OHMS LAW & POWER MEASUREMENTS

The relationship between voltage, current and resistance is called **Ohm's Law**, so named after its discovery by German physicist George Simon Ohm in 1827. Ohm discovered that there is a relatively linear relationship between the potential difference applied to the ends of a conductor, and the current that is flowing through it. The parameter that relates voltage and current is defined as the conductor's *resistance*.

From this comes the following formula: $\mathbf{R = (V/I)}$

where R is the resistance, measured in ohms (Ω)
V is the potential difference in volts (V)
I is the current in amperes (A)

As you can see from the formula, the resistance of a conductor which passes one ampere with a PD of one volt applied between its ends would therefore be 1 ohm.

The simple formula can be transposed thus:

$$\mathbf{V = I \times R} \quad \text{or} \quad \mathbf{I = (V/R)}$$

which can be very handy!

POWER IN A CIRCUIT (DC)

When electrical power is dissipated in a circuit, heat is created. The amount of heat is expressed in **watts** — whether it's from your electric kettle, a radiator or even your hifi amplifier. Here's the basic formula:

$$\mathbf{P = V \times I}$$

where P = power in watts
V = potential difference in volts
I = current in amps

Just like Ohms law this can be transposed to:

$$\mathbf{V = (P/I)} \quad \text{or} \quad \mathbf{I = (P/V)}$$

Other useful formulas relating power, voltage, current and resistance are:

$$P = I^2R \qquad P = \frac{V^2}{R} \qquad V = \sqrt{PR}$$

$$R = \frac{V^2}{P} \qquad R = \frac{P}{I^2} \qquad I = \sqrt{\frac{P}{R}}$$

POWER IN AC CIRCUITS

The calculations above only relate directly to **DC** circuit conditions, although they can be applied to a circuit carrying **AC** provided that:

1. The RMS values of the voltage and current are used (see below); and

2. There is virtually no capacitance or inductance, to produce significant phase shifts. If there *is* significant capacitance and/or inductance, power calculations become a bit more complicated as we'll see shortly.

MEASURING AC WAVEFORMS

Most circuits encountered in electronics are carrying AC, and we often need to measure AC waveforms with a view to calculating circuit component values, signal levels etc. There are several ways of describing an AC waveform, and each one has a use, depending on what you need to know.

AC signals are by definition different from one instant in time to the next. A pure AC signal swings about a zero voltage axis, going positive one moment and negative the next. This means that its *average* value over a complete cycle is zero, because the positive and negative sides of the waveform cancel out. However the positive-going part of the wave can still deliver energy, and so can the negative part. There is plenty of energy, for example, in a 240V AC power point! So we have to find an *alternative* way of describing this energy-delivering aspect of AC, other than the average value.

The parameter we use instead of the average value is the **RMS** or 'root mean square' value, which is found by squaring the instantaneous values of the AC voltage or current, *then* calculating their mean (i.e., their average) and finally taking the square root of this — which gives the *effective* value of the AC voltage or current. These effective or RMS values don't average out to zero, and are essentially the AC equivalents of DC voltage and current.

RMS POWER MEASUREMENT

When we use the effective or RMS values of AC voltages and currents, **and** we have a circuit which is resistive (i.e., with no phase shifts due to capacitance or inductance), we can simply multiply the voltage and current together to give the power dissipated — just as we can for DC. For example an AC waveform of 100V RMS applied across a resistive load (say 10 ohms) would draw the equivalent current (10A RMS) that we'd get from 100V DC, and the load would dissipate the same amount of heat energy: 1000 watts.

Another name for this 'RMS power' is ***continuous effective power***.

Note that although it's not too difficult to calculate the RMS value of regular repetitive waveforms like sine, sawtooth, triangular or square waves, it's much more difficult to do so with non-repetitive waveforms such as a music signal with non-repetitive peaks. This is why, for example, amplifier power ratings are calculated and measured with sinewave signals. Although typical amplifiers normally don't handle sinewaves, these waveforms do provide a standardised way to measure and rate amplifier performance.

POWER IN AC CIRCUITS WITH REACTANCE

If a circuit carrying AC has capacitance and/or inductance as well as resistance, these don't dissipate power themselves but the added capacitive or inductive *reactance* produces a phase shift between the voltage and current. This means that the power dissipated in the circuit's resistance can no longer be calulated simply by multiplying the RMS voltage and current. Doing this merely gives a quantity known as the circuit's 'volt-amps' (VA).

The *real* power in the circuit's resistance can only be found by multiplying the RMS voltage across it with the *proportion* of the RMS current flowing through it which is in exactly the same phase. This works out to be:

$$\mathbf{P_{REAL} = (V_{RMS} \times I_{RMS}) \times \cos(\phi)}$$

where ϕ is the *phase angle* between the voltage and current.

This real power will generally be smaller than the VA figure, because the VA turns out to include the energy that is simply stored in the circuit's reactances during one half of the AC waveform, and returned during the other.

PEAK & PEAK-TO-PEAK VALUES

There are other ways of describing an AC waveform besides the RMS value, which are sometimes useful. For example it's often necessary to know a waveform's half-wave *peak* level (to calculate wiring insulation and capacitor voltage rating requirements for example) or its *peak-to-peak* level, which is simply the total swing between the positive and negative-going peaks of the waveform.

MEASURING AC VOLTAGE & CURRENT

Many digital multimeters do not measure the RMS value of AC voltages directly. Often they simply measure the peak value, and *calculate* the equivalent RMS value — assuming a sine waveform. This calculated value is the one displayed. Older moving-coil meters tend to measure the half-wave average value, but are made to indicate the equivalent RMS.

Of course some DMM's *do* in fact measure the RMS value of voltages and currents, and these **True RMS reading** meters are generally the best type to use if you really need to know the RMS value — especially for non-sinewave voltages and currents. However you'll find that such meters tend to be somewhat more expensive than the regular type. Incidentally, it's worth remembering that a True RMS meter will also include the contribution of any DC voltage and current which may be present along with the AC.

Happily you can still get a fairly accurate idea of the RMS value of a sine waveform, knowing one of the other measurements such as the half-wave average, peak or peak-to-peak value. This can be done by calculation, or using the handy table on this page. As you can see it's also possible to work out the RMS value of a few other symmetrical and regular waveforms, such as square and triangular waves, knowing their peak, average or peak-peak values.

WAVEFORM	Half-Wave Average	RMS (Effective)	Peak	Peak-Peak
Sinewave	1.00	1.11	1.567	3.14
	0.90	1.00	1.414	2.828
	0.637	0.707	1.00	2.00
	0.318	0.354	0.50	1.00
Squarewave	1.00	1.00	1.00	2.00
Triangular or Sawtooth	1.00	1.15	2.00	4.00
	0.87	1.00	1.73	3.46
	0.50	0.578	1.00	2.00
	0.25	0.289	0.50	1.00

The important thing to bear in mind, though, when using this type of table is that you do need to know the exact basis on which your meter's measurement is made. For example if it *really* measures the peak value, and then calculates and displays the equivalent 'sinewave RMS' figure, this means you'll need to use the table differently from the situation where it measures the half-wave average and calculates the sinewave RMS figure from that. So **take care**, especially if you're not sure exactly how your meter works.

(Copyright © Jaycar Electronics, 2001)

Jaycar ELECTRONICS