Looking inside volt and ampere meters

Simple explanation without complex mathematics

by Jules Perrin VK3JFP

Ever wondered how your trusty analogue voltmeter works? A lot goes on inside the meter, but it is all based on Ohm's Law. Digital meters work on the same principles as analogue, but without a colourful display.

Moving Coil Meter (MCM)

The MCM as shown in Figure 1, is a Jaycar (0 – 30 v MU45) moving coil panel meter, and a meter like this is the heart of any voltmeter.

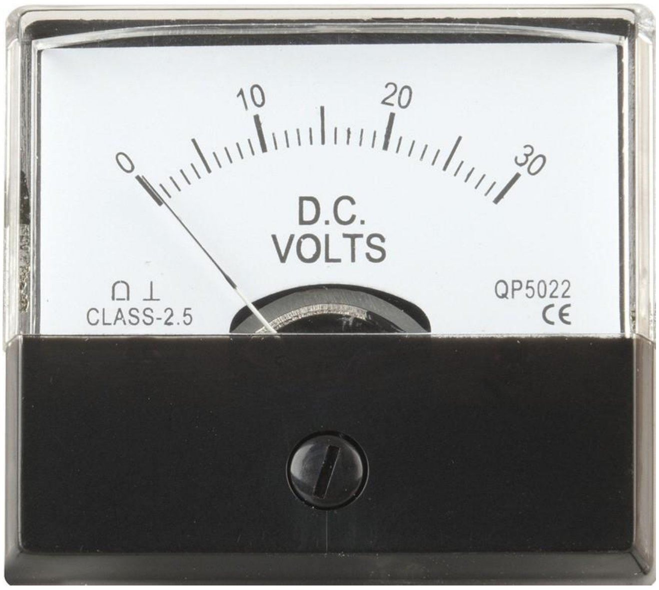

Figure 1: Moving Coil Meter (MCM).

The MCM has two permanent magnets of opposite polarity and a wound coil in the middle. The magnetic field created by the coil, as current passes through it, will be repelled or attracted by the permanent magnets. This causes the indicator to move. The distance moved is related to the amount of current and the result is read from the calibrated scale.

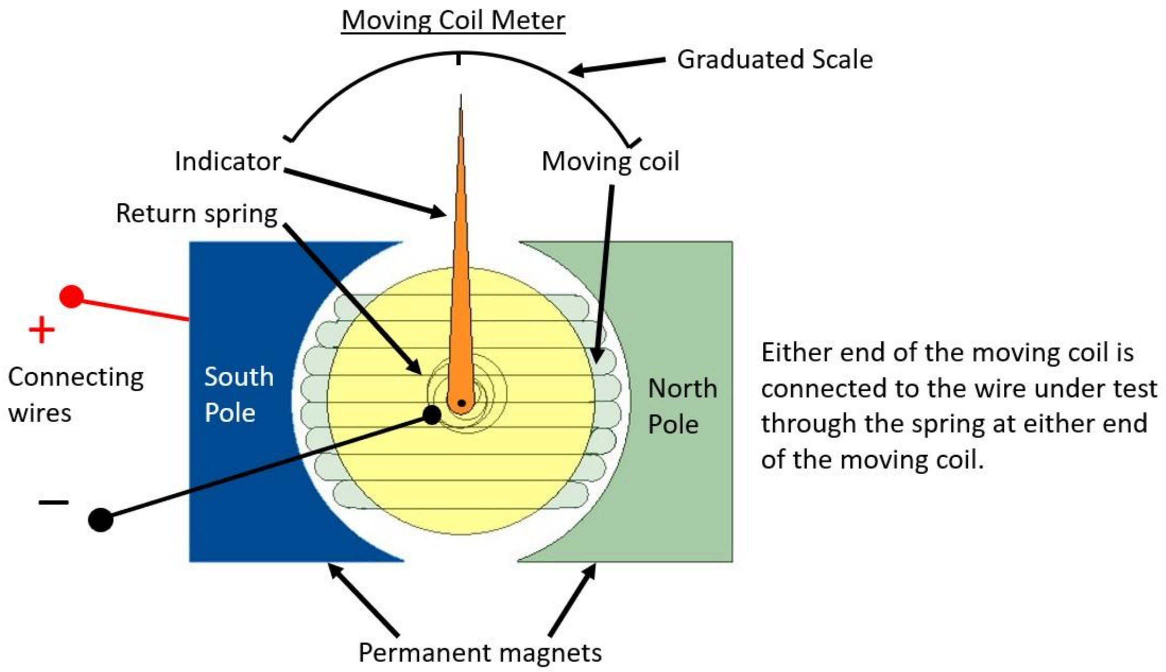

Figure 2: Moving Coil Meter (MCM) Diagram.

The MCM in Figure 1 reads 30 v at maximum deflection and the internal resistance of the meter is 30 k Ohms.

