Extending the Range of a D'Arsonval (Analog) Meter

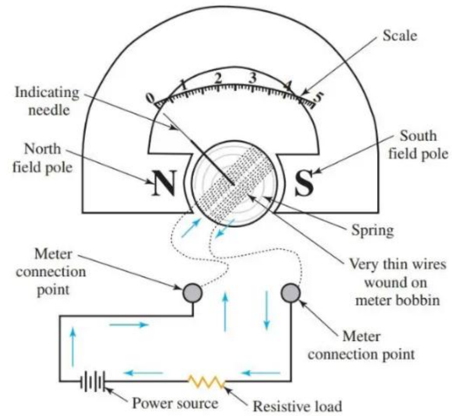

Figure 1 - D'Arsonval meter movement

At some point in time, you may find yourself in a position where you need to change the working range of an analog meter with a D'Arsonval movement so as to accommodate an increased current or voltage range. This can easily be done with the addition of a resistor or a resistor network. The intent of this article is to explain how this is done. We are going to look, for example, at the process for extending a 0-1mA meter to read 0-50mA.

First, it must be understood that such an extension is very easily made for either voltage or current individually, but that the method of accomplishing this modification is different for those two values. As was already stated, resistance is added to extend the range of the meter. Adding a resistance *in series with the meter movement* will extend the range for voltage readings, while adding a resistance *in parallel (or shunt)* will extend the range for current measurements. It then stands to reason that adding calculated resistances in both positions will allow an extension of both the voltage and the current meter ranges.

So… how much resistance is needed? As with almost everything in electronics, there are equations that are used to determine the required resistance values for the effect desired. In every case, however, these equations use the basic through-resistance of the meter movement as in input value for the calculations to be made. That means that we need to first determine the through-resistance of the meter movement that we intend to modify. ***NOTE:*** ***This resistance cannot be determined by using an ohmmeter to measure the meter resistance. Doing so will most likely result in damage to the meter movement under test, as the multimeter output current in its resistance function will often be greater than the full-scale current capability of the meter movement under test.*** Instead, we need to use a specific test method to determine the meter's through-resistance, as described below and illustrated in Figure 2.

Referring to the Figure 2 circuit diagram, resistor R1 is of a value selected based upon the test circuit voltage and the full-scale deflection value of the meter under test (MUT). Suppose, for example, that the MUT is a zero-to-one-milliampere meter. In that case, its full-scale deflection value would be 0.001A (1mA). When applying Ohm's Law to this circuit, we can determine that a resistance of 6kΩ will give us a full-scale deflection ($R = \frac{6.00}{0.001} = 6{,}000\Omega$). However, 6kΩ is not a standard resistor value.

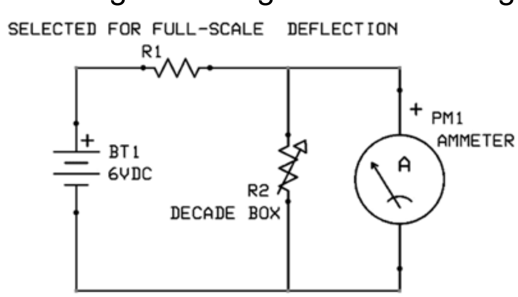

Figure 2 - Meter through-resistance test circuit

The next higher standard value would be 6.2kΩ, which would be suitable for use here. We want a resistance greater than that required for full-scale deflection so that, in this compromise situation, we end up with a deflection slightly less than full-scale rather than one that is off-scale over the upper limit of the meter's range.

