

SPECIAL REPORT:

WHAT IS SIGNAL LEVEL?

Part 1

By Ron Hranac



An Industry Expert Digs In

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When measuring signal level at the output of an amplifier, the input to a cable modem, TV set or set top, just what is it that's being measured? The short answer is we're measuring the amplitude of a signal or signals, but what does that mean? I grabbed my copy of *Webster's New World Dictionary*, and looked up both "level" and "amplitude." Here's what the dictionary has to say about the two terms.

am·pli·tude (am'plə tōōd) *n.* [see AMPLE] **1.** scope, extent, breadth, etc. **2.** abundance **3.** range from mean to extreme, as of an alternating current

lev·el (lev'l) *n.* [< L. *libra*, a balance] **5.** position in a scale of values [income *level*]

I'm not so sure that the folks who put the dictionary together had signal level in mind when defining level, so let's start with a few basics from the world of electricity and electronics. Grab a cup of coffee and a scientific calculator – yes, there is some math involved.

Current

Current can be thought of as the flow of charged particles per unit of time. Ampere is a measure of electrical current, and 1 ampere equals 1 coulomb of charge flowing past a given point in 1 second. Coulomb is a unit of measure of electrically charged particles, where 1 coulomb equals 6.242×10^{18} electrons. An analogy for current is the volume of water flowing through a garden hose, such as 1 gallon of water per second.

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Voltage

Electromotive force (EMF) is the force of electrical attraction between two points of different charge potential. EMF is more commonly known as voltage; the volt is a measure of electromotive force, and is abbreviated E or V. The potential difference between two points on a wire carrying 1 ampere of current when a power of 1 watt is dissipated between the points is 1 volt. An analogy for voltage is water pressure in a garden hose, such as 1 pound per square inch (PSI).

Resistance

Resistance (R) is an opposition to the flow of current. Ohm, abbreviated Ω , is a unit of resistance, where 1 ohm is defined as the resistance that allows 1 ampere of current to flow between two points that have a potential difference of 1 volt. A garden hose analogy is squeezing or kinking the hose to oppose the flow of water.

Ohm's Law

The previous definition is the basis for Ohm's Law, which is $R = E/I$. Here R is resistance in ohms, E is electromotive force in volts, and I is current in amperes. (Current is abbreviated I for *intensité de courant*. Why not C? That letter is used as an abbreviation for capacitance.) The formula $R = E/I$ can be shuffled around a bit to give us some of the other variations of Ohm's Law: $E = IR$ and $I = E/R$. Figure 1 shows an easy way to remember the three Ohm's Law formulas.

Using Ohm's Law, we can look at an example with 0.010 volt or 10 millivolts (mV) across a 75-ohm resistance (see Figure 2), and calculate the current:

$$I = E/R$$

$$I = 0.010 \text{ volt}/75 \text{ ohms}$$

$$I = 0.000133 \text{ ampere, or } 0.133 \text{ mA}$$

Power

Power is the rate at which work is done, or energy per unit of time, where 1 watt of power is equal to 1 volt causing a current of 1 ampere. Watt is the power required to do work at a rate of 1 joule per second. That is, a joule of work per second is 1 watt. One joule is the work done by a force of 1 Newton acting over a distance of 1 meter. The joule is a measure of a quantity of energy and equals 1 watt-second.

"Current, Voltage, Resistance - the keys to understanding signal level."

The power company meter on the side of your house measures units of kilowatt-hour, which equals the amount of energy "used" by a load of 1 kilowatt (1,000 watts) over a period of 1 hour, or 3.6 million joules.

If you think about it for a moment, 1 watt is simply the use or generation of 1 joule of energy per second. Other electrical units are in fact derived from the watt. As you've no doubt surmised by now, all of this stuff is related. For instance, 1 volt is 1 watt per ampere. Another definition of 1 watt is 1 volt of potential (EMF) "pushing" 1 ampere of current through a resistance, or $P = EI$. As was the case with Ohm's Law, a bit of equation shuffling will give us $E = P/I$ and $I = P/E$.

