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## What are Embedded - System On Chip (SoC)?

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| **Details** | |
|---|---|
| Product Status | Obsolete |
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| Connectivity | - |
| Speed | - |
| Primary Attributes | - |
| Operating Temperature | - |
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# Introduction

Cable modem termination systems (CMTSs) can report a variety of operating parameters to the end user. For example, CMTSs that use Broadcom® BCM3137, BCM3138, or BCM3140 or Texas Instruments® TNETC4522 series upstream burst receivers can provide an "upstream SNR" estimate. This function is a very useful tool, but it has resulted in much confusion. It is not unusual for a cable company's network operations center (NOC) staff to report an alarm condition when the reported upstream signal-to-noise ratio (SNR) of the CMTS drops below a defined threshold. A headend technician follows up by checking the upstream RF performance with a spectrum analyzer or similar test equipment, only to find that everything appears normal.

Data personnel in the NOC insist there must be a problem, while outside plant technicians see nothing amiss on their test equipment. What is going on here?

The discrepancy occurs from a lack of understanding about just what the CMTS upstream SNR estimate is—and what it is not.

Further confusion comes from the fact that cable modems and digital set-top boxes (STBs) can provide digitally modulated signal operating parameters such as RF signal level and SNR. These are downstream parameters at the customer premises, not upstream parameters as is sometimes incorrectly assumed. In addition, test equipment used by cable operators to characterize digitally modulated signals can measure downstream—and in some cases upstream—modulation error ratio (MER). Some of these instruments call this parameter SNR.

Also, because of the time-shared nature of the upstream, most of today's CMTSs can measure parameters on a per-*channel* basis or a per-*cable-modem* basis. Per-channel measurements provide an average of all cable modems or simply a snapshot of the most recently active cable modem(s). It is important to distinguish which type of measurement is presented.

This paper provides a background on several signal quality metrics applicable to CMTS and cable network operation and how they relate to overall performance. The CMTS upstream SNR and cable modem or STB downstream SNR estimates are explained. Noise, as discussed in this paper and unless defined otherwise, refers to *additive white Gaussian noise* (AWGN), or simply *white noise*, also known as thermal noise. Interference such as narrowband ingress and burst or impulse noise is usually treated separately.

First, what the CMTS upstream SNR estimate is not: the SNR estimate from a cable modem or CMTS is *not* the same thing as the carrier-to-noise ratio (CNR) that one measures with a spectrum analyzer.

Here is what the upstream SNR estimate is: an operating parameter provided by the upstream burst receiver used in DOCSIS® CMTSs. Similar information for downstream signals is provided by the quadrature amplitude modulation (QAM) receiver in a cable modem or STB. The SNR estimate, which is derived after the data is demodulated, is more accurately called receive modulation error ratio (RxMER), a term recently defined in the DOCSIS MIB. RxMER includes the effects of the cable network downstream or upstream noise floor, in-channel frequency response (including amplitude tilt and ripple, group delay variation, and micro-reflections), oscillator phase noise, receiver imperfections, and all other impairments that affect the receive symbol constellation. Because it measures the end-to-end performance of the communications link, RxMER is useful for tracking long-term system performance trends.

Interestingly, it is not unusual to have a reported low downstream or upstream RxMER number, yet find the measured CNR and signal levels to be just fine. Why? Because one or more impairments that cannot be seen on a spectrum analyzer—poor in-channel frequency response, including group delay variation and micro-reflections, and even upstream data collisions—may be the cause of the low reported RxMER.

This paper discusses the terms listed in Table 1.

**Table 1: Terminology for Various SNR Ratio Concepts**

| Abbreviation | Term | Definition | Units |
|---|---|---|---|
| CNR (or C/N) | Carrier-to-noise ratio | The ratio of carrier or signal power to the white-noise power in a specified bandwidth, as measured on an RF spectrum analyzer or similar equipment. | dB |
| $C/N_0$ | Carrier-to-noise - density ratio | The ratio of carrier or signal power to white-noise spectral density. | dB-Hz |
| CNIR (or C/(N+I)) | Carrier-to-noise-plus-interference ratio | The ratio of carrier or signal power to the total noise power (including white noise and interference) in a specified bandwidth, as measured on an RF spectrum analyzer or similar equipment. | dB |
| $E_S/N_0$ | Energy-per-symbol to noise-density ratio | In digital modulation, the ratio of the average energy of a QAM symbol to the white-noise spectral density. | dB |
| EVM | Error vector magnitude | The ratio of RMS constellation error magnitude to peak constellation symbol magnitude. | Percent |
| MER | Modulation error ratio | The ratio of average signal constellation power to average constellation error power. | dB |
| RxMER | Receive modulation error ratio | The MER as measured in a digital receiver after demodulation, with or without adaptive equalization. | dB |
| SNR (or S/N) | Signal-to-noise ratio | (a) A general measurement of the ratio of signal power to noise power.<br>(b) In a specific context, a measurement of the ratio of signal power to noise power made at baseband before modulation or after detection or demodulation. | dB |
| TxMER | Transmit modulation error ratio | The MER produced by a transmitter under test, as measured by an ideal test receiver. | dB |

## CNR and SNR from a Telecommunications Industry Perspective

Some of the confusion mentioned in the introduction arises from the fact that in the world of telecommunications outside the cable industry, the terms SNR and CNR are often used interchangeably. According to Roger L. Freeman's *Telecommunications Transmission Handbook*, "The signal-to-noise ratio expresses in decibels the amount by which a signal level exceeds its corresponding noise." Another reference, Tektronix's *Measuring Noise in Video Systems*, says "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 = $S_{RMS}/N_{RMS}$)." [Eq. 1]

Both of the previous SNR definitions can easily be applied to RF CNR measurements (after all, a carrier is a “signal”) as well as baseband SNR measurements (baseband video and audio are “signals,” too). If the specific measurement is not clearly defined, it is difficult to know whether SNR refers to a baseband or RF parameter. This paper distinguishes between SNR and CNR. In the subsequent sections, each term is defined and explained, and the distinction is illustrated following usage in the cable industry.

## CNR and SNR from a Cable Industry Perspective

*Modern Cable Television Technology, 2nd Ed.*, states, “Carrier-to-noise ratio (*C/N*) is defined as follows:

$$C/N(\text{dB}) \equiv 10\log(c/n) \qquad \text{[Eq. 2]}$$

where *c* and *n* are the scalar power levels of the carrier and noise, respectively.”[1]

When measuring CNR on a spectrum analyzer with thermal noise underlying the carrier, one actually is measuring not C/N but, more precisely, (C + N)/N = 1 + C/N. This distinction is not normally a concern unless the CNR is very low—say, single-digit decibel (dB) values, as we will see later.[2]

The cable industry has long used CNR and SNR to represent quite different measurement parameters, one in the RF domain (Figure 1) and the other in the baseband domain (Figure 2 on page 5). CNR is applied to the transmitted over-the-cable RF waveform, whereas SNR refers to the video and audio signal prior to modulation for broadcast, or after demodulation of the RF waveform at the receiver.

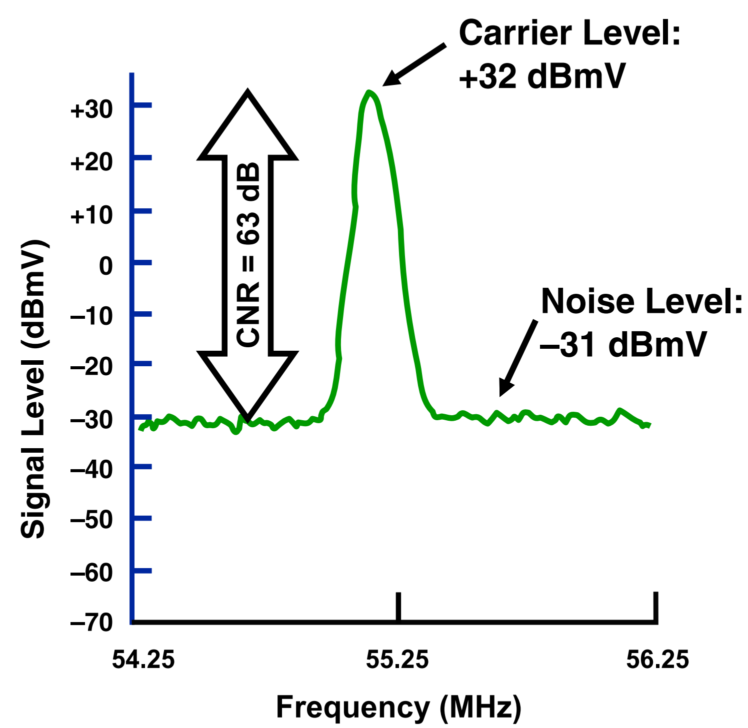



**Figure 1: RF CNR Measurement (As Detected in the Test Equipment Resolution Bandwidth)**

1. In this paper, all logarithms are base 10.
2. The expression 1 + C/N uses power quantities, not dB; that is, we are not adding 1 dB to C/N.

