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Product Status	Obsolete
Architecture	-
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RAM Size	-
Peripherals	-
Connectivity	-
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Package / Case	-
Supplier Device Package	-
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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.

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:

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

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.

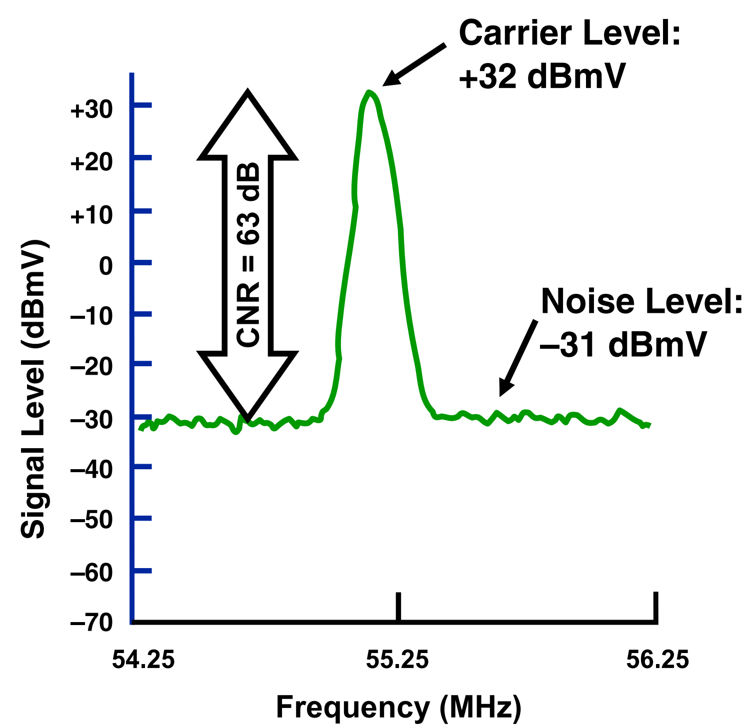

Figure 1: RF CNR Measurement (As Detected in the Test Equipment Resolution Bandwidth)

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):

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

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

$$CNR = C/N = C/(N_0B) \quad \text{[Eq. 6]}$$

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:

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

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.

Part (b) of Figure 4 shows the full-response magnitude spectrum $|H(f)|$ used in the DOCSIS upstream, representing the cascade of the transmit and receive filters. In order to make the filters realizable, an excess bandwidth of 25 percent (alpha = 0.25) is used, resulting in the S-shaped "raised cosine" roll-off regions shown in red, while the passband ideally remains flat. This spectrum possesses the Nyquist property in the frequency domain: If the frequency response $H(f)$ is replicated many times shifted by multiples of the symbol rate, and the copies are overlaid and added as illustrated in Figure 5, the result is a flat spectrum, which results in zero intersymbol interference (ISI).[5] Because of the cascading property mentioned previously, part (b) of Figure 4 also represents the power spectrum $|H_1(f)|^2$ of the transmitted signal and of the square-root Nyquist filter, described next.

