What is Signal Level?

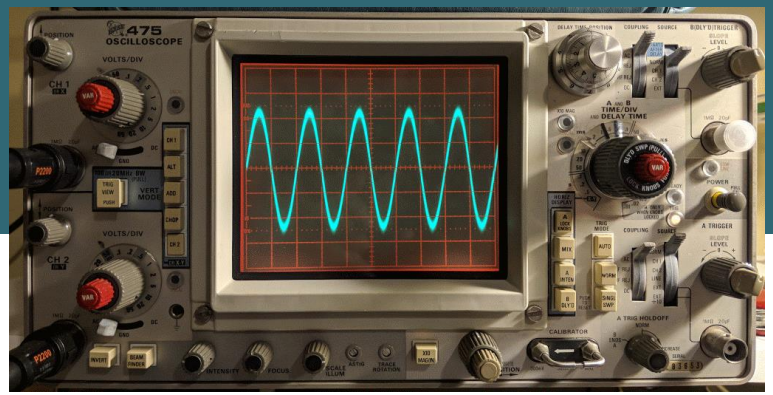
Ron Hranac

Signal Level

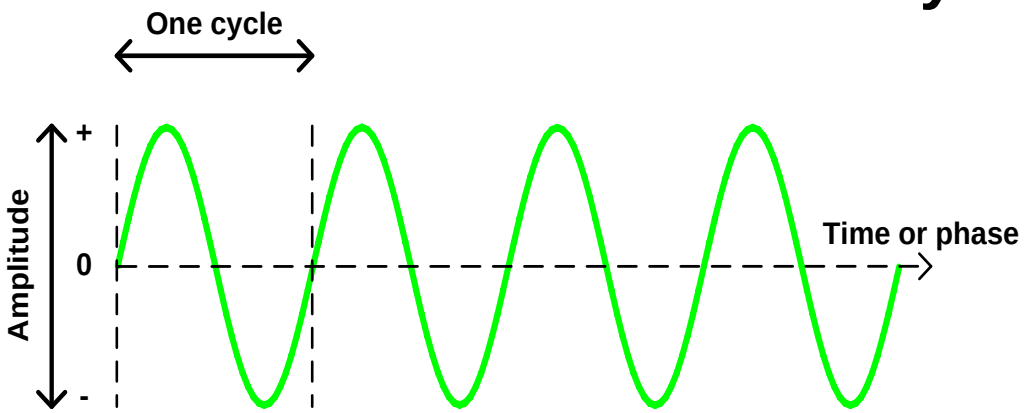
- When measuring signal level at the output of an amplifier, the input to a cable modem, TV set or set top box, just what is it that we are measuring?
- We're measuring the amplitude of a signal or signals, but what does that mean?
- Let's start with some basics…

Graphic courtesy of Sunrise Telecom

Signal Level

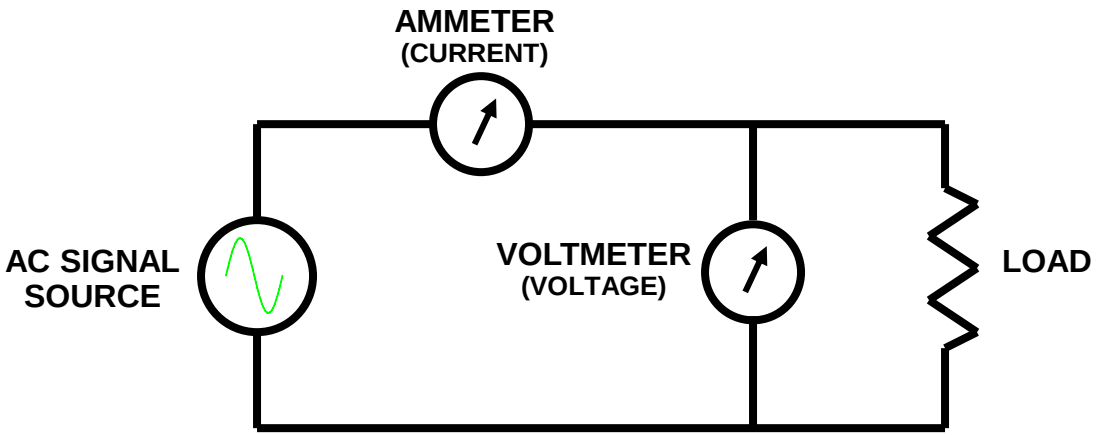


- **Consider a sine wave viewed in the time domain – that is, amplitude versus time – as might be seen on an instrument called an oscilloscope.**
- **This alternating current (AC) waveform's amplitude or level can be characterized in a variety of ways**



