METER SHUNTS & MULTIPLIERS

How do you turn a 0-1mA panel meter into one that reads 1A full scale? Or one that reads 100mA full scale? Or into a voltmeter that reads 0-100V? It's not hard to adapt almost any panel meter in this way, once you understand the concepts of current shunts and voltage multipliers.

Let's look at current shunts first. A current shunt is basically just a resistor that is connected directly across the meter movement you want to adapt — so that it *shunts* a significant proportion of the total current around it. This is the way to adapt a meter into one that measures **higher currents**.

Fig.1 shows the basic idea. M is our basic meter movement, while Rs is the shunt resistor. As you can see it's connected directly across the meter's terminals, so that all of the current the meter can't handle is able to pass through the shunt instead.

How do you work out the value of the shunt? It's easy once you understand exactly what a shunt does. Let's say we want to adapt our 0-1mA panel meter into one that measures 0-1A. That means that we want the meter to indicate full-scale deflection (FSD) when 1A is flowing — right? But the meter itself will read FSD when it has only 1mA flowing through its coil, of course. So the way we can make this happen is by arranging for the shunt to take **the remaining 999mA** of current. Or putting it in more general terms,

$$I_S = I_{TOTAL} - I_M$$

where Is is the current taken by the shunt, ITOTAL is the total current equal to the new effective FSD we want to give the meter), and IM is the meter's own basic FSD.

So that's the easy way to work out how much current we want our shunt to carry, compared with the meter itself.

As another example, how much current would the shunt need to carry to turn our 0-1mA meter into one reading 100mA? That's right, 100mA minus 1mA, or 99mA.

Now what we have to do is work out the value of the shunt resistor in order to make it carry that proportion of the current. If you look at Fig.2, you see that because the meter and shunt are connected in parallel, they always have the same voltage across them. So how do we persuade say 999mA of the total current to go through the shunt, and only 1mA through the meter?

Right again — simply by making the resistance of the shunt 1/999th that of the meter. That's because in a parallel circuit, the current will always divide in proportions which are the reciprocal of the path resistances. Or in general terms here:

$$\frac{I_s}{I_m} = \frac{R_m}{R_s}$$

or in a more convenient form for our present purposes,

$$R_s = R_m \div \left(\frac{I_s}{I_m}\right)$$

In other words, the value of our shunt resistor Rs can be found by dividing the meter resistance Rm by the desired ratio of shunt current to meter current.

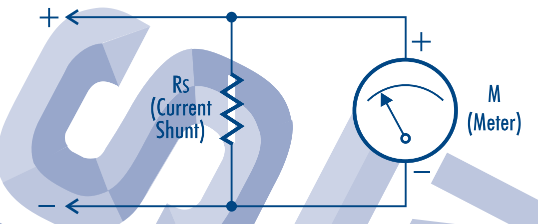

Fig.1: A current shunt is connected in parallel with the meter.

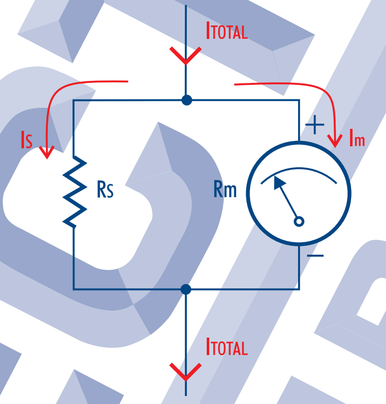

Fig.2: The shunt bypasses a large proportion of the total current around the meter, leaving it with only the current it can handle...

So in our example of turning the meter into one reading 0-100mA, the shunt would need to have a resistance of Rm divided by 99.

Meter resistance

Clearly, though, you need to know the resistance of the meter itself in order to work out the value of the shunt you're going to need.

Luckily the internal resistance of most meters is specified when you buy them new. For example the resistance of the MU-45 type 0-1mA meter movement sold by Electus (QP-5010) is specified as 200 ohms, while the more sensitive 0-50uA model (QP-5012) has a specified resistance of 3500 ohms. So it's not hard to work out the value of shunts needed to adapt either of these meters to read higher currents.

But what if you have a meter movement salvaged from a piece of equipment, and you don't know its resistance? Or even its current sensitivity? (It might already have an internal shunt, for example.) The simplest way is to measure it — but don't just slap a multimeter across it, because that could damage the meter by passing too much current through it. The best way is to use the simple test circuit shown in Fig.3.

