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Carrier-to-Noise Versus Signal-to-Noise

Ron Hranac

Abbreviations and Definitions

- **Carrier-to-noise ratio**

    C/N ratio or CNR

- **Signal-to-noise ratio**

    S/N ratio or SNR

- **In the world of telecommunications, “SNR” and “CNR” are often used interchangeably**
- **For this discussion, the ‘noise’ in CNR and SNR is assumed to be additive white Gaussian noise (AWGN)**

Abbreviations and Definitions

"The signal-to-noise ratio expresses in decibels the amount by which a signal level exceeds its corresponding noise"

***Telecommunications Transmission Handbook, 2nd Ed*., by Roger L. Freeman**

John Wiley & Sons, Inc., ©1981

Abbreviations and Definitions

"In the most general case, SNR is expressed as the ratio of rms (root mean square) signal level, S_{rms}, to the rms noise, N_{rms}, ($SNR = S_{rms}/N_{rms}$)"

Measuring Noise in Video Systems

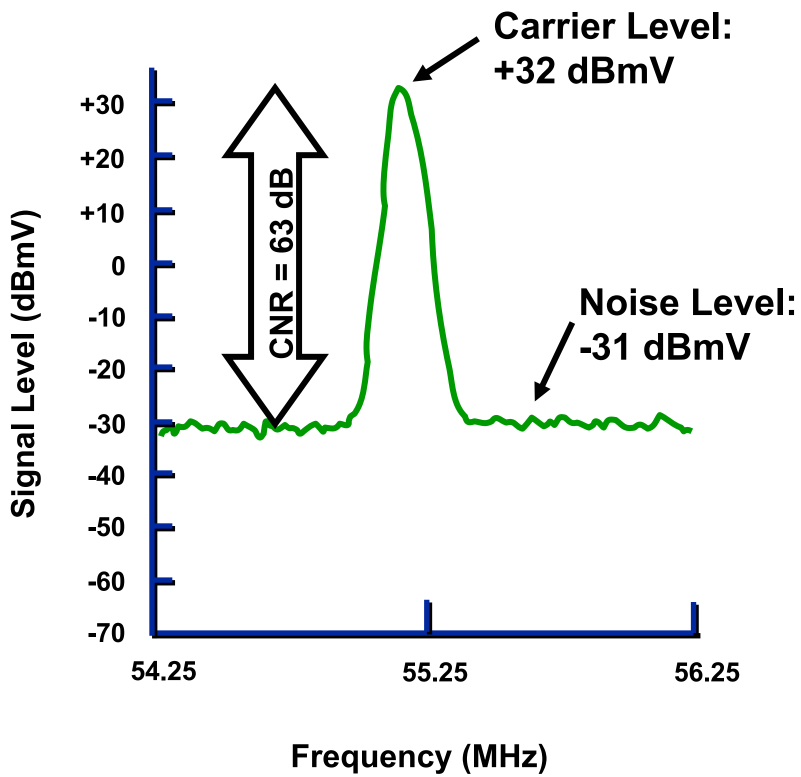
Tektronix Application Note 25W-11148-0, ©1997

Abbreviations and Definitions

- In the world of cable, we generally use CNR and SNR to represent quite different measurement parameters: one in the RF domain and the other in the baseband domain.
- Technically speaking, when measuring CNR or SNR against real thermal noise, one actually is measuring (C+N)/N or (S+N)/N.
  - Not normally an issue unless carrier-to-noise or signal-to-noise ratios are very low—say, single digit values

Carrier-to-Noise Ratio

- CNR is generally accepted to be a pre-detection measurement, that is, one made at RF
- From the perspective of analog TV channels, CNR is the difference, in decibels, between the amplitude of a TV channel's visual carrier and the rms amplitude of system noise in a specified bandwidth.



Carrier-to-Noise Ratio

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- **According to the FCC's cable rules in §76.609(e), system noise is the "total noise power present over a 4 MHz band centered within the cable television channel."**
  - **This definition is applicable only to National Television System Committee (NTSC) TV channel CNR measurements**
  - **Phase alternating line (PAL) TV channels use a slightly greater noise power bandwidth**