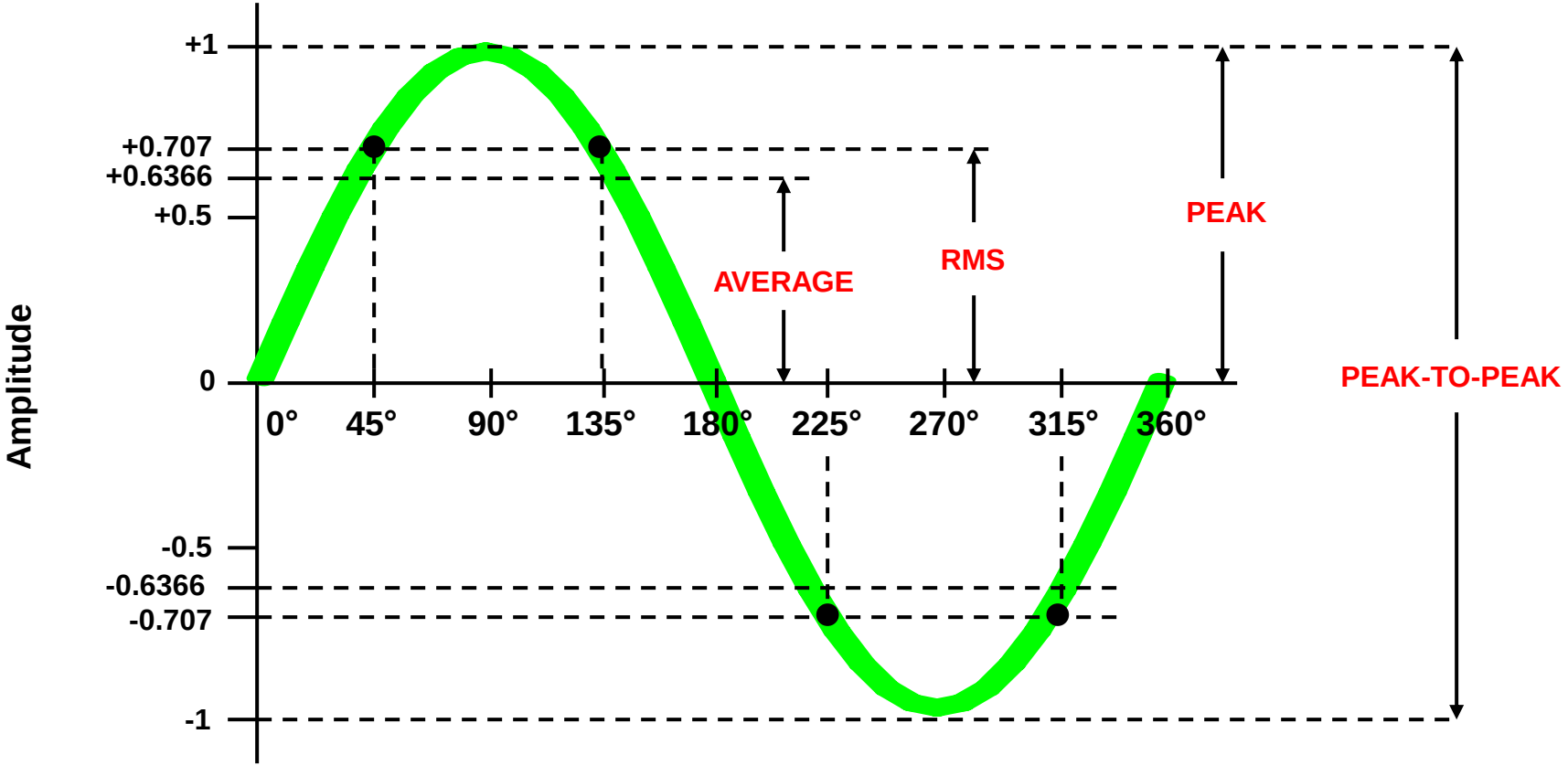
Signal Level

- **For instance, we can measure the sine wave's peak-to-peak, peak, root mean square (RMS), or average values of current and voltage**



Sine Wave: A Closeup

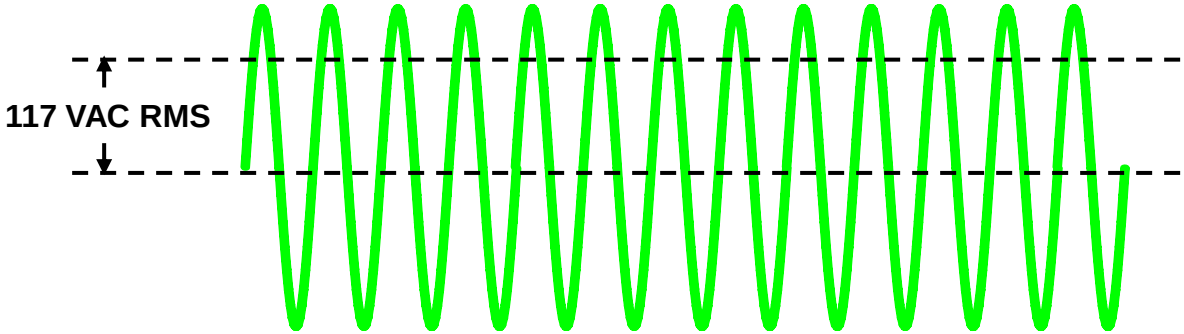
Relationships between RMS, average, peak, and peak-to-peak values of AC sinusoidal current and voltage



Example courtesy of ARRL

AC Voltage and Current

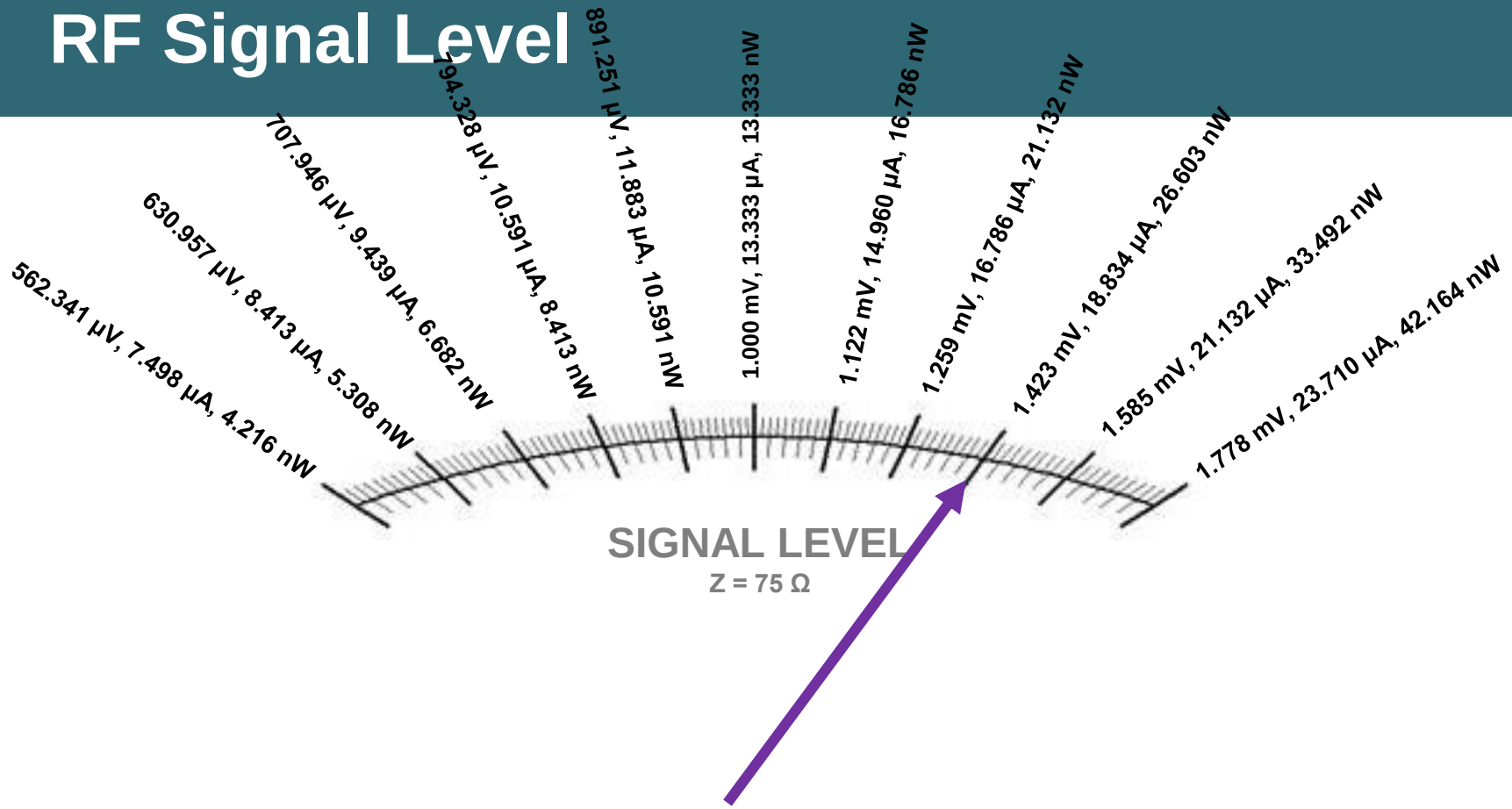
- **The voltage or current of an AC waveform is usually expressed as an RMS value**
- **For instance, the electricity from a North American household electrical outlet is a low frequency (60 Hz) sine wave whose RMS voltage is about 117 VAC**



