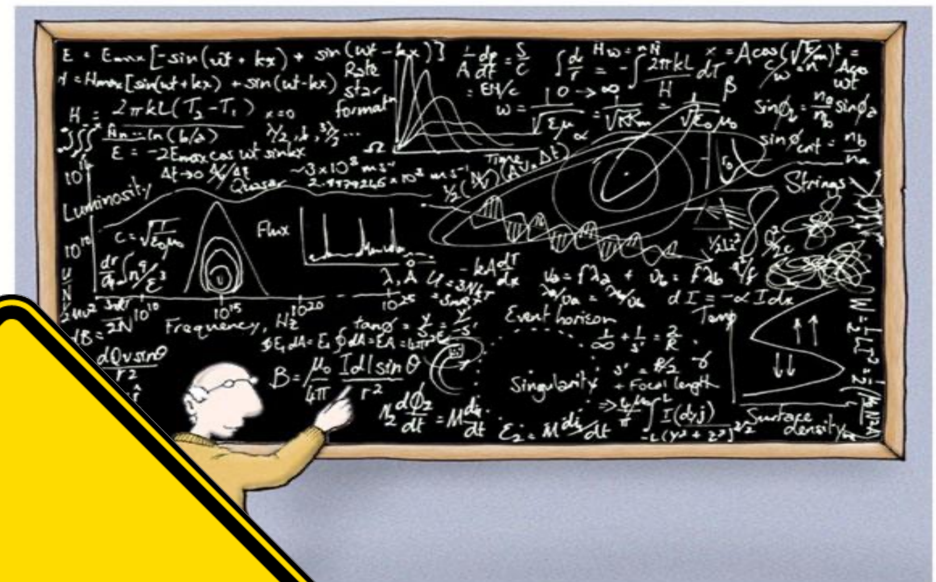
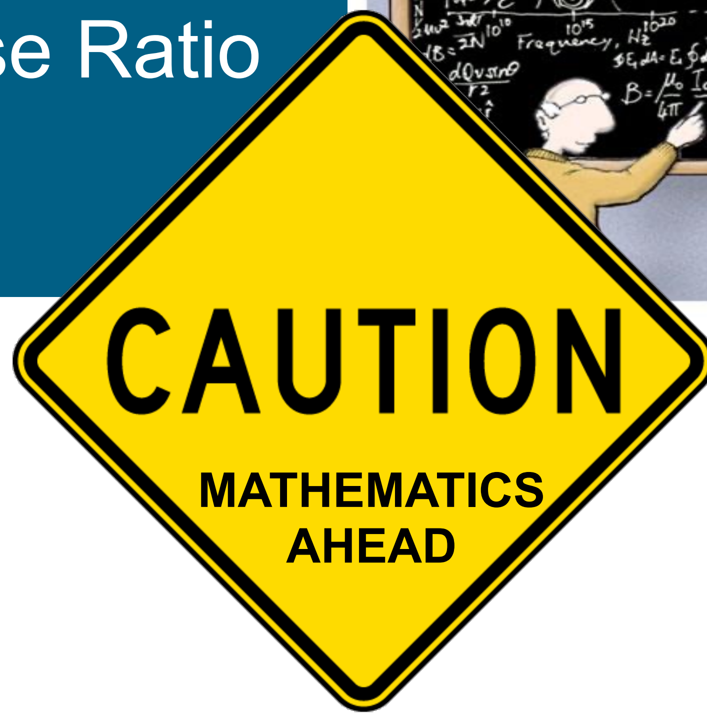
Introduction to Carrier-to-Noise Ratio

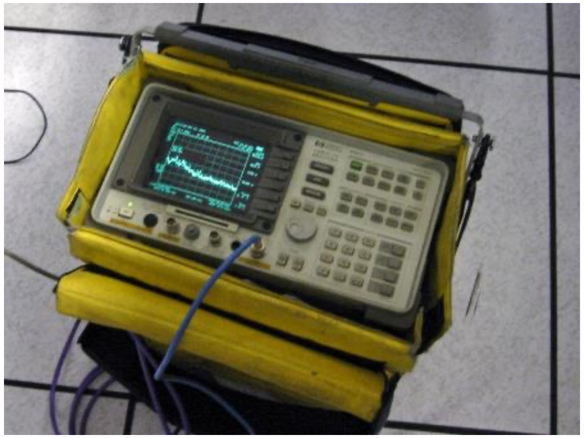




Ron Hranac

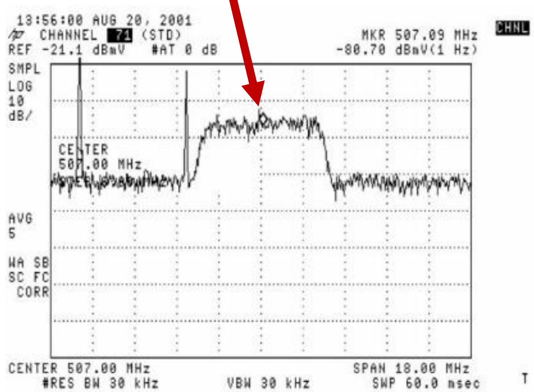
What is Carrier-to-Noise Ratio?

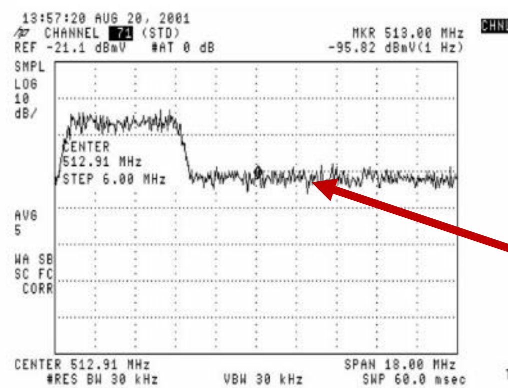
- Carrier-to-noise ratio, or CNR, is generally accepted to be a pre-detection measurement, that is, one made at RF.
- CNR measurements are commonly made using test equipment such as spectrum analyzers and signal level meters.



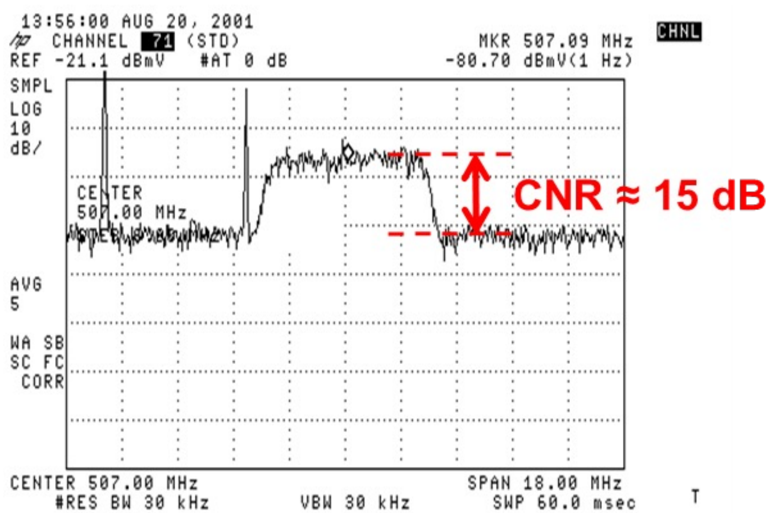
Carrier-to-Noise Ratio

Step 1: Measure C, the carrier's RF signal level.





