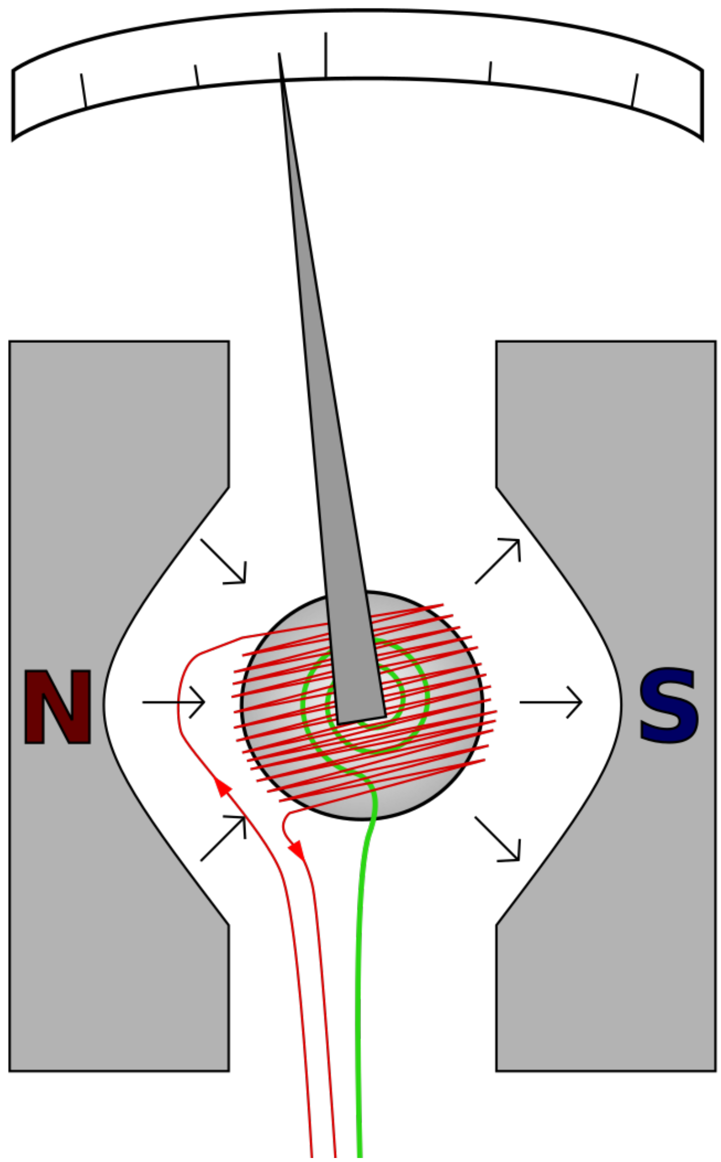
Wednesday, September 20, 2023

A Voltmeter/Ammeter Project

Some preliminaries

- All analog voltmeters are really measuring current. In other words, all analog voltage meters are ammeters (or milliammeters etc.) that are “tricked” into displaying voltage values.
- Analog meters are built as a moving coil of wire, attached to a needle indicator, and positioned within a magnetic field. As current passes through the coil, it produces a