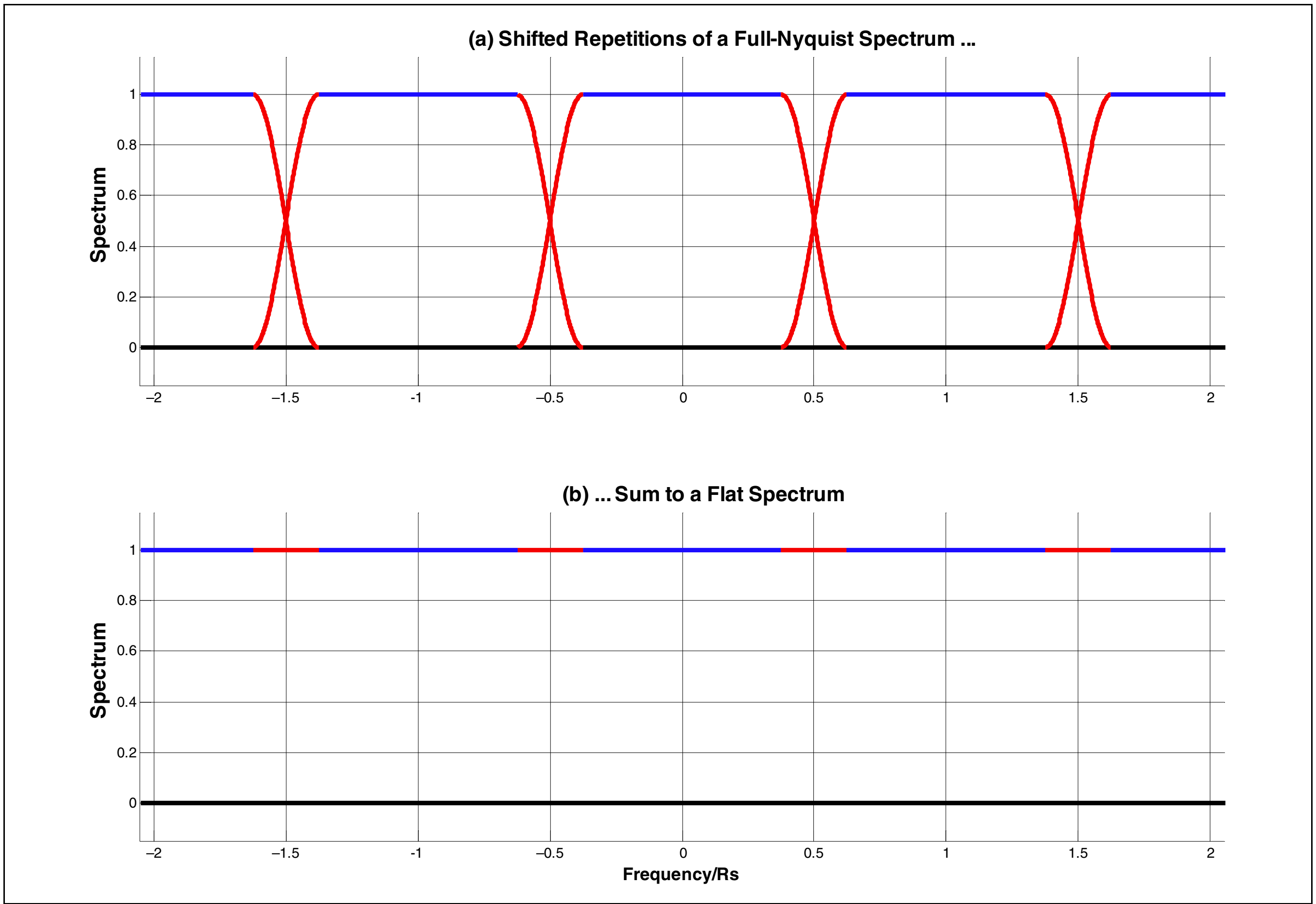

Figure 5: The Nyquist Property States That When Copies of the Spectrum Are Shifted by Multiples of the Symbol Rate and Added, the Result Is a Flat Spectrum, Which Results in Zero ISI.

In practice, the full Nyquist spectrum $H(f)$ of part (b) in Figure 4 is divided into two identical cascaded "square-root Nyquist" filters $H_1(f)$, one in the cable modem upstream transmitter and one in the CMTS burst receiver, using the matched filtering concept discussed earlier. The square-root Nyquist magnitude response $|H_1(f)|$ is shown in part (c) of the figure. Again, because of the cascading property, the power spectrum $|H_1(f)|^2$ of the square-root Nyquist filter and of the transmitted signal, is given in part (b) of the figure.

5. Historically, H. Nyquist discovered this property and published it in 1928, in the context of telegraphy.

- Be sure that the signal being measured (the information signal itself or the system noise, which is also a "signal") is at least 10 dB above the noise floor of the spectrum analyzer.[7] Sometimes, a low-noise preamplifier must be added at the spectrum analyzer input, or a test point with greater signal amplitude must be found. If measurement of a signal with very low CNR cannot be avoided, the offset caused by the analyzer noise floor can be subtracted from the raw measurement in order to correct the power readings. Figure 8 in the next section gives the applicable noise-floor correction. Care should be taken when subtracting nearly equal noise power measurements (for example, System noise + Analyzer noise floor – estimated analyzer noise floor), because the result may become zero or negative because of measurement uncertainties. In that case, more smoothing of the measurements may be needed.
- Correct the measurement to account for the ratio of the resolution bandwidth to the noise bandwidth of the analyzer. The RBW is normally expressed as the –3 dB bandwidth of the RBW filter. The equivalent noise bandwidth of the RBW filter is typically 6 to 13 percent wider than its –3 dB bandwidth, requiring a 0.25 to 0.5 dB correction, respectively, to the measurement. Consult the analyzer documentation for the exact values.

More on the Effect of Noise Floor on CNR and Power Measurements

As mentioned earlier, measuring a signal with very low CNR requires a correction to back out the noise underlying the signal. Let's look more closely at the effect of underlying noise on the measurement of CNR, or, in general, the difference between S/N and (S+N)/N. Figure 7, which shows a close-up view of a band-limited digitally modulated signal with a CNR value of only 4 dB, illustrates the effect. The blue trace, S + N, is observed on a spectrum analyzer. The underlying signal S without the noise N is shown in red in the figure; it would not be visible on the spectrum analyzer because noise is always present in a real system. The top of the blue haystack is about 1.5 dB above the top of the red haystack, showing the measurement error (S+N)/S caused by the noise-floor contribution.

7. Temporarily disconnect the spectrum analyzer RF input. The displayed noise should drop at least 10 dB. If it does not, a significant portion of the displayed noise is the test equipment noise floor adding to the cable system noise floor.

