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DBMB VOLTAGE OR POWER? PART TWO

Consider a sine wave viewed in the time domain – that is, amplitude vs. time – as might be seen on an oscilloscope. This alternating current waveform's amplitude or level can be characterized in a variety of ways. One can measure the sine wave's peak-to-peak, peak, root mean square or average values of current and voltage.

As discussed in Part 1 in the July/August issue of Communications Technology, the current or voltage of an AC waveform usually is expressed as a RMS value. For instance, the electricity from a North American household electrical outlet is a low frequency (60 Hz) sine wave whose RMS voltage is about 120 volts.

An unmodulated RF signal – also known as a continuous wave (CW) carrier – usually is a high-frequency (typically several megahertz) sinusoidal AC waveform. The amplitude of a RF signal also can be expressed in a variety of ways: peak-to-peak; peak; RMS; and average values of voltage (volts), current (amperes) or power (watts). Recall last month's example of stating common signal levels in a cable network in watts. Assuming a 75-ohm impedance network, those same signal levels can be expressed as RMS AC voltages: 0.000000013 watt becomes 0.001000 volt, 0.000000422 watt is 0.005623 volt, 0.000001333 watt is 0.010000 volt, and 0.000841276 watt is 0.251189 volt. Whether expressed in watts or volts, the small numbers clearly are quite cumbersome to handle. Surely there must be a better way.

There is: the decibel.

As mentioned in last month's column, the decibel is used to express a ratio between two power levels. That is, $dB = 10\log_{10}(P2/P1)$, where "dB" is the abbreviation for decibel; "P1" is one power level in watts, say, the output power from a device; and "P2" is the second power level in watts, perhaps the device's input power. By itself, the decibel expresses power ratios, not absolute levels. It's flat-out wrong to say something like "the input level at the set-top is 2 dB," but it's correct to say "the splitter's insertion loss is 3.5 dB" or "the amplifier's gain is 20 dB."

If a reference is appended to the decibel, then it's possible to indirectly express absolute levels. For example, one way to express power using the decibel is with "dBm," an abbreviation for "decibel milliwatt." From a numbers perspective, $dBm = 10\log_{10}(mW/1\ mW)$, where "mW" in the numerator is the power level in milliwatts that is to be converted to dBm. Let's say you have a downstream laser whose optical output power is 11 mW. Here's how we sort out what this number is in dBm:

$dBm = 10\log_{10}(11\ mw/1\ mW)$

$dBm = 10 * [\log_{10}(11\ mW)]$

$dBm = 10 * [1.0414]$

$dBm = 10.41$

While we can say 11 mW is +10.41 dBm, technically speaking, dBm actually is the ratio of some power Px to a 1 mW reference, and not an absolute level. In this example, 11 mW is 10.41 dB greater than 1 mW.

So far, so good.

In the world of dBmV, or "decibel millivolt," the reference is 1 millivolt (mV). Wait a sec – a couple paragraphs back, I said the decibel expresses a ratio between two power levels, yet here I've tacked a voltage reference onto the decibel. When we use dBmV, we are indeed using the decibel to express ratios between power levels – in a roundabout sort of way. The confusing part is that the decibel now is expressing power in terms of voltage. But just what does that mean?

"Whether expressed in watts or volts, the small numbers clearly are quite cumbersome to handle. Surely there must be a better way. There is: the decibel."
Mathematically, dBmV = 20log10(mV/1 mV), where "mV" in the numerator is the voltage in millivolts that is to be converted to dBmV. Yes, what you see in this formula suggests voltage is the reference and, in fact, it is. But we get there via power. Recall from last month's overview of the basics that the unit of electrical power, the watt, equals 1 volt multiplied by 1 ampere. Equation-wise, P = EI, where "P" is power in watts, "E" is voltage (electromotive force) in volts and "I" is current in amperes. Substituting the Ohm's Law equivalent for "E" and "I" gives us additional formulas for power: P = E2/R and P = I2R. If we substitute the right-hand side of the power equation P = E2/R for both P1 and P2 in the formula dB = 10log10(P2/P1), we get the equation dB = 10log10,[(E2/R)/(E2/R)], which can be tweaked to read dB = 10log10[(E22)/R2)/(E12/R1)].

In this example, "R" represents the 75-ohm impedance of our cable networks. Because R2 and R1 both are equal to 75 ohms, these equation terms cancel, leaving us with the equation dB = 10log10(E22/E12). This can be simplified somewhat and written as dB = 10log10(E2/E1)2, which is the same as dB = 2 x 10log10(E2/E1) or dB = 20log10(E2/E1). Finally, this gets us to our familiar dBmV formula, where "E1" in the denominator of the latter equation becomes the 1 mV reference and "E2" in the numerator is the mV value we're converting to dBmV: dBmV = 20log10(mV/1 mV). From this, it now should make sense why dBmV really is just an expression of power in terms of voltage.

What about those example per-channel signal levels that previously were expressed in watts and volts? When converted to dBmV, they become 0 dBmV for the Federal Communications Commission minimum at the subscriber terminal, +15 dBmV for the typical tap spigot level, +20 dBmV for the line extender input and +48 dBmV for the line extender output. It's clear that the decibel makes the concept of signal level a whole lot easier.

What happens when a carrier is, say, amplitude modulated? Where in the varying-amplitude signal do we measure the signal level? One way is to measure peak envelope power (PEP), which is the average power (yep, back to watts) during one cycle at the crest of the modulation envelope.

To calculate PEP, start with peak envelope voltage (PEV). For this example, let's assume the PEV of an amplitude-modulated carrier is 14.14 mV. The formula for peak envelope power is PEP = (PEV x 0.707)2/R:

= (0.01414 volt x 0.707)2/75 ohms

= (0.01)2/75

= 0.0001/75

= 0.00000133 watt, or 1.33 microwatt, during each cycle at the crest of the modulation envelope.

It would be pretty cumbersome to express cable-network signal levels along the lines of "the line extender's per-channel input signal level is 0.00000133 watt PEP." As mentioned previously, PEP is the average power of one cycle during the crest of the modulation envelope. An analog-TV channel's visual carrier modulation

crest occurs during sync pulses. Those sync pulses represent the visual carrier's maximum power, and the sync pulses have a constant amplitude even as picture content varies.

Assuming a 75-ohm impedance, 0.00000133 watt is 10 mV, or +20 dBmV. Here, +20 dBmV is the RMS value of the instantaneous sync peaks – a unit of power (
Next time, I'll get back to the decibel and show how all of this fits together.

Ron Hranac is technical leader, HFC Network Architectures, for Cisco Systems, and former senior technology editor for *Communications Technology*. Reach him at rhranac@aol.com.