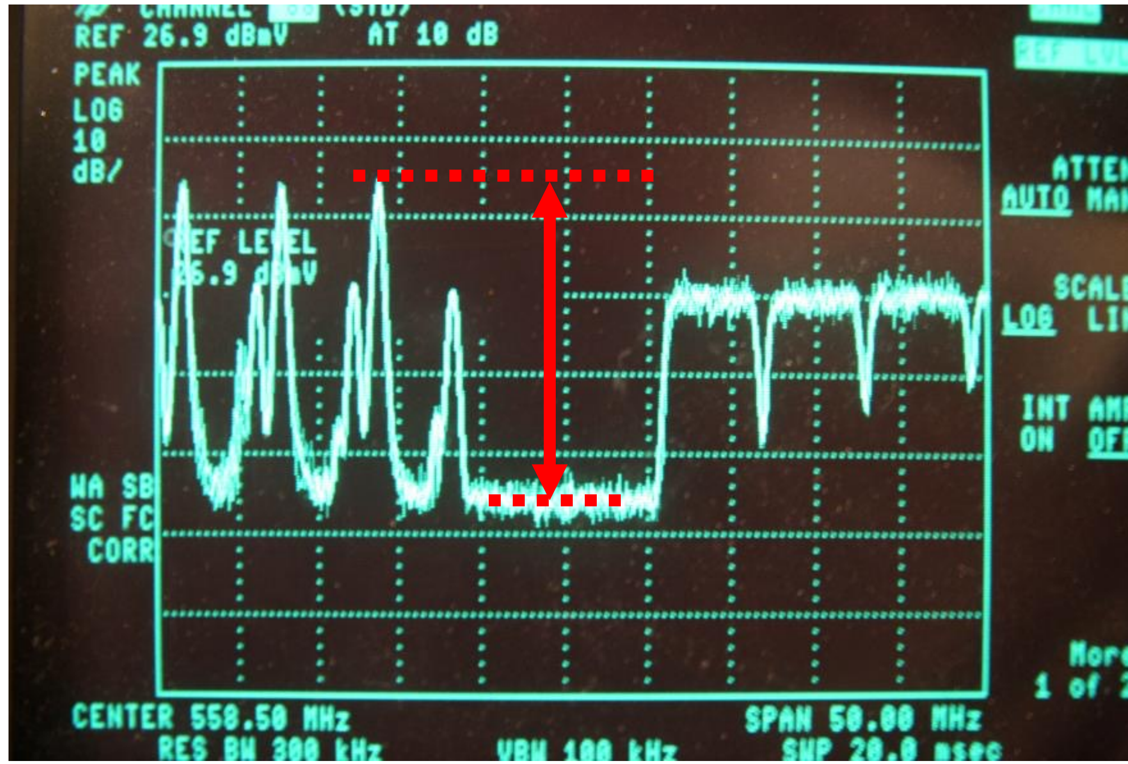
Step 2: Measure N, the noise's signal level. (Apply noise bandwidth correction if necessary.)



Step 3: The difference, in dB, between "C" and "N" is the CNR.

Carrier-to-Noise Ratio

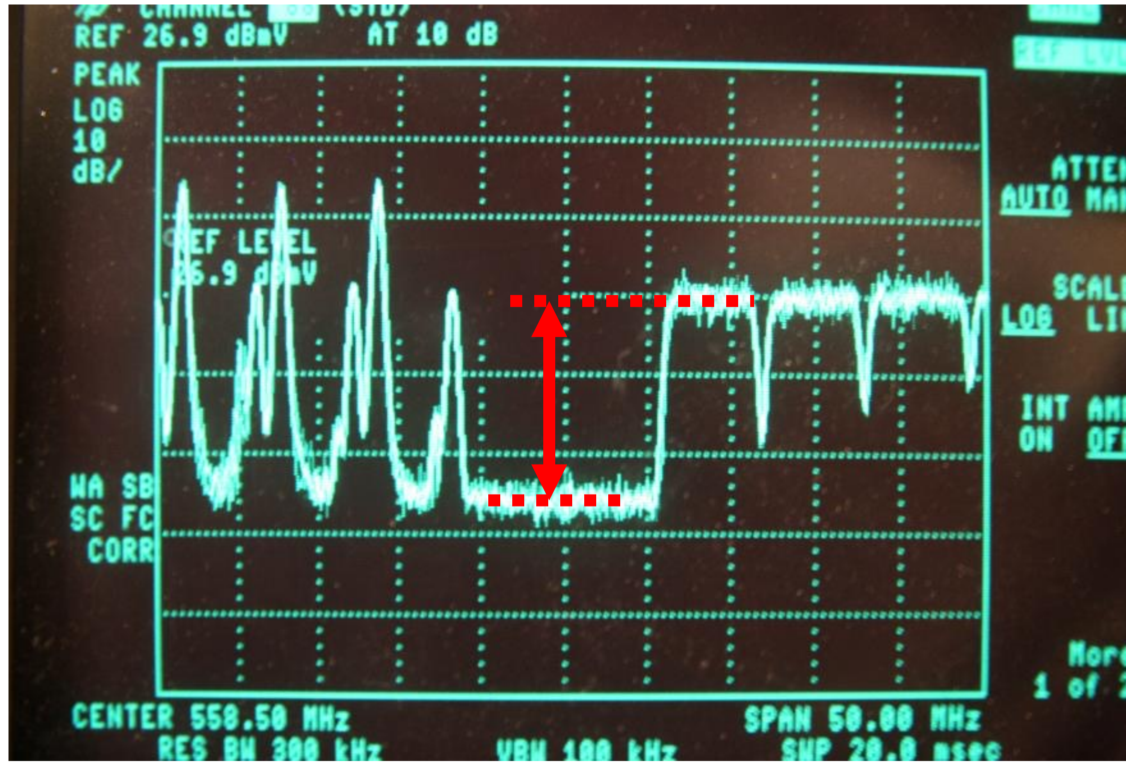
- For analog TV channels, CNR is the difference, in decibels, between the amplitude of a TV signal's visual carrier and the amplitude of system noise in a specified bandwidth (e.g., 4 MHz for NTSC video).



Looking at this spectrum analyzer screen shot, the CNR appears to be about 40 dB. But is it? More on this later.