In decibels, $C/N_0$ is expressed in dB-Hz, which means "decibels referenced to one Hz." Because $C/N_0$ is not unitless like other SNR and CNR metrics, care must be taken to reference the noise measurement to a 1 Hz noise bandwidth.

$C/N_0$ is especially useful for measuring the CNR of a narrowband signal such as an unmodulated or continuous wave (CW) carrier. Consider a spectrum analyzer capture of a CW signal in a white-noise background, with the analyzer RBW set to 100 kHz. Assume that placing the analyzer marker on the CW signal indicates an amplitude of –10 dBmV, and moving the marker to the displayed noise floor shows –40 dBmV. Be careful—this noise reading is *not* in dBmV/Hz, but represents the noise power in the analyzer RBW as mentioned previously, giving a spectral density of –40 dBmV/(100 kHz). To convert to a 1 Hz bandwidth, subtract 10log(100,000 Hz) = 50 dB-Hz. So the noise density is actually –40 dBmV – 50 dB-Hz = –90 dBmV/Hz. Some spectrum analyzers have a marker noise function that provides automatic readings in a 1 Hz bandwidth, eliminating the need for this conversion. The true $C/N_0$ is then (using dB quantities):

$$\begin{aligned} C/N_0 &= \text{Signal} - \text{Noise} + \text{RBW} \\ &= -10\ \text{dBmV} - (-40\ \text{dBmV}) + 50\ \text{dB-Hz} \\ &= 80\ \text{dB-Hz} \end{aligned} \qquad \text{[Eq. 5]}$$

To convert $C/N_0$ to CNR in a given bandwidth B, we use

$$\text{CNR} = C/N = C/(N_0 B) \qquad \text{[Eq. 6]}$$

So in decibels, to convert $C/N_0$ to CNR, subtract 10log(B). The CW signal in this example would have a CNR in a 6 MHz bandwidth (using decibel quantities) of:

$$\begin{aligned} \text{CNR} &= C/N_0 - 10\log(B) \\ &= 80\ \text{dB-Hz} - 10\log(6\ \text{MHz}) \\ &= 80\ \text{dB-Hz} - 67.8\ \text{dB-Hz} \\ &= 12.2\ \text{dB} \end{aligned} \qquad \text{[Eq. 7]}$$

This example illustrates an important principle when measuring a mix of discrete signals (CW or any signals that are much narrower than the RBW of the analyzer) and spread signals (such as noise or modulated signals that are much wider than the analyzer RBW). The spectrum analyzer marker simply measures power in the RBW. For a narrowband signal, this measurement equals the carrier power. For noise, it gives the density referenced to the RBW. Scale to a 1 Hz bandwidth to get $C/N_0$, and scale to a desired bandwidth B to get CNR.

## Digitally Modulated Signal CNR

What about CNR measurement of digitally modulated signals on a cable plant? The DOCSIS *Radio Frequency Interface Specification* states an assumed minimum 35 dB CNR for downstream digitally modulated signals. If the network analog TV channel CNR is maintained in the 46 dB or higher range, in most cases, there will be little or no problem complying with the DOCSIS assumed minimum for downstream digitally modulated signals. The DOCSIS assumed minimum upstream CNR for digitally modulated signals is 25 dB. Carrier power—the "C" in CNR—is the average power level of the digitally modulated signal, often called digital channel power. It is measured in the full occupied bandwidth of the signal; for example, 6 MHz for a North American DOCSIS downstream signal.

## QAM Spectrum Basics

Consider what a QAM signal spectrum looks like, and how we can read the signal power, noise power, and CNR from the spectrum display.

First, some background on transmit and receive filters. Figure 3 shows a communications system, which represents an upstream or downstream cable data network. Both the transmitter and receiver contain "matched filters." The purpose of the transmit matched filter is to band-limit the transmitted spectrum so that it will not interfere with adjacent channels. The purpose of the receive matched filter is to select the desired channel and to reject noise. The "matched" property of the filters implies that they have identical frequency magnitude response $|H_1(f)|$. [Eq. 10]

A time-invariant system such as a filter can be characterized by its impulse response $h(t)$ or by its frequency response $H(f)$, which comprise a Fourier transform pair. The asterisk on the receive filter in Figure 3 indicates that the receive matched filter exhibits complex conjugation of its frequency response, or equivalently, time reversal of its impulse response, relative to the transmit filter. However, this property is not of practical importance in cable systems because the filters are time-symmetric.

Matched filtering is known to maximize receive SNR in the presence of white noise. The cascade of the two matched filters gives the "full" magnitude response $|H(f)| = |H_1(f)||H_1(f)| = |H_1(f)|^2$. A signal having this full magnitude response is seen only at the output of the receive matched filter, inside of the receiver, and is not normally visible to an outside observer. However, the full-filter response is important in that it is designed to have the Nyquist property, described in the next section.

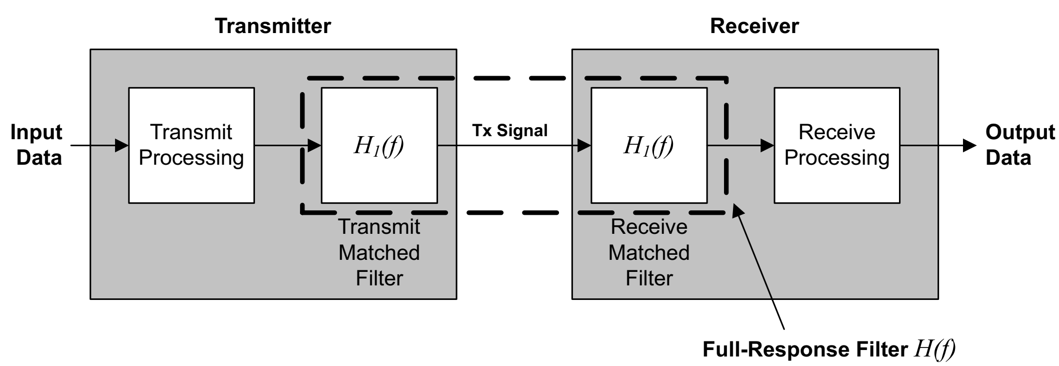



**Figure 3: General Digital Communications System Showing Matched Filters in Transmitter and Receiver**

The signal marked "Tx Signal" in Figure 3 represents the actual transmitted signal that is observable on the cable plant. (We are neglecting upconversion and downconversion to/from RF and are dealing only with "complex envelopes" in this discussion.) Because the scrambler guarantees that the QAM symbols affecting the transmit filter are white,[4] the transmitted spectrum is given its shape by the transmit filter, and its power spectrum, or power spectral density (PSD), is $|H_1(f)|^2$. Note an interesting "cascading property": The full magnitude response of the cascaded transmit and receive filters, and the PSD of the transmitted signal are both $|H_1(f)|^2$. In the former case, the squaring of the magnitude response comes

4. A "white" spectrum is one that is flat, which means it has a constant magnitude across all frequencies. This constant magnitude corresponds to statistically uncorrelated samples in the time domain.

## Practical QAM CNR Measurements

Figure 6 shows an example of measuring downstream digitally modulated signal CNR and $E_S/N_0$ using a spectrum analyzer marker noise function, which measures noise power in a 1 Hz bandwidth. The carrier is centered on the screen, and the marker noise function is activated. Make a note of the indicated marker noise amplitude of the digitally modulated signal (–80.70 dBmV in the left display), and then tune the analyzer to a frequency that allows measurement of the noise floor of the cable network. The right display shows a noise-floor amplitude of –95.82 dBmV. The difference between the two measurements is the approximate CNR and $E_S/N_0$, in this case about 15 dB.