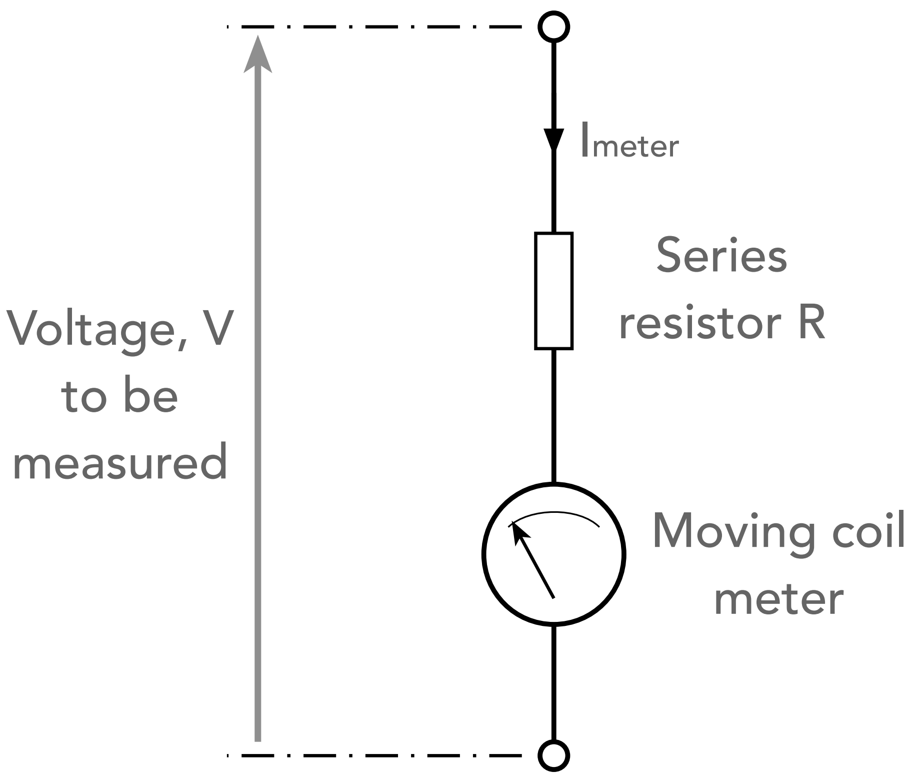
magnetic field that opposes the external field and causes the needle to move against the resistance of a small spring. The spring returns the needle to “zero” when no current is flowing.
- We’ll be using Ohm’s law a lot in this project. Remember Ohm’s law?

$$V = I \times R$$

$$R = \frac{V}{I}$$

A Voltmeter

- Now that we have the basics, how do we turn an ammeter (or milliammeter) into a voltmeter? Really rather simply: Put a resistor in series with the meter that limits the current to a range the meter is designed to handle.



- Let's try an example. Suppose we have an analog meter that is designed to measure a maximum of 100 mA. What resistance would you put in series with this meter if you wanted the meter to read 100, when 10 volts DC was applied?
- This takes us to Ohm's law. We know voltage and current, what resistance would be required?

$$R = \frac{V}{I} \quad \text{therefore} \quad R = \frac{10}{0.1} = 100 \text{ ohms.}$$

- What if we wanted to make this a 100 Volt meter? What resistance would be required?
- What if we wanted a 1 volt meter?
- Be careful about power. Make sure your resistor can handle the current/power it will dissipate.