Here the meter is connected to a 12V battery via a DMM (set to a suitable current range) and adjustable resistor RV1, which is carefully adjusted until the meter is just giving its full-scale reading. The DMM will then be showing the current needed to produce this current FSD — in other words, the meter's sensistivity.

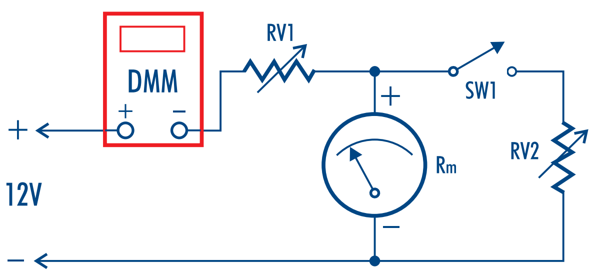

Fig.3: A simple circuit used to measure a meter's internal resistance.

Now switch SW1 is closed, to connect the second adjustable resistor RV2 directly across the meter, as a shunt. RV2 is then adjusted until the meter reading is reduced to **exactly half scale**, while monitoring the total current via the DMM, and if necessary adjusting RV1 to maintain it at the original FSD figure.

When the meter reading is exactly 50%, the value of RV2 will be equal to the meter's own resistance, because the current is being split equally through the two paths. So you can then disconnect the battery and use the DMM to measure the value of RV2 (by itself), to learn the meter's resistance.

Note that even if the meter should have a current shunt built inside it already, this test will still give you its *effective* sensitivity and resistance — **including** any internal shunt. So the figures you get will allow you to work out the value of any new shunt you need to adapt it for measuring higher currents, regardless of what may be inside the meter case.

Practical shunts

Because a current shunt is generally designed to take most of the current, leaving only a small amount to pass through the meter, most shunts need to have quite low resistance values. For example the shunt to adapt our 1mA/200Ω meter into one reading 0-1A needs a resistance of only 200Ω/999, or 0.20Ω. Similarly the shunt needed to adapt it for reading 0-100mA would need a resistance of only 200Ω/99, or 2.02Ω.

And these values need to be quite accurate, because the accuracy of the resulting 0-1A or 0-100mA meter depends directly on the shunt taking 999/1000ths or 99/100ths of the total current, respectively.

So practical shunts often have to have quite low values, yet be quite accurate. And of course they have to be able to carry the necessary current level (i.e., virtually all of the current being measured), without overheating.

For this reason, current shunts used to adapt meters for measuring very high currents are generally made from stout strips of nichrome or some similar metal with a very low temperature coefficient of resistance (tempco), carefully filed or machined until they reach the exact resistance needed.

This isn't very practical for hobbyist use. But if you only need moderately low shunt values, say for adapting a meter to read 0-10mA or 0-100mA, you can often achieve the value you need simply by using parallel combinations of standard low value resistors — preferably the metal film type, for stability.

For example to get a shunt of 2.02Ω, to adapt an Electus QP-5010 meter into one measuring 0-100mA, you could use a combination of six low value 1% metal film resistors in parallel: four of 10Ω value (RR-0524), one of 20Ω (RR-0531) and one of 22Ω (RR-0532). This combination will give a value very close to 2.02Ω.

You can use the same idea to make practical shunts for most common meters, to adapt them for measuring current up to about 500mA or so. It's really only when you want to make them measure significantly higher currents that you need to worry about pieces of nichrome wire or metal strip.

MULTIPLIERS

Now let's look at **multipliers**, which are used to adapt meters for measuring higher *voltages*. Unlike a current shunt, which as we've seen is wired in parallel with the meter, a multiplier is a resistor connected in *series* with the meter.

To understand how a multiplier works, first think about the meter itself. As we've already seen, a meter has two key parameters: its *sensitivity*, usually specified in terms of the current needed to indicate FSD, and its *internal resistance*.

Now using Ohm's law, it's easy to work out the voltage drop across the meter when it's carrying its FSD current:

$$V_m = I_m \times R_m$$

So when our 0-1mA meter with a resistance of 200Ω is reading FSD, for example, it will have a voltage drop of (1mA x 200Ω) or 200mV. Similarly a 50uA/3500Ω meter like the Electus QP-5012 will have a voltage drop of (50uA x 3500Ω) or 175mV.

These figures are sometimes called the **voltage sensitivity** of the meter movements, because they basically show the voltage that needs to be applied directly across the meter to produce its full-scale reading. As you can see the voltage sensitivity of most meter movements is typically quite low: 200mV or less.

