METER FORMULAS

DIRECT CURRENT:
If you want a meter to read 10 milliamperes full scale and you have a 1 mA meter, you have to have the basic meter read 1 milliampere and the resistor to take/carry nine milliamperes. This way, the circuit carries a total of ten milliamperes, one through the meter and nine through the resistor. As you think about the value, you quickly realize that the resistor must be the resistance of the meter divided by nine. That way, the meter takes one tenth and the shunt resistor, since it's lower in value, takes nine.

The meter's shunt resistance may be calculated if these two things are known:
- resistance of the coil and
- current for full-scale deflection.

$$R_{SHUNT} = \frac{R_{METER}}{n-1}$$

where *n* is the scale multiplication factor desired.

$$n = \frac{FSD_{DESIRED}}{FSD_{ACTUAL}}$$

Therefore, if 10 mA is the actual current for full-scale deflection without a shunt and 100 mA is the full scale deflection that is the desired value, *n* = 10.

Rmeter is the resistance of the meter in ohms and *Rshunt* is the required shunt resistance in ohms.

$$R_{SHUNT} = \frac{I_{FS} \bullet R_M}{I_{SCALE} - I_{FS}}$$ I_{SCALE} is the current scale that is desired

A Digital Multimeter, not a VOM, can be used to measure the internal resistance (R_{METER}) of a meter. Measure across the meter terminals and expect about a one-third scale meter deflection.

DC VOLTAGE:

To measure voltage, connect a resistor in series with the moving coil to limit current at the voltage being measured. This is referred to as the multiplier string.

If a meter has an internal resistance of 50 ohms and requires 1 mA for full scale deflection, a resistance of 950 ohms connected in series will require a voltage of

E = 0.001 A x (950 + 50) ohms
E = 0.001 x 1000 = 1 volt for full-scale deflection.

USE THIS FORMULA:

$$R_{Multiplier} = \frac{V_{SCALE} - (I_{FS} \times R_{Meter})}{I_{FS}}$$

As noted above, R_{Meter} can be determined by using a Digital Multimeter and making an Ohm Measurement across the meter terminals.

Another Formula Method
The connected series resistance is the multiplier to give the desired full-scale voltage.

Desired voltage = *Current full scale* x (*Rseries* + *Rmeter*)

- If the desired full scale measurement is 10 volts, and
- full scale current is 1 mA, and
- *Rmeter* is 50 ohms then

10 V = 0.001Amp x (*Rseries* + *Rmeter*)
(*Rseries* + *Rmeter*) = 10 V / 0.001 A = 10 Kohms

or another way: (using a meter with 50 ohm internal resistance):

Rseries = *Rmeter*(*n*-1)

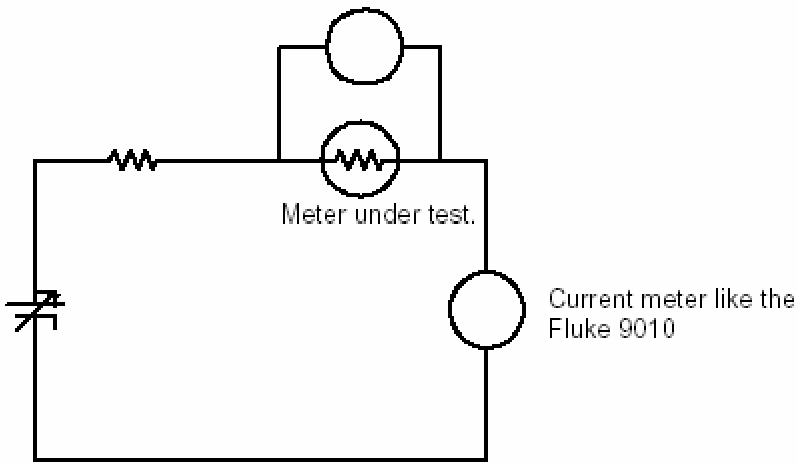
Rseries is the series resistance required, *Rmeter* is the resistance of the meter, and *n* is the scale multiplication solved for in the example below.