$$P = I^2 \times R$$

$$P = 0.1^2 \times R = 0.01 \times R$$

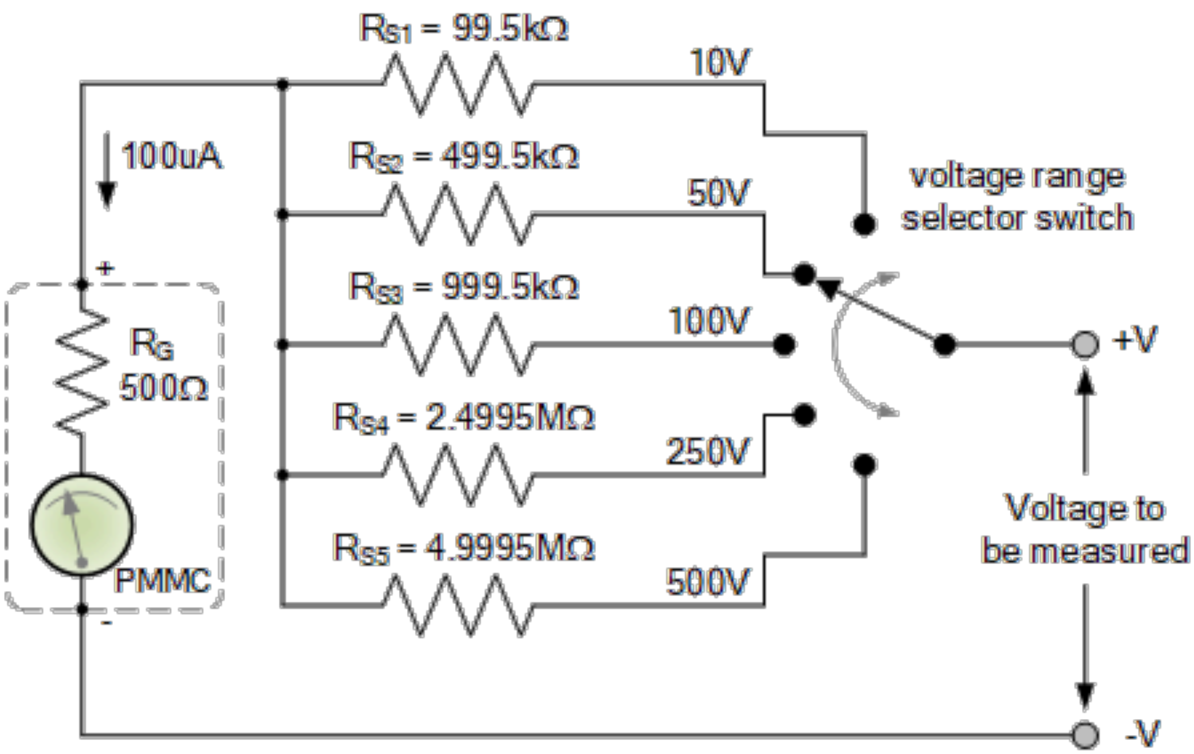
At 100 Ohms, P = 1 watt,
at 10 Ohms, P = 0.1 watt, but
at 1000 Ohms, P = **10 watts**! That's a big resistor and a lot of power - heat.

- So how do we fix this so we don't draw so much current when we measure voltage? Use a more sensitive meter!
- Let's try this same example with a 50 uA meter. This is what the Simpson Model 260 uses.
- If full scale on this meter only requires 0.000050 Amperes, then what resistance will we need to get 50 volts to read full scale?

$$R = \frac{V}{I} \quad \text{therefore} \quad R = \frac{50}{0.000050} = 1{,}000{,}000 \text{ Ohms or 1 MegOhm}$$

- What rating must this resistor have in terms of power? 0.0025 watts. Not so bad.
- As an aside, if you divide 1 MOhm by 50 volts you get 20,000 Ohms/volt. Now look at the small print at the bottom of the Simpson meter.

• How do we make a meter that has more than one range? Add a switch and more resistors.