RF Signal Level

- **An unmodulated RF signal – also known as a continuous wave or CW carrier – is a high frequency (typically several kHz, MHz, or more) sinusoidal AC waveform**
- **The amplitude of an RF signal also can be expressed in a variety of ways: voltage (volts), current (amperes) or power (watts)**

RF Signal Level



- **Imagine a signal level meter that directly reported voltage, current, and power. That would be cumbersome to say the least!**

RF Signal Level

- **Let's look at an example of measuring RF signal voltages in a cable network**
- **Per-channel signal voltages in a 75 ohms impedance cable network can vary over a considerable range of values**

  Line extender output: 0.100 volt, or 100 mV RMS

  Tap spigot output: 0.00708 volt, or 7.08 mV RMS

  TV set input: 0.001 volt, or 1 mV RMS

  Line extender input: 0.010 volt, or 10 mV RMS

The Decibel and dBmV

- **A convenient way to deal with this wide variety of signal levels is to use the decibel**

  A signal level in millivolts may be expressed in decibels as a ratio of that signal level to 1 mV across 75 ohms (13.33 nanowatts). This is called decibel-millivolts (dBmV), which is technically a unit of power expressed in terms of voltage.

- **Mathematically, dBmV = $20\log_{10}$(millivolts/1 mV)**
- **For example, 10 mV RMS is +20 dBmV:**

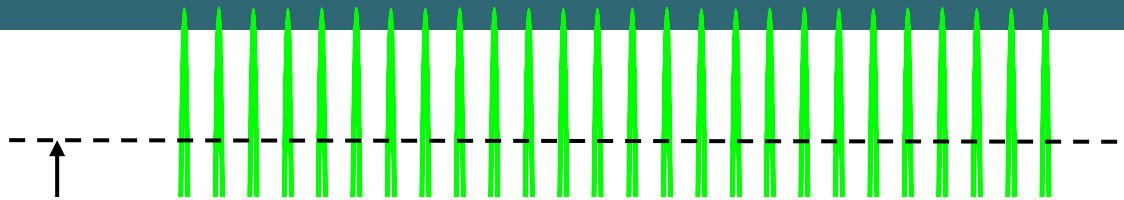
  dBmV = $20\log_{10}$(10 mV/1 mV)

  dBmV = 20 * [$\log_{10}$(10)]

  dBmV = 20 * [1]

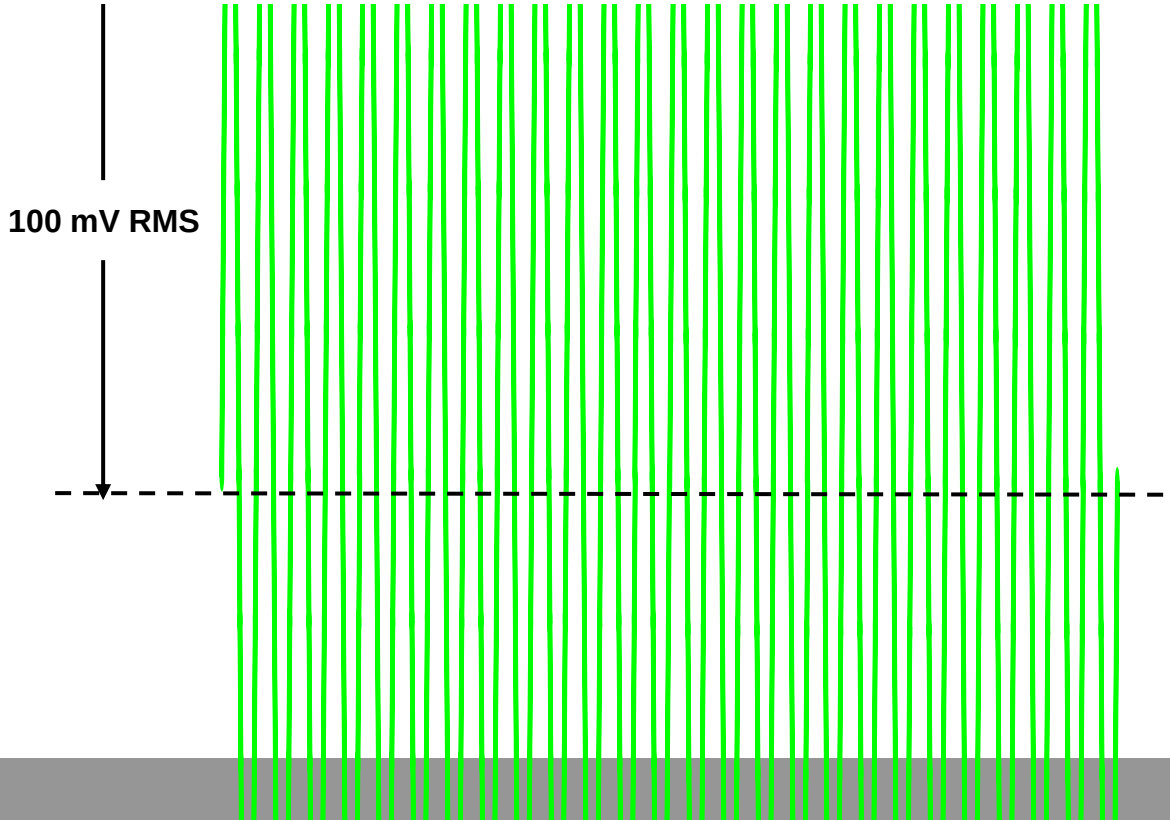
  dBmV = 20

Unmodulated Carrier Signal Level



- **The previous examples become**

Line extender output: 100 mV RMS = +40 dBmV



Unmodulated Carrier Signal Level

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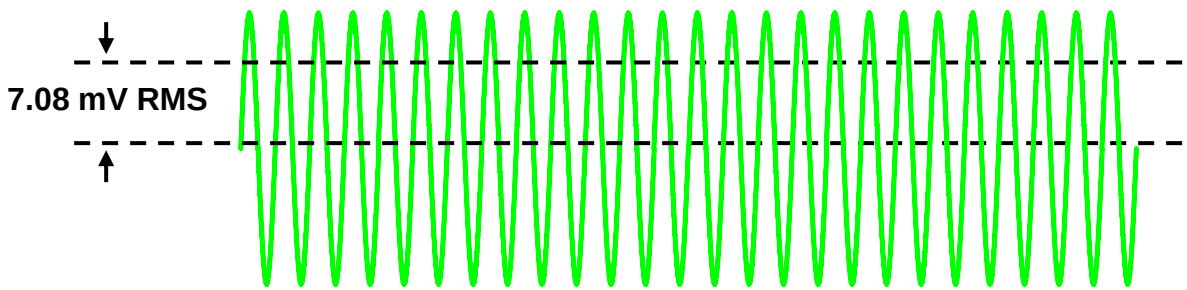
  Line extender output: 100 mV = +40 dBmV