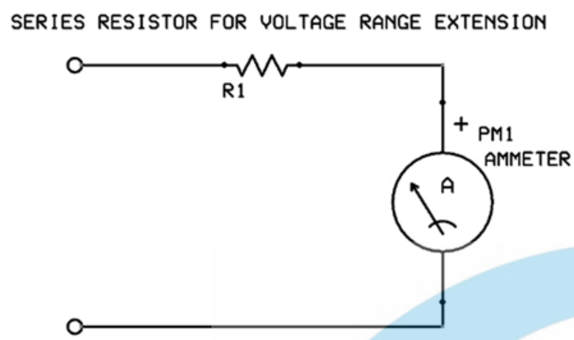

Figure 3 - Voltage range extension arrangement

In series with the meter, this resistor will produce a calculated meter deflection of about 0.0009677A or 0.9677mA. The resulting meter deflection will most likely be slightly different, based upon the resistor's actual value within its tolerance range.

The next step is to place a decade resistance box in shunt across the meter, illustrated as R2 in the Figure 2 circuit diagram. Now begin adjusting the decade box until a meter deflection of fifty-percent of the original reading is achieved. At this point, the decade box and the meter are each flowing the same current through their respective branches of the parallel circuit, indicating that their resistances are matched. Disconnect the decade box, and without changing its adjustment or knob positions at all, measure the resistance through the decade box. The value measured there will be the same as the resistance through the meter. That value can then be used as the meter resistance (R_M) in the equations used later. This test was performed on the bench using a zero-to-one-milliampere meter, a 6.2kΩ 1%-tolerance resistor that measured out at 6209 ohms, and a decade box having twenty-percent resistors inside. The 50% deflection point came at an indicated resistance of 68Ω on the decade box, which measured out to be an actual 79.1Ω. That means that the meter through-resistance has to be that same value, or an equal 79.1Ω.

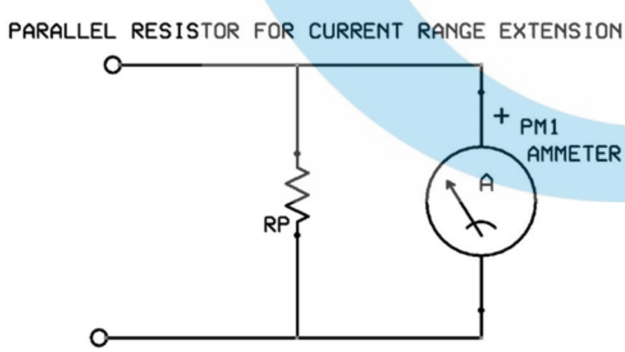

Figure 4 - Current range extension arrangement

Now for the remaining equations… we are interested in the following values:

- R_M – the meter through resistance (already determined through bench testing to be 79.1Ω);
- I_M – the current through the meter;
- V_M – the voltage across the meter;
- M – the multiplication factor to achieve the desired meter range;
- R_S – the series resistance needed for voltage range extension; and
- R_P – the parallel resistance needed for current range extension.

Calculation of the V_M and I_M values are straightforward Ohm's Law exercises:

$$I_M = \frac{E}{R} = \frac{6.00}{(6209 + 79.1)} = \frac{6.00}{6288.1} = 0.000954183A = 0.954mA$$

$$V_M = (I \times R) = (0.000954A \times 79.1\Omega) = 0.0754614V = 75.461mV$$

Although R_M was already determined to be 79.1Ω, we should look at the equation that will support that determined value:

$$R_M = \frac{V_M}{I_M} = \frac{75.461mV}{0.954mA} = 79.099\Omega$$

The equation used to derive the multiplication factor *(M)* is also relatively simple:

$$M = \left[\frac{(required\ full - scale\ deflection)}{(initial\ full - scale\ deflection)}\right] = \frac{50mA}{1mA} = 50$$

Finally, we get to the last two equations, those for the serial resistance *(R_S)* needed for voltage range extension, and the parallel resistance *(R_P)* needed for current range extension:

$$R_S = [R_M \times (M - 1)] = 79.1\Omega \times 49 = 3875.9\Omega\ \ or\ \ 3.9k\Omega$$

$$R_P = \left[\frac{R_M}{(M - 1)}\right] = \frac{79.1}{49} = 1.6142857\Omega\ \ or\ \ 1.61\Omega$$

Note that we did not state a voltage range extension to be sought. That value was provided simply to illustrate the execution of the equation to derive a series resistance value (Figure 3) that would extend the voltage range by a factor of 50 over its original voltage range. Our stated purpose here was to derive a current range extension from one milliampere to fifty milliamperes.