To adapt such a meter for measuring much higher voltages — say 0-20V, or 0-50V — the simplest approach is to

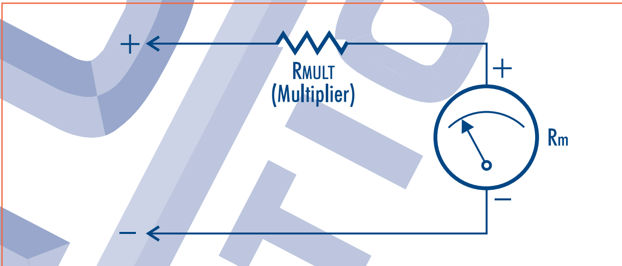

Fig.4: A multiplier is connected in series with the meter, not across it.

connect a resistor in **series** with it, to drop the excess voltage. This is exactly the idea of a *multiplier* resistor: it effectively 'multiplies' the voltage sensitivity of the basic meter to allow measuring higher voltages, without affecting its current sensitivity.

But how do we work out the value of the multiplier resistor? It's not hard.

First, work out the total resistance necessary to pass the FSD current of the meter, knowing the full-scale voltage we want our voltmeter to read:

$$R_T = V_{FSD} / I_m$$

where R_T is the total resistance, V_{FSD} is the FSD voltage we want for our voltmeter, and I_m is the meter's current sensitivity.

For example, let's say we want to turn our 0-1mA meter into a 0-50V voltmeter. R_T will need a value of 50V/1mA, or 50kΩ — right?

Similarly if we want to use a 0-50uA meter as a 0-20V voltmeter, the value of R_T will need to be 20V/50uA, or 400kΩ.

Now the meter itself has its own internal resistance, of course. And this will form part of the total resistance, whether we like it or not. So in order to find the required value of multiplier resistance as accurately as possible, we need to *subtract* the meter resistance from the total resistance we just worked out:

$$R_{MULT} = R_T - R_m$$

So because our 0-1mA meter has a resistance of 200Ω, the actual value of multiplier we'll need to turn it into a 0-50V voltmeter will be (50kΩ - 200Ω), or 49.8kΩ. Similarly the multiplier needed to turn our 50uA/3500Ω meter into a 0-20V voltmeter will be (400kΩ - 3.5kΩ) or 396.5kΩ. Get the idea?

Needless to say these multiplier values again need to be quite accurate, because the accuracy of the resulting voltmeter will depend on them quite heavily. Luckily because multiplier resistor values are much higher than those for current shunts, it's generally much easier to make up the value you need using standard 1% metal film resistors — this time series combinations.

For example to make up our 49.8kΩ multiplier, you'd use say a 47kΩ resistor (RR-0612) and a 2.7kΩ (RR-0582) in series, giving very close to the correct value. Similarly to make up the 396.5kΩ multiplier you'd use say two 180kΩ (RR-0626) resistors and a 36kΩ (RR-0609) in series, again giving very close to the correct value.

If you work out the exact figures, you'll find that they're within 0.2% or so of the correct figure. There's no point in striving for higher accuracy, because meter movements themselves are generally only rated to an accuracy of 2.5%, and metal film resistors have a tolerance of 1%.

When you want to make the meter into a voltmeter for high voltages, it's actually a good idea to split the multiplier into two or more physical resistors so they share the voltage drop. Metal film resistors are generally not designed to drop more than 200V or so, and they may break down if more than this is applied. So bear this in mind too when you're choosing the resistor values.

Choosing a meter

It's not difficult then, to turn almost any meter into a voltmeter, simply by connecting a suitable multiplier resistance in series. But does this mean that we can choose any meter we like for use as a voltmeter — is a 0-1mA meter just as good as a 50uA meter, given the appropriate multiplier?

No, for a very simple reason. In most circuits when we want to measure a voltage, we want do so while causing the absolute minimum disturbance to the circuit itself. And not surprisingly there will be less disturbance when less current needs to be drawn by the meter. So if a choice of meters is available, it's always better to use the one that needs less current: say the 50uA meter instead of the 1mA meter.

Remember when we worked out those multiplier values, for example. To turn the 1mA meter into a 0-50V voltmeter we ended up with a total resistance of 50kΩ, while for the 50uA we needed a total resistance of 400kΩ just to produce a 0-20V voltmeter. If we wanted to use the 50uA meter to read 0-50V, we'd end up with a total resistance of 1MΩ — much higher than 50kΩ, and therefore much less likely to disturb the circuit we're measuring in.