  Tap spigot output: 7.08 mV RMS = +17 dBmV



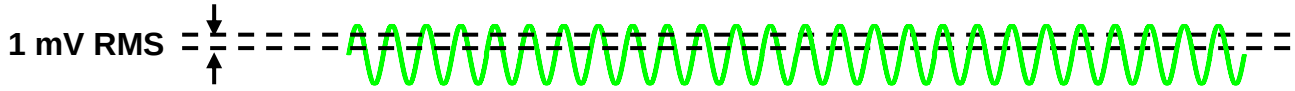
Unmodulated Carrier Signal Level

- **The previous examples become**

  Line extender output: 100 mV = +40 dBmV

  Tap spigot output: 7.08 mV = +17 dBmV

  TV set input: 1 mV RMS = 0 dBmV



Unmodulated Carrier Signal Level

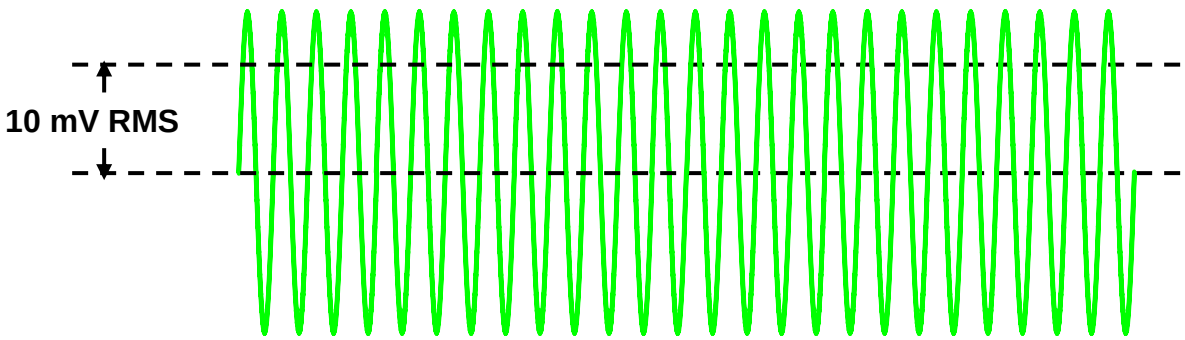
- **The previous examples become**

  Line extender output: 100 mV = +40 dBmV

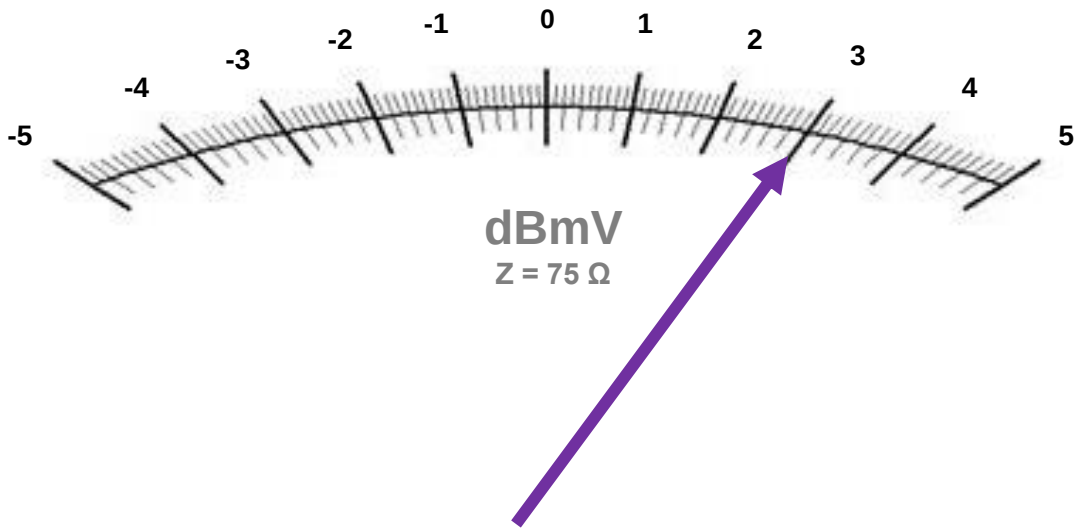
  Tap spigot output: 7.08 mV = +17 dBmV

  TV set input: 1 mV = 0 dBmV

  Line extender input: 10 mV RMS = +20 dBmV



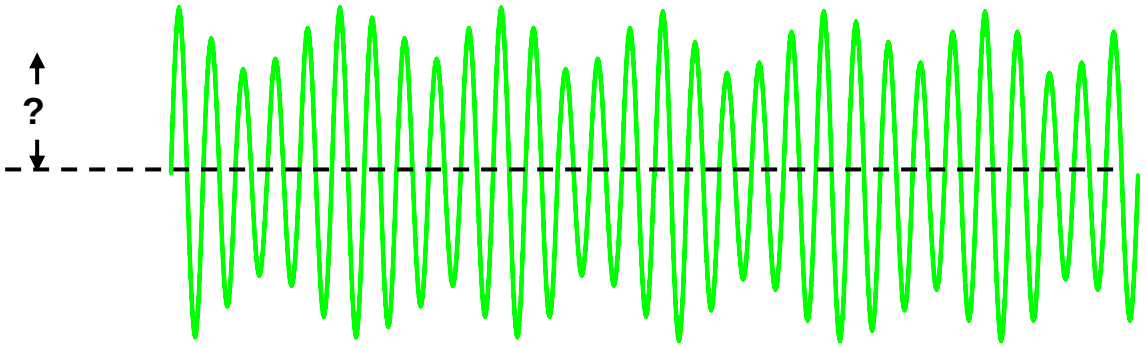
Remember That Meter a Few Slides Back?