I meter = E meter / R meter = 30 / 30000 = 0.001 A or 1 mA

Now we know that when we are using this meter, only 1 mA can flow through the meter. This is known as the Full Scale Deflection (FSD) current. This is not ideal for a good voltmeter and should ideally be in the micro amperes range. These numbers work well however for the purposed of this example.

DC Voltmeter

A voltmeter measures the Electromotive Force (EMF) difference between two points.

Using different meters for different voltage ranges is not practical. So, we adapt the circuit to meet the intended range.

A voltmeter needs to be more versatile than measuring only one voltage. So, other resistors are applied in accordance with Ohm's Law. The resistor configurations are called shunts or multipliers.

Take the example where we want the meter to read 0 to 90 v. Knowing the limitations of the meter, we need to drop 60 v before the 1 mA FSD reaches the meter. This requires a resistor of 60,000 Ω in series with the meter movement.

By placing a resistor in series with the meter, it is called a **multiplier**. The resistance the meter now applies to the load under test is greater. See Figure 3. All the requirements of Ohm's Law are met, and the meter can be recalibrated to read 0 – 90 v.

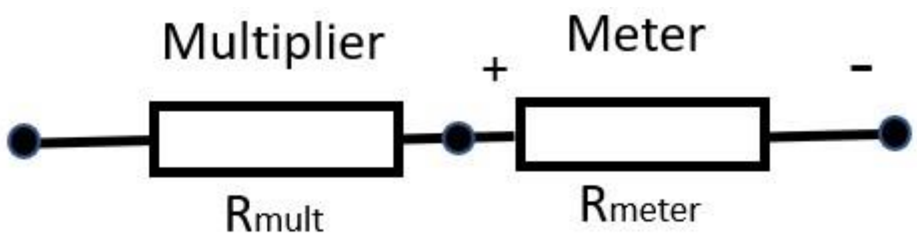

Figure 3: Multiplier circuit calculations.

If we want the meter to measure the following ranges, the table shows the shunts or multipliers to be included.

Measurement Range DC	FSD Meter Current	Meter Ohm's	Multiplier Ohm's	Shunt Ohm's	Circuit Current
0 – 3 v	1 mA	30000 Ω		333.3 Ω	10 mA
0 – 10 v	1 mA	30000 Ω		1,111.1 Ω	10 mA
0 – 50 v	1 mA	30000 Ω	20,000 Ω		1 mA
0 – 90 v	1 mA	30000 Ω	60,000 Ω		1 mA
0 – 200v	1mA	30000 Ω	170,000 Ω		1 mA

Recalibrating the meter to read less than 30 v requires a **shunt** resistor. This will draw more current from the circuit under test. Assuming the measuring circuit (i.e. the meter and the shunt) is allowed to draw 10 mA. This is arbitrary and I am only using these numbers as examples. See Figure 4.

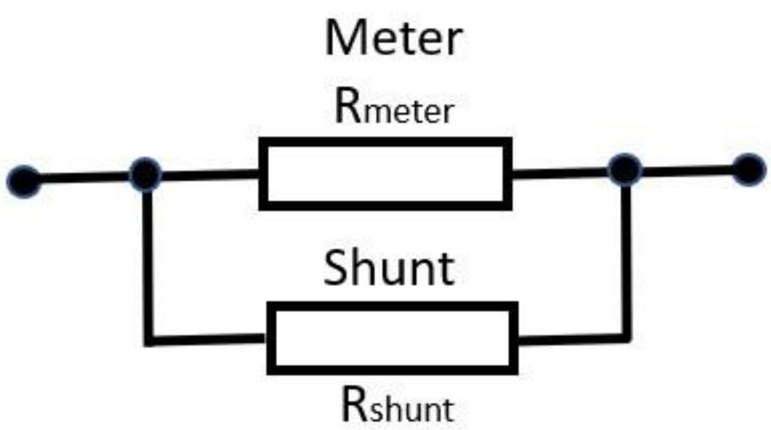

Figure 4: Shunt circuit calculations.

AC Voltmeter

In alternating current, the electrons change direction repeatedly. The deflection of the needle on a DC meter would be constantly trying to change. The trick is to include a half or full wave rectifier before the DC meter. This introduces a new term, Root Mean Square (RMS) value, (also called effective voltage), of the sine wave. See Figure 5. The RMS is 0.707 of the peak value. The definition of RMS is that it is equivalent voltage to the DC voltage value that will produce the same heating effect or power dissipation. For instance, normal domestic AC in Australia is 240 v AC with a frequency of 50 Hz. The RMS voltage is 240 volts, so the peak value is 340 volts.