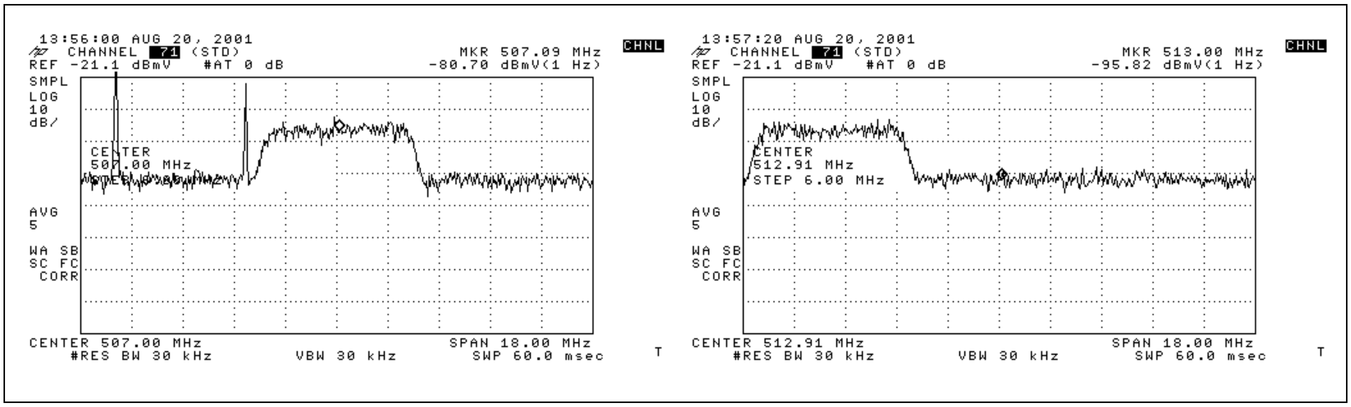



**Figure 6: Digitally Modulated Signal CNR (This Example Shows an Approximate CNR of 15 dB.)**

For best accuracy, noise should be measured using sample detection, which is typically employed by a spectrum analyzer marker noise function. Marker noise measurements usually encompass a range of frequency samples, starting from the marker and going plus or minus a small number of points out of the total available in the analyzer trace, so proper placement of the marker away from the carrier is important for accuracy. Refer to the analyzer documentation.

## Signal and Noise Measurements on a Spectrum Analyzer

A few practical tips are worth noting when measuring modulated signals and noise on a spectrum analyzer.[6]

- Ensure that the spectrum analyzer uses sample detection when measuring noise or noise-like signals. If log/peak detection is used, a detector correction factor (typically 2.5 dB—consult the spectrum analyzer documentation) needs to be applied to the measurement result. Of course, if the signal and noise have the same statistics (Gaussian or nearly so), the same correction factor will be added to both the signal and noise measurements, and the correction will cancel out when measuring the CNR.

6. For a thorough treatment of this subject, refer to Agilent Application Note 1303, “Spectrum Analyzer Measurements and Noise: Measuring Noise and Noise-like Digital Communications Signals with a Spectrum Analyzer.”

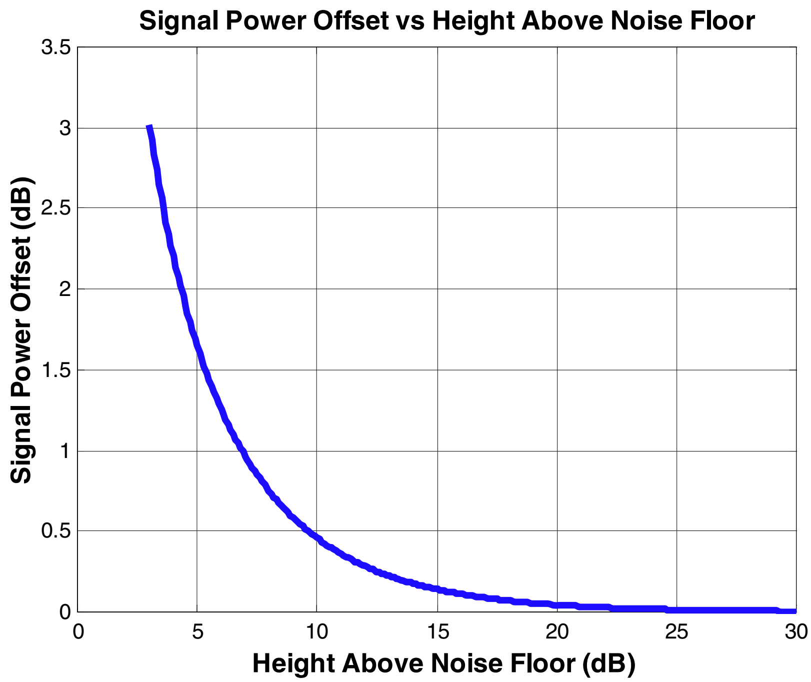



**Figure 8: Signal Power Measurement Correction Relative to Noise Floor**

Returning to the example in Figure 7, the height of the haystack above the noise as seen on the spectrum analyzer will be:

$$\begin{aligned} \text{haystack\_height\_dB} &= 10\log(1 + 10^{\text{true\_CNR\_dB}/10}) \\ &= 10\log(1 + 10^{4/10}) \\ &= 5.45 \text{ dB} \end{aligned} \quad \text{[Eq. 17]}$$

and, reversing [Eq. 17], the true CNR follows:

$$\begin{aligned} \text{true\_CNR\_dB} &= 10\log(10^{\text{haystack\_height\_dB}/10} - 1) \\ &= 10\log(10^{5.45/10} - 1) \\ &= 4 \text{ dB} \end{aligned} \quad \text{[Eq. 18]}$$

In summary: In the example in Figure 7, measuring a signal with a very low CNR of 4 dB requires subtracting 1.5 dB from the haystack-height CNR reading in order to back out the noise underlying the signal. To measure the CNR of normal QAM signals with CNR greater than about 15 dB, such a correction is not necessary. For measurement of system noise power that is less than 10 dB above the spectrum analyzer noise floor, a correction from Figure 8 is required to back out the analyzer noise-floor contribution.

## CNR at the CMTS Upstream Input Port

In most cases, the CNRs for all modems at a given CMTS upstream port are identical, or nearly so. Cable modem upstream transmit levels are managed by the CMTS ranging process to provide the same receive

## Carrier-to-Noise-Plus-Interference Ratio

Often we need to make a distinction between the underlying thermal noise floor, which is flat, and narrowband interference, which appears as spectral lines or narrow humps on a spectrum analyzer display. In that case, we use the term "carrier-to-noise-plus-interference ratio" (CNIR). In DOCSIS, the CMTS upstream receive CNIR is defined in the MIB as the ratio of the expected commanded received signal power to the noise-plus-interference in the channel. Both the digitally modulated signal power and noise-plus-interference power are referenced to the same point—the CMTS input. The expected commanded received signal power is the power of an upstream burst that has been correctly adjusted by the CMTS ranging process. The noise-plus-interference power is the total power measured when no desired signal is present, that is, during quiet times on the upstream, when only the unwanted noise and interference are present. Note that one reason for not including narrowband interference with white noise when measuring CNR is that devices such as ingress cancellers can reduce the effect of narrowband ingress, whereas white noise cannot be similarly mitigated.

## Digitally Modulated Signals and Baseband SNR

RF CNR is fairly straightforward for digitally modulated signals. But what about baseband SNR? Rather than using our previous definition of baseband video or audio SNR, we must look for a different way to measure baseband data SNR.

## Views of a QAM Waveform

For further insight, consider the DOCSIS 256-QAM downstream signal shown in Figure 9. In (a), we see the familiar haystack spectrum of a QAM signal. Its shape is flat on the top, except for implementation imperfections and measurement noise, and, in this example, the channel has inserted some slight amplitude ripple and tilt as well. The height of the spectrum above the noise floor is 45 dB, which is the CNR and $E_S/N_0$ value. Its width at the –3 dB point is equal to the symbol rate $R_S$ = 5.36 MHz. Its sides are shaped by the transmit filter, with excess bandwidth equal to 12 percent; that is, the signal occupies 12 percent more bandwidth than an ideal brick-wall signal of the same symbol rate, because of the roll-off region. (As a quick check, 6 MHz occupied bandwidth ÷ 5.36 MHz symbol rate = 1.12.)

the histogram or probability density function (PDF) of the I or Q component of the QAM signal. The QAM signal approaches a Gaussian distribution, shown as a dotted red line, although the QAM distribution bulges more and has limited tails compared to the reference Gaussian distribution, which has the same standard deviation (signal level) as the QAM signal.

Baseband SNR could be defined as the ratio of the average power in the complex baseband (I and Q) signal to the average noise power in the symbol rate bandwidth. However, this definition would just replace RF CNR with an equivalent complex baseband CNR, because it does not include demodulation of the signal. For a digital SNR, we wish to measure the QAM signal after demodulation all the way down to its received constellation symbols. That is where RxMER comes in.

## The SNR of a Demodulated Digital Signal: RxMER

The solution is to define a new quantity to represent the SNR of a digital baseband signal: receive modulation error ratio. RxMER is defined as the ratio of average constellation symbol power to average constellation error power, expressed in dB. As we will see, RxMER looks at the demodulated complex baseband constellation symbols and measures their quality. The RxMER measurement gives the near “bottom line” status of the communications link, because it is these demodulated symbols that will go on to produce correct bits, or bit errors, at the receiver output after processing by the forward error correction (FEC) decoder.