- **Things are so much easier when using dBmV!**

Modulated Carrier Signal Level

- **What happens when the carrier is, say, amplitude modulated?**
- **Where in the varying amplitude signal do we measure the signal level?**

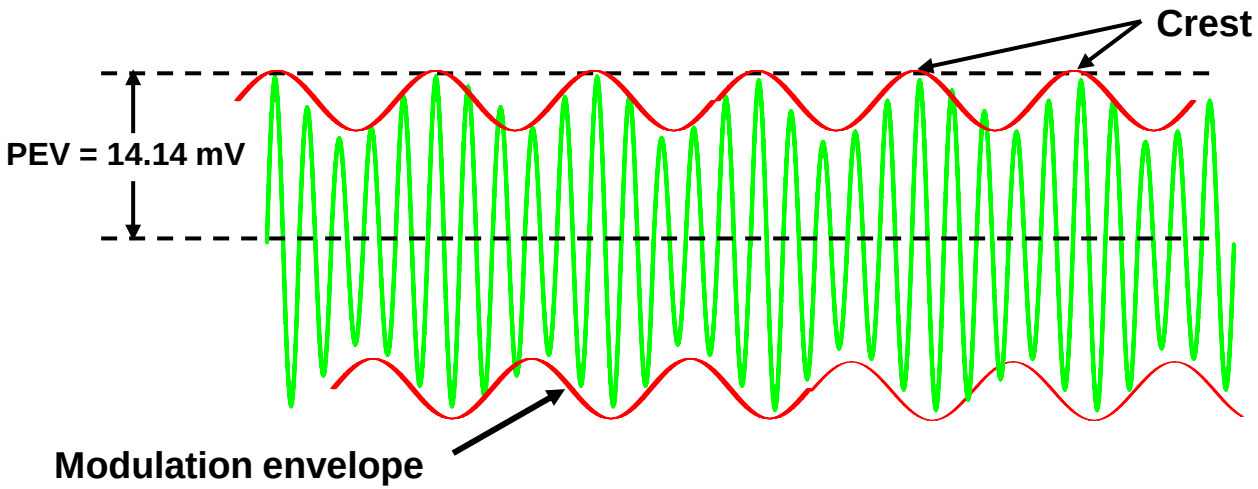


Peak Envelope Power

- **One way is to measure peak envelope power (PEP)**

  PEP is the average power (watts) during one cycle at the crest of the modulation envelope

- **Start with peak envelope voltage (PEV)—for this example let's assume the PEV is 14.14 mV**



Peak Envelope Power

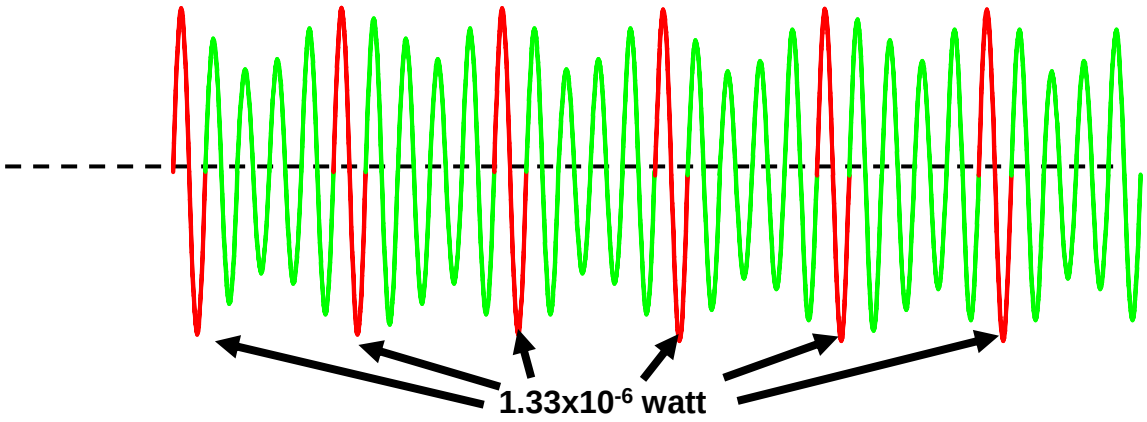
- **PEP = (PEV x 0.707)^2/R**

  = (0.01414 volt x 0.707)^2/75 ohms

  = (0.01)^2/75

  = 0.0001/75

  = 1.33x10^{-6} watt, (0.00000133 watt, or 1.33 µW), during each cycle at the crest of the modulation envelope



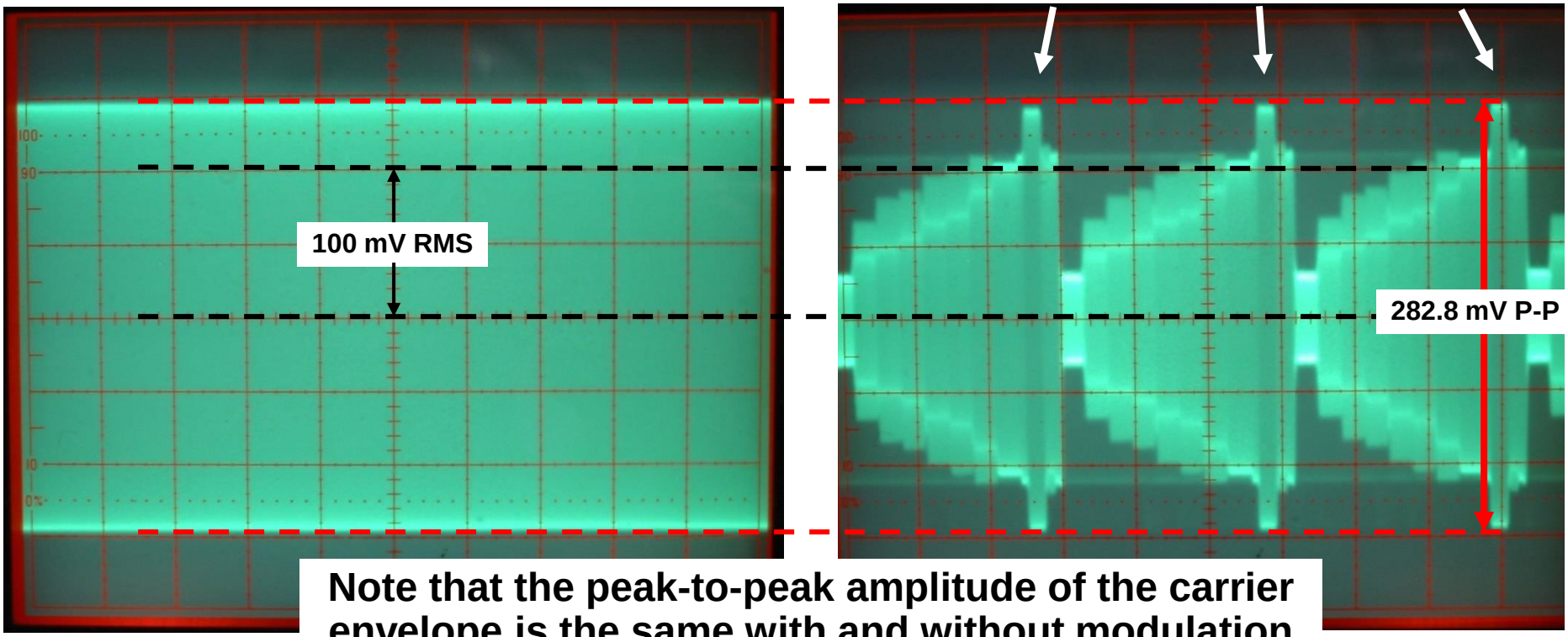
Measuring RF Signal Level

- It would be quite cumbersome to express cable network signal levels in PEP – as in “the line extender’s per-channel input signal level is 0.00000133 watt PEP”
- PEP is the average power of one cycle during the crest of the modulation envelope, which occurs during an analog TV channel’s visual carrier sync pulses
- The sync pulses represent the carrier’s maximum power; the sync pulses have a constant amplitude even as picture content varies
- Assuming 75 ohms impedance, 0.00000133 watt is 10 mV RMS, or +20 dBmV
- Here, +20 dBmV is the RMS value of the instantaneous sync peaks – a unit of power (0.00000133 watt PEP) expressed in terms of voltage