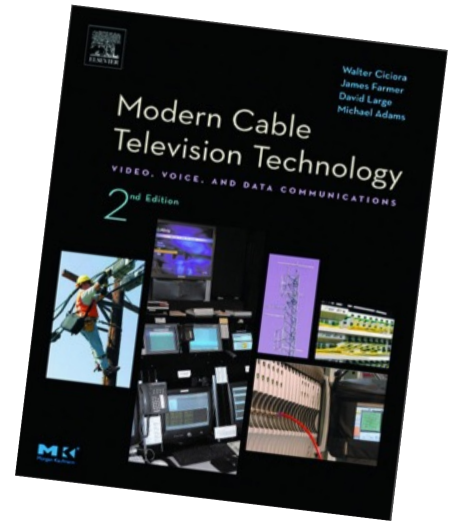
Carrier-to-Noise Ratio

- For SC-QAM channels, CNR is the difference, in decibels, between the amplitude of the "haystack" and the amplitude of system noise (no bandwidth correction needed).
- The same is true for OFDM signals (measure from the top of the haystack, not the top of the pilots).



Here the CNR appears to be about 25 dB or so. But is it? More on this later, too.

CNR Number Crunching



From the book *Modern Cable Television Technology, 2nd Ed.*:

Carrier-to-noise ratio (C/N) is defined as follows:

$$C/N(dB) \equiv 10log\left(\frac{c}{n}\right)$$

where c and n are the scalar power levels of the carrier and noise respectively.

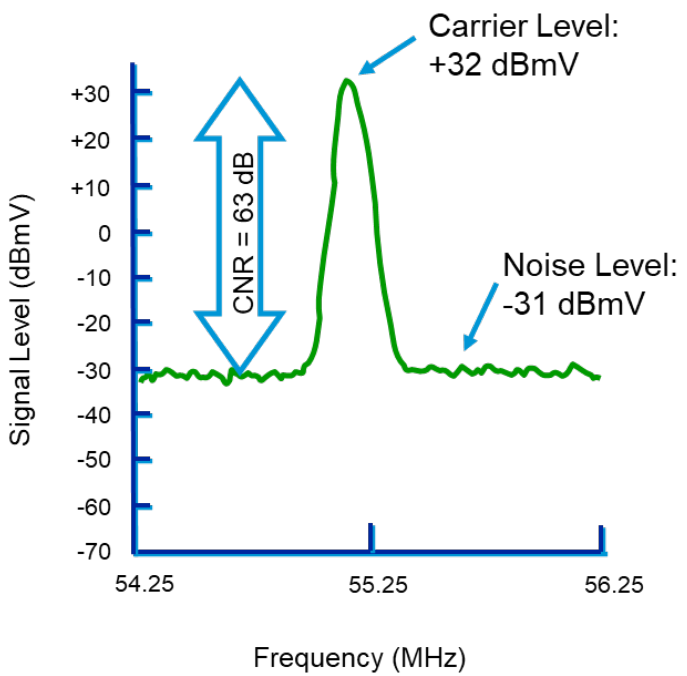
Example: $10log\left(\frac{0.001333333333\,watt}{0.00000042164\,watt}\right) \equiv 45\ dB$

** Note: Here, scalar quantities are in units of watts, and logarithmic quantities are in units of dBmV. Assume the carrier power is 0.001333333333 watt and the noise power is 0.00000042164 watt, or +50 dBmV and +5 dBmV respectively. The ≡ in the formula means "identical to."*

What is Carrier-to-Noise Ratio?

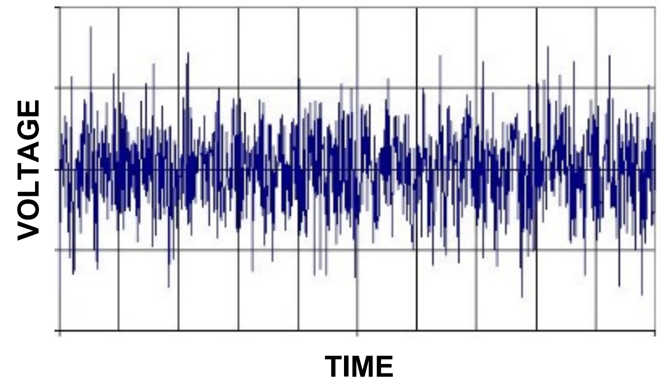
"SCTE 270 2021r1" defines CNR as follows:

The ratio of carrier or signal power to the thermal noise power in a specified bandwidth, as measured on an RF spectrum analyzer or similar equipment. Note that "noise" can also refer other types of noise, such as relative intensity noise, shot noise, etc., but does not refer to transient noise.



CNR on a spectrum analyzer is the difference, in dB, between a carrier's signal level in dBmV and the signal level of the noise (in a specified bandwidth) in dBmV.

Thermal Noise



According to a Hewlett-Packard application note* on noise figure measurement, thermal noise is defined as “the fluctuating voltage across a resistance due to the random motion of free charge caused by thermal agitation.”

Translation: Atomic particles in a resistor (or impedance) jiggle around more at higher temperatures, less at lower temperatures. That atomic-level “jiggling” creates measurable noise.

* *Fundamentals of RF and Microwave Noise Figure Measurement*
(Application Note 57-1, Hewlett-Packard, July 1983)

Thermal Noise: gnarly part

The H-P application note goes on to say, “The probability distribution of the voltage is Gaussian with mean square voltage

$$e_n^{\,2} = 4kT\int_{f1}^{f2} R(f)p(f)\,df$$

Thermal Noise

Available noise power may be expressed in joules/second (watts) using the formula $P = kTB$, where

P = power in watts (W)

k = Boltzmann's Constant (1.38 x 10^{-23} joules/kelvin)

T = temperature in kelvin (K)

B = bandwidth in hertz (Hz)

Thermal Noise

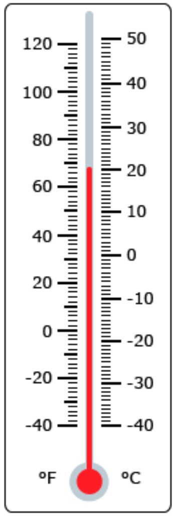
To get thermal noise power into the world of the more familiar dBmV, start with a variation of the gnarly formula a couple slides back. From that formula, one can derive the following formula for calculating the open circuit noise voltage e_n from a resistance or impedance:

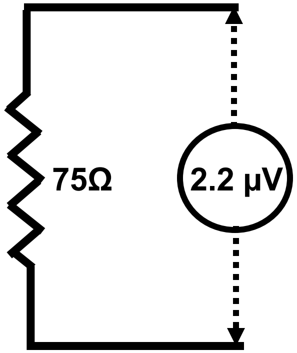
$$e_n = \sqrt{4kTBR}$$

Thermal Noise

Here's how to calculate the open circuit noise voltage over a 4 MHz bandwidth generated by a 75 ohms (Ω) resistor at room temperature (68 °F or 293.15 K):

$$e_n = \sqrt{4 * (1.38 * 10^{-23}) * 293.15 * 4{,}000{,}000 * 75}$$
$$e_n = \sqrt{4.85 * 10^{-12}}$$
$$e_n = 2.2033075 * 10^{-6} volt$$
$$e_n = 2.2033075\ microvolts\ (\mu V)$$