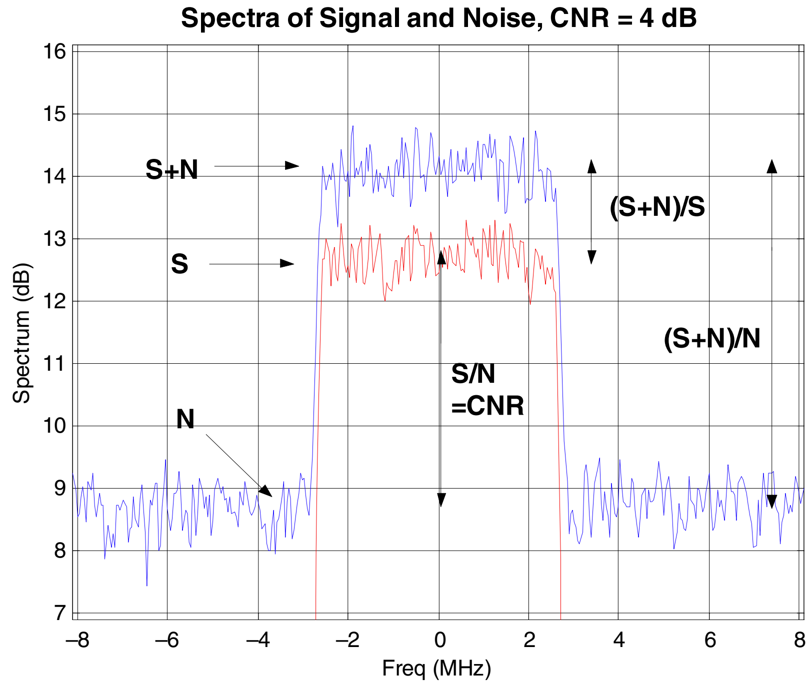

Figure 7: Close-Up View of Signal and Noise As Measured on a Spectrum Analyzer

When we measure the signal power on the analyzer, we observe the absolute height of the Signal + Noise haystack (blue trace). Expressing this measurement in units of power (non-dB) gives us the quantity (S+N). When we take the uncorrected CNR measurement, as discussed earlier, we measure the distance in dB from the flat top of the blue Signal + Noise haystack down to the noise floor. Converting to a unitless ratio (again non-dB) gives us the quantity (S+N)/N. We can manipulate these two quantities algebraically to get the desired values. First, we compute the error or offset to the signal power measurement caused by the noise floor, that is, the ratio (S+N)/S:

$$\frac{S+N}{S} = 1 + \frac{1}{\left(\frac{S+N}{N}\right) - 1} \qquad \text{[Eq. 11]}$$

Next, we derive the true power S of the underlying signal:

$$S = \frac{(S+N)}{1 + \frac{1}{\left(\frac{S+N}{N}\right) - 1}} \qquad \text{[Eq. 12]}$$

Finally, we compute the true CNR, that is, S/N:

$$\frac{S}{N} = \left(\frac{S+N}{N}\right) - 1 \qquad \text{[Eq. 13]}$$

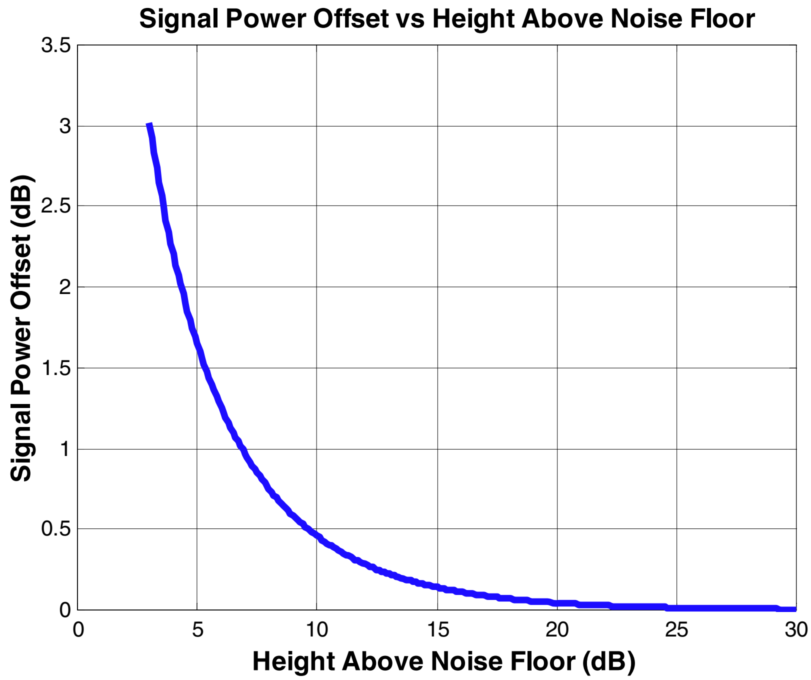

Figure 8: Signal Power Measurement Correction Relative to Noise Floor

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

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

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

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

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 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.

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:

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

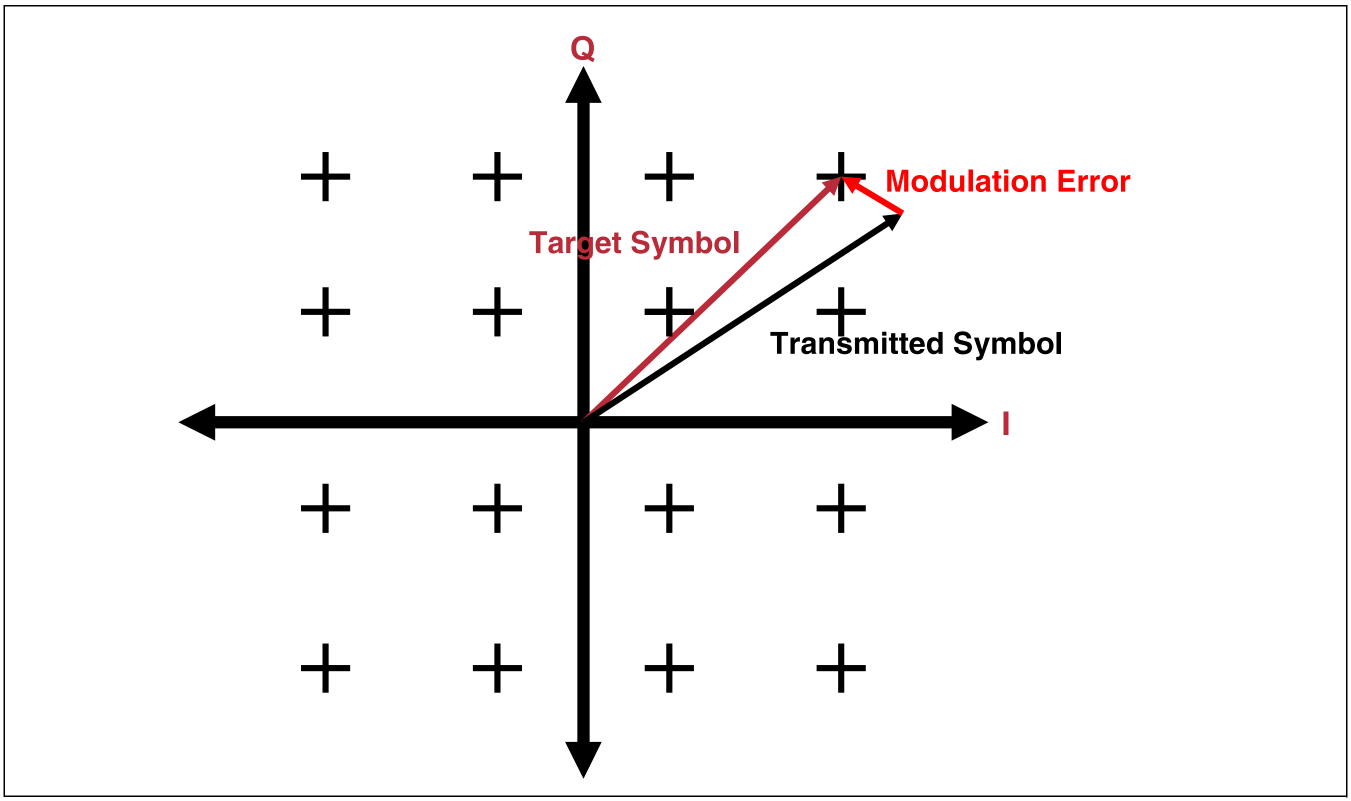

Figure 13: Modulation Error Is a Measure of Modulation Quality. (Source: Hewlett-Packard)

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):

MER(dB) = 10log(Average symbol power ÷ Average error power) [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.

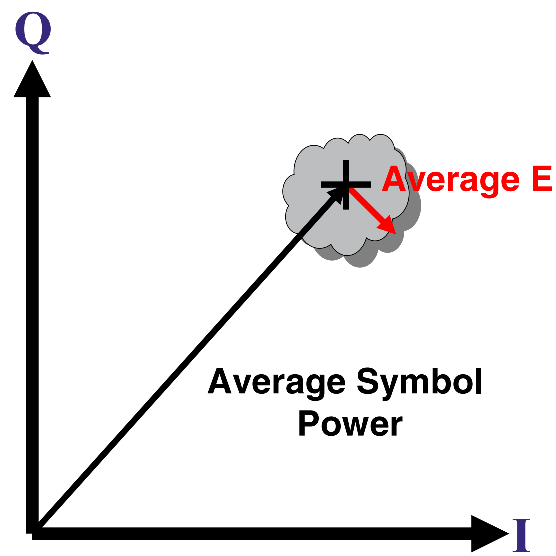

Figure 14: Modulation Error Ratio Is the Ratio of Average Symbol Power to Average Error Power. (Source: Hewlett-Packard)

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

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

where I and Q are the real (in-phase) and imaginary (quadrature) parts of each sampled ideal *target symbol* vector, δI and δQ 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.

control analogous to the video averaging function on a spectrum analyzer. A smaller number of symbols allows the observation of transients in the MER measurement, which can highlight the effects of burst noise, distortion, clipping, and pulsed ingress.

