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THE POWER OF QAM

By RON HRANAC

If you have an analog TV channel whose visual carrier level is 0 dBmV and a 6 MHz wide 64-QAM (quadrature amplitude modulation) signal whose digital channel power is 0 dBmV, which one has more power?

Let's look at this subject more closely and see what the numbers say. Grab a cup of coffee and your scientific calculator. Yep, there's math coming up.

Grrr, math...

Calculating power (P) in direct current (DC) circuits is straightforward. It's the product of voltage (E) and current (I), or P = EI. Another way to express power is voltage squared divided by resistance, or P = E2/R. When we move to alternating current (AC), things aren't quite so simple. In an AC circuit, the instantaneous values of voltage and current are varying continuously in time. How can useful quantities for these varying values be defined?

To get AC voltage and current quantities that are equivalent to DC, we use root mean square (RMS) values. For instance, 10 millivolts (mV) RMS AC voltage causes the same average power dissipation in a resistor as does a 10 mV DC voltage. Likewise, 0.133 milliamperes (mA) RMS of AC has the same heating effect as 0.133 mA of DC.

What about power in an AC circuit? Because the instantaneous values of AC voltage and current vary in time, we generally measure average power. Otherwise, each time the instantaneous values of voltage and current are multiplied to calculate power, the answer would be different. So average power it is.

If voltage and current are in phase in an AC circuit, average power is the product of RMS voltage and RMS current, or Pavg = ErmsIrms. But the formula has to be tweaked when voltage and current aren't in phase: Pavg = ErmsIrmscos[theta symbol], where [theta symbol] is the phase angle difference.

For this example, let's assume voltage and current are in phase. What power does a 0 dBmV signal represent? We know that 0 dBmV in a 75 ohm impedance cable network is 1 mV (0.001 volt) RMS because that's the definition of 0 dBmV. The power can be calculated using the formula Pavg = Erms2/R:

= 0.0012/75
= 0.000001/75
= 0.000000013333 watt (W) or 13.33 nanowatts (nW)

If the analog TV channel's visual carrier is 13.33 nW and the 64-QAM signal's digital channel power is 13.33 nW, the two power levels look the same! But are they?

When we measure an analog TV channel's visual carrier level, what is being measured? Technically, it's the RMS amplitude of the instantaneous sync peaks. This happens to be equal to peak envelope power (PEP), which is the average power (watts) during one cycle at the crest of the modulation envelope. With a modulated visual carrier, the crest of the modulation envelope occurs during sync peaks. Mathematically, PEP = (PEV x 0.707)2/R. This formula is a variation of Pavg = Erms2/R.

A sine wave's RMS voltage is 0.707 of the peak voltage. For example, if the RMS voltage is 0.001 V, the peak voltage is 0.001414 V. This is a peak to average ratio of 0.0014141/0.001 = 1.414, or, in decibels, 20log(1.414) = 3 dB. The PEP of a modulated visual carrier whose peak envelope voltage (PEV) is 0.001414 volt during sync peaks is:

= (0.001414 x 0.707)2/75
= (0.001)2/75
= 0.000001/75
= 13.33 nW

Consider a 0 dBmV Ch. 2 visual carrier: Each 4.7 microsecond (µs) duration sync pulse comprises about 259 cycles of the 55.25 MHz RF signal. The average power of each cycle during sync peaks is 13.33 nW. During active video portions of the RF envelope, the average power for each cycle of RF is less (and varies with picture content), which is why we measure the modulated visual carrier's signal level only during the sync peaks. We know from our previous calculation that 13.33 nW is 0 dBmV, or 1 mV RMS in a 75 ohm impedance—in other words, the RMS amplitude of the instantaneous sync peaks!

Average power

When we measure a 64-QAM signal's digital channel power, we are measuring its average power. That power is spread over the 6 MHz occupied bandwidth of the channel, unlike an analog TV channel that has the vast majority of its power concentrated in the visual carrier.

Measurement of digital channel power can be done using a couple different methods. One way is to connect a thermocouple power meter directly to the output of the signal source, say, a QAM modulator. The power meter will tell us the signal's average power. That's not really practical, though, since most of us don't have a thermocouple power meter handy. As well, if other signals are present in the spectrum, the power meter will measure all of them at the same time. We have to isolate the desired QAM channel with a filter, then compensate for the filter's insertion loss, connecting cable loss, etc.

Most modern signal level meters (SLMs), QAM analyzers and spectrum analyzers that support digital channel power measurements do so by measuring the digitally modulated signal's amplitude at several points in the 6 MHz bandwidth, then integrating the measurement results into the average power value for the whole channel. This method often yields accuracy comparable to a thermocouple power meter.

Peak power

So far I've talked about average power, but it's important to understand that analog TV channels and digitally modulated signals also have peak power content. While we rarely measure peak power, we do need to understand peak-to-average power ratio. If the power peaks are too high, nasty things like laser clipping can happen.

Let's go back to our 0 dBmV Ch. 2 visual carrier and remove the baseband video modulation. The resulting continuous wave (CW) carrier is a sinusoidal signal. The CW carrier's amplitude is the same as the modulated carrier: 0 dBmV or 13.33 nW. Its peak-to-average ratio is 3 dB, which means instantaneous peak power (not PEP) is 26.66 nW.

What about a 0 dBmV 64-QAM signal? Its average power also is 13.33 nW, but its peak-to-average power ratio is a bunch more than a CW carrier's. The peak-to-average ratio of a QAM signal is a function of the modulation type, data transmit filter, trajectory overshoot and other factors, but can range from 6 to 13 dB or more. HEYS Professional Services' Francis Edgington has measured practical peak-to-average power ratios for 64-QAM signals in the 6.3 to 7.3 dB range, and 6.5 to 7.5 dB range for 256-QAM signals.

Back to the original question: Which signal has more power? If we compare a 0 dBmV CW carrier to a 0 dBmV 64-QAM signal, the average power is identical: 13.33 nW. A thermocouple power meter will show 13.33 nW for each signal. If you look at the two signals side by side on a spectrum analyzer with its resolution bandwidth (RBW) set to, say, 100 kHz, the CW carrier will appear to be about 15~17 dB higher than the QAM signal, even though they have the same average power. This apparent discrepancy has to do with the narrow RBW filter—a wider filter setting will cause the QAM signal's displayed amplitude to increase.

When video modulation is applied to the TV channel, the power meter will read low, even though the PEP is still 13.33 nW. The difference between the TV and QAM signals is that analog visual carriers are negatively modulated, so they reach PEP only during sync pulses. The average power, depending on video content, is about 6 dB below sync peak power. In contrast, the QAM signal is modulated both upwards and downwards from the average level. Comparing the levels of QAM and TV signals is like comparing apples to oranges—the reference levels are completely different. In fact, a QAM signal that is "6 dB lower" than a TV signal actually has about the same average power and about the same PEP as the analog TV channel's visual carrier.

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