POWER—WATT'S IT ALL ABOUT?

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Q: Peak Envelope Power (PEP), RMS, average power...the list goes on and on. And I haven't even mentioned some of those strange ad-hype specs the manufacturers use to rate their products. I thought power was power and watts was watts. I'm confused. Please pardon the pun, but "watt's" it all about?

A:The watt, of course, is the power unit most often associated with electrical devices and transmitter output. Electrical power is calculated by voltage across a load multiplied by the current through that load:

$P = E \times I$, or:

1 W = 1 Volt $\times$ 1 Ampere

Ohm's Law and a little substitution also give us:

$P = I^2 \times R$

$P = E^2 / R$

Q: This sounds simple enough. Why does it cause so much confusion?

A: Although this is rather straightforward when dc is considered, things become less apparent with ac. Remember, ac is constantly changing. Let's consider a sine wave such as in Figure 1A. It's fairly obvious that the positive and negative halves during one complete cycle are equal, and therefore cancel. This is why the dc voltage (the reading a dc voltmeter would indicate when measuring an ac voltage) is zero.

Look at the case of a half sine wave shown in Figure 1B. A full-wave rectifier produces this type of waveform when a sine wave, such as shown by Figure 1A, is applied to it. For simplicity, we'll consider only a single half cycle with a peak voltage of 1 V. We'll compare the relative size of the half-sine curve to the 1 V dc curve, or rectangle, during the same time interval. Using this technique, we can illustrate visually how we arrive at the equivalent average (dc) voltage produced by the half sine wave.

First, we approximate the area of the half sine curve by using a series of rectangles, as shown in Figure 1C. Then we calculate the area of each rectangle by multiplying its length times its width. Finally, we approximate the total area under the half-sine curve by summing all the rectangle areas. The narrower we make each rectangle, the closer our approximation becomes.

By using an advanced form of mathematics called *calculus*, we can determine the exact *area* of a half-sine wave with a peak of 1 V and a width of π as being equal to *2*. (π, pronounced like "pie," is the ratio of the circumference to the diameter of any circle. It's a constant, approximately equal to 3.14159. The precise reasoning for selecting π is based on mathematics and is beyond the scope of our discussion.)

Compare the area (or size) of the dc rectangle as shown in Figure 1D with the half-sine curve during the same time interval (see Figure 1E). As we have already discovered, the area of this half-sine wave (the crosshatch portion) is 2. The area of the dc rectangle from 0 to pi is equal to $1 \times \pi$. The comparison, or ratio, between the two areas is:

$$\frac{\text{acsinearea}}{\text{dcrectanglearea}} = \frac{2 \quad 2}{\text{¼}3{:}14159} = 0{:}6366$$

This is the ratio between the dc, or average voltage produced by a half sine wave and its peak, or maximum, voltage.

If, for example, you want to calculate the average output voltage of a full-wave bridge rectifier having an input of 50 V peak, multiply the 50 V times 0.6366 to obtain 31.83 V. A half-wave type rectifier would obviously produce half of that, or 15.92 V.

Q: This is simpler than I thought. Do I assume correctly that we can also multiply peak ac voltage by 0.6366 to obtain the equivalent dc power?

A: Don't jump to conclusions. No matter how logical your assumption might seem, it's erroneous. Remember, power is equal to E^2/R. Power does not follow a sine curve, but rather a *sine-squared* curve! We must square each point along the sine curve to obtain the corresponding point on the sine squared curve.

The sine-squared curve in Figure 1F shows the instantaneous power developed across a 1-Ω load during one complete cycle of the voltage sine wave in Figure 1A. Notice that both the negative and positive halves of the sine curve correspond to symmetrical positive power curves. Negative power is not developed since a negative number multiplied by a negative number always produces a *positive* number. Notice, too, that the peak power is again equal to 1 since 1^2 is still equal to 1.

Just as we did with the sine curve, we can approximate the area of the power curve with a series of rectangles. Calculus in this case determines the exact area to be π/2, or 1/2 π. (The dc power curve is the same as the voltage curve because 1^2 is equal to 1, and 1 times π is still π.) Again, compare the ac versus dc results:

$$\frac{\text{acpower}}{\text{dcpower}} = \frac{1/2\pi}{\pi} = \frac{1}{2}$$

Q: So...I need to multiply the peak of the ac voltage by 1/2 to obtain the equivalent dc power, right?

A: Wrong. We need to take the square root to get volts from power:

$$\sqrt{\frac{1}{2}} = \frac{1}{\sqrt{2}} = \frac{1}{1.414} = 0.707$$

Q: Hey, I remember that number from my General class license studies. Isn't it used to determine Root Mean Square, or RMS, power?