- *Unequal occurrence of symbols*: The average constellation power is a known constant for each constellation, such as 64-QAM or 256-QAM, and does not need to be computed. Some MER implementations nevertheless compute the average constellation power by taking the complex magnitude-squared of the received ideal symbols and averaging it over a given number of captured symbols *N*. For large *N*, this works fine and approaches the average constellation power. However, if the MER measurement is performed over just a few symbols (for example, $N < 100$), the result may be unreliable because, in some cases, many large QAM symbols (near the outer edges of the constellation) will happen to be transmitted, and in other cases, many small QAM symbols (in close to the origin, or center of the constellation) may happen to be transmitted.
- *Nonlinear effects*: Nonlinearities in the signal path, including laser clipping and amplifier compression, can affect outer constellation points more severely than inner points. As an example, in one return-path system with nonlinearities present,[11] the equalized RxMER (24-tap equalizer) of a QPSK signal was measured at 38.0 dB, a level that seemed to promise good margin for higher orders of modulation. However, with 16-QAM, the equalized RxMER was 31.9 dB, and with 256-QAM, the equalized RxMER was 30.2 dB. Hence, when measuring MER, it is important to measure the same constellation that will be used for transmitting data. It is also important to capture a large enough data sample to ensure that all symbols occur with equal likelihood.
- *Linkage of carrier loop bandwidth to capture length*: Some MER measurement equipment does not have an explicit carrier tracking loop. Instead, a block of *N* received symbols is captured and averaged. The averaging produces an effective carrier tracking loop with equivalent one-sided noise bandwidth $BL = R_S/2N$, where R_s is the symbol rate. To achieve the DOCSIS specification value of BL = 50 kHz, for example, would require $N = 54$ symbols at $R_s = 5.36$ MHz. As mentioned previously, measuring MER over such a small number of symbols can give unreliable results.
- *Implementation-loss MER ceiling*: Even if the input E_S/N_0 is very high, the MER reading will saturate at a value reflecting the implementation loss of the receiver. The receiver contributes noise to the MER measurement because of front-end noise figure; imperfect time, frequency, or phase tracking; round-off effects; imperfect equalization; etc. For example, it is unusual in a 256-QAM receiver for the MER measurement to go much above 40 to 45 dB, even when there is no noise at the receiver input, as mentioned previously in the description of Table 4.
- *Symbol-error MER floor*: The slicer produces the hard decision by taking the soft decision and finding the nearest ideal constellation point. If the wrong constellation point is chosen, a symbol error occurs. The error vector magnitude then indicates the distance to the nearest symbol point, which may be closer than the correct symbol, meaning that the error will seem smaller than it really is, and the MER will seem better than its true value. As a general rule, the MER measurement is not valid when the input E_S/N_0 is below the point that produces roughly a 1-percent symbol error rate (before trellis or FEC decoding), as mentioned previously in the description of Table 4.
- *Analog front-end noise*: The analog front end of the receiver contributes thermal noise and possibly spurious products, effectively raising the noise floor of the system and lowering the RxMER relative to the CNR measurement. This effect is most pronounced at low RF input levels.
- *Phase noise*: Phase noise is a slowly varying random phase in the received signal. The analog tuner is a primary contributor of phase noise in the receiver. The carrier phase tracking loop in the receiver

11. Reported by Cooper, et al. in a paper presented at SCTE Cable-Tec Expo 2006.

Table 5: MTA Ratio for Square and Double-Square QAM Constellations

Constellation (DS = Double-Square)	MTA Ratio for Constellation Symbols (dB)
QPSK and BPSK	0
16-QAM and 8-QAM-DS	2.55
64-QAM and 32-QAM-DS	3.68
256-QAM and 128-QAM-DS	4.23
1024-QAM and 512-QAM-DS	4.50
Limit for infinite QAM	4.77

We can now convert from MER to EVM using the formula:

$$EVM\_\% = 10 \times 10^{-(\overline{MERdB + MTAdB})/20} \quad \text{[Eq. 28]}$$

where:

- *EVM_%* is error vector magnitude (percent).
- *MER_dB* is modulation error ratio (dB).
- *MTA_dB* is maximum-to-average constellation ratio (dB).

MTA Versus Peak-to-Average Ratio of an RF Signal

It is important not to confuse MTA with the peak-to-average ratio (PAR) of the actual transmitted signal. MTA accounts only for the distribution of the ideal QAM constellation symbols. Because of the subsequent spreading, filtering, and modulation processes that operate on the symbols, the effective PAR of a single modulated RF carrier will typically lie in the range of 6 to 13 dB or more. (The effect of filtering was illustrated previously by the long tails in the distribution in part (c) of Figure 9 on page 21.) The actual PAR value depends on the modulation, excess bandwidth, and whether preequalization or S-CDMA spreading is in use.[13] The PAR of a combined signal containing multiple carriers (such as the aggregate upstream or downstream signal on the cable plant) can become very large. Fortunately, the peaks occur very seldom, and the aggregate signal can often be treated like a random Gaussian signal.

MER and EVM Equipment and Example Measurements

Specialized test equipment such as a vector signal analyzer is generally needed to measure downstream or upstream EVM in a cable network, although some QAM analyzers support its measurement because the equipment must incorporate a digital QAM receiver in order to demodulate the signal to its complex baseband symbol constellation. Figure 16 on page 36 shows a downstream 256-QAM digitally modulated signal whose EVM is 0.9 percent (circled). This value is representative of what might be seen at a headend or hub site, or at the downstream output of a node.

13. HEYS Professional Services' Francis Edgington has measured practical PAR values in the 6.3 dB to 7.3 dB range for 64-QAM signals and 6.5 dB to 7.5 dB range for 256-QAM signals.