## Equalized and Unequalized RxMER

Returning to Figure 9, we see in part (d) the received QAM constellation before equalization. Although the CNR on the spectrum display is 45 dB, the channel imperfections have caused the constellation to exhibit an RxMER value of only 26 dB. After the adaptive equalizer compensates for the channel response, the RxMER is restored to 45 dB, as shown in part (e) of Figure 9. This discussion shows that when we discuss RxMER, it is important to specify whether we are talking about the equalized or unequalized value.

Figure 10 shows a diagnostics page screen capture from a residential cable modem.[8] The indicated signal-to-noise ratio is 36 dB (circled). Most cable modems provide an equalized RxMER measurement of the downstream 64- or 256-QAM digitally modulated signal. For the example in Figure 10, a QAM analyzer provided a nearly identical equalized MER measurement of the cable modem received 256-QAM signal (35 dB).

8. Many DOCSIS cable modems allow viewing the diagnostics page on the computer connected to the modem. To access the diagnostics page on modems that support this function, type **http://192.168.100.**1 in the browser address or URL window.

the nearest ideal symbol, or hard decision, from the QAM constellation. The decisions are passed to the Trellis decoder, descrambler, deinterleaver, Reed-Solomon (RS) FEC decoder and MPEG deframer, and on to the MAC layer, which assembles and outputs received packets to the user.

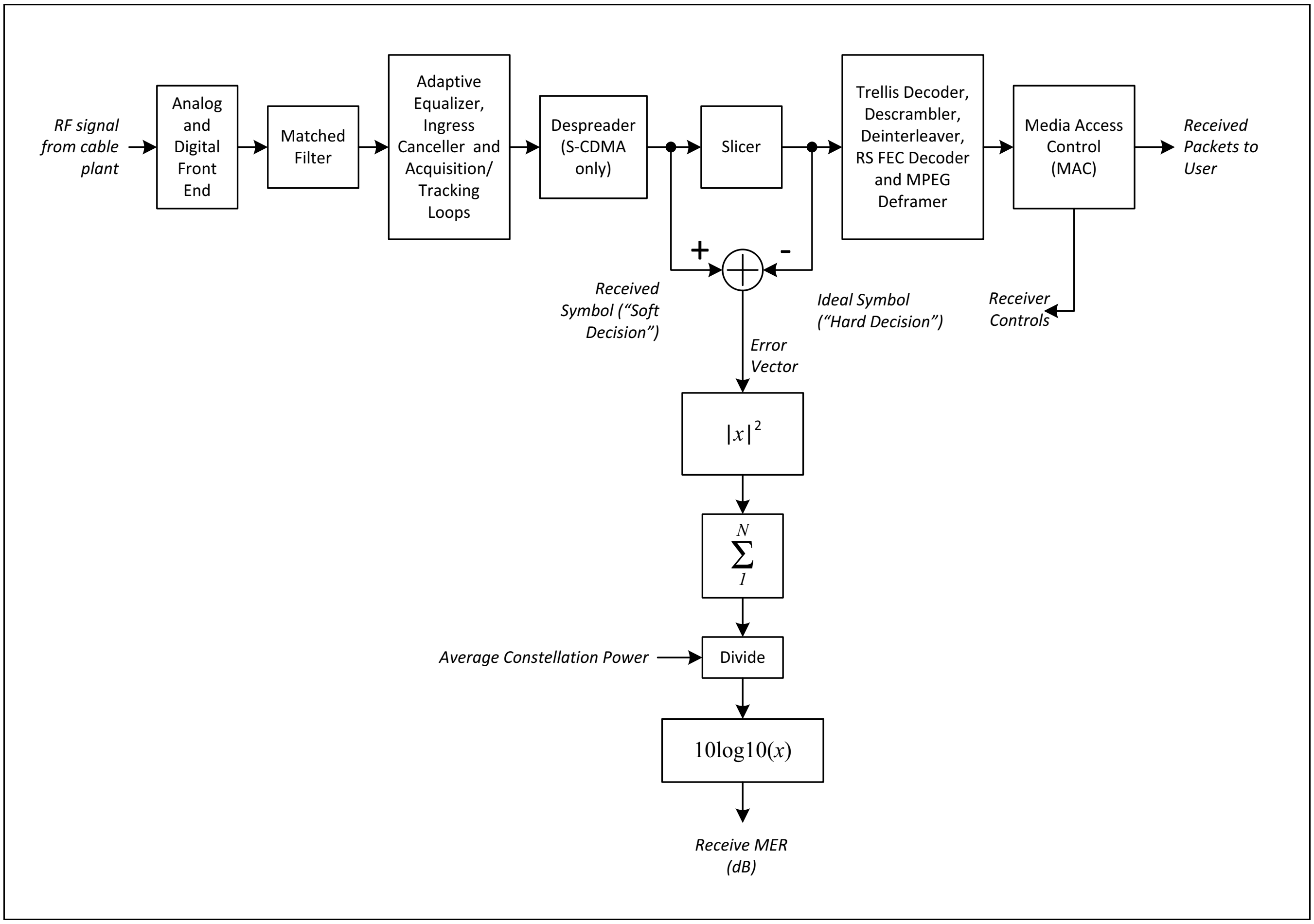



**Figure 11: Block Diagram of Generalized Digital QAM Receiver, Showing Computation of Receive MER**

of the constellation points, and the magnitude of the error between them would be zero. In a real-world receiver, subtracting the hard-decision vector from the soft-decision vector gives the error or noise vector at each symbol time. The implicit assumption is that a low symbol error rate exists – that is, very few decisions are incorrect, ensuring that the "decision-directed" error vector from the nearest symbol nearly always equals the true error vector from the correct reference symbol.

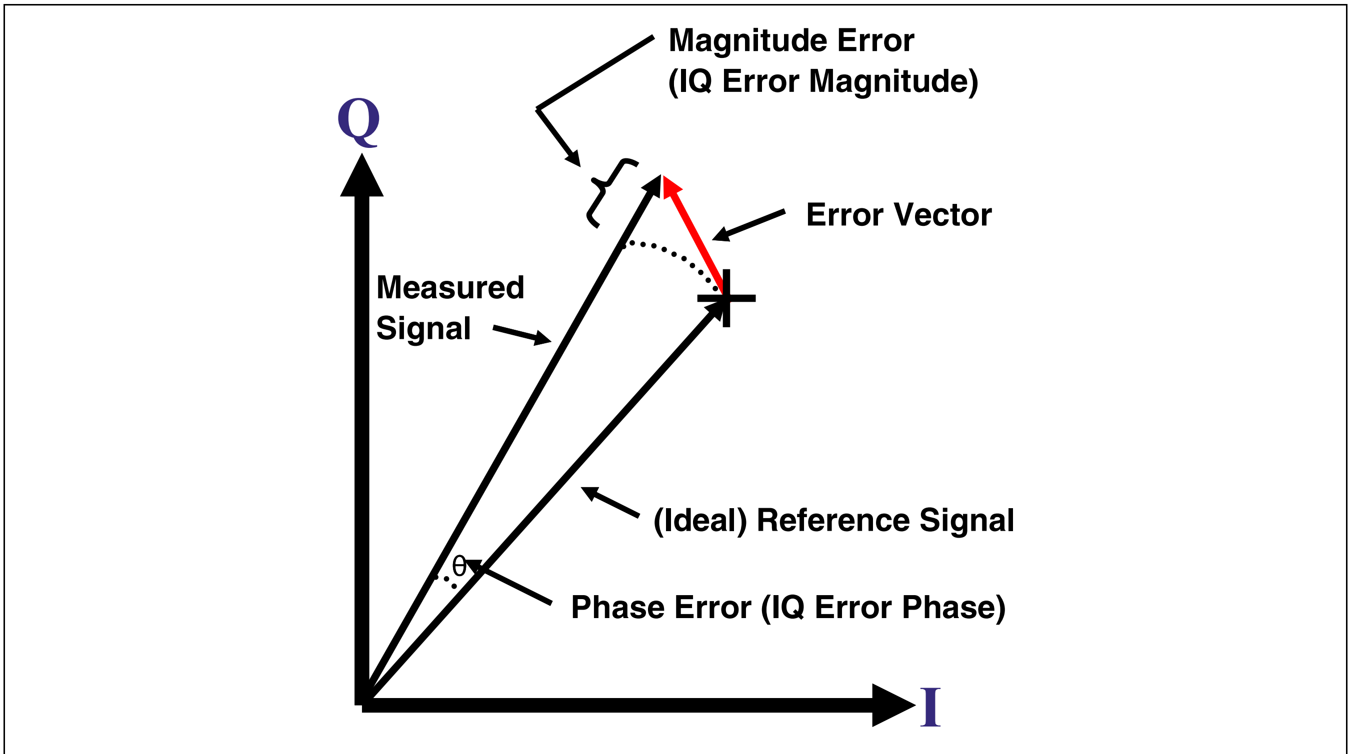



**Figure 12: The Error Vector Is the Difference Between the Measured Signal (Soft Decision) and the Reference or Target Signal (Hard Decision). (Source: Hewlett-Packard)**

For RxMER, we are concerned with the average power of the error vector, which is computed, as shown previously in Figure 11, by taking the squared magnitude of the complex error vector and accumulating or averaging it over a given number of symbols *N*. This process gives the error vector power (or noise power) at the slicer. Because we want the ratio of signal to noise, we divide the average signal power (a known constant for each constellation, such as 64-QAM or 256-QAM) by the average error vector power. We then take the logarithm to convert to decibels, giving RxMER in dB. To summarize: RxMER is simply the ratio of average symbol power to average slicer error power, expressed in dB.