Rseries = *Rmeter(n - 1)*
Rseries = 50Ω(*n* - 1)
10,000Ω = 50Ω*n* - 50Ω
10050 = 50*n*
n = 201
substitute back into formula
R_{series} = 50Ω(201-1) = 10Kohms

Another procedure to find the measured value of R_{Meter} is outlined below:

To use a VOM or other meter that reads the desired range, say 100 mA in this case, wire it in series with a battery, adjustable resistor, and the meter to be shunted. Then it's a simple matter to select the shunt wire for the meter to be modified, so that both meters indicate the desired current (100 mA).

Usually this information is included with the meter but it can also be measured. To measure I_{FS}, connect a source to the meter through a resistor and a current meter. Place a voltmeter across the meter under test. Increase the supply voltage until full scale current is read on the meter under test. I_{FS} will be the current read on the current meter.



Circuit for finding I_{FS} and R_M

Once I_{FS} is measured, measure the voltage across the meter under test and then divided that by I_{FS} to calculate R_M.

Practical Pointers

For true high voltage supplies (1000 volts DC and greater), almost all of the current through the dropping resistors goes through the meter. In the case of a 1 mA meter at 1000 volts, 0.9 mA, or 900 micro amps passes throught the meter. A safety resistor, 100Kohm, is placed in parallel (connected to the positive terminal of the meter) and then to ground. About 9 microamps goes through the 100K resistor.
The voltage across the 100K resistor is about 0.09 volts when that happens.

The reason for the 100K resistor is so that the voltage at the voltmeter tap doesn't soar when the meter isn't connected, or in case the meter movement goes open circuit – an important safety issue.

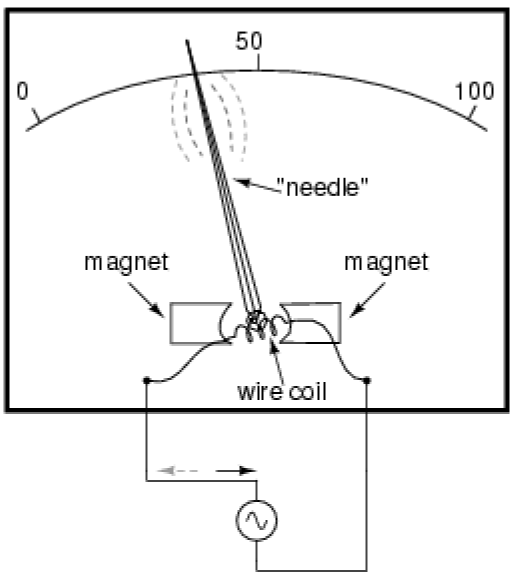
If the high voltage is 3000 volts, the reason for using three 1 meg resistors rather than one 3 meg resistor is to avoid putting too many volts across one resistor. Many resistors have a max voltage rating - typically only 500 volts. Special HV resistors are available, but are relatively uncommon.

If it were me, I'd use a string of six 470K resistors plus one selected 270K resistor for the multiplier string to the meter (totals 3.090 MegOhm).

AC Voltage Measurement

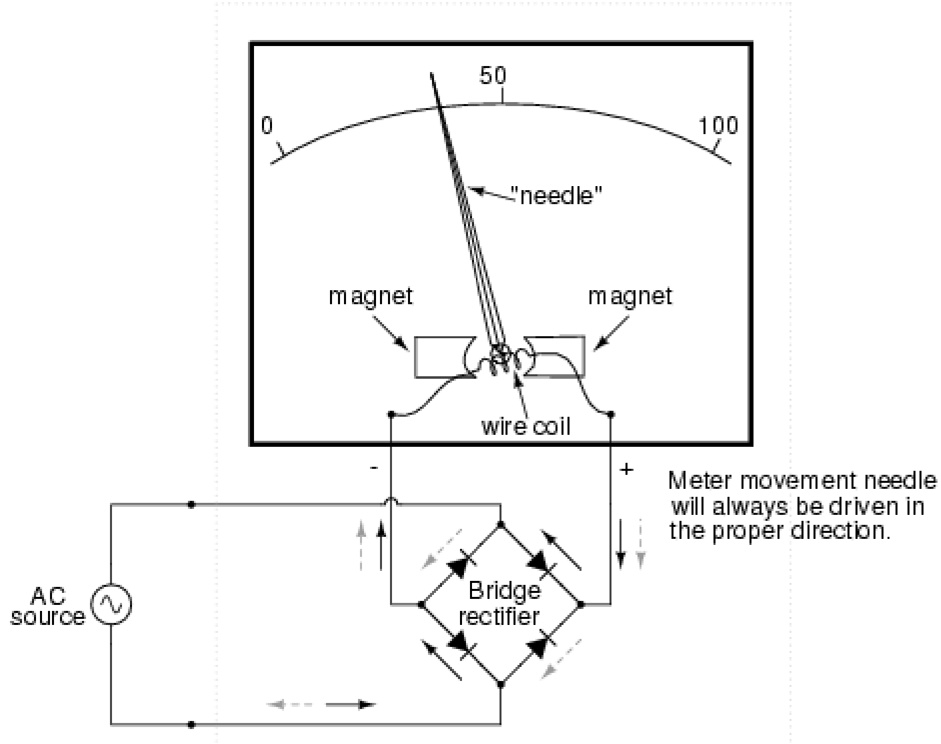
One can make a DC ammeter work on AC by putting it across the DC output of a four-diode full wave bridge.
A 0.1 or 1 mf capacitor will stop the needle from vibrating.
Keep in mind there is a 0.7 volt drop per diode per half cycle.