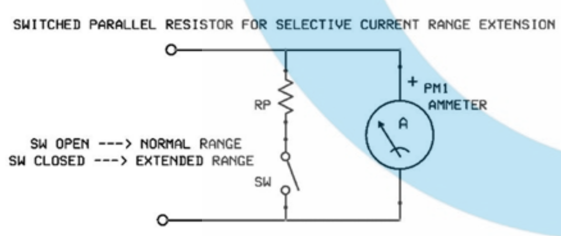

Figure 5 - Circuit for selective current range extension

In the case of the current range extension sought here (Figure 4), it is advisable to source a precision resistor at 1.6Ω, as the calculated 1.61Ω value will likely be next to impossible to find. If a different compromise value is the only option available, a value slightly higher than the calculated value is normally preferred over a lower value as already explained.

It is also interesting to note that this range extension can be made selective through use of a switch that connects the resistance in shunt across the meter (Figure 5). This permits dual-range use of the meter, either at its original range of zero to one-milliampere or at its extended range of zero to fifty-milliamperes. However, it is important that the resistor selected for this duty be of sufficient power handling capability to sustain the continuous wattage that will be impressed upon that resistor. For example, if the maximum circuit voltage were to be nine volts, and if the maximum current to the meter is expected to be

50mA, the resistor should be rated at least 500mW. This is because the maximum anticipated power to be handled by the meter circuit is 9.0V x 0.050A, or 0.450W (450mW). In reality, a one-watt resistor would be preferred in this situation. Granted, while not all of the current will flow through the resistor, so the 500mW device will certainly be adequate, it is nonetheless good design practice to build in a cost-effective margin of safety.

As an interesting side note, it should be understood that the method by which voltage and current ranges are varied on standard multimeters is by exactly this method. Selecting a different range via the function or range switch of the multimeter simply switches in the correct resistance, in either parallel for current or series for voltage, into the meter circuit.

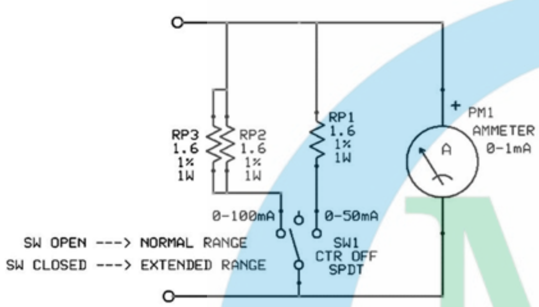

Figure 6 - Circuit for 0-50mA & 0-100mA range extensions

In the equipment on which I was working when this topic came up, I wanted to extend the range of a 0-1mA meter, on a selective basis, to read 0-50mA. I ended up with a 1.6Ω 1% 1W resistor and a subminiature toggle switch to accomplish the conversion. The equipment was a vintage *Radio Shack Model 28-280 Electronics Learning Lab*. I wanted for my grandson to be able to understand the current draw of the LED's installed there, as well as any other small circuits that he might build on the breadboard portion of the unit. However, the typical current draw for red LED's is in the area of 20 to 30 milliamperes, well beyond the 1mA limit of the meter as provided on the unit. I actually considered going with a SPDT switch (having a center-off position) and two different resistors, one for range extension to 50mA and another for range extension to 100mA (Figure 6). As I write this paragraph, I have not yet made a firm decision in that regard.

However, I *did* create a custom label for the meter face that carries the markings for the 0-50mA range, and it was simple to add the 0-100 markings (Figure 7), or else to simply use the 0-1mA markings and multiply the reading by a factor of 100.