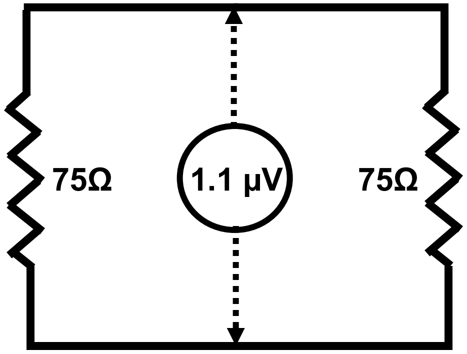
Thermal Noise

- When this 75 ohms impedance noise source is terminated by an equal value resistance – say, connected to the input of a 75 ohms impedance amplifier – the thermal noise is $e_n/2$ or 1.10165375 μV.

  The formula to convert microvolts to dBmV is $20log_{10}(microvolts/1{,}000)$, which gives us -59.16 dBmV.

  That is, 1.1 μV = -59.16 dBmV

Note: Some prefer to calculate thermal noise in a 4 MHz bandwidth at a standard noise temperature T_0 (usually 290 K or 62.33 °F), which gives $e_n/2$ = 1.0957 μV = -59.21 dBmV.



Carrier-to-Noise Ratio

- The carrier-to-noise ratio of an individual amplifier can be calculated with the formula

$$CNR_i = N_t - NF + I$$

where

CNR_i is the carrier-to-noise ratio of an individual amplifier

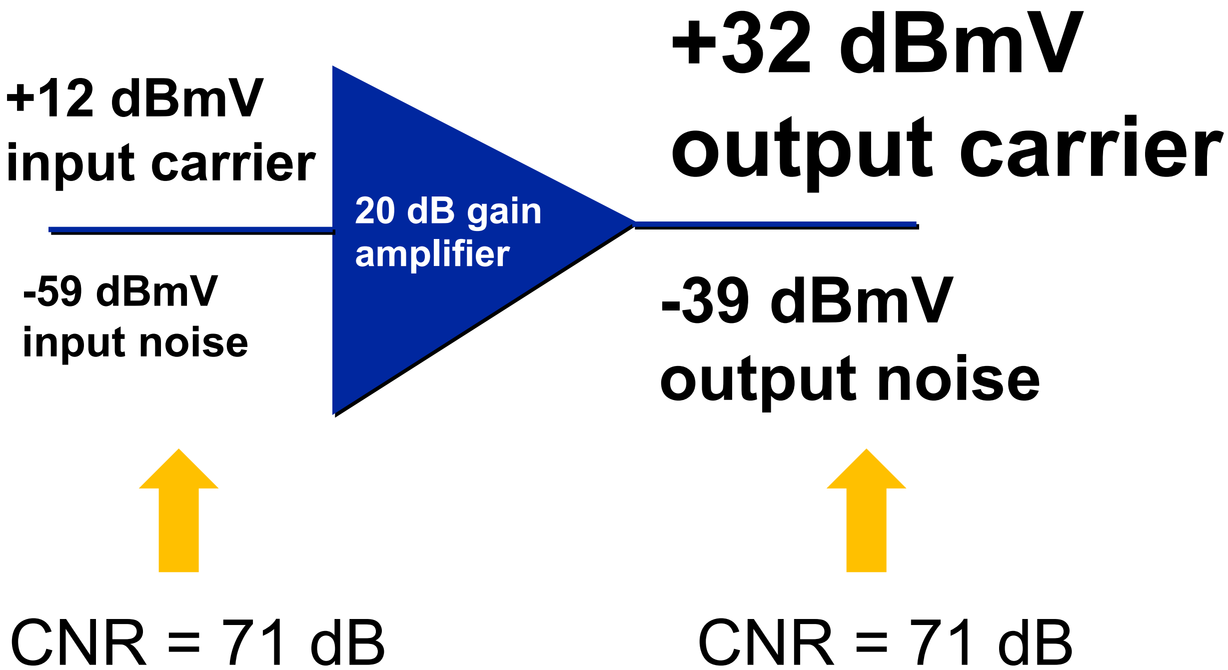
N_t is the thermal noise floor (expressed as a positive number so the formula's answer will come out positive) in dBmV

NF is the amplifier's noise figure in dB

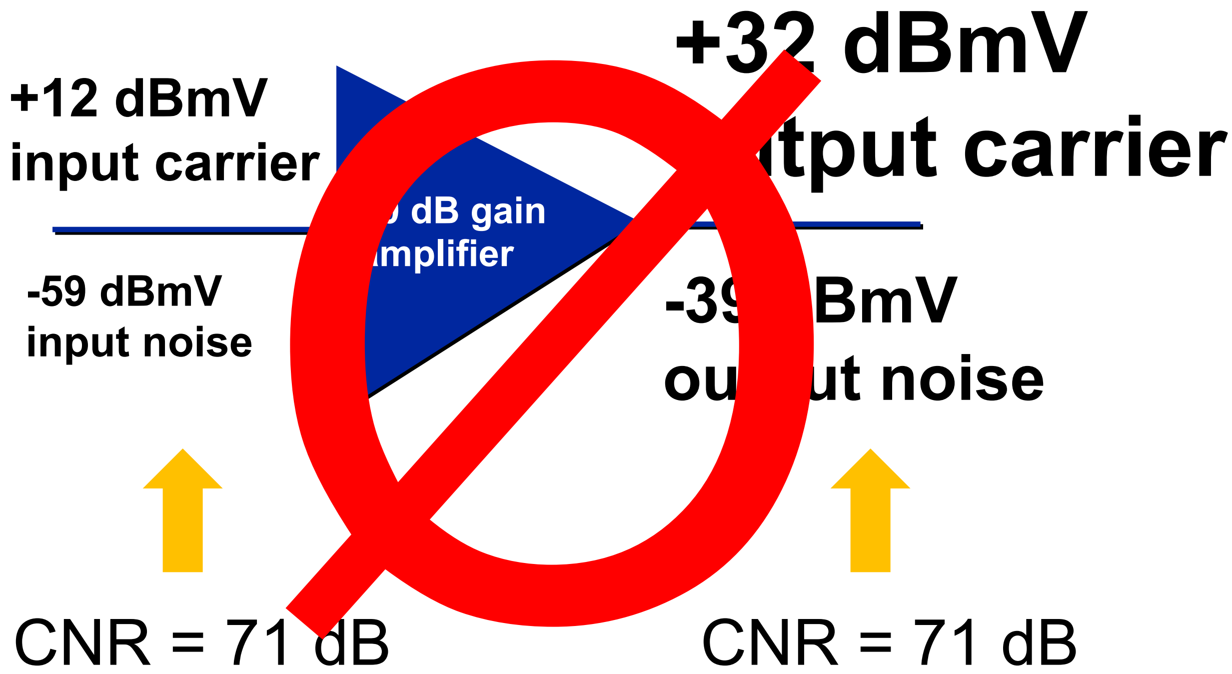
I is the amplifier's RF input level in dBmV

> Note: The formula assumes that the amplifier's plug-in attenuator and equalizer are 0 dB values. If other than 0 dB, the additional insertion loss must be added to the noise figure number. For example, if the amplifier's actual noise figure is 10 dB, the attenuator is 0 dB, and the equalizer has 1 dB of insertion loss, change the noise figure value to 11 dB.