A: Exactly! The expression Root Mean Square, or RMS, comes from its derivation: Take the voltage at each point along the sine curve, square it, take the average (mean), then take the square root of the average. As the number of points taken along the curve approaches infinity, the result becomes 0.707!

It's important to understand that these conversions apply *only* to an ac sine wave with no dc offset. Other waveforms obviously require different ac-to-dc voltage and power ratios.

Q: Now here's a tough one: I've often heard the term reactive power bandied about. What's this? Is it the power generated by a nuclear power plant?

A: No, but you raise an interesting point. Reactive power is the *apparent* power "dissipated" by a reactive component, such as a capacitor or inductor. These components do not actually dissipate power. Take a look at Figure 2 and you'll see why.

Although both types of reactance cause a 90° phase shift between voltage and current, we have selected inductive reactance for our example. If we multiply the instantaneous voltage in Figure 2A times the instantaneous current in Figure 2B, a curious thing happens. (Remember, a positive number multiplied by a negative number produces a negative number.) These purely reactive loads return all the power they absorb back to the circuit. This is why you see equal amounts of power above and below the reference line in Figure 2C. The average over one complete cycle is zero! Reactive power is measured in *vars*, a shortened form of volt-ampere, reactive.

What if our load has both a resistive and a reactive component? As you've probably guessed, simply multiplying the voltage times the current no longer yields the true power. (The reactance still causes some of the power to be returned to the circuit.) The result in this case is called *apparent* power. Apparent power is actually a combination of the *reactive* and *true* power with the following relationship:

$$\text{ApparentPower} = \sqrt{\text{TruePower}^2 + \text{ReactivePower}^2}$$

The true power in an ac circuit is a function of the phase angle between the voltage and current in that circuit:

True Power = Apparent Power × the cosine of the phase angle

Q: Now that we've covered the basics, let's concentrate on transmitter output power. What FCC Rules regarding transmitter output power are of concern to us as amateurs?

A: Part 97.313 of the FCC Rules govern transmitter output power in the amateur service. These rules limit hams to "...the minimum transmitter power necessary to carry out the desired communications." In addition, they also specify a maximum power limit of 1500 W peak envelope power (PEP). Other limits may also apply, depending on your license, band, frequency and geographic location. Refer to the Washington Mailbox in the September 1994 *QST*, or *The FCC Rule Book* for details.

Part 2 of the FCC Rules defines PEP as "...the average power supplied to the antenna transmission line by a transmitter during one RF cycle at the crest of the modulation envelope, taken under normal operating conditions."

Q: What do you mean by modulation envelope? And how can peak envelope power also be an average power? Aren't the terms "peak" and "average" mutually exclusive?

A: The output of any transmitter has an envelope associated with it. See Figure 3. The envelope is the wave shape defined by the maximum RF peaks, and is shown in thick black lines.

In order for a signal to convey information, such as speech, it must be modulated in some way. Several modulation schemes are possible, and two of the most common are Amplitude Modulation (AM) and Frequency Modulation (FM). AM (and SSB) require that the transmitter output power vary in accordance with the speech, while in FM the frequency is varied. CW is also a form of amplitude modulation where the output power is varied (on and off) to convey information.

The peak envelope power of an SSB or AM signal occurs at the highest crest of the modulation envelope. (The point at which PEP occurs has been labeled in Figure 3.) The easiest way to appreciate the meaning of PEP is to calculate it. Let's assume a 50-Ω load and a peak voltage at the modulation crest of 110 V.

$$PEP = \frac{(V\text{peak} \times 0.707)^2}{R} = \frac{(110 \times 0.707)^2}{50} = 121\,\text{W PEP}$$

The peak envelope power calculation uses the peak voltage during the maximum RF cycle, and converts it to an RMS value by multiplying by 0.707. The instantaneous peak voltage during the maximum modulation crest is treated as if it were a complete cycle of a sine wave. This is why the terms “average” and “peak” are not mutually exclusive in this case. Although PEP is the peak power—it’s *averaged* over one complete RF cycle as if it were a sine wave.

A CW signal is either on or off, and it maintains a constant amplitude during the “on” state. The PEP of a CW signal is therefore the normal steady-state key-down output power of the transmitter. An FM signal does not vary in amplitude, therefore the PEP is also the same as the steady-state power.