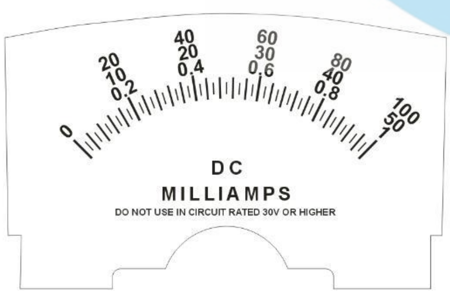

Figure 7 - Custom meter face label

As a mental exercise, let's go ahead and calculate the resistance needed in this case, to achieve the 100mA range extension. The resulting equation would be:

$$R_P = \frac{R_M}{(M-1)} = \frac{79.1}{99} = 0.79898\overline{89} = 0.80\Omega$$

That was a predictable result, and better yet, it will *not* require any additional components beyond those that I already have on hand. To achieve the 0.80Ω value, I can just use two of the 1.6Ω 1% 1W resistors taken in parallel. This also kicks the power rating for that resistance up to 2W, a desirable condition as the calculated power for that circuit would be 900mW ($100mA \times 9.00V = 900mW$). I like having some headroom when it comes to power ratings of resistors.

Figure 8 - Radio Shack 28-280 electronic trainer

Any way you look at it, this is a simple process that will easily extend the useful range of an installed ammeter, so long as there is space in the physical installation for the resistor(s) to be placed and room for the switch if the setup is to be selective. The selective arrangement permits greater reading accuracy at the lower current levels, while still providing for the increased current capability in the higher range(s). Ammeters are typically low-resistance devices so that they do not cause any significant voltage drop when they are connected in series into a working circuit. Remember that voltmeters are simply ammeters that have resistances in series with the meter so as to reduce the circuit loading imposed by the meter. The meter is then calibrated based on the current that would flow to provide full-scale deflection, and equated to the voltage that would cause that current flow. A voltmeter is connected in parallel with the circuit under test.

Figure 9 - Ammeter original appearance

This article was not intended to be a full treatment of the subject, but merely a quick glance at the means used to safely and usefully extend the range of a small panel ammeter in a basic electronics trainer.

I decided finally to go for both the 0-50mA and the 0-100mA range extensions on the Radio Shack 28-280 trainer. The meter face plate label depicted in Figure 7 reflects that last-minute decision. The next few photos, Figure 8, Figure 9, and Figure 10 help to show the changes that I made to the appearance of the unit. Figure 8 shows the front panel of the device. Figure 9 shows what the ammeter looked like to begin with, and Figure 10 shows what the ammeter looks like after the modifications.

The operation is quite simple. The user would use the toggle switch to set the meter to the anticipated current range for the job at hand, then back it down to a lower range if the reading turns out to be within that lower range. Thus, if a user were to start out with the meter set to the 0-100mA scale and the actual reading turns out to be quite a bit lower, the range can be changed to the 0-50mA range if that will more accurately show the measured value. Note that the switch is currently in the 0-1mA (center) position as depicted in Figure 9.

Figure 10 - Modified ammeter on panel

I have a second one of these trainers, which I will probably leave in its original condition, but one never knows, huh? I might just decide to modify that one as well. I have all of the hard work – for example, making the label for the meter face – already done. It is now just a matter of throwing parts at it, and I certainly have plenty of those on hand!

All of this discussion is a means of illustrating the simplicity of extending the capability of almost any panel meter that may be encountered in the course of experimenting or tinkering with electronics. Very often, the uninitiated hobbyist will believe that the rating of the installed ammeter or voltmeter must dictate the range limits of that meter in routine use. We have now seen, however, that this is clearly *not* the case. We have seen how, with some readily-available resistors and a little bit of applied mathematics, we can bend the existing meter to our will and thereby make that meter function within whatever range we choose.