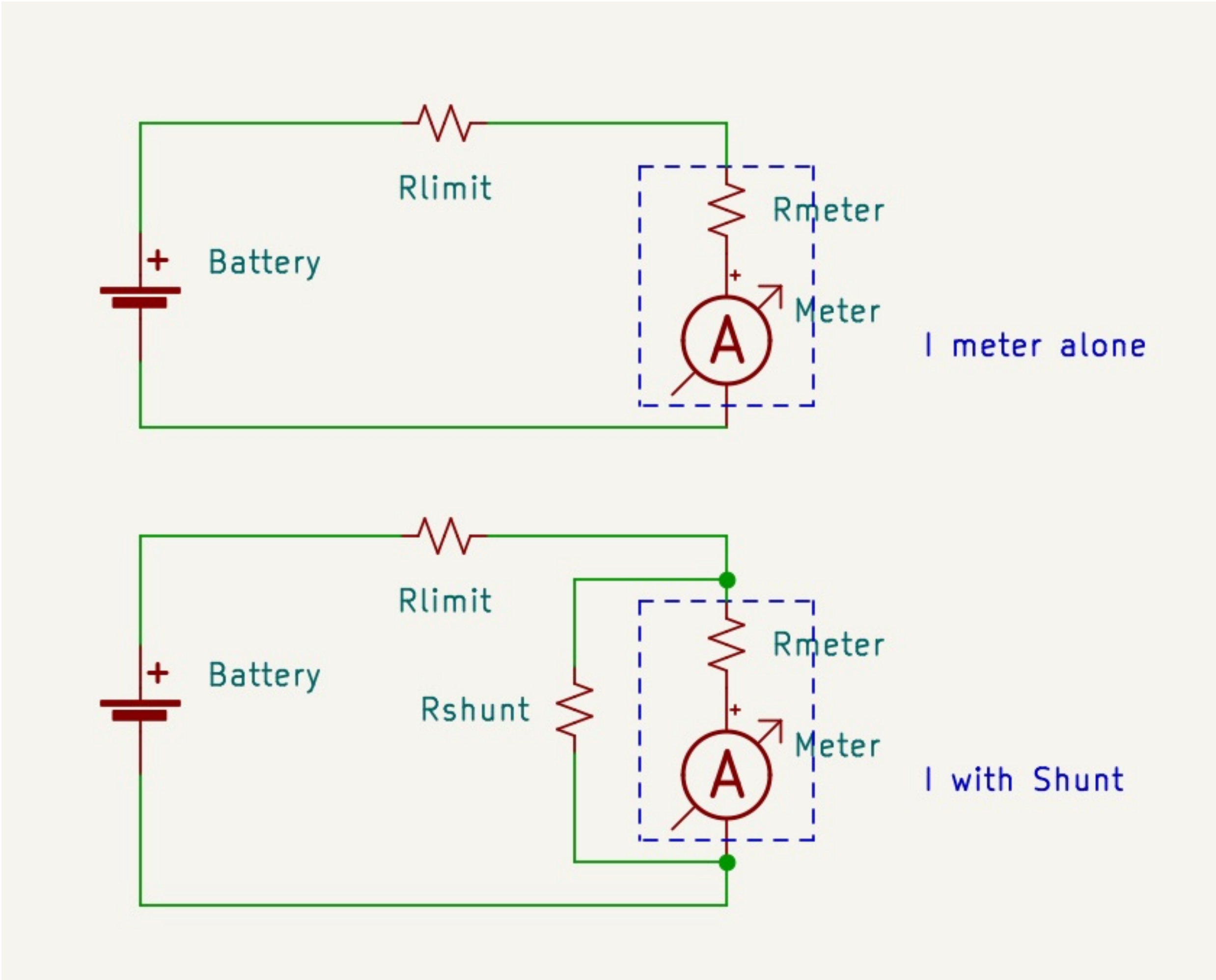


• What the above diagram illustrates, moreover, is that you need to take the internal resistance of the meter into account when calculating the required resistance. I've skipped that step because, for the moment, we don't know what the internal resistances of the various meters are? That'll come next.

Measuring the internal resistance of a meter

• Measuring the internal resistance of a meter requires two steps and some calculations.

1. Using the meter itself, record the current flowing through it with just a limiting resistor like the one you used to make it a voltmeter.
2. Wire a shunt resistor across the meter and now record the current flowing through the meter.



- A few notes: The voltage applied to the meter in step 1 will be the same voltage applied in step 2.
- The limiting resistor can be any value that allows an accurate reading of the current displayed on the meter.
- The shunt should be chosen, experimentally, to reduce the meter current by 1/3 to 2/3 the non shunted value.
- The calculations are as follows:

$$R_{meter} = R_{shunt} \times \frac{I_m - I_s}{I_s}$$

- Where I_m is the current through the meter alone, and I_s is the current displayed with the shunt in place.

- This assumes that the limiting resistor R_{limit} much greater than the internal resistance of the meter.
- A more complete formula is as follows:

$$R_{meter} = R_{shunt} \times \frac{I_m - I_s}{I_s - \frac{R_s}{R_l} \times (I_m - I_s)}$$

- Where R_l is the value of the limiting resistor, R_{limit} and R_s is the shunt resistance R_{shunt}
- For my 50 uA meter, the calculations are as follows:
- Using a value for R_{limit} as 220 kOhm, the current, I_m, displayed was 48 uA.
- Using a shunt value of 988 Ohm (actually a 1 K resistor but measured, it was less), the current, I_s, was 15.5 uA.
- Applying the first formula above

$$R_{meter} = 988 \times \frac{48.0 - 15.5}{15.5} = 2070 \text{ Ohms}$$

- Using the "complete" formula, above, the result is 2090 Ohms, so that means that internal resistance of this meter is approximately 2 kOhm