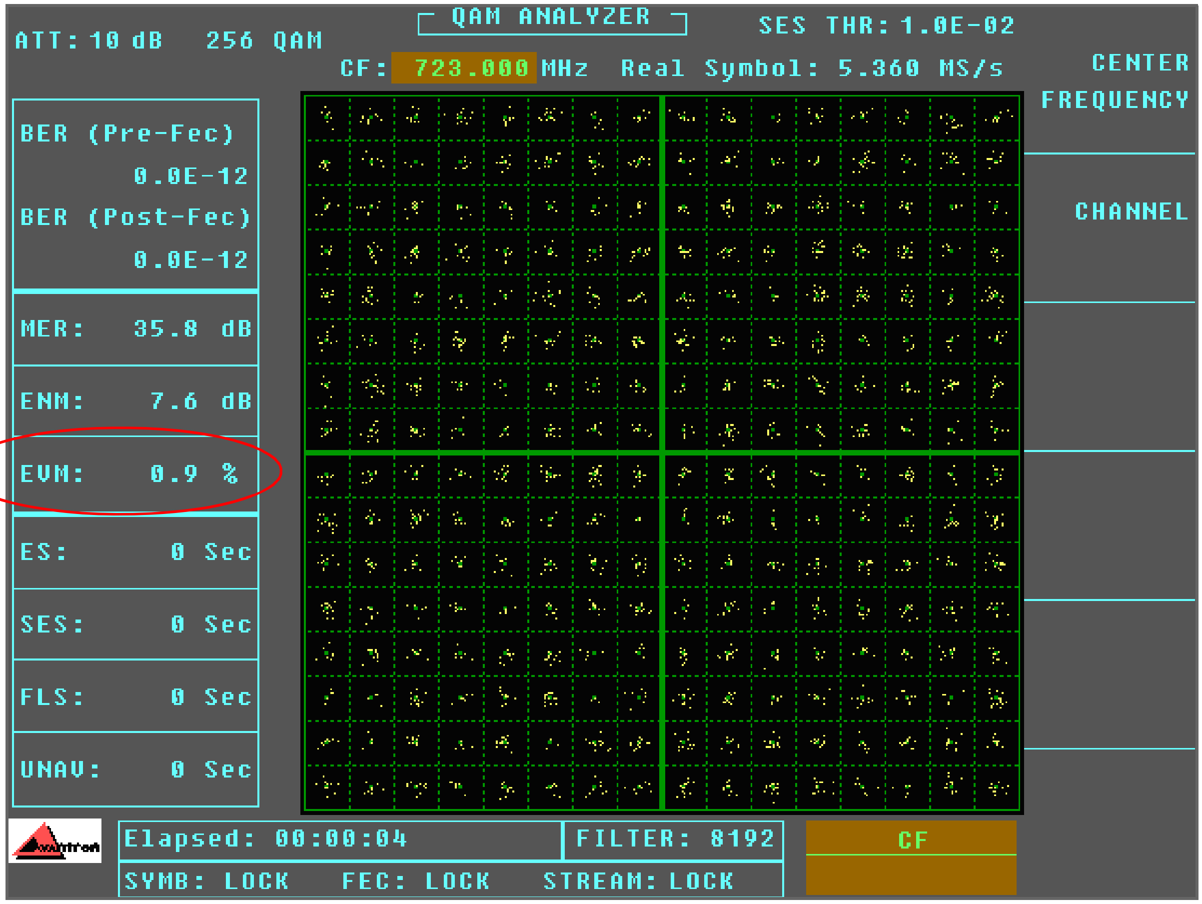

Figure 16: The EVM of This Downstream 256-QAM Digitally Modulated Signal Is 0.9 Percent. (Courtesy of Sunrise Telecom)

Figure 17 and Figure 18 on page 37 show two examples of a 16-QAM upstream digitally modulated signal. The constellation in Figure 17 illustrates a relatively unimpaired signal[14] whose unequalized MER is 27.5 dB. Figure 18 shows an impaired signal, where the unequalized MER is only 19 dB. This level is close to the failure threshold for unequalized, uncoded 16-QAM for some demodulators. In fact, in Figure 18, we can see that some soft decisions are close to the decision boundaries. Note that there is really no way to tell for sure *what* is causing the low MER in Figure 18 by simply observing the display—it could be because of low CNR or perhaps because of one or more linear or nonlinear distortions.

14. The signal has a slight amount of phase noise, observable in the angular spread of the corner constellation points, but is otherwise what could be considered a "clean" signal.