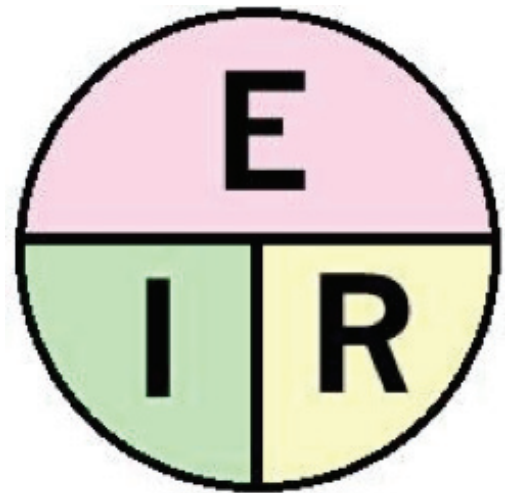


Figure 1. Ohm's Law simplified

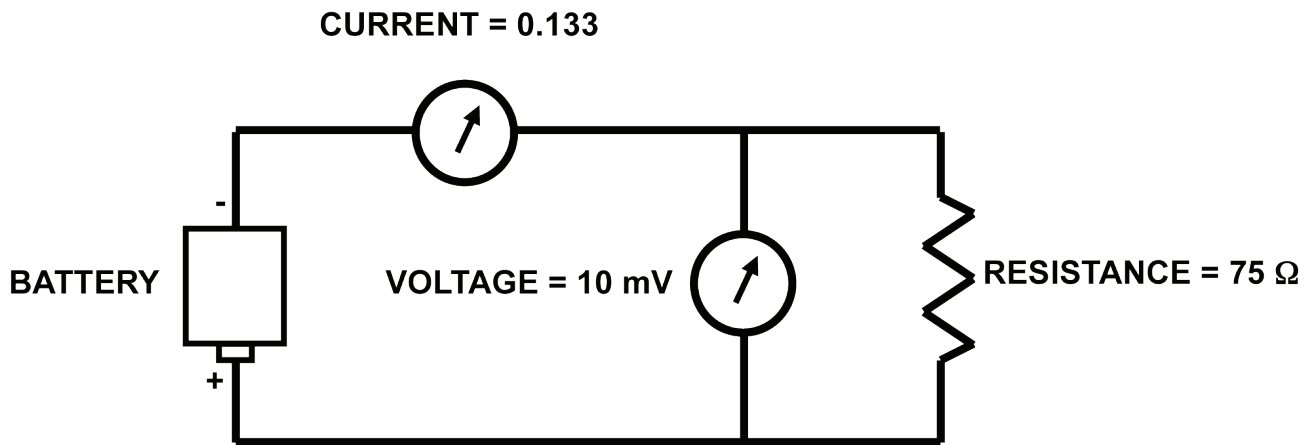


Figure 2. Calculating current in a DC circuit

Using your scientific calculator and some basic algebra, substitute the Ohm's Law equivalents for E and I into the formula $P = EI$, and the result is two other common expressions of power: $P = E^2/R$ and $P = I^2R$.

Power in DC circuits

Power calculations and measurements in direct current (DC) circuits and applications are relatively straightforward. For example, if you have a 75-ohm resistor with an applied voltage of 10 millivolts, the power dissipated by the resistor is 1.33 microwatt ($P = E^2/R = 0.010^2/75 = 1.33 \times 10^{-6}$ watt or 1.33 μW), as shown in Figure 3.