Carrier-to-Noise Ratio

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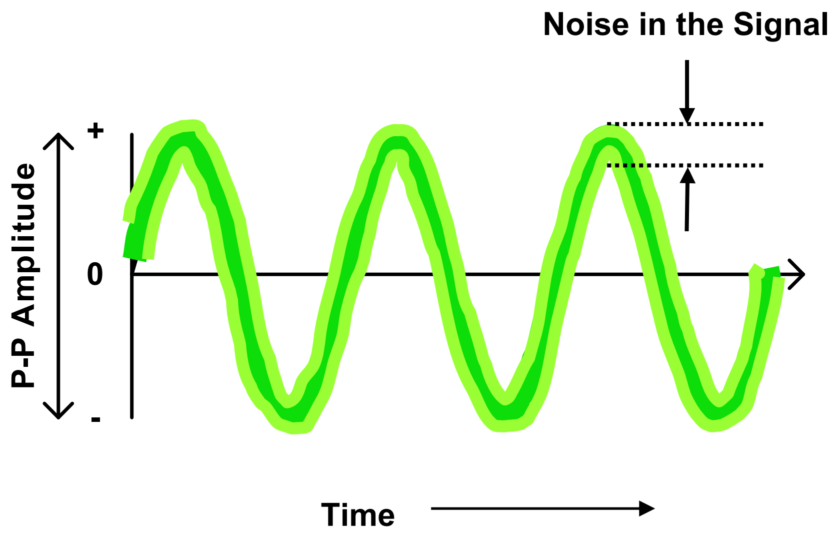
- **The FCC doesn't actually use the term CNR in the rules. §76.605(a)(7) states "The ratio of RF visual signal level to system noise shall…not be less than 43 decibels."**
- **That's in line with the generic definition of SNR, although most cable operators understand it to mean CNR**
- **Good engineering practice targets end-of-line analog TV channel CNR in the 45 to 49 dB range**

Signal-to-Noise Ratio

- **In cable industry vernacular, SNR is generally accepted to be a pre-modulation or post-detection measurement, that is, one made on a baseband signal such as video or audio.**



Signal-to-Noise Ratio

- **From the previously mentioned Tektronix Application Note: "In video applications, however, it is the effective power of the noise relative to the nominal luminance level that is the greater concern."**
- **The Application Note goes on to define video SNR in dB as $20\log(L_{nominal}/N_{rms})$, where $L_{nominal}$ has a value of 714 millivolts peak-to-peak (100 IRE) for NTSC or 700 mV p-p for PAL. These luminance values exclude sync.**

Signal-to-Noise Ratio

- **Translation: Baseband video SNR is the ratio of the peak-to-peak video signal, excluding sync, to the noise within that video signal.**

  The noise is measured in a specified bandwidth, usually defined by a combination of low pass, high pass and weighting filters.

  Those filters limit the measured noise to a bandwidth that is roughly the same as the video signal, and may be used to remove certain low frequency noise from the measurement.

  Weighting filters are used to simulate the eye's response to noise in the TV picture, and are based on standards such as RS-170A, RS-250B and NTC-7.

CNR vs. SNR Recap

- **CNR is a pre-detection measurement performed on RF signals**

  Raw carrier power to raw noise power in the RF transport path only—say, a coaxial cable distribution network or a standalone device such as a converter or headend hetrodyne processor

  Ideal for characterizing network impairments

- **SNR is a pre-modulation or post-detection measurement performed on baseband signals**

  Includes noise in original signal, transmitter or modulator, transport path, and receiver & demodulator

  Ideal for characterizing end-to-end performance—the overall signal quality seen by the end user

Digitally Modulated Carrier CNR

- DOCSIS specifies a minimum 35 dB CNR for downstream digitally modulated carriers, and 25 dB for upstream digitally modulated carriers
- Carrier amplitude is the digitally modulated carrier's average power level
- Noise power bandwidth is *not* 4 MHz!
- The correct noise power bandwidth is one that is equivalent to the digitally modulated carrier's symbol rate

  Symbol rate bandwidth **is numerically equal to the symbol rate—e.g., 1280 ksym/sec = 1.28 MHz**

CNR Noise Power Bandwidth

Downstream

Channel Bandwidth	Symbol Rate	Modulation Format	Noise Power Bandwidth
6 MHz	5.056941 Msym/sec	64-QAM	5.06 MHz
6 MHz	5.360537 Msym/sec	256-QAM	5.36 MHz
8 MHz	6.952 Msym/sec	64- or 256-QAM	6.95 MHz

CNR Noise Power Bandwidth

Upstream

Channel Bandwidth	Symbol Rate	Modulation Format	Noise Power Bandwidth
200 kHz	160 ksym/sec	QPSK or 16-QAM	0.16 MHz
400 kHz	320 ksym/sec	QPSK or 16-QAM	0.32 MHz
800 kHz	640 ksym/sec	QPSK or 16-QAM	0.64 MHz
1.6 MHz	1280 ksym/sec	QPSK or 16-QAM	1.28 MHz
3.2 MHz	2560 ksym/sec	QPSK or 16-QAM	2.56 MHz
6.4 MHz	5.12 Msym/sec	64-QAM or 128-QAM TCM	5.12 MHz