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Making an Ammeter

- So now that we can measure and calculate the internal resistance of the meter itself, we're ready to make an ammeter.
- Since the meter we're using measures milliamperes (or even micro amperes), we can't just run 30 amperes through it and hope for it to survive. Instead, most of the current needs to be diverted around the meter via a shunt resistor. So what value do we use?

$$R_{shunt} = \frac{R_{meter}}{(\frac{I}{I_m} - 1)}$$

- Where I is the desired current to be measured and I_m is the current the meter can handle.
- Eg. For my 50 uA meter, the meter's internal resistance is approximately 2.07 kOhm. If I want to turn this into a mA meter so that 50 mA (50000 uA) shows full scale, then

$$R_{shunt} = \frac{2070}{(\frac{50000}{50} - 1)} = \frac{2070}{999} = 2.07 \text{ Ohms}$$

- In other words, I'd need to put a ***2.07 Ohm shunt*** across the meter to turn it into a mA meter.
- E.G. I couldn't find a 2 ohm resistor in my junk box, but I did find a 1 Ohm resistor. What would be the effect of shunting the 50 uA meter with a 1 Ohm resistor? The short answer is twice the current would be shunted through the lower value resistor and 1/2 the current calculated would actually go through the meter.
- If I put a 1 kOhm resistor in series with my meter, and shunted it with my 1 Ohm resistor, what would/should the reading be if I applied 10 volts?
- Assuming the resistance in the meter would be very low, which it would be if shunted by a low value resistor, then …

$$I = \frac{V}{R} = \frac{10}{1000} = 0.01 \text{ or 10 mA}$$

- Now since the shunt is 1/2 the calculated value it should be, then only 1/2 the current will flow through the actual meter - 5 uA in this case.

Now for the project at hand: An Ammeter for high current DC (30 Amps)

- As hopefully was demonstrated by the exercise above, finding the right size shunt for a meter can be problematic. My solution was to buy a meter-shunt combination that is designed to measure up to 30 Amperes. (Yeah, that's cheating and I know.) That saved me the trouble of having to find/design a low resistance, high current shunt for this purpose. The shunt, in this case, is actually a bar of metal.

- Here's the link to that item: https://www.amazon.com/dp/B09BF5M69P?ref=ppx_yo2ov_dt_b_product_details&th=1

A Voltmeter that measures up to 30 volts DC.

- I already have a meter that is graduated in steps up to 30 which should be adequate for this purpose. There is a problem, however. Though it has the right markings on the face of it, nothing tells me what the actual current is that causes the needle to deflect to 30.
- The solution is rather simple. Just pass a known current through the non shunted meter and see what deflection is caused by that current. Then use "reverse engineering" to figure out what series resistance, R_{limit}, is required to produce a deflection of "30" when 30 volts is applied to the Series Resistor-Meter combination.
- Start with a relatively high value resistance, say 100 kOhm, in series with the meter at 10 volts. Then try 10 kOhm, then 1 kOhm.
- By doing the above, I found that 1 kOhm was not enough series resistance but 10 k was too much. I then put a variable resistor in series with the 1 kOhm resistor and adjusted it so that when 10 volts was applied to the resistor-meter series combination (without the shunt in place), the meter read "10" on its scale.
- It turned out to use about 1.52 kOhm in series with the meter. The meter reads full scale, "30", when 19.7 mA is flowing through the meter. I.E. The meter is actually approximately a 20 mA meter.
- The reason manufacturers use a non-standard mA meter in this application is that it makes adjustment easier. They mass produce shunts that have approximately the same resistance, and then, internally, adjust the meter to produce the proper reading when the shunt is in place.

Final thoughts

- As you may have discovered, very sensitive meters have relatively high (in the kOhm range) internal resistance. Lower sensitivity meters have lower resistances, in the Ohm to 10s of Ohm range.
- Now that you know all about meters, can you make an S-meter???