Ammeters & Shunts

A Basic Introduction

An ammeter is a device designed to accurately measure and display electrical current in a readable form, which could be a moving coil meter, a LED bargraph display or a digital panel meter. The basic unit of electrical current is Amperes, usually shortened to Amps. Milliamps, (that is, one one-thousandth of a Amp) is a more convenient measurement for lower power circuits

When designing an ammeter, external resistors, usually referred to as shunt resistors (or sometimes current resistors), are connected in parallel with the meter input to extend or convert the range. This arrangement divides the current being measured so the majority flows through the shunt resistor and a small portion goes to the meter. Commercially made shunt resistors are calibrated: for example, the Jaycar QP-5417 has a voltage drop of 50mV across it when the current flowing through it is 200A. This calibrated information is stamped on the side of the shunt.

Moving coil meter - examples

As an example, take a Jaycar QP-5010 moving coil meter with a 0 - 1mA movement and 200Ω coil resistance. If we wanted to change the Full Scale Deflection (FSD) range of the meter from the original 1mA, to say 1A, 10A or 100A, we would have to do two things:

1. Re-label the meter's scale (ie "1A", "10A" etc) and
2. Add an appropriate shunt resistor that will change the FSD range accordingly.

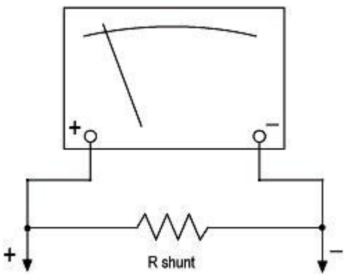

Fig 1. Moving coil ammeter:
FSD = 1mA (no shunt resistor)
SD = 200A (with 1mΩ shunt resistor)

To create a 0 - 1A ammeter, having a 1A full scale deflection (FSD), we need to determine the shunt resistance required to bypass the majority of the current, so that only 1mA flows through the coil movement.

	FSD	R_{shunt}	Total
Volts (V)	0.2V (calculated)	0.2V	0.2V
Current (I)	0.001A (1mA)	0.999A (calculated)	1A
Resistance (R)	200 Ω	0.2002 Ω	

Using Ohm's Law: V = R x I, we calculate the FSD voltage across the meter: V = 200 x 0.001= 0.2V.

The current flowing through the shunt resistor is the difference between the total current (1A) and the current through the meter (1mA). Therefore the current through the shunt resistor is 0.999A, although in this case the difference between that and the total current is only 0.1%, and can be ignored.

Using Ohm's Law again to calculate the shunt resistance gives us: Rshunt = 0.2V/ 0.999A. Therefore, Rshunt = 0.2002Ω, or typically 0.2Ω. This can also be expressed as 200mΩ ("Milli-Ohms").

The tolerance of the shunt resistor should be typically 0.5%, however for non-critical applications, a suitable shunt can be made by connecting a number of 1 Watt resistors in parallel. For example, the 0.2Ω example above could also be made from 5 x 1Ω 1W resistors connected in parallel.

The next important parameter to determine is the required power rating of the shunt resistor. In this example, Rshunt would be subjected to currents up to 1A, therefore, the power dissipation in Rshunt (for 1A) is V times the current through Rshunt: in this case 0.2V x 0.999A = 0.2W. Note, if a shunt resistor overheats it can permanently change the resistance of the shunt, and hence the accuracy of the measurement. To prevent overheating, the power rating of the shunt should be at least two to three times the power dissipation expected in Rshunt. In this example the minimum power rating of the shunt resistor would need to be 0.4W or preferably higher.

Commercially made high power shunt resistors have four screw terminals: two high current terminals for measuring system current, and two low current terminals for connecting to the moving coil meter or digital panel meter. Illustrated below is the Jaycar QP-5417 200A shunt resistor. **Note that most of the current Jaycar range of high power shunts are designed to have a 50mV drop at the rated current, not 200mV, and so are not suitable for use with 200mV FSD meters.**

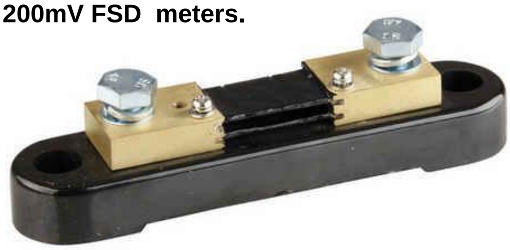

Fig 2. Typical shunt resistor Jaycar QP-5417

(An exception is the Jaycar RR-3420, a 0.01 Ω PCB mount shunt that will turn a 200mV FSD meter into a 20A FSD meter).