Digitally Modulated Carrier CNR vs. BER

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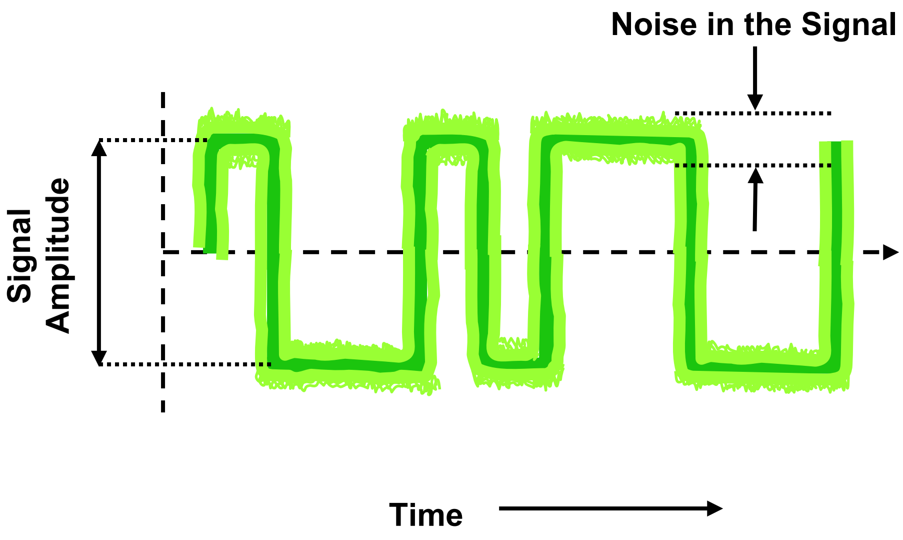
Modulation format	1.0E-04 BER	1.0E-06 BER	1.0E-08 BER	1.0E-10 BER	1.0E-12 BER
ASK & FSK	7 dB	9 dB	10 dB	11 dB	12 dB
BPSK	9 dB	11 dB	12 dB	13 dB	14 dB
QPSK	12 dB	14 dB	15 dB	16 dB	17 dB
16-QAM	19 dB	21 dB	22 dB	23 dB	24 dB
32-QAM	21 dB	23 dB	24 dB	25 dB	26 dB
64-QAM	25 dB	27 dB	28 dB	29 dB	30 dB
256-QAM	32 dB	34 dB	35 dB	36 dB	37 dB

Digitally Modulated Carrier SNR

- **If one assumes that SNR is a baseband measurement, there really is no easy way to measure baseband data SNR**



Digitally Modulated Carrier SNR

- **A better parameter is modulation error ratio (MER) or error vector magnitude (EVM)**

  MER and EVM take into account the combined effects of CNR; transmitter, upconverter or CMTS phase noise; impairments such as second and third order distortions; group delay; in-channel frequency response problems (amplitude tilt or ripple) and microreflections.

Why Measure MER?