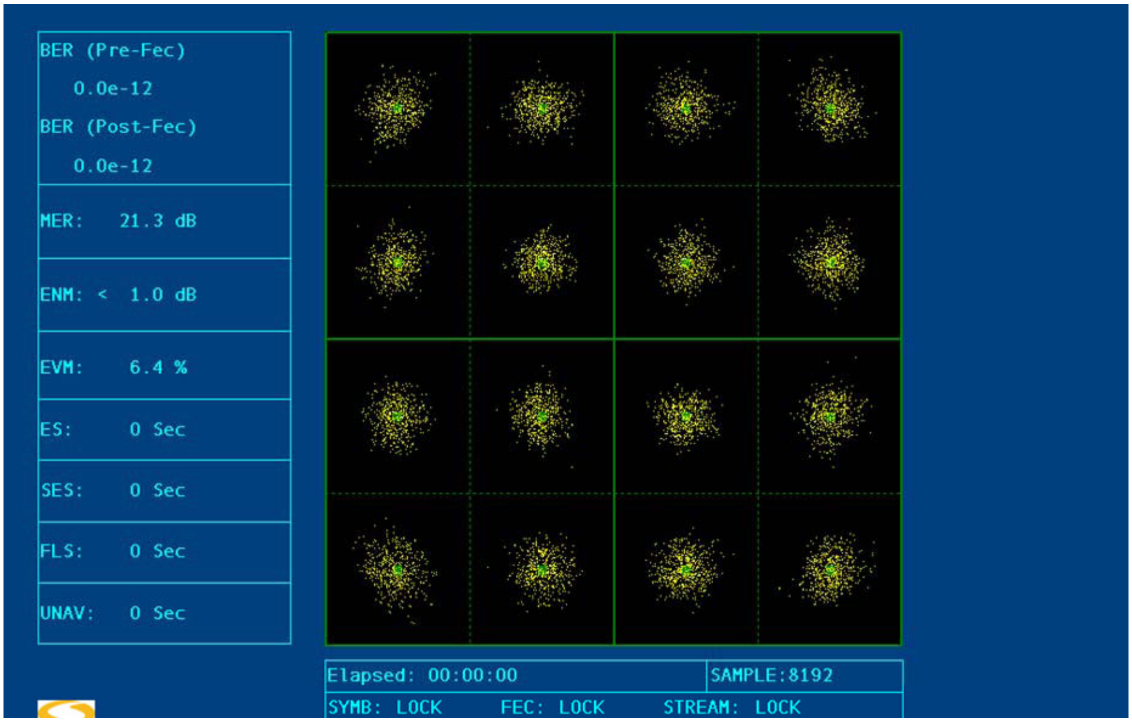

Figure 20: Upstream Unequalized MER for the Digitally Modulated Signal in Figure 19 Is Only 21 dB, and the EVM Is a Relatively High 6.4 Percent. (Courtesy Sunrise Telecom)

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.

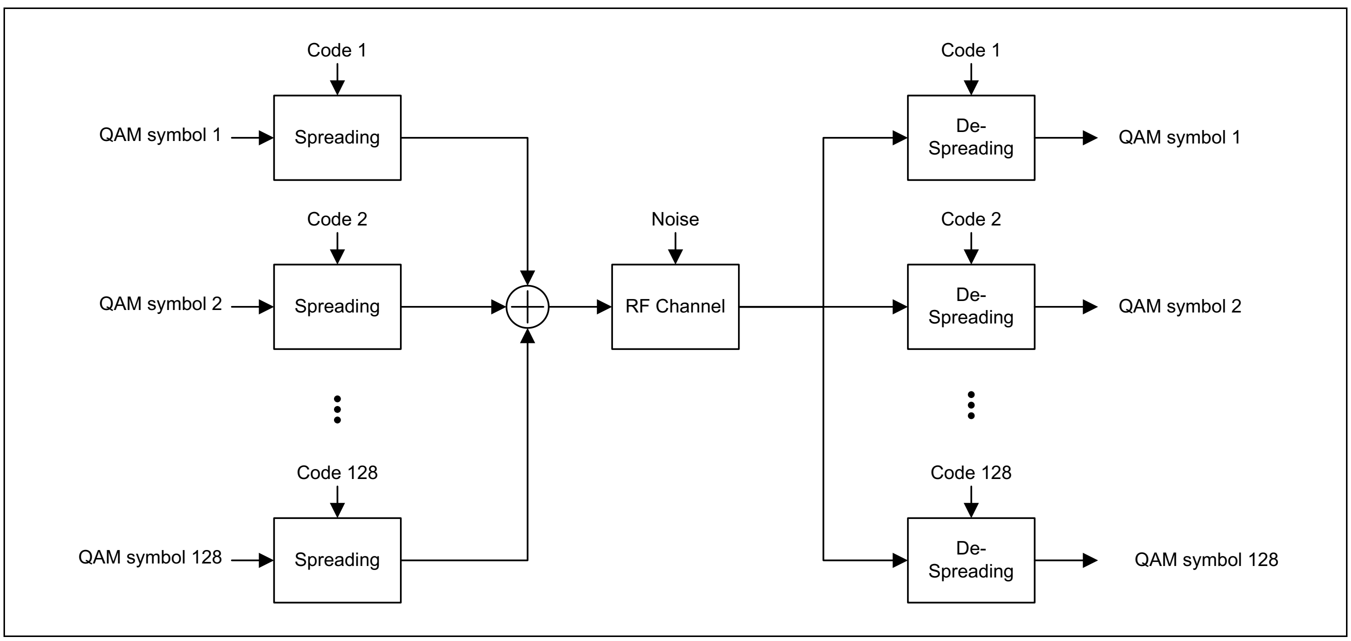

Figure 21: Upstream S-CDMA Data Transmission Consists of Spreading at the Transmitter and Despreading Each Code at the Receiver.

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.

References

Agilent Technologies, "Digital Modulation in Communications Systems – An Introduction"; Application Note 1298, ©2001.

Agilent Technologies, "Spectrum Analyzer Measurements and Noise: Measuring Noise and Noise-like Digital Communications Signals with a Spectrum Analyzer"; Application Note 1303, ©2003.

Agilent Technologies, "Using Error Vector Magnitude Measurements to Analyze and Troubleshoot Vector-Modulated Signals"; Product Note PN 89400-14, ©2000.

Agilent Technologies, "Cable Television System Measurements Handbook – NTSC Systems"; Technical Note, 1994: http://www.home.agilent.com/agilent/facet.jspx?to=80030.k.1&cc=US&lc=eng&sm=g&k=Cable+Television+System+Measurements+Handbook.