On the other hand for use as a **current** meter, it's generally better to use a less sensitive meter like a 1mA movement. This is because these movements have a lower internal resistance (like 200Ω instead of 3500Ω), so they will generally need a lower shunt resistance to adapt them for higher current measurement. And the lower the shunt resistance, the lower the voltage drop or 'voltage burden' that will be produced in the circuit when the meter and shunt are being used. Remember that to measure a current, the circuit must be generally be *broken* to connect the meter in series — so in this case, it's the voltage drop of the meter and shunt that will cause the disturbance.

Digital panel meters

Until now, we've been looking at what you need to adapt traditional moving-coil (or moving iron) meters so they will measure higher currents or voltages. But more and more, you might prefer to use a digital panel meter (DPM) instead. They're not much dearer nowadays, after all.

So what's different about DPMs? Can you use current shunts and multipliers with them, in the same way? Not quite, but there are similarities.

The main thing to realise is that a DPM is basically a digital voltmeter, not a current activated device like a meter. Most of them have a voltage sensitivity of 200mV, which is very similar to that of a meter movement, but on the other hand like a DMM they tend to have an internal resistance of 10MΩ or higher — much higher than a meter movement. As a result of this much higher resistance, we need to change the way we adapt a DPM for either current or voltage measurement. But often it makes things easier rather than harder.

When you want to measure a current, for example, you don't have to worry about the DPM's internal resistance any more. It's now so much higher than the shunt that you can ignore it. All you need to do is work out the value of 'shunt' resistor necessary to drop the DPM's full-scale reading voltage, when the desired full-scale current is flowing through it (Fig.5). So by Ohm's law:

$$R_S = V_{FSR} / I_{FSR}$$

Where R_S is the required shunt resistor value, V_{FSR} is the DPM's voltage sensitivity for full-scale reading, and I_{FSR} is the full-scale current reading we want to give it.

So to adapt either the Electus QP-5570 or QP-5580 DPMs (both of which have a voltage sensitivity of 200mV) to read say 0-100mA, for example, you'd need a shunt resistor of (200mV/100mA) or 2.00Ω. Similarly to make them read 0-10mA, you'd need a shunt of 20.0Ω. As you can see, it's even easier to work out the shunt value than it was before. The values are likely to be 'rounder numbers' too, and easier to achieve as a result.

There's even more reason to be accurate in achieving the right shunt value, though, because DPMs are much more accurate themselves than meter movements — typically 0.1%. So it's worth going to a bit more trouble to get the correct shunt value, to make sure that this higher accuracy isn't degraded.

When it comes to adapting your DPM for measuring higher voltages, though, things are a little more complex. In most cases we can't use a simple series multiplier resistor any

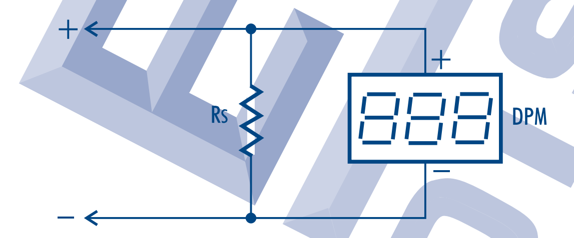

Fig.5: A shunt is also used to adapt a DPM for current measurement, but its value is easier to work out...

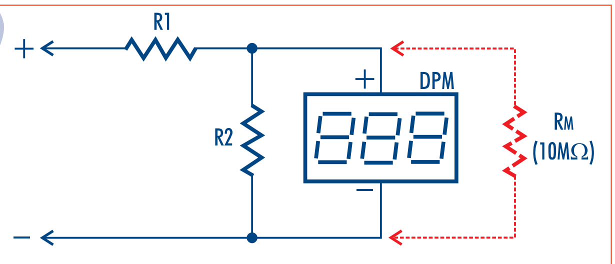

Fig.6: For voltage measurement, though, you need a resistive divider rather than a simple multiplier.

This table will save you having to work out common shunt and multiplier values for the meters and DPMs stocked by Electus.