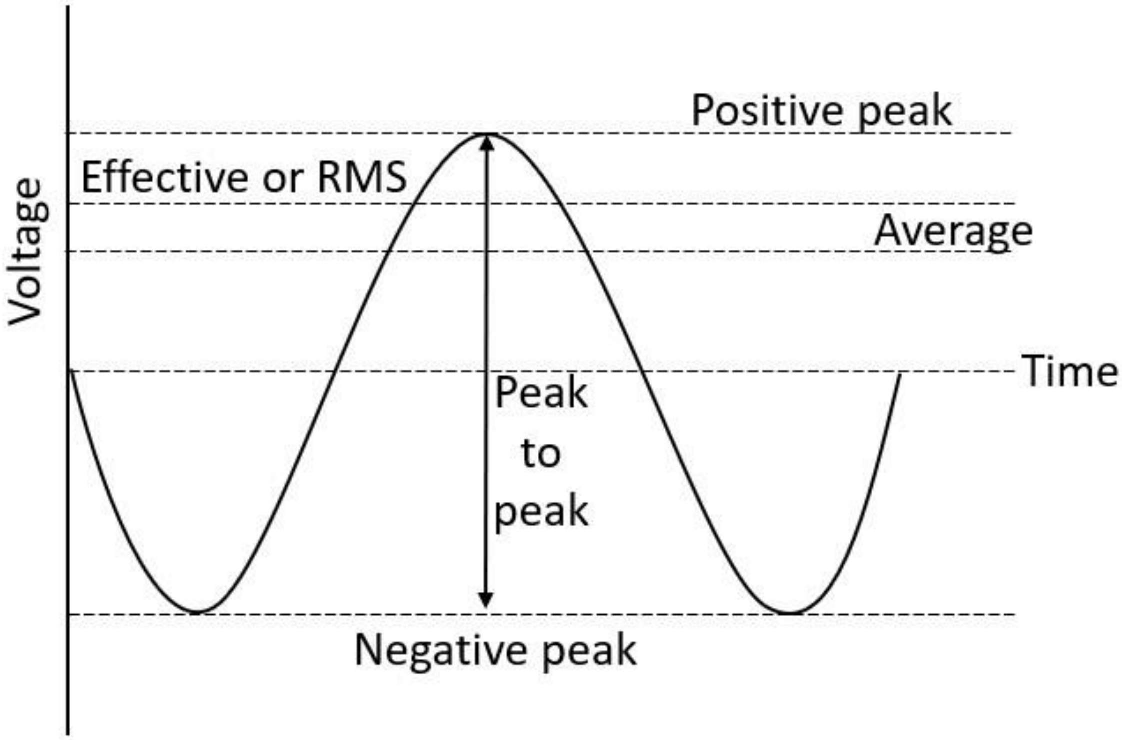

Figure 5: RMS diagram.

Using a half wave rectifier before the DC voltmeter will provide a DC reading equal to 0.45 of the RMS.

Using a full wave rectifier before the DC voltmeter will provide a DC reading equal to 0.9 of the RMS.

In measuring various AC ranges, multipliers and shunts are included in the measuring circuit. The graduated scale on the meter would be marked according to the calculated measurements.

Ammeter

An ammeter measures the flow of electrons between two points. This means the ammeter is placed in the circuit to make the measurement. Using different meters for different current ranges is not practical. So, we adapt the circuit to meet the intended meter ranges.

The meter is limited in that it can only tolerate 1mA of current. This is the FSD. If we want to recalibrate the meter to read 3 A, we need to pass 2.99 A though a shunt resistor. The meter is still a voltmeter in that it is measuring the voltage drop across the shunt and displaying the result in amperes. The wiring for the circuit needs to be capable of handling the planned current.

Ampere Range	Meter Current	Meter Ohms	Shunt Current	Shunt Ohms
0 – 3 A	1 mA	30000 Ω	2.99 A	10 Ω
0 – 10 A	1 mA	30000 Ω	9.99 A	3 Ω
0 – 50 A	1 mA	30000 Ω	49.99 A	0.6 Ω
0 – 100 A	1 mA	30000 Ω	99.99 A	0.3 Ω

The shunt resistor in an ammeter cannot have a great effect on the current flow as the meter is in the circuit. This means the shunt resistor is always a small value. The formula for the shunt resistor is based on the ratio of the current though the devices.

Shunt resistor value = I meter x R meter / (Maximum current to be measured - current through meter)

In the case of the 50 A range the formula would be:

Shunt Ω = 0.001 x 30000 / (50 – 0.001)

= 30 / 49.99

=0.6001 Ω

New Technology

The continued miniaturisation and lower cost of electronic components and equipment led to the developed to better ways to make displays and measurements. These changes also led to a greater accuracy level than an analogue dial. Analogue meters are subject to parallax errors by the operator. This error is caused by the apparent position of the meter scale plate relative to meter pointer, and the viewing position of the person reading the meter. (The meter must be read at 90 degrees to the scale plate to overcome parallax error.)

Some improvement examples are as follows.

- Pocket sized meters
- Digital meters with back light and hold function.
- Clamp ammeters
- Multimeters including additional functions

If you have a topic you would like to nominate to be covered in a future instalment of Newcomers' Notebook, email Jules at jp.bqt@bigpond.net.au

Have fun and stay safe.