AC electromechanical meter movements come in two basic arrangements: those based on DC movement designs, and those engineered specifically for AC use. Permanent-magnet moving coil (PMMC) meter movements will not work correctly if directly connected to alternating current, because the direction of needle movement will change with each half-cycle of the AC. (Figure below) Permanent-magnet meter movements depend on the polarity of the applied voltage (or, you can think of it in terms of the direction of the current).



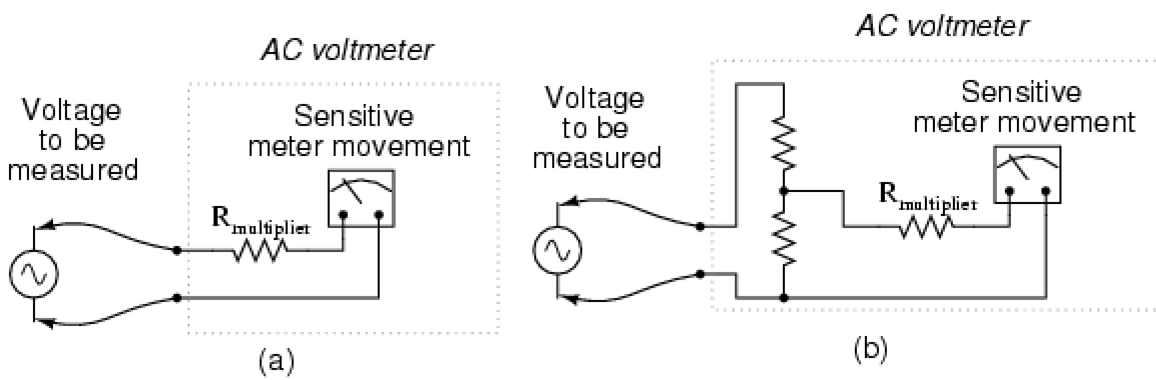
Passing AC through this D'Arsonval meter movement causes useless flutter of the needle.

In order to use a DC-style meter movement such as the D'Arsonval design, the alternating current must be *rectified* into DC. This is most easily accomplished through the use of devices called *diodes*. They each act like a one-way valve for electrons to flow: acting as a conductor for one polarity and an insulator for another. Oddly enough, the arrowhead in each diode symbol points *against* the permitted direction of electron flow rather than with it as one might expect. Arranged in a bridge, four diodes will serve to steer AC through the meter movement in a constant direction throughout all portions of the AC cycle: (Figure below)



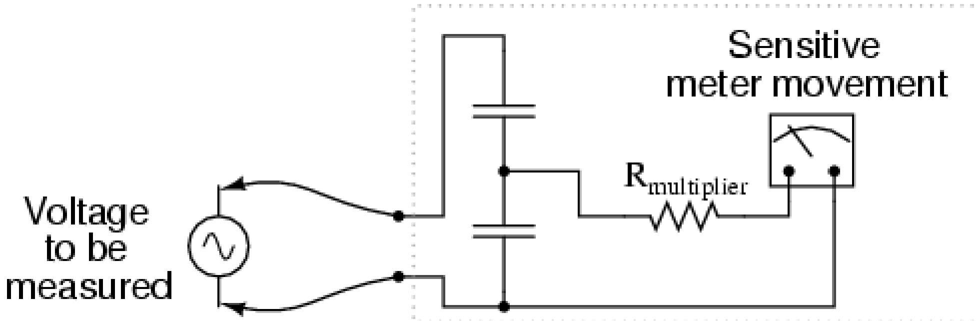
Passing AC through this Rectified AC meter movement will drive it in one direction.