## More About Modulation Error Ratio

Modulation error ratio is digital complex baseband SNR—in fact, in the data world, the terms "SNR" and "MER" are often used interchangeably, adding to the confusion about SNR, especially considering that, as mentioned previously, in the telecommunications world, the terms "CNR" and "SNR" are often used interchangeably.

Why use MER to characterize a data signal? It is a direct measure of modulation quality and has linkage to bit error rate. Modulation error ratio is normally expressed in decibels, so it is a measurement that is familiar to cable engineers and technicians. It is a useful metric with which to gauge the end-to-end health of a network, although by itself, MER provides little insight about the type of impairments that exist.[9]

Figure 13 illustrates a 16-QAM constellation. A perfect, unimpaired 16-QAM digitally modulated signal would have all of its symbols land at exactly the same 16 points on the constellation over time. Real-world impairments cause most of the symbol landing points to be spread out somewhat from the ideal symbol landing points. Figure 13 shows the vector for a *target symbol* – the ideal symbol we want to transmit. Because of one or more impairments, the *transmitted symbol* vector (or received symbol vector) is a little different than ideal. *Modulation error* is the vector difference between the ideal target symbol vector and the transmitted symbol vector. That is:

$$\overrightarrow{\text{Modulation Error}} = \overrightarrow{\text{Transmitted Symbol}} - \overrightarrow{\text{Target Symbol}} \qquad \text{[Eq. 20]}$$

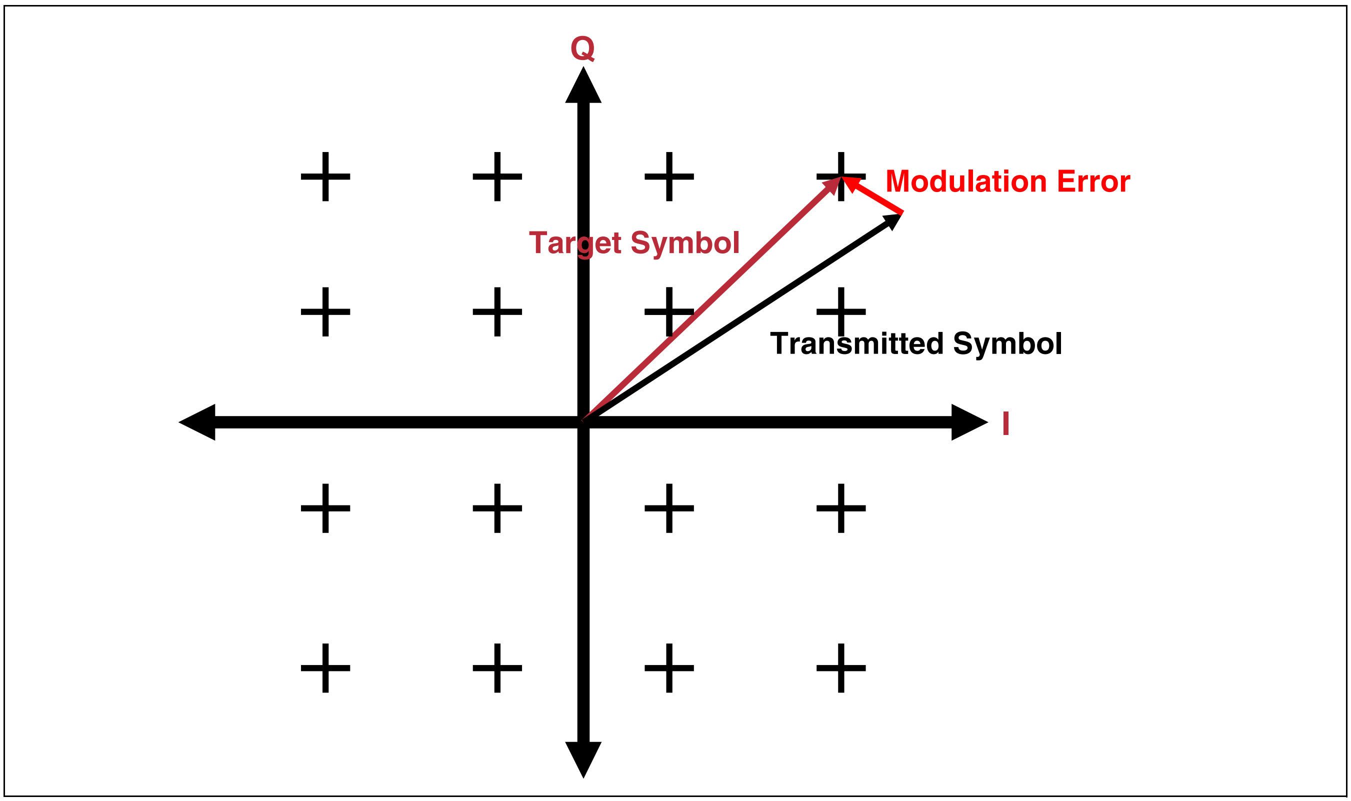



**Figure 13: Modulation Error Is a Measure of Modulation Quality. (Source: Hewlett-Packard)**

If a constellation diagram is used to plot the landing points of a given symbol over time, the resulting display forms a small "cloud" of symbol landing points rather than a single point. Modulation error ratio is the ratio of average symbol power to average error power (refer to Figure 14 on page 28):

$$\text{MER(dB)} = 10\log(\text{Average symbol power} \div \text{Average error power}) \qquad \text{[Eq. 21]}$$

In the case of MER, the higher the number, the better.

9. The reader is referred to the literature for discussions of visual constellation impairment evaluation.

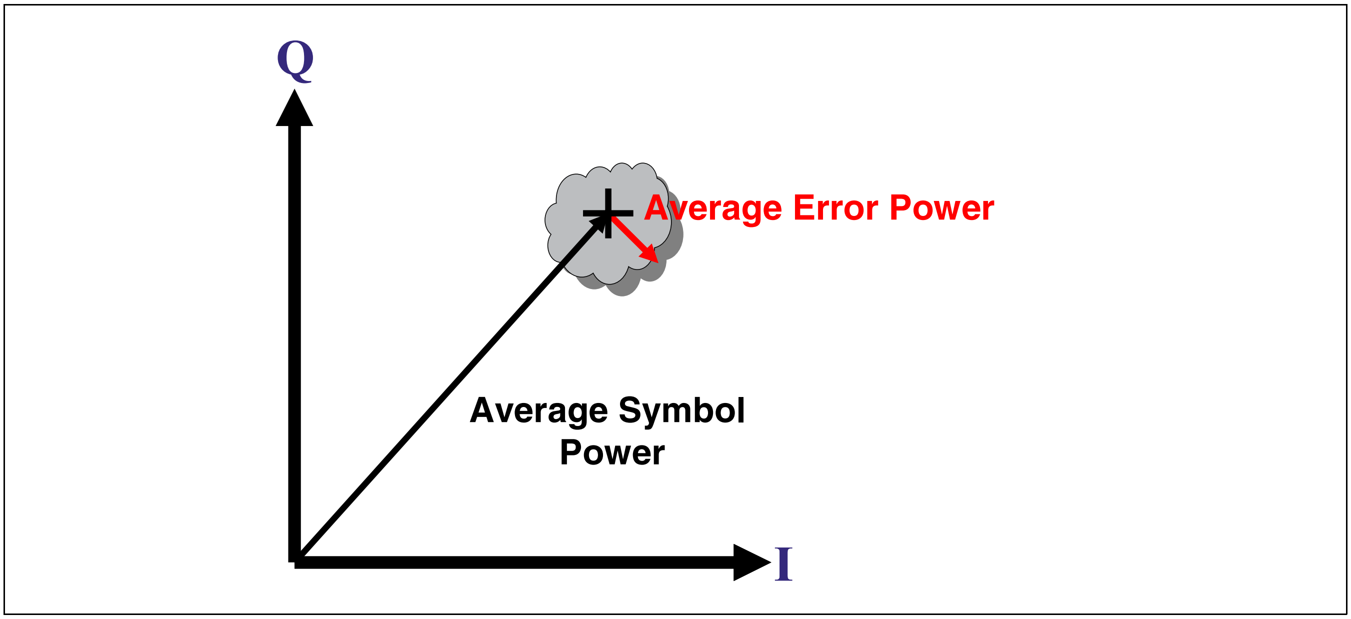



**Figure 14: Modulation Error Ratio Is the Ratio of Average Symbol Power to Average Error Power. (Source: Hewlett-Packard)**