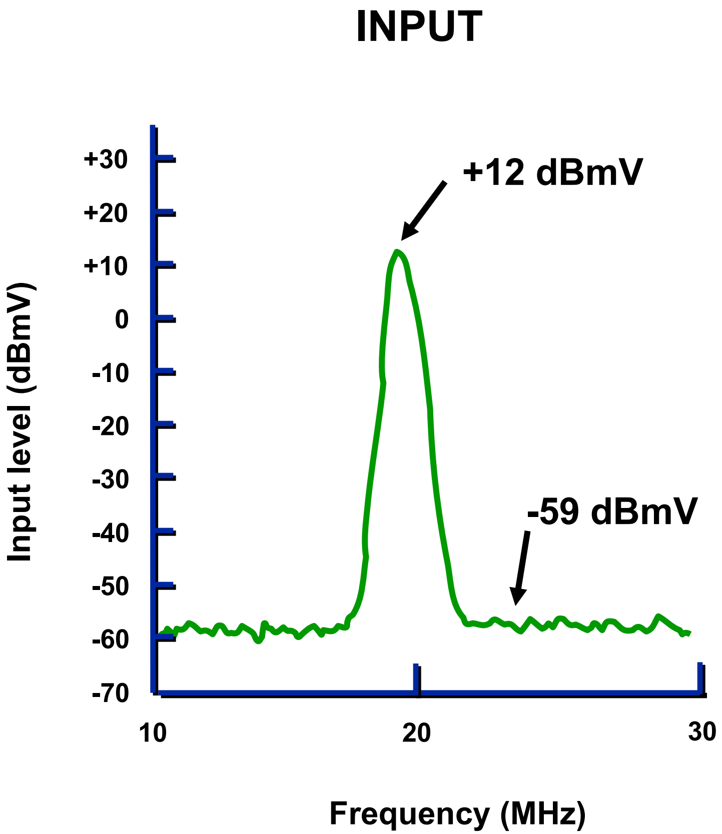
The Perfect Amplifier

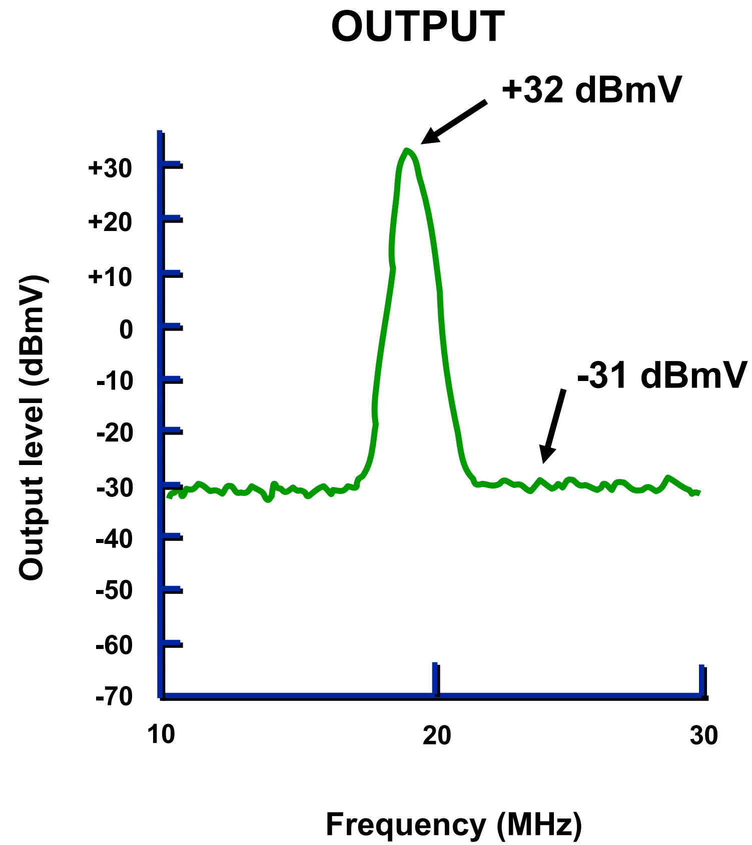


The Perfect Amplifier



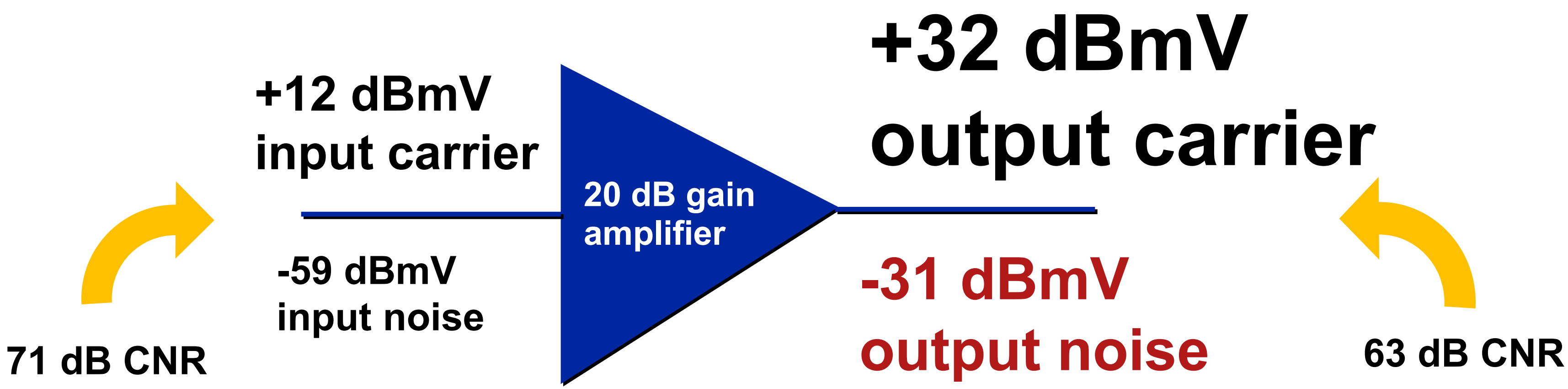
In the Real World…





The noise level at the amplifier output has increased more than the carrier level because of added noise from amplifier circuits.