Under FCC “grandfathering,” double-sideband full-carrier AM users were allowed to use the old measure of 1000-W dc input to the transmitter’s final amplifier until June 2, 1990. The reason was that the 1500-W PEP output limit meant an approximate 3-dB reduction in maximum power permitted for AM operations. The FCC has declined to extend this exemption, so AM operators must observe the new standard.

Q: Am I required to have a means of measuring the output power from my transmitter? How do I measure PEP?

A: The FCC does *not* require you to provide PEP measuring equipment and techniques. As a practical matter, most amateur transmitters and many common amplifiers are not even capable of producing anywhere near the 1500-W PEP limit.

If, however, you choose to operate a 1500-W amplifier at or near the legal limit, you must have the capability to ensure compliance with FCC Rules. The Commission has chosen and published the following procedures of measurement:

(1) Read an in-line peak reading RF wattmeter that is properly matched (commercial units are available), and

(2) calculate the power using the peak RF voltage as indicated by an oscilloscope or other peak-reading device. Multiply the peak RF voltage by 0.707, square the result and divide by the load resistance (the SWR must be 1:1).

SSB average power as indicated by an ordinary wattmeter is dependent on your voice characteristics. It can also be increased by speech processing. For ordinary speech, the average power is considerably *less* than the PEP. *You must use a PEP reading wattmeter to measure the peak envelope power of an SSB signal.*

We welcome your suggestions for topics to be discussed in Lab Notes, but we are unable to answer individual questions. Please send your comments or suggestions to: Lab Notes, ARRL, 225 Main St, Newington, CT 06111.

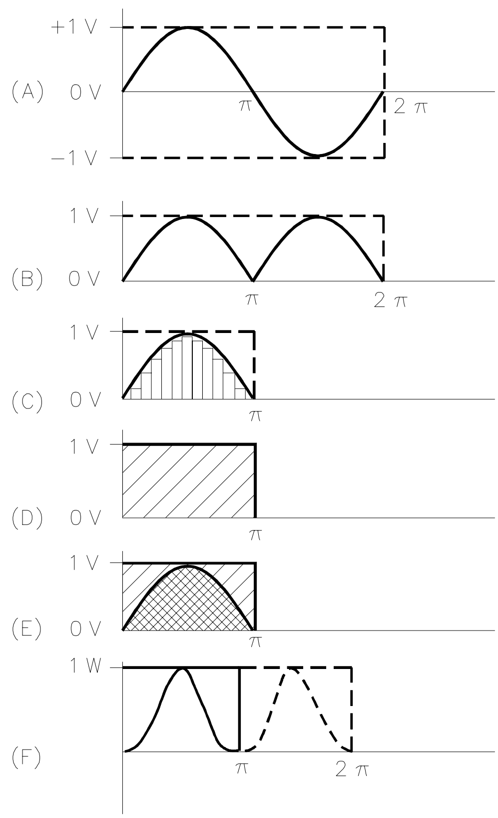

Figure 1—**A**: One cycle of sine-wave voltage; **B**: The output waveform of a half-wave rectifier; **C**: Determining the area under a half-sine curve with a peak of 1 V. The exact area is 2; **D**: The area under a dc "curve" taken during the same time interval as a half sine curve and having the same peak voltage (1 V). The area is π; **E**: Area comparison between the ac and dc waveforms. The ac waveform is 2/π, or 0.6366 of the size of the dc wave form; **F**. The sine-wave curve for instantaneous power over one complete voltage sine wave cycle.