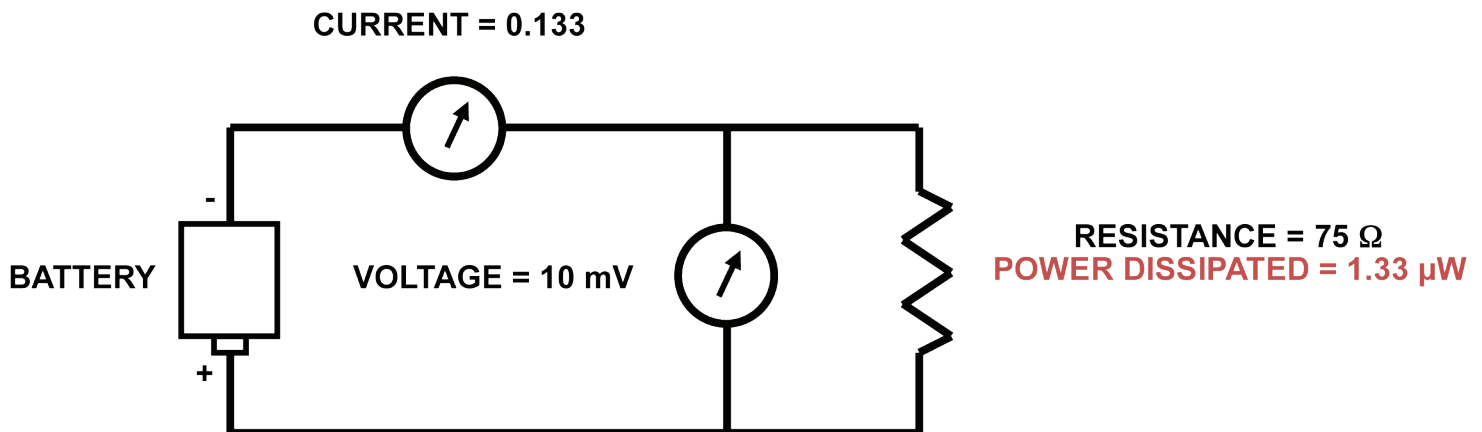


Figure 3. Calculating power in a DC circuit.

Power in AC circuits

Because the previous example is a DC circuit, the voltage is a constant 10 millivolts and the current a constant 0.133 milliamperes. As long as the resistor's value remains fixed, it's easy to calculate dissipated power. Alternating current (AC) circuits and applications are more complicated because the instantaneous voltage and current are not constant. In order to equate the varying AC waveform to a DC equivalent component, one must work in the world of root mean square (RMS) voltage and current.

In an AC circuit, the instantaneous values of voltage and current are varying continuously over time. How can we define useful values for these varying quantities? Root mean square gives us effective quantities equivalent to DC values. That is, RMS equates the values of AC and DC power to heat in a resistor by the same amount. (In

“...in an AC circuit, the instantaneous values of voltage and current are varying continuously over time.”

case you were wondering, an RMS value is found by squaring the individual values of all the instantaneous values of voltage or current in a single AC cycle. Take the average of these squares and find the square root of the average.)

For instance, 10 mV RMS AC voltage causes the same average power dissipation in a given resistor as does a 10 mV DC voltage. Likewise, 0.133 mA RMS alternating current has the same heating effect as 0.133 mA direct current. Root mean square values simplify calculations by making the product of RMS voltage and RMS current equal to average power: $P_{AVG} = E_{RMS} I_{RMS} \cos \theta$, where θ is the phase angle

between the current and voltage. In a purely resistive circuit where voltage and current are in phase, the formula is $P_{AVG} = E_{RMS} I_{RMS}$.

Consider measuring the power of an unmodulated RF carrier – commonly called a continuous wave or CW carrier – which really is nothing more than a sinusoidal AC waveform. AC power measurement can be a bit tricky because the product of voltage and current varies during the AC cycle by twice the frequency of the sine wave.

In other words, the output of a signal source such as a sinusoidal RF signal generator is a sine wave current at the desired frequency, but the product of the signal’s voltage and current has what amounts to an equivalent average DC component along with a component at twice the original frequency. In most cases of RF power measurement, “power” refers to the equivalent average DC component of the voltage and current product.

If you connect a thermocouple power meter to the output of an RF signal source, the power meter’s power sensor will respond to the RF carrier’s DC component by averaging. The averaging usually is done over many cycles, which, at RF, still can be a relatively short period of time.

Otherwise, if the power meter simply measured an instantaneous point in the sine wave, then measured that sine wave at another instantaneous point, the reported power value would vary according to the instantaneous product of the voltage and current at each measurement point.

This is the primary reason why most RF carrier power measurements are expressed in average power. In the next installment, we’ll apply the basics discussed here to a more in-depth understanding of signal level.

Look for Part Two of this Special Report in October.



Ron Hranac is the Technical Leader for Cisco Systems.

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