Mathematically, a more precise definition of MER (in decibels) follows:

$$MER = 10\log_{10}\left[\frac{\sum_{j=1}^{N}\left(I_j^2 + Q_j^2\right)}{\sum_{j=1}^{N}\left(\delta I_j^2 + \delta Q_j^2\right)}\right] \quad \text{[Eq. 22]}$$

where $I$ and $Q$ are the real (in-phase) and imaginary (quadrature) parts of each sampled ideal *target symbol* vector, $\delta I$ and $\delta Q$ are the real (in-phase) and imaginary (quadrature) parts of each *modulation error* vector. This definition assumes that a long enough sample is taken so that all the constellation symbols are equally likely to occur.

In effect, MER is a measure of how "fuzzy" the symbol points of a constellation are. Table 4 summarizes the approximate $E_S/N_0$ range that will support valid MER measurements for various DOCSIS modulation constellations. The two values in the table for the lower threshold correspond to ideal uncoded symbol error rate (SER) = $10^{-2}$ and $10^{-3}$, respectively. The upper threshold is a practical limit based on receiver implementation loss. Outside the range between the lower and upper thresholds, the MER measurement is likely to be unreliable. The threshold values depend on receiver implementation. Some commercial QAM analyzers may have values of the lower $E_S/N_0$ threshold 2 to 3 dB higher than those shown in the table.

**Table 4: Valid MER Measurement Ranges**

| Modulation Format | Lower $E_S/N_0$ Threshold | Upper $E_S/N_0$ Threshold |
|---|---|---|
| QPSK | 7–10 dB | 40–45 dB |
| 16 QAM | 15–18 dB | 40–45 dB |
| 64 QAM | 22–24 dB | 40–45 dB |
| 256 QAM | 28–30 dB | 40–45 dB |

Good engineering practice suggests keeping RxMER in an operational system at least 3 to 6 dB or more above the lower $E_S/N_0$ threshold.[10] This guideline will accommodate numerous factors that can affect operating headroom, including temperature-related signal-level variations in the coaxial plant, amplifier and optoelectronics misalignment, and imperfect calibration of test equipment. The lower $E_S/N_0$ threshold can be thought of as an “MER failure threshold” of sorts, that is, when unequalized RxMER approaches the lower $E_S/N_0$ threshold, the channel may become unusable with the current modulation. Possible workarounds include switching to a lower order of modulation, using adaptive equalization, or identifying and repairing what is causing the low RxMER in the first place.

## Transmit MER

Although this paper is mainly concerned with RxMER, transmit MER (TxMER) is also of interest. TxMER is defined as the MER produced by a transmitter under test, as measured by an ideal test receiver. In a real test, the receiver is, of course, not ideal and will introduce its own degradations to MER measurement. The receiver contribution, if small (a few dB) and accurately measurable, can be used to correct the TxMER measurement. In addition, DOCSIS provides the following method for removing the effects of the frequency response of a test receiver on a TxMER measurement. First a near-ideal test transmitter is connected to the test receiver, and the receiver equalizer coefficients are allowed to converge in order to compensate for the frequency response of the test bed. The receive equalizer is then frozen, and the transmitter under test is connected in place of the test transmitter. The MER reading taken from the test receiver is the unequalized TxMER measurement. The test receiver is again allowed to adapt its equalizer coefficients, and the resulting MER reading is the equalized TxMER measurement.

## Factors Affecting MER Measurement

Because MER is a digital computation performed on digital quantities in the receiver, it is by nature extremely accurate in itself. However, the measured value can be affected by many things. As a result, MER may not accurately reflect the CNR or $E_S/N_0$ at the input to the receiver.

- *Statistical variation*: The number of samples $N$ over which the MER (or RxMER) is averaged affects the reliability of the measurement. For independent samples, the standard deviation of a measurement is in general proportional to $1/\sqrt{N}$, so, for example, averaging over 10,000 samples will result in 10 times smaller standard deviation of the MER measurement than using 100 samples. A smaller standard deviation means the MER measurement will appear more stable. Conversely, taking fewer samples can also offer advantages. In a sense, the number of samples $N$ provides a

10. Many cable operators use the following unequalized MER (RxMER) values as minimum acceptable operational values: QPSK ~18 dB; 16-QAM ~24 dB; 64-QAM ~27 dB; and 256-QAM ~31 dB.