When a sensitive meter movement needs to be re-ranged to function as an AC voltmeter, series-connected “multiplier” resistors and/or resistive voltage dividers may be employed just as in DC meter design:



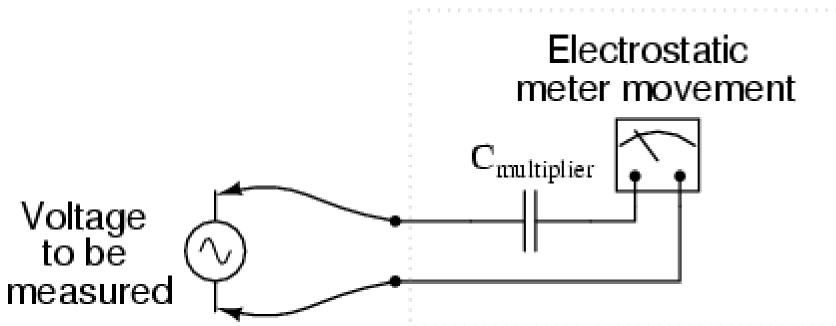
Multiplier resistor (a) or resistive divider (b) scales the range of the basic meter movement.

Capacitors may be used instead of resistors, though, to make voltmeter divider circuits. This strategy has the advantage of being non-dissipative (no true power consumed and no heat produced):



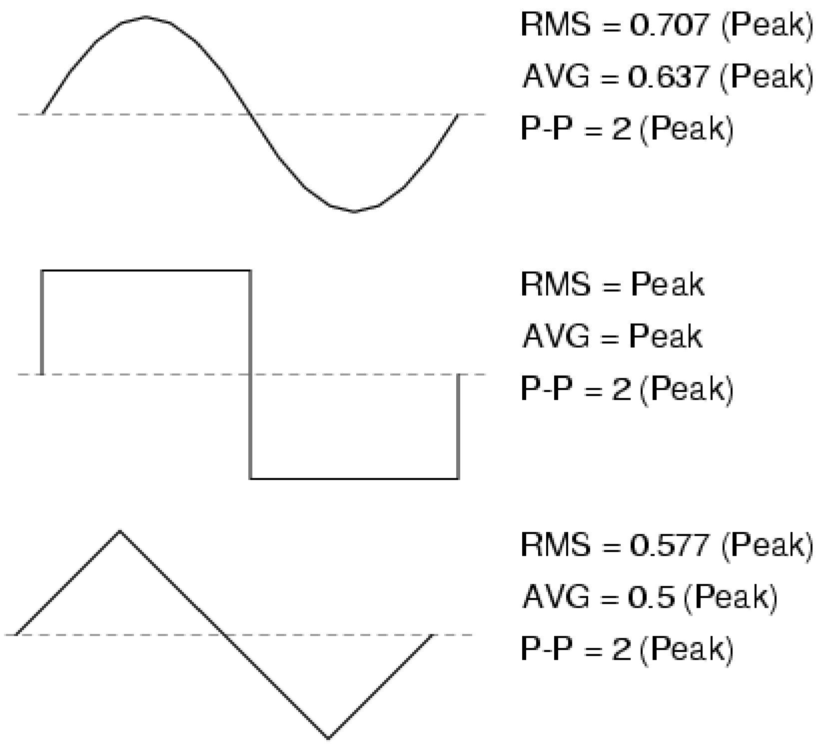
AC voltmeter with capacitive divider.

If the meter movement is electrostatic, and thus inherently capacitive in nature, a single “multiplier” capacitor may be connected in series to give it a greater voltage measuring range, just as a series-connected multiplier resistor gives a moving-coil (inherently resistive) meter movement a greater voltage range:



An electrostatic meter movement may use a capacitive multiplier to multiply the scale of the basic meter movement..