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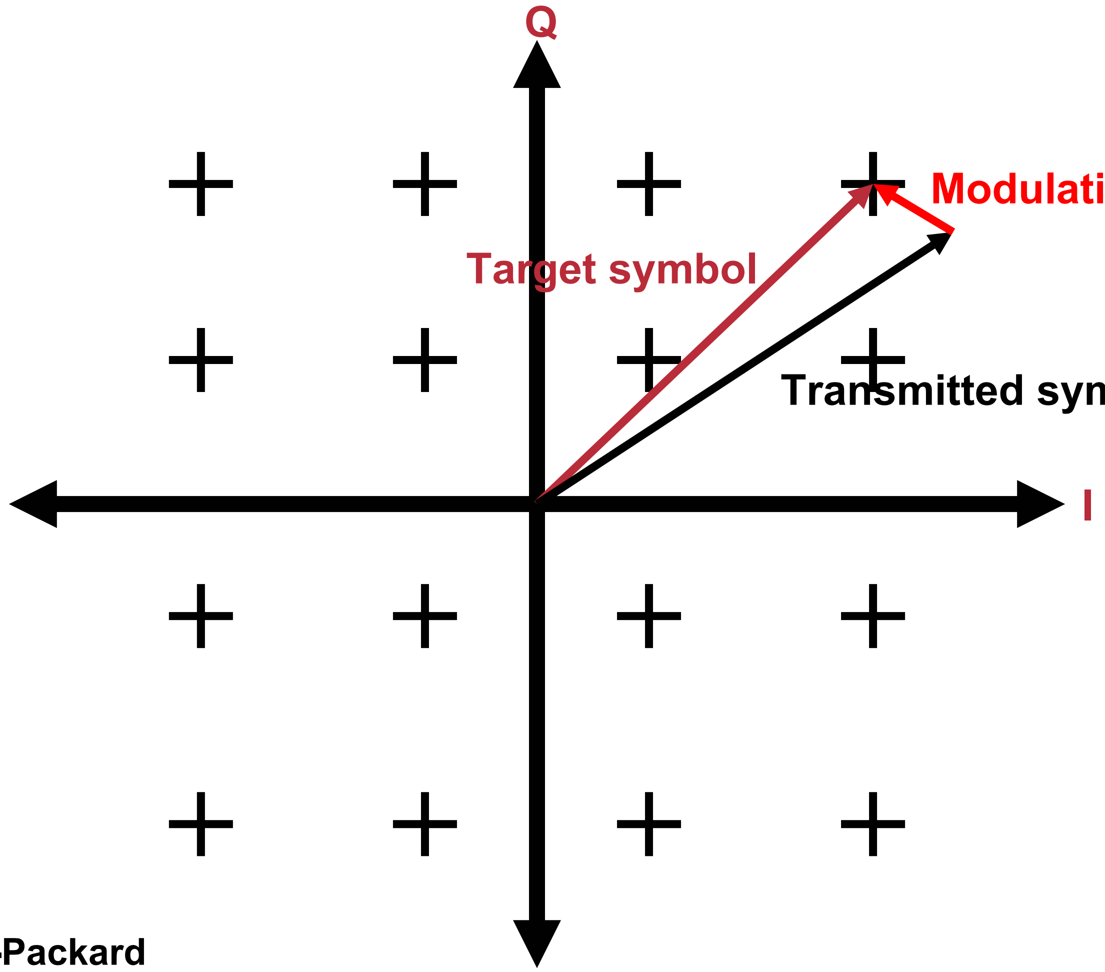
- Somewhat analogous to in-channel signal-to-noise ratio ("MER" and "SNR" are often used interchangeably)
- Direct measure of modulation quality
- Direct linkage to BER
- Can be used in conjunction with adjacent channel power to estimate linear distortions
- Good metric for end-to-end health of a network, but provides little insight about the *type* of impairment

Source: Hewlett-Packard

Modulation Error Ratio: Modulation Quality

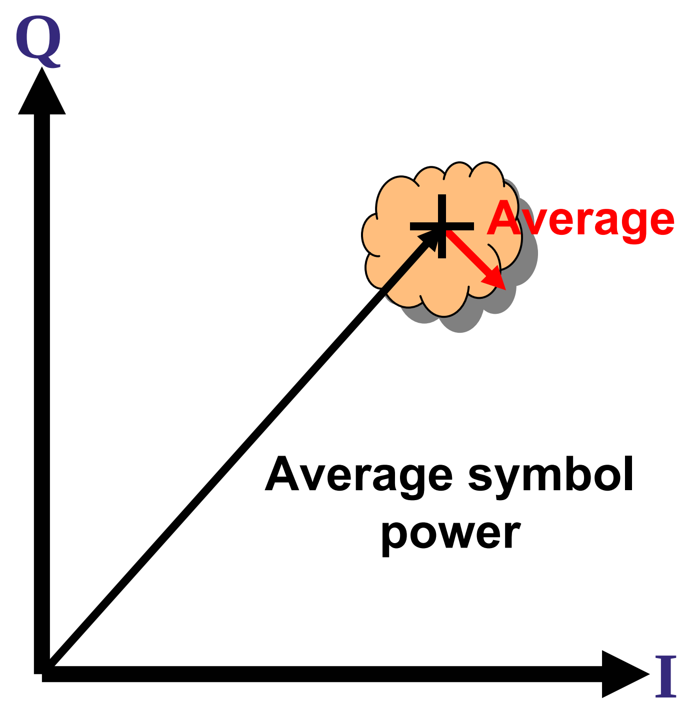
Modulation error = Transmitted symbol – Target symbol



Source: Hewlett-Packard

Modulation Error Ratio

MER = 10log(average symbol power/average error power)