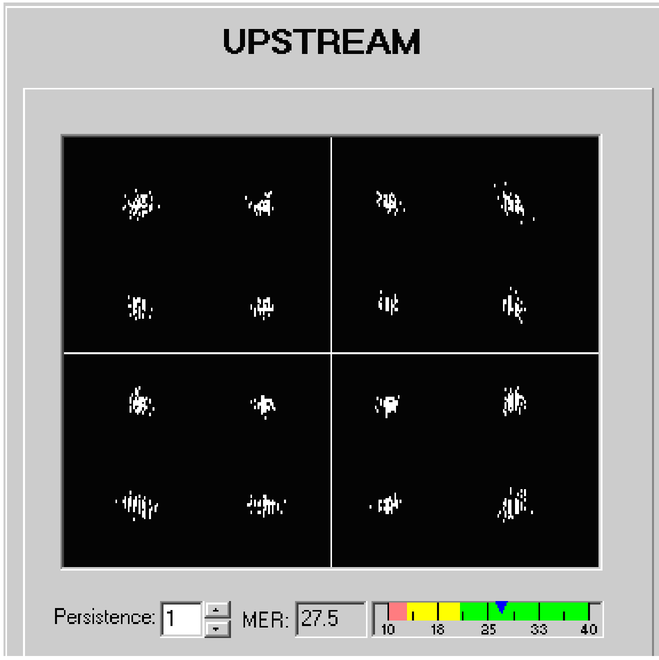



**Figure 17: Unimpaired 16-QAM Digitally Modulated Signal; the Unequalized MER Is 27.5 dB. (Courtesy Filtronic-Sigtek)**

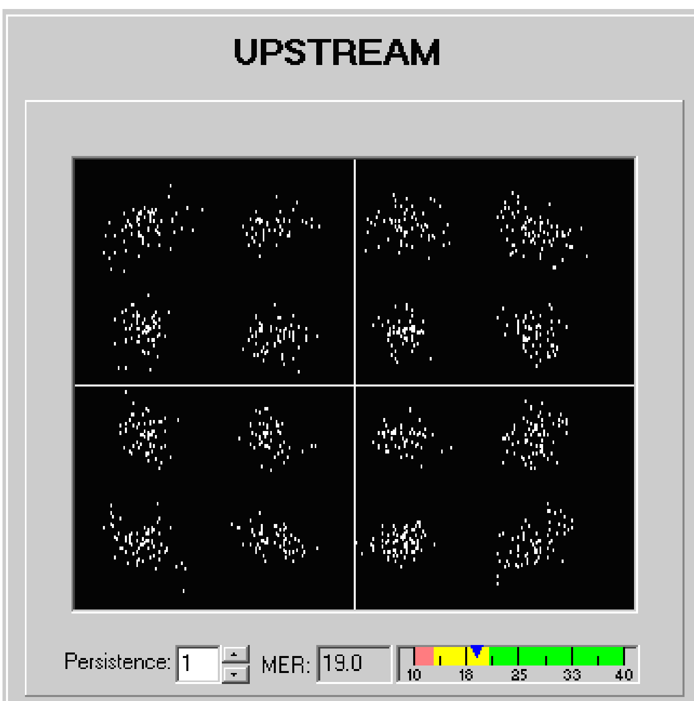



**Figure 18: Impaired 16-QAM Digitally Modulated Signal; the Unequalized MER Is 19 dB (Courtesy Filtronic-Sigtek)**

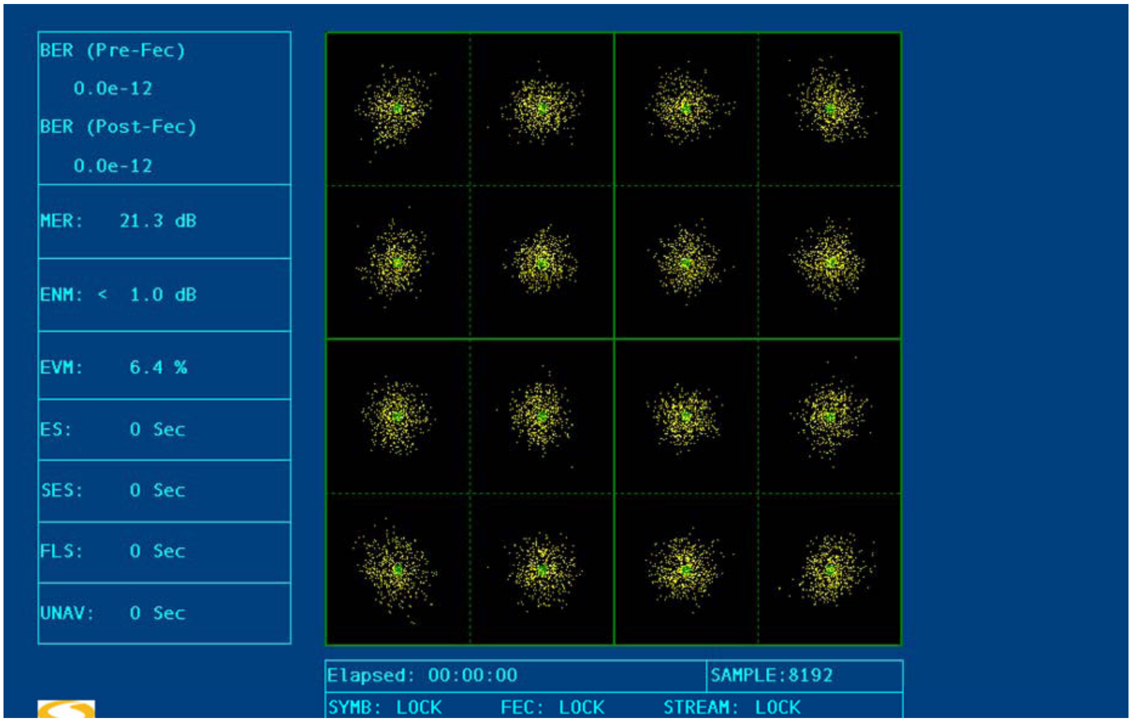



**Figure 20: Upstream Unequalized MER for the Digitally Modulated Signal in Figure 19 Is Only 21 dB, and the EVM Is a Relatively High 6.4 Percent. (Courtesy Sunrise Telecom)**

Figure 19 on page 38 and Figure 20 emphasize the SNR (RxMER) versus CNR confusion that often occurs in cable systems. The cable operator's NOC might find that the CMTS reported upstream SNR (RxMER) is low (~21 dB in this instance), while a spectrum analyzer shows good CNR (~36 dB) and no apparent problems. The fact that unequalized 16-QAM would not work on this particular upstream—and QPSK was fine—indicates something is amiss.

## TDMA and S-CDMA Effects on Upstream RxMER Measurement

Beginning with DOCSIS 2.0, both TDMA and S-CDMA modes are included in the upstream. In S-CDMA mode, multiple cable modems can transmit at the same time, while being separated by orthogonal spreading codes. Because various numbers of codes can be transmitted or quiet in a given S-CDMA frame, care must also be taken to properly normalize the signal measurement to avoid errors in S-CDMA MER measurement. In TDMA mode, upstream transmissions have a burst nature: Multiple cable modems share the same upstream frequency channel through the dynamic assignment of time slots. The effects of TDMA and S-CDMA on MER measurement are discussed in the following sections.

## TDMA Burst Effects on SNR Measurement

Because a TDMA signal is bursting on and off, care must be taken to measure the signal power only when the signal is on. If an RF spectrum analyzer is used to measure CNR, the duty factor must be accounted for. The TDMA duty factor can be estimated and normalized out of the CNR measurement. For example, if the channel is active 90 percent of the time, the factor 10log(0.9) = –0.46 dB results; a correction of

0.46 dB must be added to the CNR measurement. Another approach is to measure both signal and noise with the spectrum analyzer in maximum-hold mode, resulting in the analyzer trace filling in the areas where the signal was off. However, this method is susceptible to errors in that the highest TDMA user's power is being measured, not the average signal power; and any high-noise excursions are measured, not the average noise.

CMTS burst receivers can measure RxMER on each upstream burst that is received, thereby avoiding the problem of the quiet times when no signal is present. Because the receiver synchronizes to each upstream burst, it ignores the dead times between bursts.

As mentioned previously, the DOCSIS MIB defines the CNIR measurement as the ratio of expected burst signal power to average noise plus interference during the times when no signal is present. This measurement is tailored to the TDMA nature of the upstream.

## S-CDMA Transmission and $E_S/N_0$ or RxMER per Code

S-CDMA introduces a new SNR concept: $E_S/N_0$ or RxMER per code. First, let's review the basics of S-CDMA. Figure 21 shows the fundamental concept of S-CDMA data transmission: Each symbol of data is multiplied by a spreading code at the cable modem transmitter and summed with other spread symbols originating both from the same cable modem and from other cable modems on the plant. The composite signal travels across the upstream RF channel, where noise is unavoidably added. At the CMTS burst receiver, the signal is applied to 128 despreaders, which reverse the process by multiplying by the respective spreading codes and summing over all 128 chips in the code. This process reproduces the original data symbols at the receiver output, perturbed, of course, by the noise.

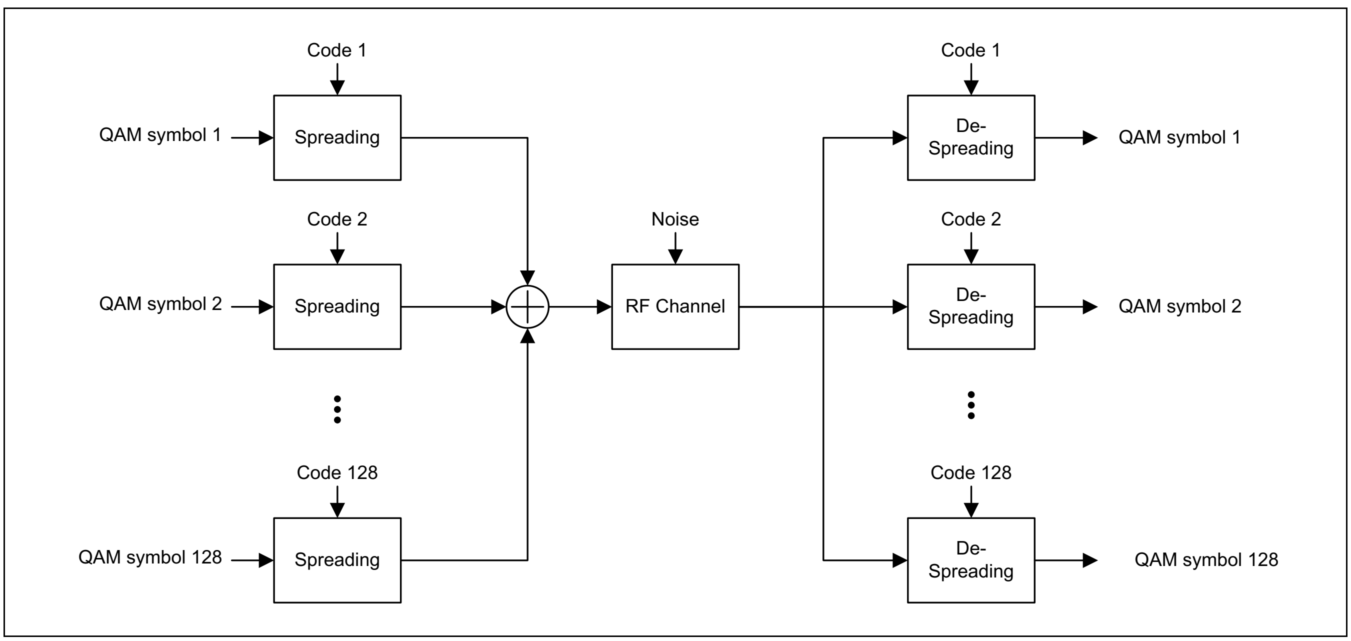



**Figure 21: Upstream S-CDMA Data Transmission Consists of Spreading at the Transmitter and Despreading Each Code at the Receiver.**