Noise Figure



In this example, the output CNR is worse than the input CNR by 8 dB! The degradation of the carrier-to-noise ratio through the amplifier is called the amplifier's noise figure. Don't worry, you don't have to calculate noise figure. Amplifier manufacturers publish noise figure in their product specifications.

Carrier-to-Noise Ratio

For example, the CNR of an amplifier with 8 dB noise figure and +12 dBmV input is

$$CNR_i = N_t - NF + I$$

$$CNR_i = 59.16 - 8 + 12$$

$$CNR_i = 63.16\ dB$$

Combining Like Carrier-to-Noise Ratios

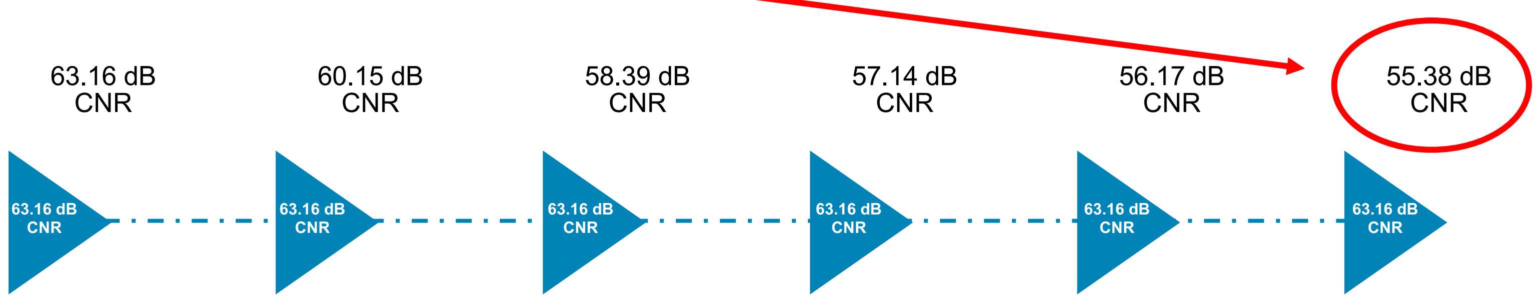
A cascade of identical amplifiers will have a CNR of

$$CNR_t = CNR_i - 10\log_{10}(N)$$

So a cascade of six identical amplifiers, each with 8 dB noise figure, +12 dBmV input, and a stand-alone CNR of 63.16 dB, will have an end-of-line CNR of

$$CNR_t = 63.16 - 10\log_{10}(6)$$

$$CNR_t = 55.38\ dB$$



Combining Like Carrier-to-Noise Ratios

A cascade of identical amplifiers will have a CNR of

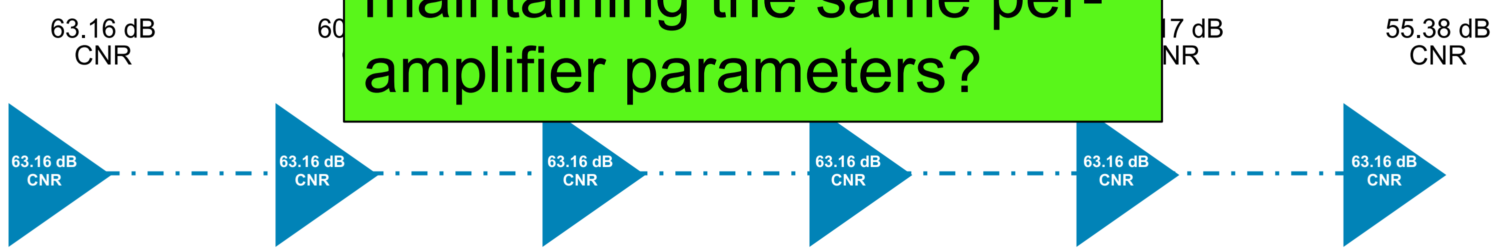
$CNR_t = CNR_i - 10log_{10}(N)$

So a cascade of six identical amplifiers, each with 8 dB
noise figure, + … alone CNR of
63.16 dB, will …

$CNR_t = 63.16$ …

$CNR_t = 55.38$ …

What happens to the end-of-line CNR if the cascade length doubles from six to 12 amplifiers, while maintaining the same per-amplifier parameters?