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Digital Panel Meter - examples

Digital panel meters can be used in much the same way to create an ammeter, by connecting a shunt resistor across the voltage input. Instead of using a moving coil meter with a range of 0-1mA as described in the above example, the Jaycar QP-5570 digital panel meter (or voltmeter) with a 200mV input could be used. Note that in this case the Full Scale reading is “1999”, and the correct decimal point must be selected to scale the range correctly. This also means that, unlike a moving coil meter where you can pretty much put any numbers you like on the scale, the digital panel meter can only ever display numbers between 0 and 1999.

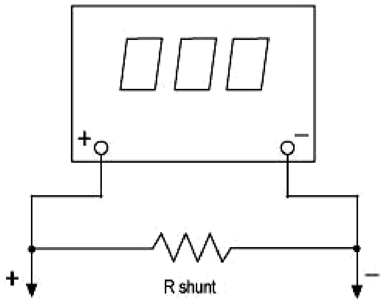

Fig 3. Digital ammeter:
Input voltage = 200mV
FSD = 2A (with 100mΩ shunt resistor)

The current through the voltmeter can be considered negligible if the voltmeter input impedance is high enough, and the shunt resistor can be sized according to how many volts or millivolts of drop will be produced per amp of current. To set up an ammeter with a 2A, 20A, or 200A range using a 200mV digital panel meter, we would have to do two things: select and wire up the appropriate decimal point on the digital panel meter, and connect the digital panel meter input across the shunt resistor. To design a 0 - 2A ammeter, you need to first use Ohm’s Law to determine the shunt resistance required to create a 200mV drop when 2A of current is flowing through it.

In this case Rshunt = 200mV ÷ 2A = 100mΩ.The next important parameter to determine is the power rating of the shunt resistor. In this example, Rshunt would be subjected to currents up to 2A. Therefore, the power dissipation in Rshunt (for 2A) is, V times the current through the shunt resistor: 0.2V x 2A = 0.4W. Now, remember from the moving coil example, the power rating should be at least two to three times the power dissipation in Rshunt . In this example the minimum power rating of the shunt resistor would be 0.8W or preferably higher.

We could do the same exercise for 200A ammeter design using a 200mV digital panel meter; in this case the shunt resistors would now be 0.001Ω (1mΩ) at 80W.

Making Your Own Shunt Resistors

High-current shunts designed for 200mV full-scale meters are no longer readily available. However if your application does not warrant the cost of a dedicated shunt resistor, you can make your own shunts from resistance wire (Jaycar WW-4040) or even brass sheet or rod.

You will first need to determine the resistance of the material you want to use for the shunt, but it is not practical to measure such low resistances with a conventional multimeter

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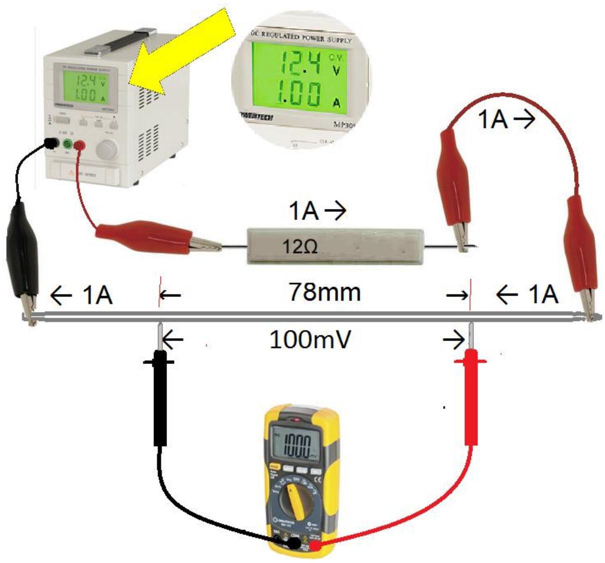
However, if you have access to any sort of variable voltage power supply and a digital multimeter with a DC Amps range, you can determine the resistance indirectly by passing a known current through a sample of the material, and measuring the voltage drop across it.

The simplest approach is to arrange for this current to be exactly one Amp, as then the voltage dropped across it will also be directly equal to the resistance. For example, 1A passing through 0.02Ω will produce 0.02 Volts across it; 1A passing through 0.013Ω will produce 0.013 Volts and so on.



In this example, a 78mm section of resistance material (eg brazing rod, resistance wire, brass strap etc) was found to produce a 100mV voltage drop when 1 Amp is passed through it. (Here we show a power supply with an accurate built-in Ammeter, and the voltage is adjusted so that the Ammeter reads exactly 1 Amp. With the 12Ω shown, that would require about 12 Volts).