Source: Hewlett-Packard

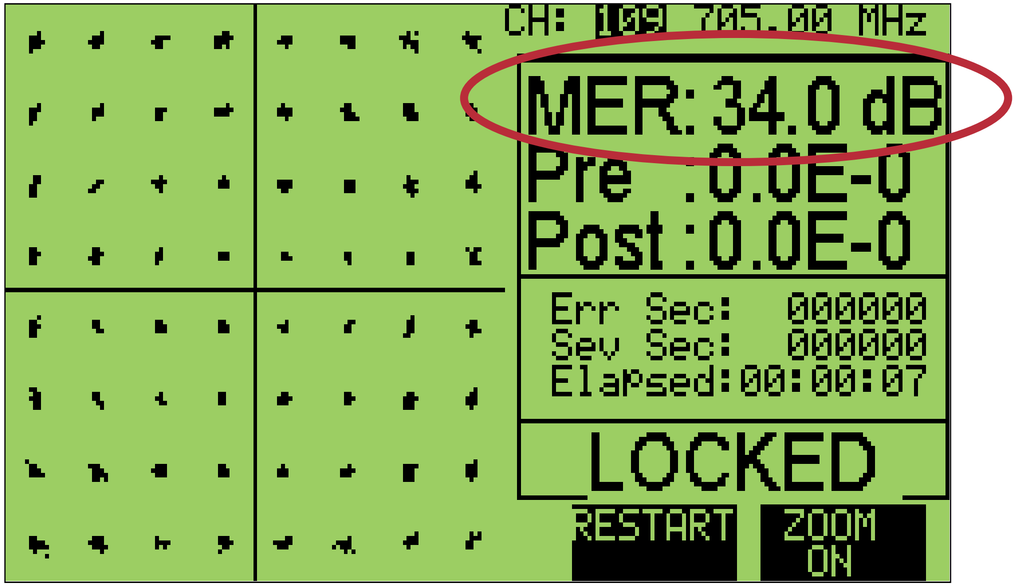
Modulation Error Ratio

- **Minimum recommended downstream MER (includes 3 to 4 dB of headroom for reliable operation)**

  64-QAM: 27 dB

  256-QAM: 31 dB

- **Typical headend and node downstream MER should be 34 to 36 dB or greater**

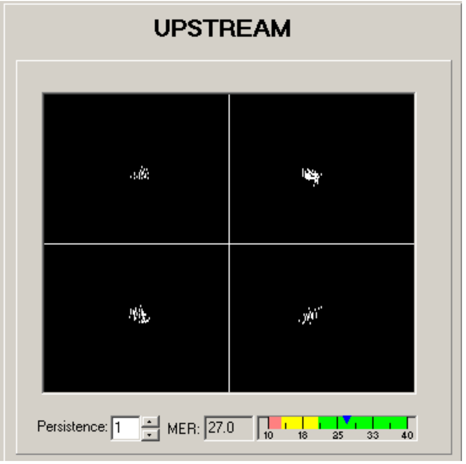


Graphic courtesy of Sunrise Telecom

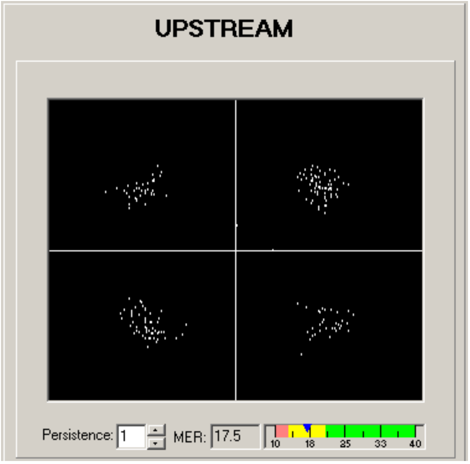
Modulation Error Ratio

- **QPSK typically requires a minimum MER of 10~13 dB, depending on CMTS make/model**
- **Noise appears random**
- **CW produces “donut” shape**