Ciciora, W., J. Farmer, D. Large, and M. Adams, *Modern Cable Television Technology*, 2nd Ed.; Morgan Kaufmann Publishers, 2004.

Cooper, M., J. Finkelstein, and J. Moran, "Maximizing Throughput in the Return Path via DOCSIS 2.0." In *Proceedings Manual and Collected Technical Papers*, SCTE Cable-Tec Expo 2006, Denver, Colo.

Currivan, B., T. Kolze, J. Min, and G. Ungerboeck, "Physical-Layer Considerations for Advanced TDMA CATV Return Path." In *Annual Review of Communications*, International Engineering Consortium, vol. 55, Chicago, 2002.

Currivan, B., "Cable Modem Physical Layer Specification and Design." In *Cable Modems: Current Technologies and Applications*, International Engineering Consortium, Chicago, 1999.

DOCSIS 2.0 Radio Frequency Interface Specification: http://www.cablemodem.com/specifications/specifications20.html.

DOCSIS 3.0 Radio Frequency Interface Specification: http://www.cablemodem.com/specifications/specifications30.html.

DOCSIS Downstream RF Interface Specification: http://www.cablemodem.com/specifications/d-rfi.html.

Downey, J. "Upstream FEC Errors and SNR as Ways to Ensure Data Quality and Throughput." Cisco Systems (Document ID: 49780): http://www.cisco.com/en/US/tech/tk86/tk319/technologies_white_paper09186a0080231a71.shtml.

Edgington, F. "Digital RF Measurements Show Return System Suitability for Increased Data Rate/Bandwidth." In *Proceedings Manual and Collected Technical Papers*, SCTE Cable-Tec Expo 2004, Orlando, Fla.

Freeman, R. L., *Telecommunications Transmission Handbook*, 2nd Ed., John Wiley & Sons, Inc., 1981, ISBN 0-471-08029-2.

Howald, R. L., "QAM Bulks Up Once Again – Modulation to the Power of Ten." In *Proceedings Manual and Collected Technical Papers*, SCTE Cable-Tec Expo 2002, San Antonio, Tex.: http://broadband.motorola.com/ips/pdf/QAM.pdf.

Howard, D., B. Currivan, T. Kolze, J. Min, and H. Samueli, "Last Mile HFC Access." In *Broadband Last Mile: Access Technologies for Multimedia Communications*, CRC Press, Boca Raton, Fla., 2005.

Hranac, R. and M. Millet. “Upstream Power Measurements: Watts Up Doc?” *Communications Technology*, December 2000.

Hranac, R., “Linear Distortions, Part 1.” *Communications Technology*, July 2005.

Hranac, R., “Linear Distortions, Part 2.” *Communications Technology*, Aug. 2005.

Hranac, R., “CNR Versus SNR.” *Communications Technology*, Mar. 2003.

Hranac, R., “Spectrum Analyzer CNR Versus CMTS SNR.” *Communications Technology*, Sept. 2003.

Hranac, R., “More on CMTS SNR.” *Communications Technology*, Oct. 2003.

Hranac, R., “CMTS Upstream SNR Revisited.” *Communications Technology*, Apr. 2006.

Hranac, R., “Cable Modem Upstream Signal Levels.” *Communications Technology*, May 2006.

Hranac, R., “More on Cable Modem Upstream Signal Levels.” *Communications Technology*, June 2006.

Kolze, T., “An Approach to Upstream HFC Channel Modeling and Physical-Layer Design.” In *Cable Modems: Current Technologies and Applications*, International Engineering Consortium, Chicago, 1999.

NCTA Recommended Practices for Measurements on Cable Television Systems, 3rd Edition, National Cable & Telecommunications Association, Washington, D.C., 2002

Nyquist, H., “Certain Topics in Telegraph Transmission Theory.” Transactions of the A. I. E. E., pp. 617–644, Feb. 1928.

Proakis, J., *Digital Communications*. McGraw-Hill, 3rd Ed., 1999.

Simon, M., S. Hinedi, and W. Lindsey, *Digital Communication Techniques*. Prentice-Hall, Englewood Cliffs, N.J., 1994.

Tektronix, “Measuring Noise in Video Systems.” Application Note 25W-11148-0, 1997.

Terreault, G., “Signal Impairments: A Closer Look at MER and BER.” *Communications Technology*, Dec. 2002.

Williams, T., “Upstream Data Impairments, Part 1.” *Communications Technology*, Nov. 2003.

Williams, T., “Upstream Data Impairments, Part 2.” *Communications Technology*, Dec. 2004.

Acknowledgments

Authors: Ron Hranac (Cisco Systems, Inc.) and Bruce Currivan (Broadcom Corporation)

The authors would like to acknowledge the contributions of the following reviewers:

Arris International, Inc.: Scott Brown

Broadcom Corporation: Victor Hou, Tom Kolze (special mention), Jonathan Min, and Rich Prodan

BigBand Networks: Hal Roberts

Cisco Systems, Inc.: John Downey, Rick Meller, and Greg Taylor

HEYS Professional Services: Francis Edgington

Motorola, Inc.: Jack Moran

Sunrise Telecom, Inc.: Gerard Terreault

Xytrans Corporation: Rob Howald