Time Domain View of Unmodulated Versus Modulated TV Carrier

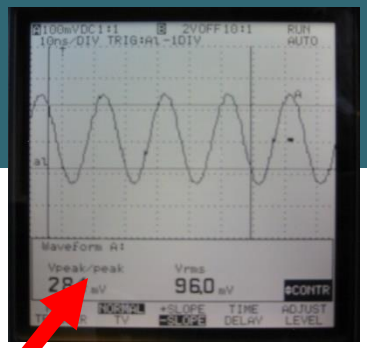
This unmodulated analog TV signal's visual carrier amplitude is 100 mV RMS, or +40 dBmV

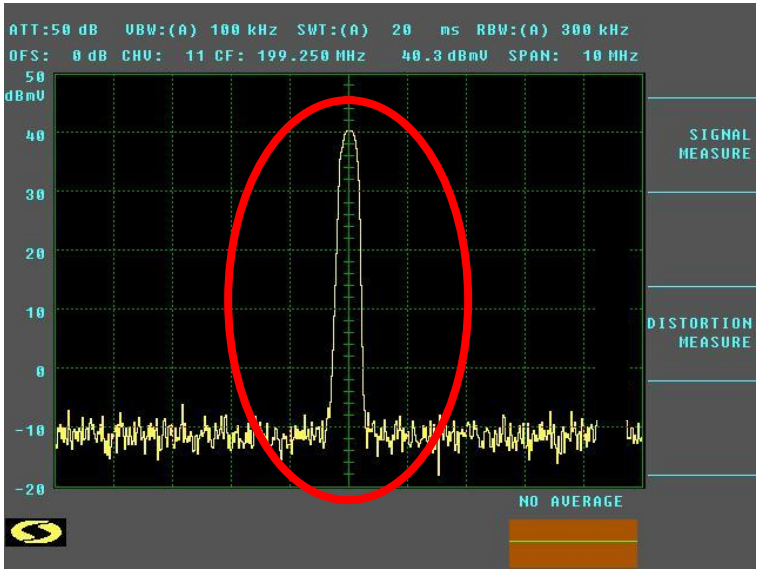
When video modulation is applied, the carrier's amplitude is measured just during the sync peaks. Here, too, the level is 100 mV RMS, or +40 dBmV.



Note that the peak-to-peak amplitude of the carrier envelope is the same with and without modulation

Unmodulated Visual Carrier





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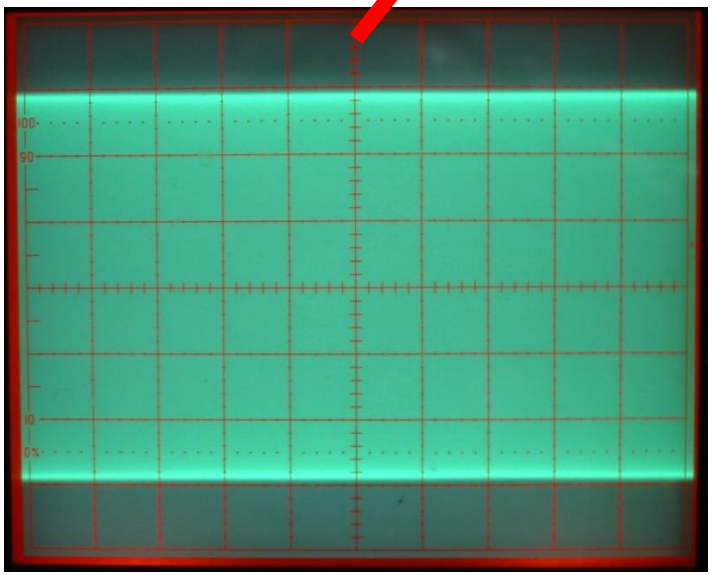
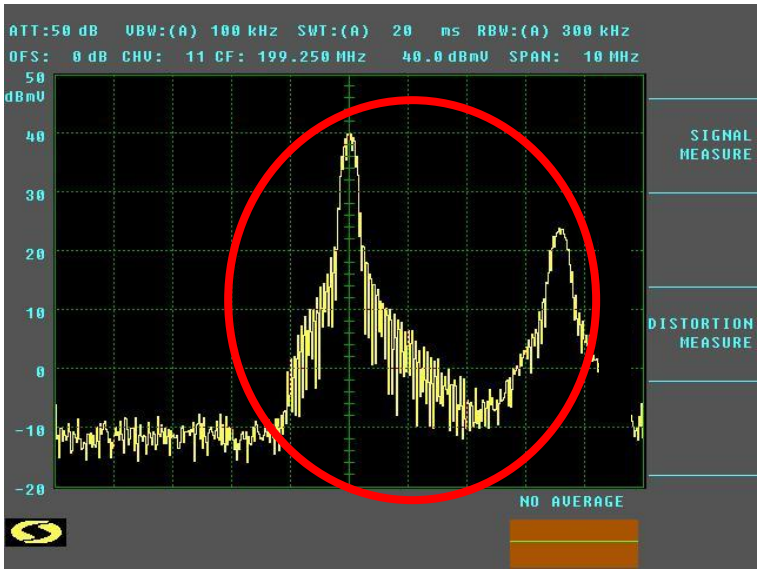


Frequency domain:
Amplitude versus frequency

Time domain:
Amplitude versus time

Modulated Visual Carrier



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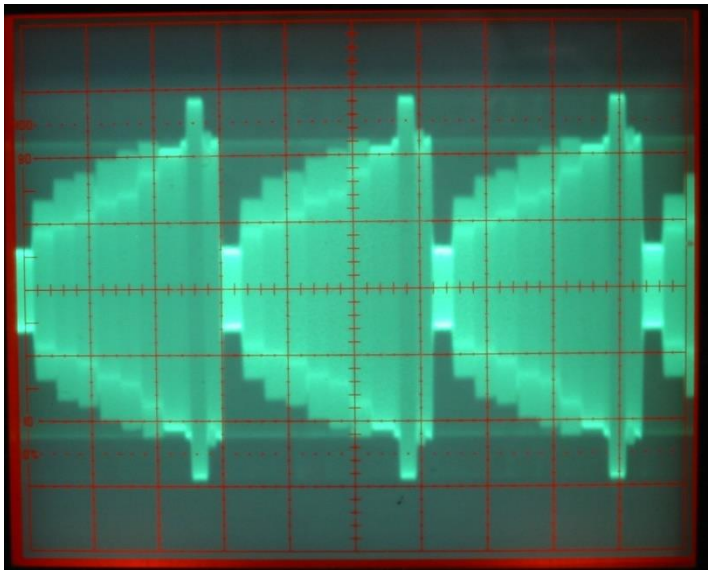