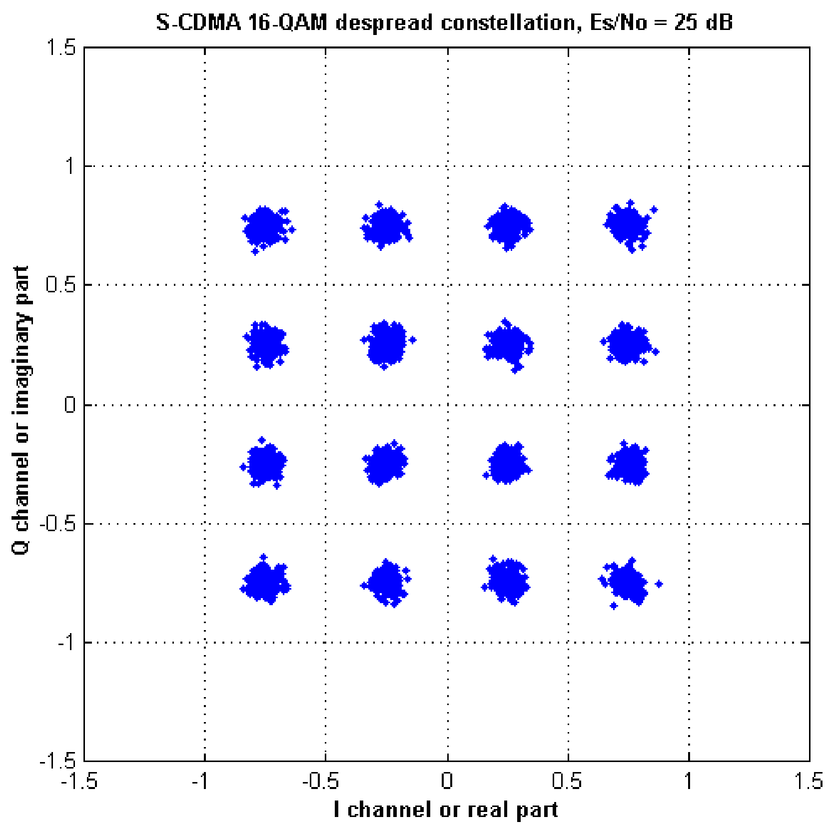
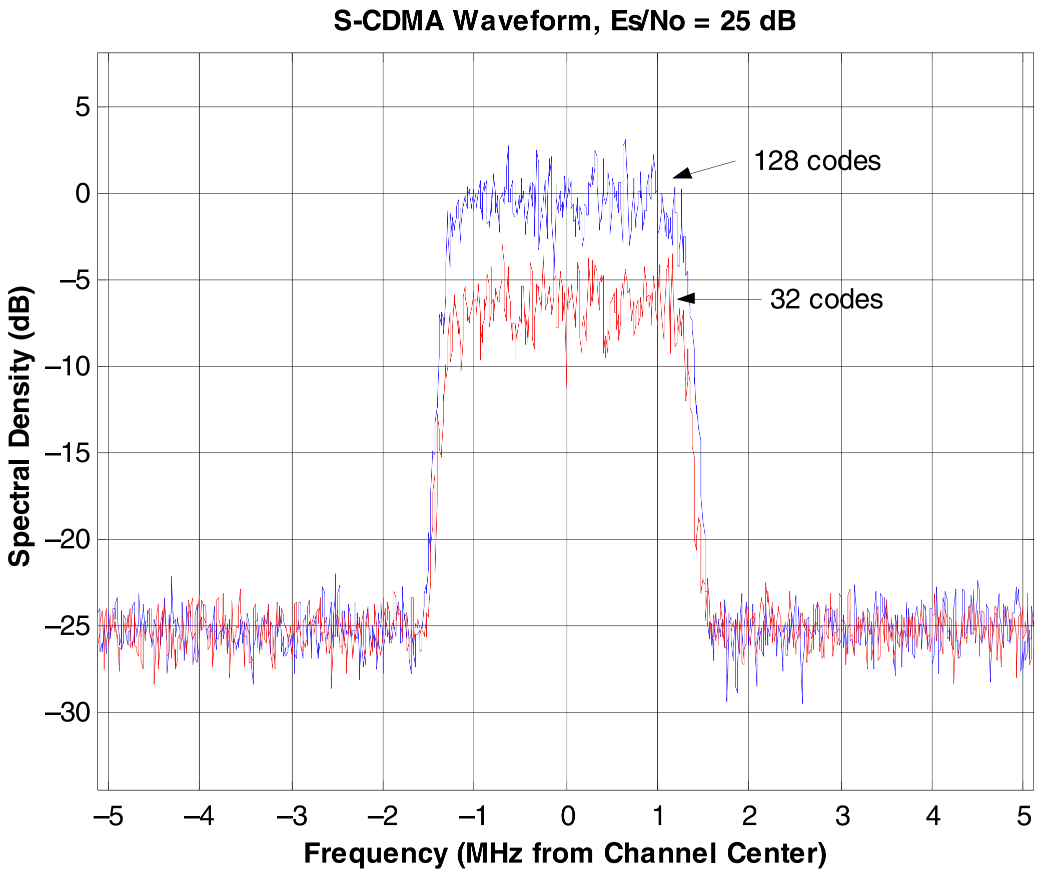



**Figure 23: S-CDMA 16-QAM Constellation with 25 dB RxMER**

## Divergence of CNR and MER in S-CDMA

Because the codes are effectively independent, as shown previously in Figure 22, turning some codes off reduces the total signal power in the channel but does not affect the $E_S/N_0$ on the other codes, meaning the CNR seen on a spectrum analyzer will appear to fluctuate as some codes are transmitted and others are not, but the $E_S/N_0$ per code will remain constant. This effect is seen in Figure 24. In the upper trace, all 128 active codes are transmitted. The CNR, $E_S/N_0$ per code, and RxMER per code are all approximately equal to 25 dB. In the lower trace, all but 32 of the codes have been turned off, while keeping the received power per code unchanged. The CNR is reduced by 6 dB, but the $E_S/N_0$ per code and received RxMER remain approximately unchanged at 25 dB. Thus, in S-CDMA, the CNR measured on a spectrum analyzer can vary dynamically, and is a valid indication of the $E_S/N_0$ or RxMER per code only when all active codes are being transmitted in a given frame.




Upper trace: all 128 active codes are transmitted; CNR = 25 dB.
Lower trace: only 32 of the 128 active codes are transmitted; CNR reduces to 19 dB, but $E_S/N_0$ per code is still 25 dB because of 6 dB spreading gain.

**Figure 24: S-CDMA Upstream Spectrum with $E_S/N_0$ per Code = 25 dB**

## Spreading Gain in S-CDMA

A "spreading gain" or "processing gain" results when fewer than all the active codes are transmitted; in the lower trace of Figure 24, the spreading gain is 10 log(128/32) = 6 dB. Of course, the throughput is also reduced by a factor of 4 for this frame. This situation might occur temporarily in a lightly loaded S-CDMA upstream channel, in which the CNR might be seen varying up and down dynamically by a few dB, analogous to the carrier pulsing on and off in a lightly loaded TDMA upstream. The RxMER, however, remains steady at 25 dB in both the S-CDMA and TDMA cases. In fact, the RxMER may even show a slight improvement when fewer codes are transmitted, because spreading gain tends to reduce residual ISI effects.

## Conclusion

This paper investigated the common ways that signal-to-noise ratio is defined and measured in digital transmission over cable systems. It shows that RF and baseband measurements of CNR and SNR have to be treated differently, and that digitally modulated signals require their own precise definition and measurement of SNR.

CMTSs can report what has for many years been called upstream SNR, a parameter that is often confused with CNR. In reality, the upstream SNR of a CMTS is equalized MER or, in some cases, unequalized MER—specifically, as defined in the DOCSIS MIB, RxMER. Cable modems and most digital STBs also can report an SNR value. This value is not CNR, but is equalized downstream RxMER. Likewise, QAM analyzers and similar test equipment used by the cable industry can report MER values for downstream—and, in some cases, upstream—digitally modulated signals. These values, too, are not CNR, but are RxMER, as discussed in this paper. Most QAM analyzers report equalized MER measurements, although some also can provide unequalized MER measurements (or the equivalent of unequalized measurements). RxMER provides a "baseline" indication of signal quality, but must be interpreted carefully to gain the full value of this important measurement.