How Many Volts IS This?

The RMS Role

Douglas Brooks

A few months ago a personal computer trade magazine reviewed surge voltage protecting power strips for home use. During the course of the article they offered an explanation of what "120 Volt RMS" power (what we typically have in our homes and offices) means. The problem was—the definition they offered was wrong!

In the next issue they published some of the letters they received, made an embarrassed apology, and gave a corrected definition. Problem was—it was wrong too! Two issues later they finally got it right in a very brief, to-the-point, and not too obvious notice deep inside the magazine.

Actually, many people don't know what "120 Volt RMS" truly means. And when they find out, they wonder why in the world we would use such a measure. So here is your opportunity to test your knowledge. We all know that the 120 Volt power supplied to our homes is alternating current (AC) following a sinusoidal waveform (see **Figure 1**(a)). When we say that the voltage is 120 V. RMS, do we mean:

- (a) The average value of the voltage is 120 Volts?
- (b) The peak value of the waveform is 120 Volts?
- (c) The peak-to-peak value of the waveform is 120 Volts?
- (d) None of the above?

When we took Trigonometry in High School we learned that a sine wave cycles between +1 and -1 around a horizontal axis whose value is zero. The waveform is symmetrical around that axis. Therefore, the *average* value of a sine wave is zero. So much for choice (a)! It turns out that choices (b) and (c) are not correct, either. The correct answer is (d), none of the above.

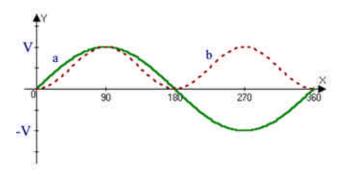


Figure 1 Normalized voltage (a) and power (b) waveforms for a sinusoidal signal.

Let's start the explanation of why with a discussion of power. Power is defined as

Voltage*Current (or P=V*I).

By Ohm's Law, V=I*R, or I=V/R. Therefore, by substitution, Power= V^2/R . So if we apply a voltage sine wave (V*sin(Q)) across a resistor, the power applied to the resistor is given by the expression $P=V^2*\sin^2(Q)/R$ (shown in Figure 1(b)). It can be shown that the *average* power delivered to the resistor is $V^2/2*R$.

Now here is the key question. What DC (direct current) voltage will deliver the SAME power to the resistor as the AC waveform we have just been considering? The answer is:

Equivalent DC Volts = $(V^2/2)^5 = .707*V$. THIS is defined as the RMS voltage. It is the

DC voltage that would deliver the SAME power to a resistive load as would the AC waveform.

Now, back to our home example. If our household voltage is 120 V. RMS, then 120 Volts is .707*V, where V is the peak voltage. This means the peak voltage is 120/.707 or 169.7 Volts. And the peak-to peak voltage at our wall outlets is 2 times this or 339.5 Volts! Expressed another way, the formula for the voltage at our wall outlets is 169.7*sin(Q) where (Q) represents the angular position within one cycle.

Calculating the RMS Value:

So what does RMS actually mean? The term stands for "Root-Mean-Square," which represents the method of calculation of the value. The calculation works like this:¹

- 1. Take the waveform and divide it into a "large" number of individual increments
- 2. For each increment, SQUARE the voltage value
- 3. Sum these squared values over all increments and then calculate their MEAN value.
 - 4. Take the square ROOT of this mean.

That's how you get the Root-Mean-Square value!

Every waveform has a different RMS value. It is only a sine wave whose RMS value is .707*V. A DC waveform has an RMS value = V! RMS values for other common waveforms are published in standard reference texts.

Measuring RMS Values:

Measuring the true RMS value of a waveform is not easy. Inexpensive AC voltmeters simply rectify the waveform (by passing it through a diode, for example), measure an average value of the rectified waveform, and apply a correction factor (assuming a sine wave). Such meters, therefore, are only accurate for sinusoidal waveforms. They do NOT accurately measure any other waveform shape.

So-called "True" RMS meters in the past have depended on some sort of power measurement to derive the correct RMS value. Now that calculational power is so much more economically available, meters can analyze a waveform's shape and actually mathematically calculate the correct RMS value. In general, if an AC meter does not explicitly say it gives a "true" RMS reading, you can assume that it is accurate only for a sinusoidal waveform.

Footnote:

1 The formal equation for RMS is

$$V_{rms} = \sqrt{\frac{1}{T} \int_{t_0}^{t_0 + T} v(t)^2 dt}$$

where V(t) is the AC variable, t is time, and T is the period of one complete cycle.