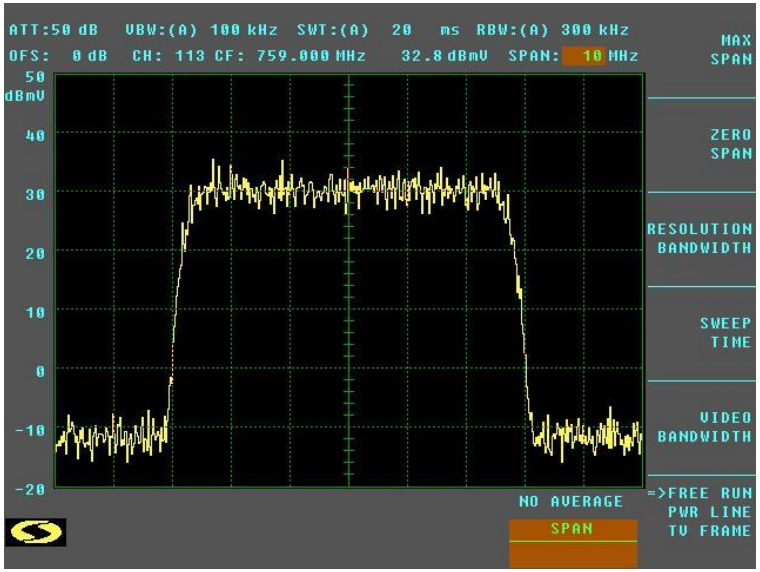
Frequency domain:
Amplitude versus frequency

Time domain:
Amplitude versus time

What about SC-QAM signals?

- As just discussed, the level of an analog TV signal is the PEP of its visual carrier.
- When measuring the level of an SC-QAM signal, we measure that signal's average power (not its PEP), also called digital channel power or digital signal power.
- Most digital-capable signal level meters, QAM analyzers, and similar test equipment measure the level at several points across the SC-QAM signal's occupied bandwidth – say, 6 MHz – then integrate the results to provide the average power of the entire "haystack." Results are typically comparable to what a thermocouple power meter would measure.

64-QAM Digitally Modulated Signal



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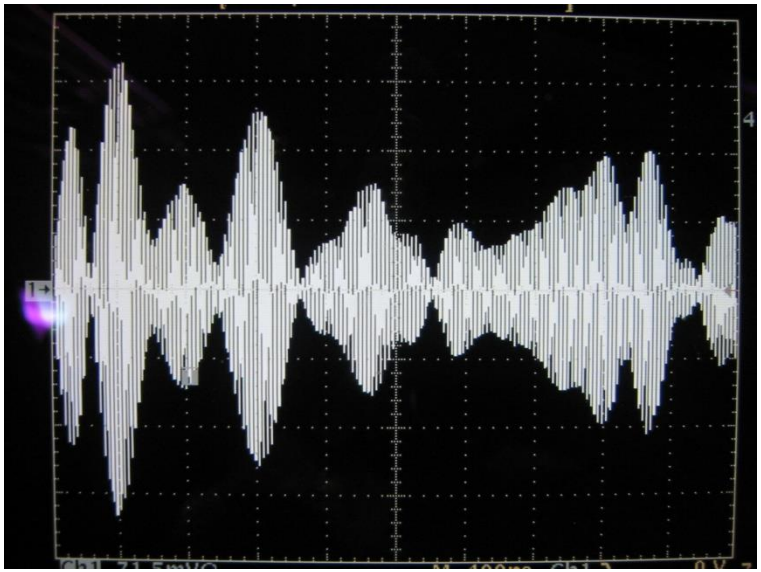


Frequency domain:
Amplitude versus frequency

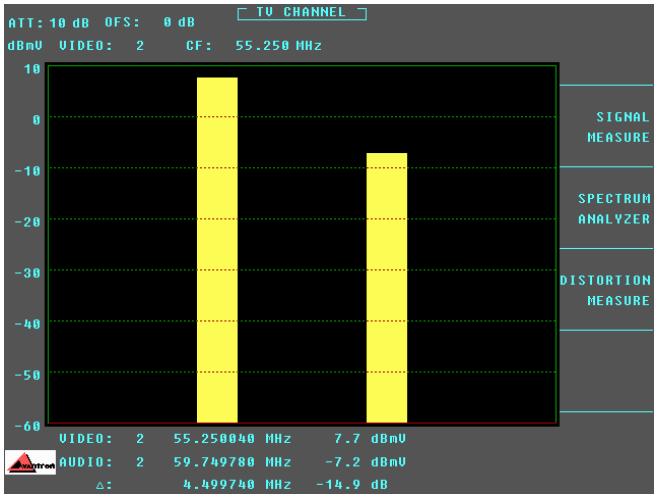
Time domain:
Amplitude versus time

Wrapping up: What is signal level?

- **Signal level is the amplitude of a signal, specifically the RF power of that signal.**
- **Signal level in cable networks is expressed in dBmV (not dB)***

  dBmV is a unit of power expressed in terms of voltage

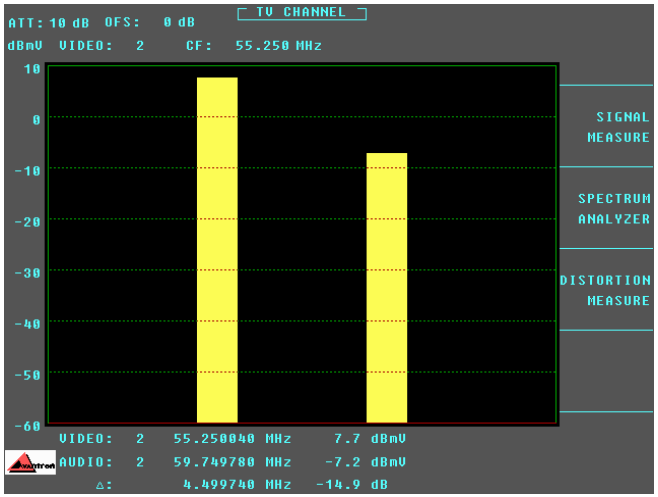
- **In the case of an analog TV channel's visual carrier, signal level is the carrier's peak envelope power**



