – Multirange Multimeter

The leads on the voltmeter are shown by the + and − signs. When this voltmeter is switched to the 2.5 volt scale, can you see that the only multiplier resistance used is the 48KΩ. So the total resistance of the voltmeter is 48KΩ + 2000 ohms = 50KΩ.

The total resistance of this voltmeter on the 2.5 volt scale is 50KΩ.

If we divide the total resistance of the voltmeter by the scale to which it is switched, we get the sensitivity of the voltmeter in Ohms-per-volt:

Ohms-per-volt = Total resistance / scale = 50KΩ / 2.5 = 20,000 ohms per volts.

This sensitivity works for all other scales as well. If we want to know the total resistance of the voltmeter on any scale just multiply the sensitivity by that scale.

Example: What is the total resistance of this voltmeter if it is switched to the 10 volt scale?

Total resistance of voltmeter = ohms-per-volt x scale.
Total resistance of voltmeter = 20,000 x 10 = 200,000 ohms.

Is this right? Check it in the circuit. On the 10 volts scale the voltmeters resistance consists of:
150KΩ + 48KΩ + 2000Ω = 200,000 ohms.

Using this method you can work out quickly the total resistance of any voltmeter on any scale – provided you know the ohms-per-volt.

A QUICK WAY TO WORK OUT SENSITIVITY

A quick way of working out the ohms-per-volt or sensitivity of **any** voltmeter is to take the reciprocal of the full-scale deflection current of the movement. In the last example, current FSD is 50uA, and so the reciprocal of 50uA is 1/50 x 10^{-6} which gives 20,000 ohms per volt.

We need to know the sensitivity of a voltmeter so that we can determine if it is going to significantly affect the circuit in which it is placed.

Suppose we were using a 20,000 ohms-per-volt voltmeter on a 10 volt range. The voltmeters resistance would be 20,000 x 10 = 200K. So our voltmeter has a resistance of 200,000 ohms when switched to the 10 volt range. When we place our voltmeter in parallel with a component in order to measure the voltage across that component, the voltmeter is adding 200,000 ohms of resistance across the circuit.

Now, if the component we are measuring the voltage across is a 1000 ohm resistor, placing the voltmeter resistance of 200KΩ in parallel with 1000Ω is not going to disturb the resistance of the circuit much at all. However, if we were to use the same voltmeter across a 200KΩ resistor, we would be reducing the resistance of the 200KΩ resistor to 100KΩ. 200K in parallel with 200K is 100KΩ.

This does not always matter as long as you know what affect the voltmeter is having on the circuit. In some cases though, the interaction of the voltmeter with the circuit may cause the circuit to stop operating, particularly in high resistance radio frequency circuits.

Very good voltmeters have a very high resistance in the vicinity of 10MΩ per volt. Whether or not you have to be concerned about the interaction of the voltmeter and the circuit still depends on the circuit in which you are taking the measurement.

Most digital meters have an input resistance which is not scale dependent. So you may see a digital voltmeter with 10MΩ resistance irrespective of the voltage scale used.

OHMMETERS

Basically, an ohmmeter consists of an internal battery, the meter movement and a current limiting resistance. To measure resistance, the ohmmeter leads are connected across the resistance to be measured, with the power off in the circuit being tested. Only with the power off can you be sure that it is only the ohmmeters battery that is producing current and deflecting the meter movement. Since the amount of current through the meter depends on the external resistance, the scale can be calibrated in ohms.

The amount of deflection on the 'ohms' scale indicates directly the measured resistance. The ohmmeter reads up-scale regardless of the polarity of the leads because the polarity of the internal battery determines the direction of current through the meter movement.

The leads of a meter are normally coloured 'black' for negative and 'red' for positive. It is important to remember that a multi-function meter, when switched to ohms, may, because of the internal battery or cell, supply a positive voltage to the negative lead and vice-versa for the other lead. This can be of particular importance when testing semiconductors.

The ohmmeter circuit shown in figure 7 has 1500 ohms of resistance. The 1.5 volt cell will then produce 1mA if the leads are shorted, and the pointer will go to full scale. In a practical ohmmeter a small variable resistor would be in series to 'zero' the meter exactly.
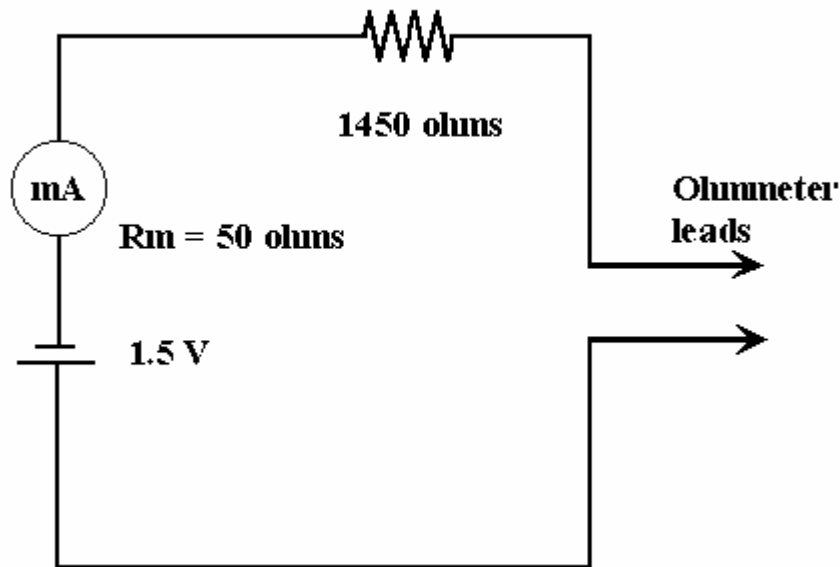

Figure 7.

So when the ohmmeter leads are short-circuited the meter will show full scale or zero resistance. With the ohmmeter leads open (not touching), the current is zero and the ohmmeter indicates infinite resistance.

Therefore, the meter face can be marked zero ohms at the right for full-scale deflection and infinite ohms on the left for no deflection. The in between values can be marked in ohms by calibrating the meter against known resistances.

MULTIMETERS

All of the above meters can be built into the one box. Shunts, multipliers and the battery can be switched in and out of circuit as required to perform the various functions.

End of Reading 15.
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