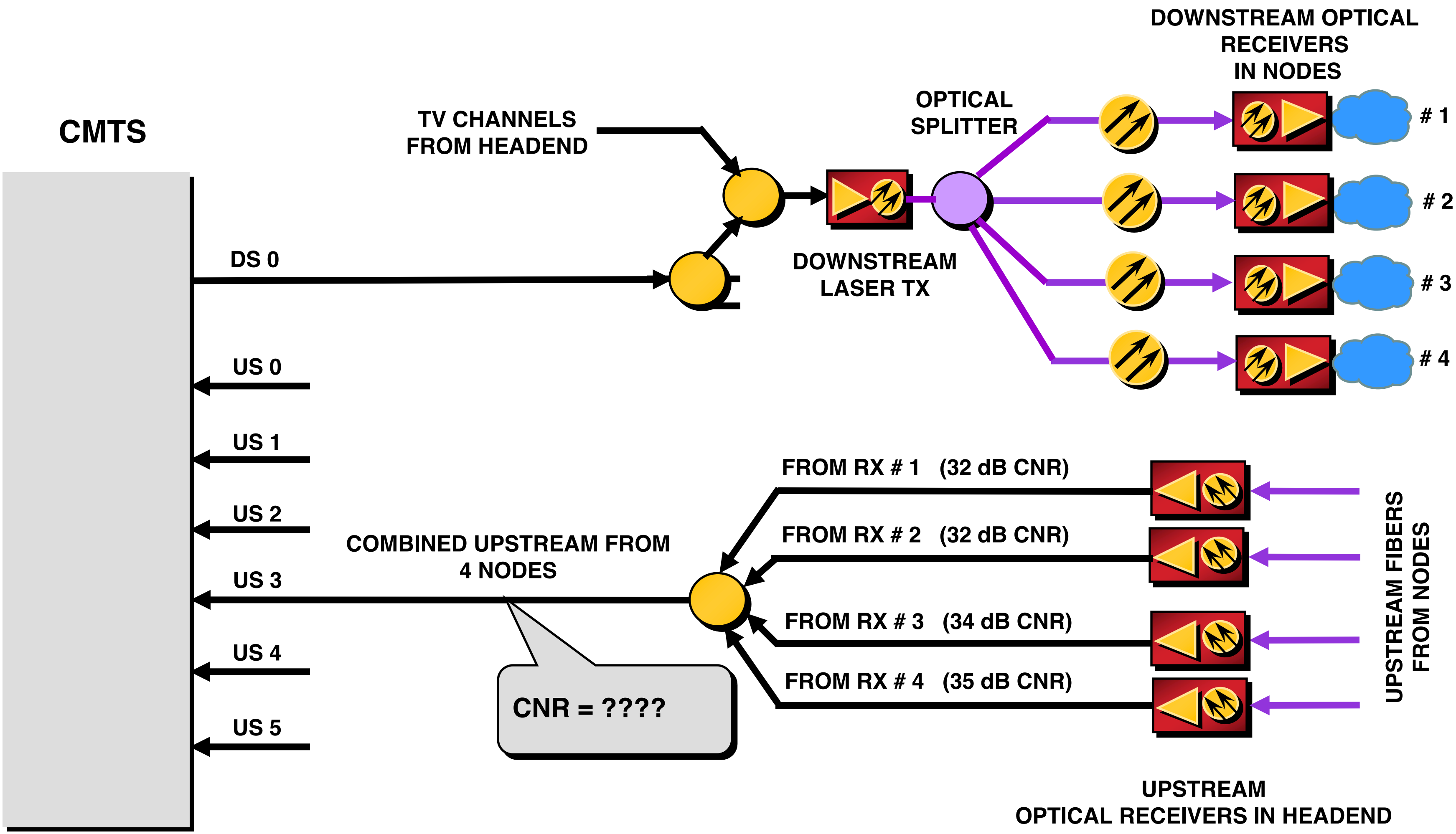


Combining Unlike Carrier-to-Noise Ratios

- To combine different carrier-to-noise ratios, use the formula

$$CNR_t = -10log_{10}\left(10^{\frac{-CNR_1}{10}} + 10^{\frac{-CNR_2}{10}} + \cdots 10^{\frac{-CNR_n}{10}}\right)$$

Carrier-to-Noise Ratio



Check the Math…

$$CNR_t = -10log_{10}(10^{\frac{-CNR_1}{10}} + 10^{\frac{-CNR_2}{10}} + \cdots 10^{\frac{-CNR_n}{10}})$$

$$CNR_t = -10log_{10}(10^{\frac{-32}{10}} + 10^{\frac{-32}{10}} + 10^{\frac{-34}{10}} + 10^{\frac{-35}{10}})$$

$CNR_t = -10 * \log_{10}(10^{-3.2} + 10^{-3.2} + 10^{-3.4} + 10^{-3.5})$

$CNR_t = -10 * \log_{10}(0.000631 + 0.000631 + 0.000398 + 0.000316)$

$CNR_t = -10 * \log_{10}(0.00198)$

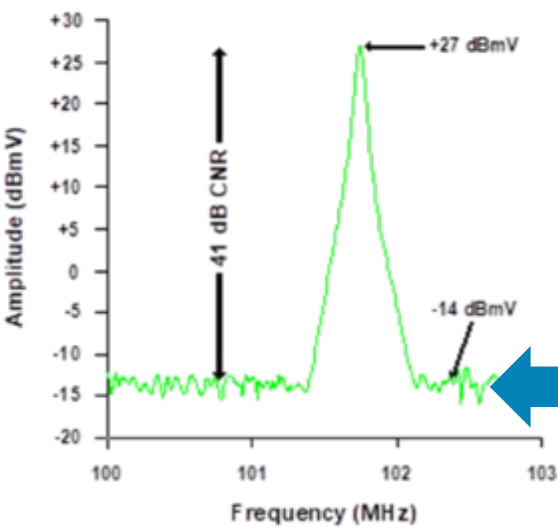
$CNR_t = -10 * (-2.70)$

$CNR_t = 27.04$ dB

Practical CNR Measurements

Carrier-to-noise ratio (CNR): The ratio of carrier or s... noise power in a specified bandwidth, as measure... r or similar equipment. Note that "noise" can also refe... as relative intensity noise, shot noise, etc., but does n... e.

Before measuring CNR, make sure the displayed noise floor is the system's noise, not the test equipment's noise.



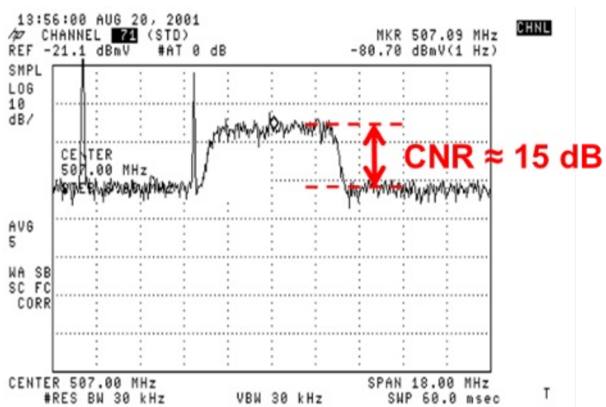
The noise floor measurement may have to be corrected to a specified bandwidth (e.g., 4 MHz for NTSC analog visual CNR measurements). For instance, if the spectrum analyzer's resolution bandwidth (RBW) is 300 kHz, the noise power correction for 4 MHz is

$$10\log_{10}(4{,}000{,}000/300{,}000) = 11.25 \text{ dB}$$

That is, 11.25 dB must be added to the 300 kHz RBW noise measurement. In this example, -14 dBmV + 11.25 dB = -2.75 dBmV, making the corrected CNR = 29.75 dB rather than the indicated 41 dB.

Practical CNR Measurements (cont’d)

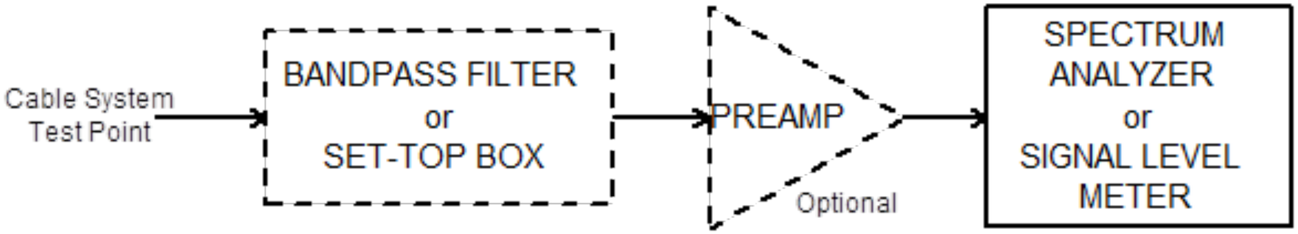
Carrier-to-noise ratio (CNR): The ratio of carrier or signal power to the thermal noise power in a specified bandwidth, as measured on an RF spectrum analyzer or similar equipment. Note that “noise” can also refer other types of noise, such as relative intensity noise, shot noise, etc., but does not refer to transient noise.



For SC-QAM CNR measurements, a noise floor correction is not necessary. (Just make sure the displayed noise is not test equipment noise.)