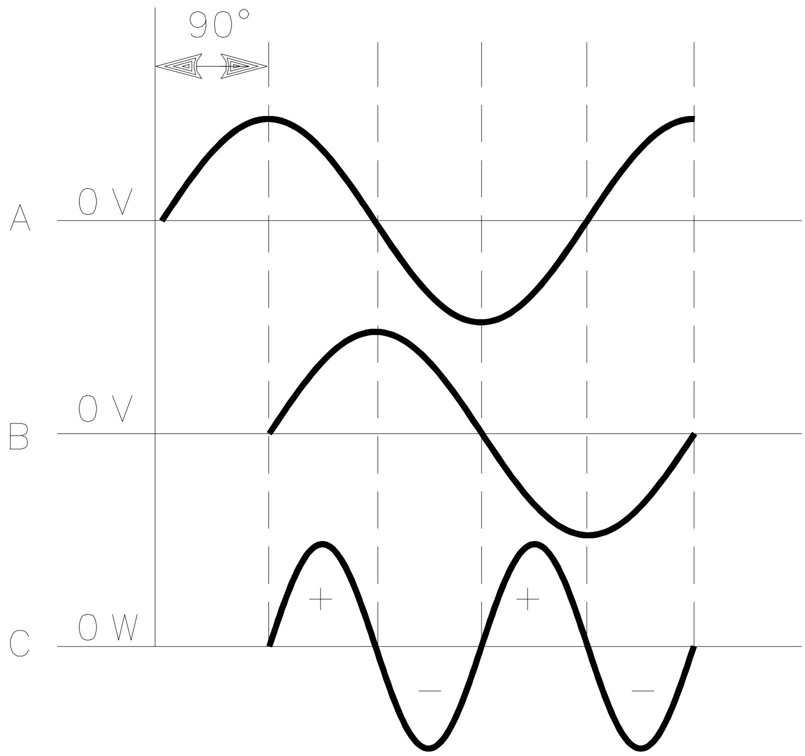

Figure 2—**A**: Voltage waveform across a pure inductance; **B**: Current through the inductor lags the voltage by 90°; **C**: Power developed by the same inductive load during one complete cycle. Each point on the voltage curve is multiplied by the corresponding point on the current curve. Note that “negative” power is developed.

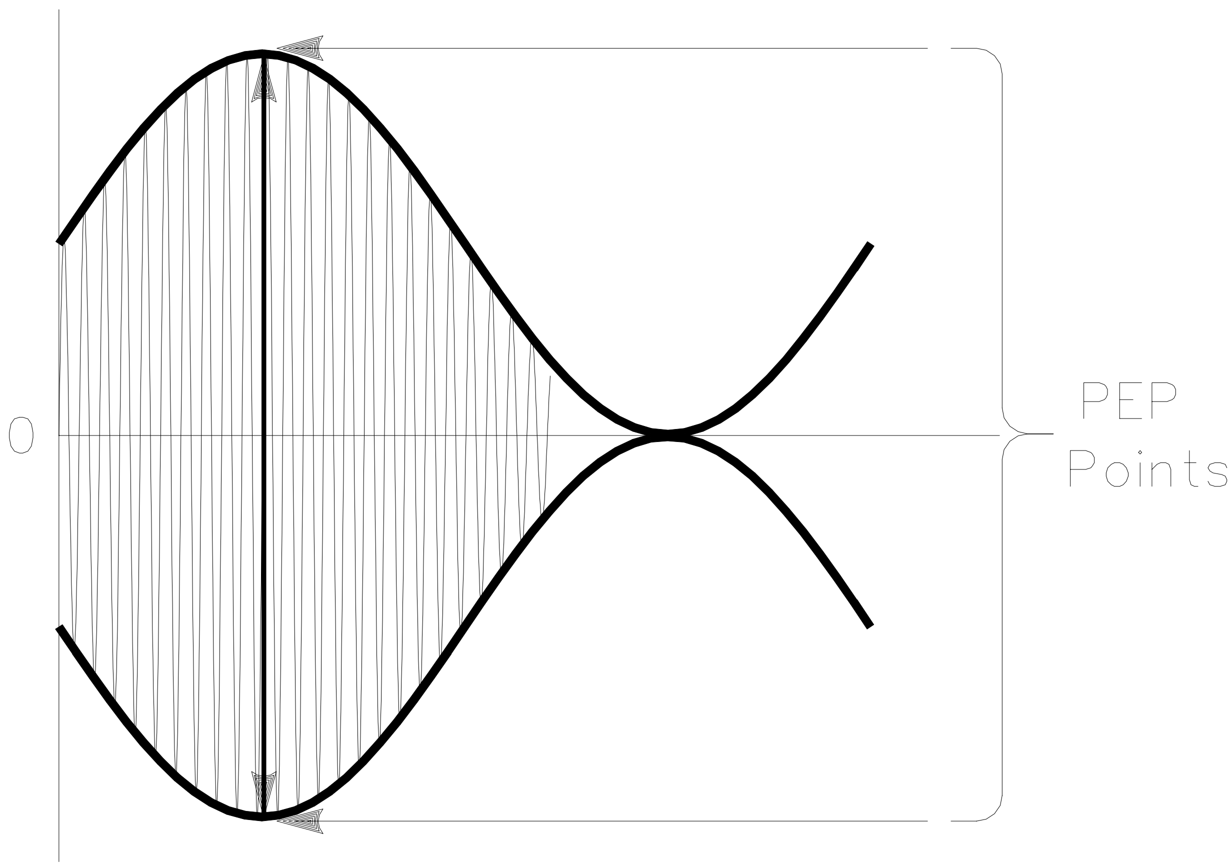

Figure 3—The thick black lines show modulation envelope for one audio cycle of AM. PEP occurs at the PEP points shown.