There is another factor crucially important for the designer and user of AC metering instruments to be aware of. This is the issue of RMS measurement. AC measurements are often cast in a scale of DC power equivalence, called *RMS* (**R**oot-**M**ean-**S**quare) for the sake of meaningful comparisons with DC and with other AC waveforms of varying shape. None of the meter movement technologies so far discussed inherently measure the RMS value of an AC quantity. Meter movements relying on the motion of a mechanical needle (“rectified” D'Arsonval, iron-vane, and electrostatic) all tend to mechanically average the instantaneous values into an overall average value for the waveform. This average value is not necessarily the same as RMS, although many times it is mistaken as such. Average and RMS values rate against each other as such for these three common waveform shapes:



RMS, Average, and Peak-to-Peak values for sine, square, and triangle waves.

Since RMS seems to be the kind of measurement most people are interested in obtaining with an instrument, and electromechanical meter movements naturally deliver *average* measurements rather than RMS, what are AC meter designers to do? Cheat, of course! Typically the assumption is made that the waveform shape to be measured is going to be sine (by far the most common, especially for power systems), and then the meter movement scale is altered by the appropriate multiplication factor. For sine waves we see that RMS is equal to 0.707 times the peak value while Average is 0.637 times the peak, so we can divide one figure by the other to obtain an average-to-RMS conversion factor of 1.109:

$$\frac{0.707}{0.637} = 1.1099$$

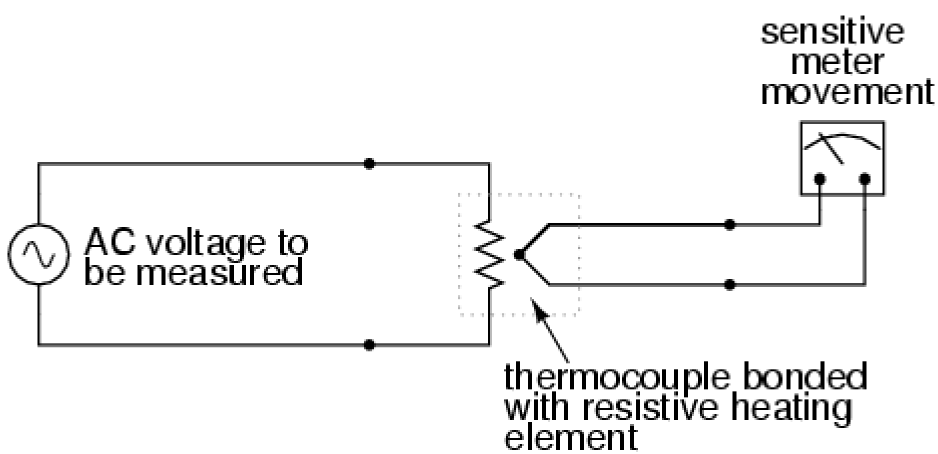
In other words, the meter movement will be calibrated to indicate approximately 1.11 times higher than it would ordinarily (naturally) indicate with no special accommodations.

It must be stressed that this “cheat” only works well when the meter is used to measure pure sine wave sources. Note that for triangle waves, the ratio between RMS and Average is not the same as for sine waves:

$$\frac{0.577}{0.5} = 1.154$$

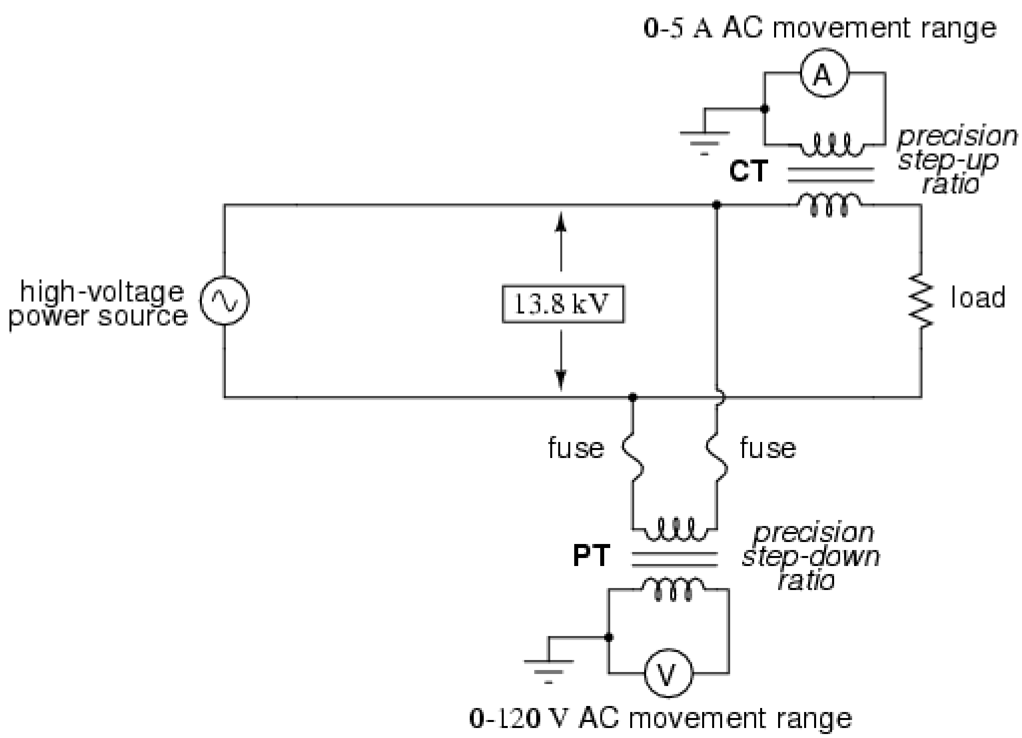
With square waves, the RMS and Average values are identical! An AC meter calibrated to accurately read RMS voltage or current on a pure sine wave will *not* give the proper value while indicating the magnitude of anything other than a perfect sine wave. This includes triangle waves, square waves, or any kind of distorted sine wave. With harmonics becoming an ever-present phenomenon in large AC power systems, this matter of accurate RMS measurement is no small matter.

A CRT with its practically weightless electron beam “movement” displays the Peak (or Peak-to-Peak if you wish) of an AC waveform rather than Average or RMS. How do you determine the RMS value of a waveform from it? Conversion factors between Peak and RMS only hold so long as the waveform falls neatly into a known category of shape (sine, triangle, and square are the only examples with Peak/RMS/Average conversion factors given here!). One answer is to design the meter movement around the very definition of RMS: the effective heating value of an AC voltage/current as it powers a resistive load. Suppose that the AC source to be measured is connected across a resistor of known value, and the heat output of that resistor is measured with a device like a thermocouple. This would provide a far more direct measurement means of RMS than any conversion factor could, for it will work with ANY waveform shape whatsoever:



Direct reading thermal RMS voltmeter accommodates any wave shape.

Calibrating AC voltmeters and ammeters for different full-scale ranges of operation is much the same as with DC instruments: series “multiplier” resistors are used to give voltmeter movements higher range, and parallel “shunt” resistors are used to allow ammeter movements to measure currents beyond their natural range. However, we are not limited to these techniques as we were with DC: because we can use transformers with AC, meter ranges can be electromagnetically rather than resistively “stepped up” or “stepped down,” sometimes far beyond what resistors would have practically allowed for. Potential Transformers (PT's) and Current Transformers (CT's) are precision instrument devices manufactured to produce very precise ratios of transformation between primary and secondary windings. They can allow small, simple AC meter movements to indicate extremely high voltages and currents in power systems with accuracy and complete electrical isolation (something multiplier and shunt resistors could never do): (Figure below)



(CT) Current transformer scales current down. (PT) Potential transformer scales voltage down.

REVIEW:

- Polarized (DC) meter movements must use devices called *diodes* to be able to indicate AC quantities.
- Electromechanical meter movements, whether electromagnetic or electrostatic, naturally provide the *average* value of a measured AC quantity. These

instruments may be ranged to indicate RMS value, but only if the shape of the AC waveform is precisely known beforehand!

- So-called *true RMS* meters use different technology to provide indications representing the actual RMS (rather than skewed average or peak) of an AC waveform.

-30-