Practical CNR Measurements (cont'd)

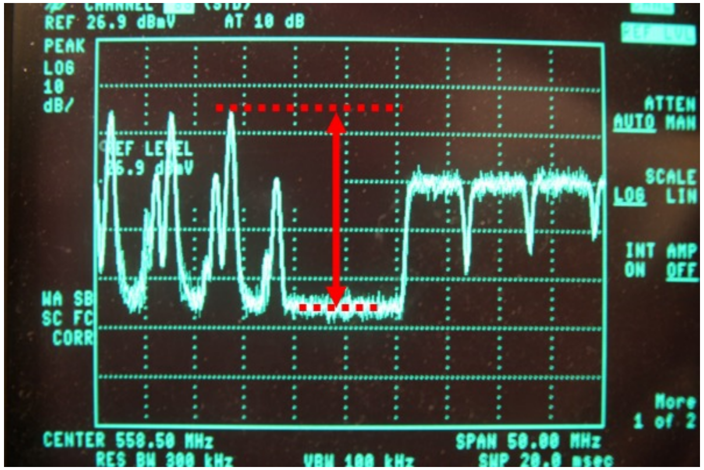
Note that in some instances it may necessary to use an external bandpass filter and possibly also a preamplifier when making some CNR measurements.

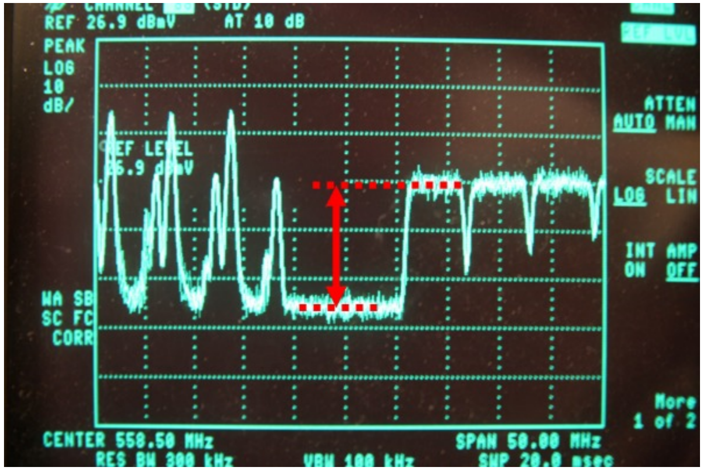


Practical CNR Measurements (cont’d)

- Remember the examples at the beginning of the presentation? Are the displayed CNRs accurate?

- The answer is no. Why? The displayed noise floor is that of the test equipment, not the system. In order to get an accurate noise floor measurement, one would have to find a hotter test point, or use a preamplifier (and maybe also a bandpass filter). Also, the noise floor for the analog TV channel CNR has not been corrected to 4 MHz.

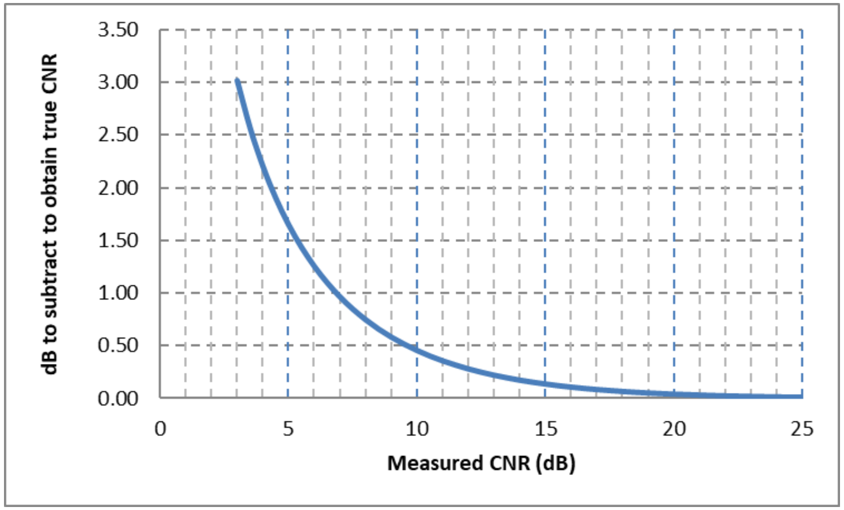




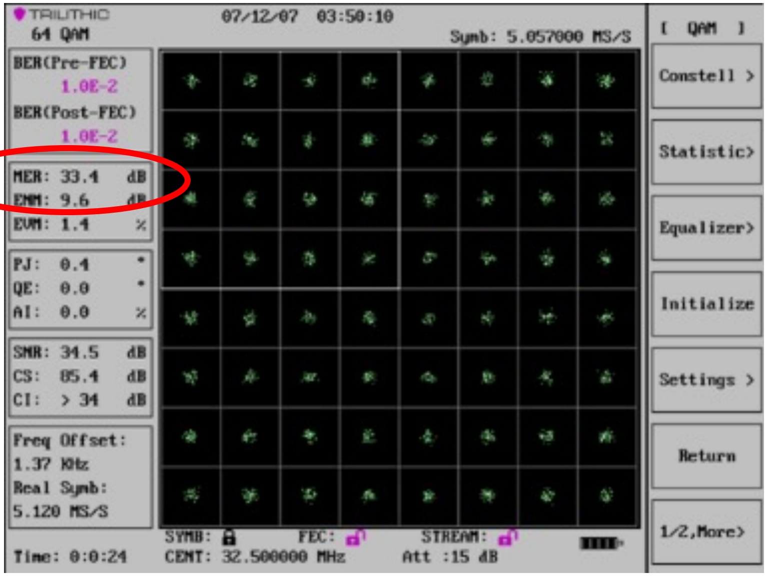
Practical CNR Measurements (cont'd)

- When a signal's amplitude is close to the level of noise surrounding it, the measured signal amplitude can appear too high by up to several dB. This is because the spectrum analyzer actually measures the amplitude of the signal plus the noise.

- For low-value CNR measurements, a "noise-near-noise" correction is necessary. For more on this, see Section 14.4 of *SCTE 270 2021r1 Mathematics of Cable*.



Are CNR and RxMER the Same Thing?



- The short answer is no. CNR is one of several parameters that contributes to the reported RxMER.
  - Other contributors to reported RxMER include transmitter and receiver phase noise; nonlinear distortions (CTB, CSO, CPD, etc.); linear distortions (micro-reflections, amplitude ripple/tilt, group delay distortion); in-channel ingress; laser clipping; and so on.
- RxMER can never be higher than CNR, and is usually at least a couple dB lower than the CNR.

Want to Learn More?

- ✓ For more, see Sections 12, 13 and 14 in the operational practice ***SCTE 270 2021r1 Mathematics of Cable***, which is available on SCTE's standards download page:

https://www.scte.org/standards/library/catalog/

- ✓ Another good resource is ***SCTE 183 2023 SCTE Measurement Recommended Practices For Cable Systems***, also available on SCTE's standards download page.