***Note: dB (not dBmV) is used to express gain, loss or attenuation, return loss, structural return loss (SRL), isolation, carrier-to-noise ratio (CNR), signal-to-noise ratio (SNR), receive modulation error ratio (RxMER), and similar parameters.**

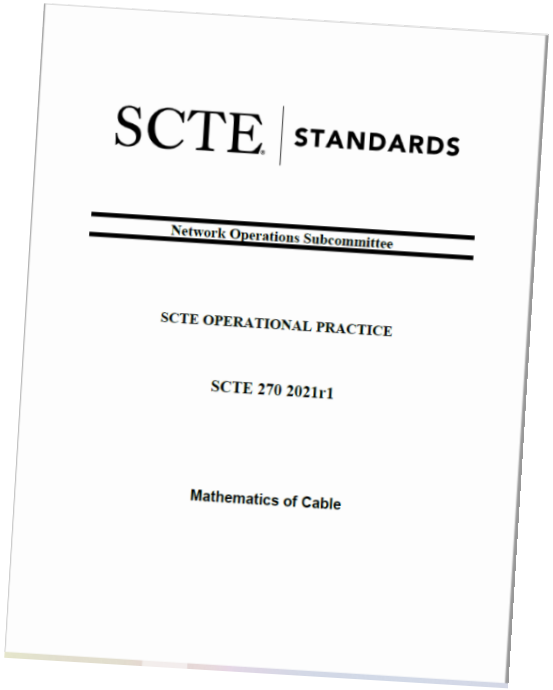
Wrapping up: What is signal level?

- **The signal level of an SC-QAM signal is its average power, also called digital channel power or digital signal power**
- **The signal level of a downstream OFDM signal is the average power per 6 MHz**
- **The signal level of an upstream OFDMA signal is the average power per 1.6 MHz, although some prefer to normalize that power to 6.4 MHz**



Are you a cable math fan?

- **Go to SCTE's website (https://www.scte.org)**
- **Navigate to the standards download page: (https://www.scte.org/standards/library/catalog/).**
- **Download a copy of SCTE 270 2021r1 "Mathematics of Cable"**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Mathematics of Cable

Q and A

Using the decibel for voltage ratios

Or why $20\log_{10}$ instead of $10\log_{10}$?

- **The decibel, while technically a ratio of two power levels, also can be used to represent the ratio of two voltage levels, assuming the two voltages are across (or in) the same impedance.**
- **Here is how that relationship is derived: 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 in volts, and I is current in amperes. Substituting the Ohm's Law equivalent for E and I gives additional formulas for power: $P = E^2/R$ and $P = I^2R$. If the right-hand side of the power equation $P = E^2/R$ is substituted for both P_1 and P_2 in the formula $dB = 10\log_{10}(P_1/P_2)$, the equation becomes $dB = 10\log_{10}[(E^2/R)/(E^2/R)]$ which is the same as $dB = 10\log_{10}[(E_1^2)/R_1)/(E_2^2/R_2)]$. In this example, R represents the 75 ohms impedance of a cable network. Since R_1 and R_2 are both equal to 75 ohms, those equation terms cancel, leaving the equation $dB = 10\log_{10}(E_1^2/E_2^2)$. This can be simplified somewhat and written as $dB = 10\log_{10}(E_1/E_2)^2$ which is the same as $dB = 2 * 10\log_{10}(E_1/E_2)$ or $dB = 20\log_{10}(E_1/E_2)$.**

Power

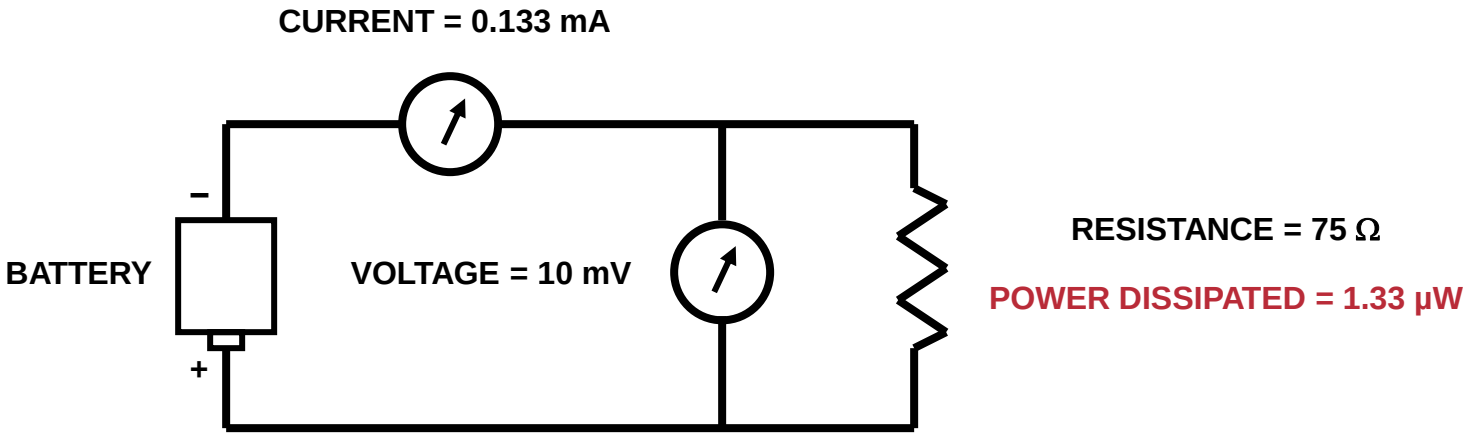
- **Power is the rate at which work is done, or energy per unit of time. 1 watt of power is equal to 1 volt causing a current of 1 ampere.**
- **Watt is the power required to do work at a rate of 1 joule per second (J/s). That is, a joule of work per second is 1 watt.**
- **One joule is the work done 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.**

Power

- **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 $I = P/E$.**
- **Using your trusty scientific calculator and some basic algebra, substitute the Ohm's Law equivalents for E and I into the formula P = EI, and you'll get a couple 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 mV, the power dissipated by the resistor is 1.33 microwatt (μW). That is, $P = E^2/R = 0.010^2/75 = 1.33 \times 10^{-6}$ watt or 1.33 μW.**



Power in AC Circuits

- **Because the previous example is a DC circuit, the voltage always will be 10 mV and the current 0.133 mA. As long as the resistor's value remains constant, it's easy to calculate dissipated power.**
- **Alternating current (AC) circuits and applications are much 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.**

Root Mean Square

- **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?**
- **RMS gives us effective quantities equivalent to DC values.**
- **For instance, 10 mV RMS AC voltage causes the same average power dissipation in a 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!**
- **RMS values simplify calculations by making the product of RMS voltage and RMS current equal to average power: $P_{AVG} = E_{RMS} \times I_{RMS} \cos \theta$.**