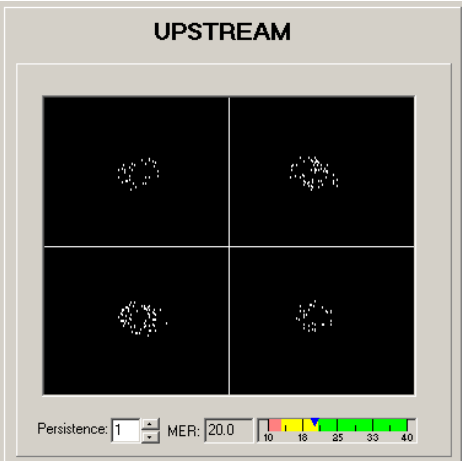
Ideal



Noise



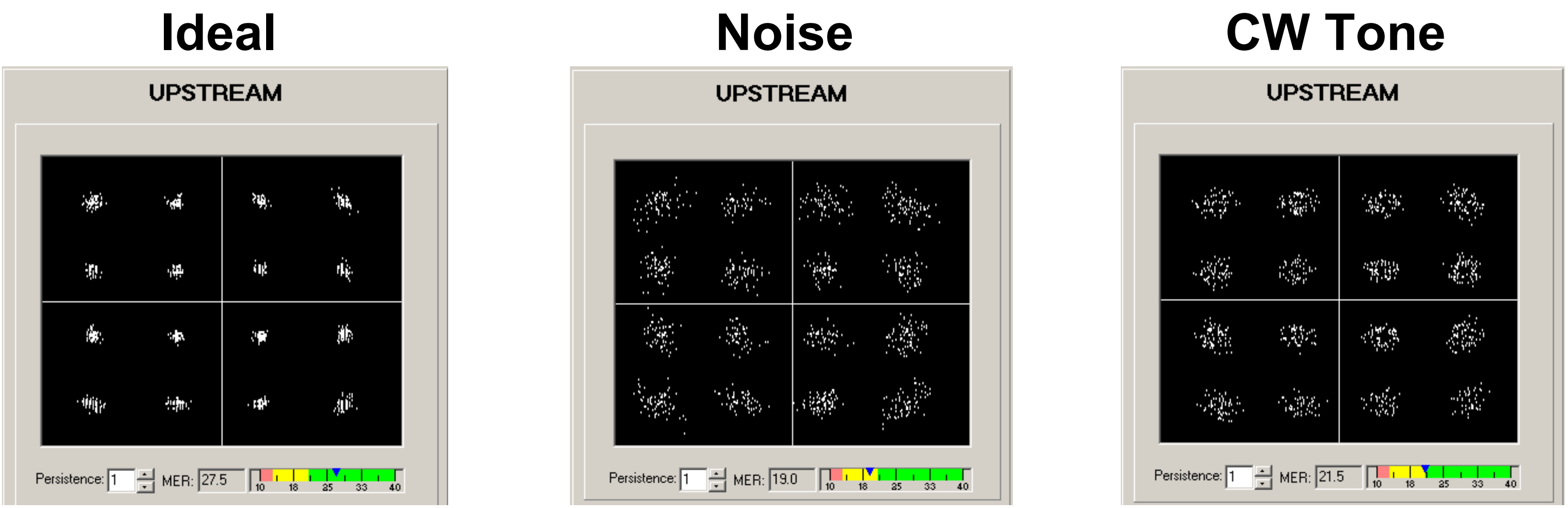
CW Tone



Courtesy of Filtronic Sigtek, Inc.

Modulation Error Ratio

- 16-QAM typically requires a minimum MER of 17~20 dB, depending on CMTS make/model
- Noise appears random
- CW produces “donut” shape



Courtesy of Filtronic Sigtek, Inc.

Why Measure EVM?

- Many engineers are familiar with EVM
- More comfort with a linear measurement
- Links directly with the constellation display
- Linear relationship between EVM and constellation “cloud” size
- No direct link between EVM and BER

Source: Hewlett-Packard

Error Vector Magnitude: Modulation Quality

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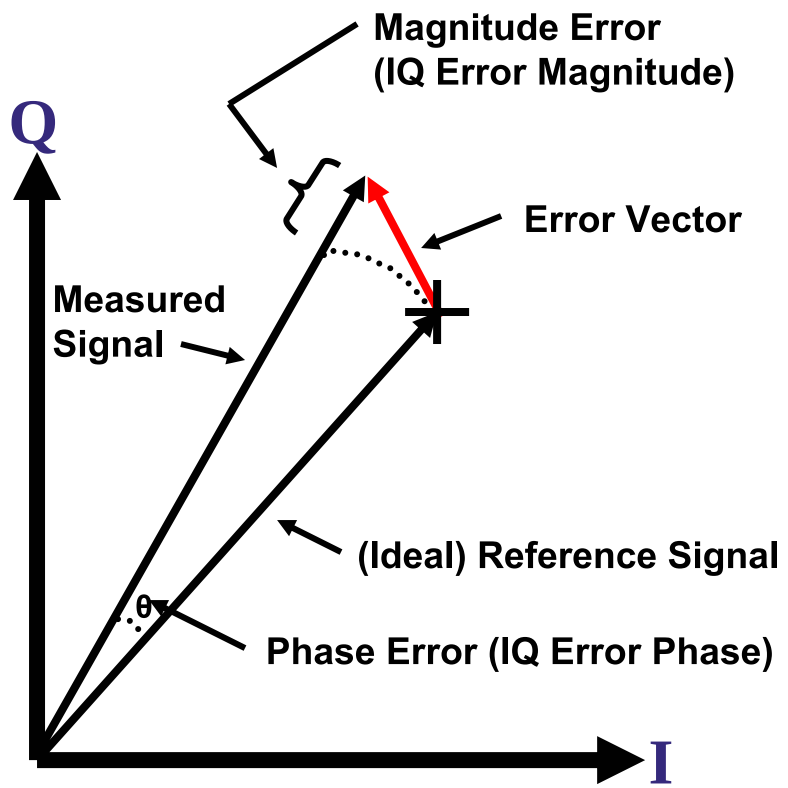
Error Vector Concept

EVM: The magnitude of the vector drawn between the ideal (reference) state position and the measured state position.