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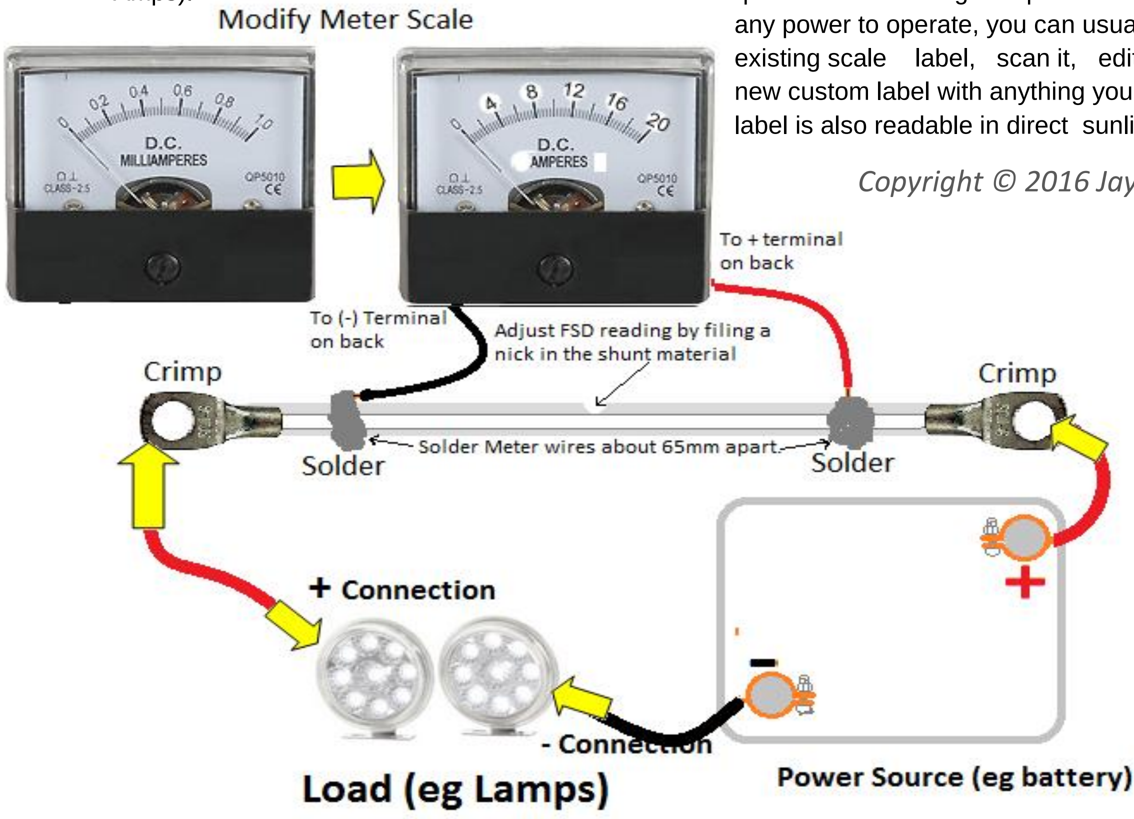
That means that a 78mm length of the resistance wire has a resistance of 100mΩ. From that we can calculate that a 1 Metre (1,000mm) length of the same material will have a resistance of about 1,000 ÷ 78 x 0.1 = 1.28Ω, or 1.28 milliohms per millimetre. From that information you can make up resistances of virtually any value.

This does not mean that you need to actually cut your resistance material to exactly 78mm to use it; all that is required is the meter connections are spaced 78mm apart. In practice it is somewhat easier to deliberately make the connections slightly closer together so that the meter initially reads low, and then carefully file away some of the shunt material until the correct reading is obtained.

Below is an example of how to convert a 1mA 200mV FSD panel meter to a 20 A range. This is using the same shunt material as the example given above. If the material is in the form of a rod, it is probably easiest to make the high power connections with heavy-duty crimp connectors as shown.

As described above, the meter wires are soldered to the shunt about 65mm apart so the meter reads low. (For example it might read 19 Amps when the actual current flowing is 20 Amps).



You then need to remove some of the shunt material, most easily by filing a nick (or a series of nicks) with a triangular file. This will increase the resistance slightly, resulting in slightly more current being diverted into the meter movement and increasing the reading. You of course need some other means of monitoring the actual current (multimeter Amps range etc) in order to do this calibration.

Note that under no circumstances should you connect the meter wires directly to the crimp connections. With heavy current flows, there will inevitably be small and fluctuating voltage drops developed between the crimp connectors and the shunt material, which will produce an erratic meter reading. (The commercially-made shunt shown on page 1 has the same type of "4-wire" connection).

You can use the same approach to make a 20A digital panel meter, however, there are some drawbacks to this. Most important, a digital meter requires power to operate, and in many cases you cannot use power from the same circuit you are measuring. This is because the signal input terminal are biased one or two volts higher than the meter module's negative Power DC connection. You need to establish whether your module permits "common ground" operation.

The old-fashioned moving-coil meter actually has quite a few advantages. Apart from not needing any power to operate, you can usually remove the existing scale label, scan it, edit and print outa new custom label with anything you like on it. The label is also readable in direct sunlight.

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