ELECTUS METER	SHUNT VALUE (FOR CURRENT RANGE)					MULTIPLIER VALUE (FOR VOLTAGE RANGE)					
	10mA	20mA	50mA	100mA	500mA	5V	10V	20V	50V	100V	500V
QP-5010 (0-1mA/200Ω)	22.2Ω	10.53Ω	4.08Ω	2.02Ω	0.40Ω	4.80kΩ	9.80kΩ	19.8kΩ	49.8kΩ	100kΩ	500kΩ
QP-5012 (0-50uA/3500Ω)	17.6Ω	8.77Ω	3.50Ω	1.75Ω	0.35Ω	96.5kΩ	197kΩ	397kΩ	1MΩ	2MΩ	10MΩ
QP-5570 (LCD DPM. 200mV/10MΩ)	20.0Ω	10.0Ω	4.00Ω	2.00Ω	0.40Ω	R1= 1MΩ R2= 41.8kΩ	R1= 1MΩ R2= 20.5kΩ	R1= 1MΩ R2= 10.1kΩ	R1= 1MΩ R2= 4.00kΩ	R1= 1MΩ R2= 2.00kΩ	R1= 1.53MΩ R2= 612.2Ω
QP-5580 (LED DPM. 200mV/10MΩ)	20.0Ω	10.0Ω	4.00Ω	2.00Ω	0.40Ω	R1= 1MΩ R2= 41.8kΩ	R1= 1MΩ R2= 20.5kΩ	R1= 1MΩ R2= 10.1kΩ	R1= 1MΩ R2= 4.00kΩ	R1= 1MΩ R2= 2.00kΩ	R1= 1.53MΩ R2= 612.2Ω

more, because the DPM's own internal resistance is already so high (10MΩ). You'd need a whopping 40MΩ series resistor just to turn it into a 0-1V meter, for example. The circuit loading would be absolutely negligible, but finding or making up an accurate and stable 40MΩ multiplier wouldn't be easy.

So with a DPM, we need to use a **voltage divider** to adapt it for measuring higher voltages, rather than a simple multiplier. It's still fairly straightforward, though; see Fig.6.

If you like, you can think of resistor R1 as our original multiplier resistor, and R2 as an extra resistor added across the DPM to bring its 10MΩ internal resistance down to a suitably lower value. Or if you prefer, you can think of R1 and R2 simply as a voltage divider across the input voltage, and designed to 'break it down' to the 200mV needed by the DPM. To make the DPM read 0-20V you need a divider ratio of 20V/200mV or 100:1, for example.

The formula relating division ratio to R1 and R2 is:

$$V_R = (R1 + R2)/R2$$

where V_R is the divider ratio, expressed as a number, and R1 and R2 are the resistor values — although strictly speaking R2 here is really the parallel combination of resistor R2 and the DPM's own input resistance R_M.

The only thing you have to bear in mind is that to minimise the voltmeter's loading on the circuit you're measuring, the total resistance of the voltage divider should be as high as possible. But that may call for impractically high resistor values, especially for R1, and also mean that you *will* need to take the DPM's resistance R_M into account when you're working out the value for R2 (because of its shunting effect). So there's a bit more to it than simply picking a pair of resistors to give the right voltage division ratio.

Often, though, it *can* be that simple. If you want to make your DPM into a 50V meter, for example, it would probably be quite acceptable in terms of circuit loading to have the total divider resistance around 1MΩ. So since the divider ratio would be (50/0.2) or 250, you could pick a 1MΩ resistor for R1, and a value of 4.0kΩ for R2. Since R_M is 10MΩ, it'll have a very small shunting effect on R2 — about 0.04%. This can probably be ignored.

In fact with R1 fixed at 1MΩ, you can probably ignore the effect of R_M across R2 for any division ratio larger than 150 — corresponding to a 0-30V range or higher. You only need to take R_M into account for lower ratios; i.e., lower voltage ranges.

Finally, you again need to remember resistor voltage ratings when you're making a voltage divider to adapt a DPM into a voltmeter. So when you're building a divider for very high input voltages (say above 200V), it's again a good idea to split R1 into a number of series-connected resistors so they share the voltage drop.

Obviously most of the divider's voltage drop is across R1 (i.e., all but 200mV), and as we mentioned before metal film resistors generally aren't designed to withstand more than about 200V. So for a voltmeter designed to measure up to say 500V full scale, it would be a good idea to use say three 510kΩ resistors in series for R1, giving it a value of 1.53MΩ but with the three resistors able to share the load. Your corresponding value for R2 would be 612.2Ω, so the shunting effect of R_M would of course be negligible. Using a 620Ω resistor in parallel with one of 47kΩ would probably be close enough.

To save you time and effort, the table above shows the shunt and multiplier values for adapting Electus meters and DPMs for many common current and voltage ranges.