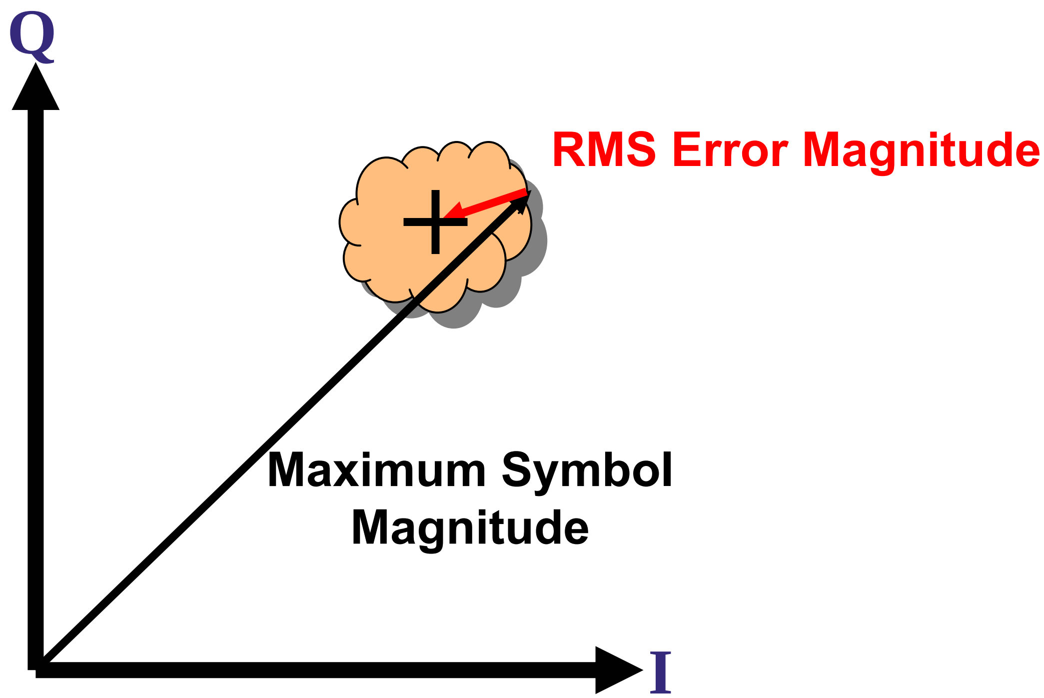


Source: Hewlett-Packard

Error Vector Magnitude

EVM = (RMS error magnitude/maximum symbol magnitude) x 100%

By convention, EVM is reported as a percentage of peak signal level, usually defined by the constellation's corner states

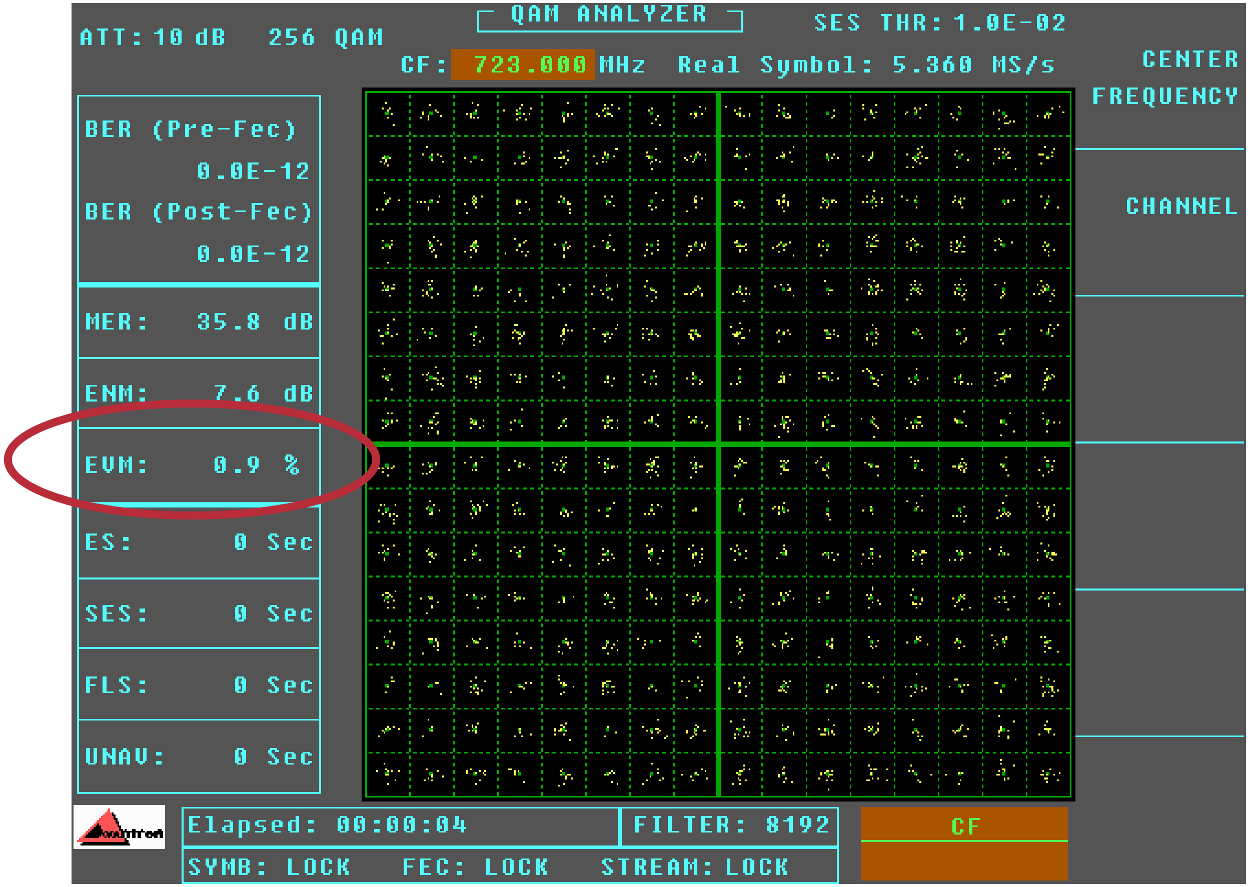


Source: Hewlett-Packard

Error Vector Magnitude

- Some QAM analyzers measure downstream EVM

- Upstream EVM usually must be measured with a vector signal analyzer



Graphic courtesy of Sunrise Telecom

What About CMTS Upstream SNR?

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- Broadcom 3137 burst demodulator chip used in most CMTSs can provide upstream SNR estimate
- CMTS SNR estimate is *NOT* the same thing as CNR that one would measure with a spectrum analyzer or similar test equipment
- SNR estimate is more like MER or EVM

    Group delay, microreflections, poor in-channel frequency response and similar impairments will degrade SNR estimate, even though CNR appears fine

- Good tool for tracking average long-term trends

What About CMTS Upstream SNR?

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- **Because of differences in the algorithms for CMTS-reported SNR versus a spectrum analyzer CNR measurement, there can be differences between the two values—especially if the CNR is extremely low or high. However, for the range of 15~25 dB CNR, where AWGN is the primary noise impairment, the two measurements should agree to within less than 2 dB.**

What About CMTS Upstream SNR?

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- Impulse noise and certain other fast transient impairments generally will not show up in CMTS SNR estimate
- CMTS-reported SNR is a post-detection measurement. Anything that impairs proper demodulation (collisions, high burst/impulse noise, improper modem operation) or deficiencies in the data base (changes during the measurement process, blending of combined node performance) can skew reported SNR values.

What About CMTS Upstream SNR?

- Other factors that may degrade CMTS-reported SNR, even when CNR is good, include improper modulation profiles, bad timing errors, and poor headend combiner/splitter isolation
- CMTS-reported SNR will always be less than—or at best equal to—CNR, but should never be better than CNR

Summary

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- **CNR is a measure of pre-detection signal quality**
- **CNR is ideal for characterizing performance of the *cable network***
- **SNR, MER and EVM are measures of post-detection signal quality**
- **SNR is a useful metric with which to quantify a baseband signal—say, the video quality seen on a TV set**
- **SNR, MER and EVM—along with bit error rate—are ideal for characterizing the health of a *digital signal***

References

- Hranac R., "CNR versus SNR" March 2003 *Communications Technology*
- Hranac R., "Spectrum analyzer CNR versus CMTS SNR" September 2003 *Communications Technology*
- *Telecommunications Transmission Handbook, 2nd Ed*., by Roger L. Freeman, John Wiley & Sons, Inc., ©1981
- *Measuring Noise in Video Systems,* Tektronix Application Note 25W-11148-0, ©1997
- Agilent Product Note 89400-8: *Using Vector Modulation Analysis in the Integration, Troubleshooting, and Design of Digital RF Communications Systems* (Application Note 5091-8687E)
- Agilent Product Note 89400-14: *Using Error Vector Magnitude Measurements to Analyze and Troubleshoot Vector-Modulated Signals* (Application Note 5965-2898E)

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