Two important parameters that are often used to characterize digitally modulated signals are BER and MER. But just what do these abbreviations mean, what do they tell us, and why should they be part of our maintenance and troubleshooting toolbox? This SCTE Cable-Tec Expo pre-conference tutorial answers these questions and more!

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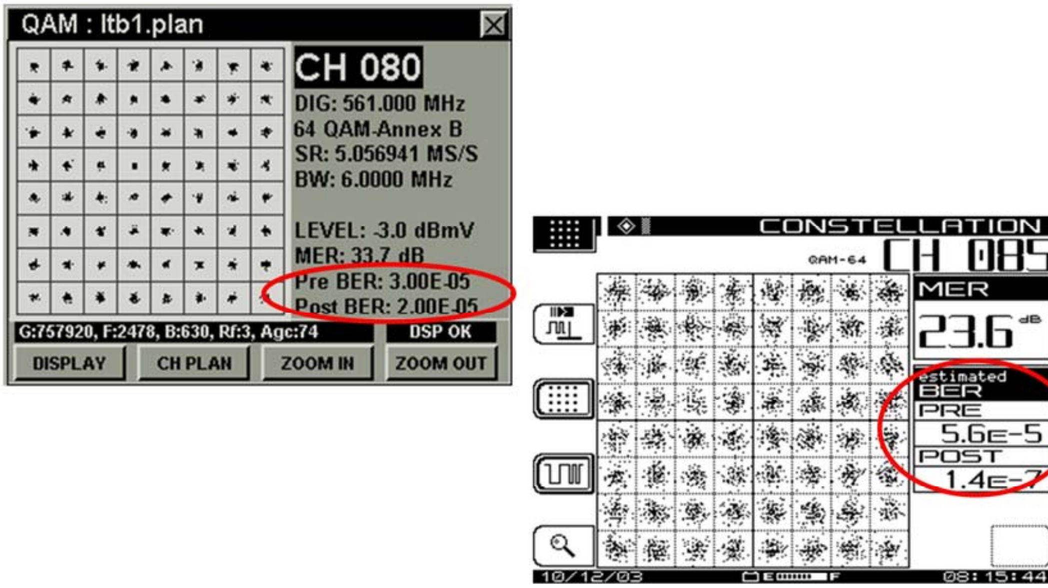
What is BER?



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BER is one of several performance metrics used in the world of data transmission. QAM (quadrature amplitude modulation) analyzers commonly report BER, as do some digital set tops and cable modems. BER is an abbreviation for bit error rate or bit error ratio, the latter actually being more technically correct.

What do the two QAM analyzer displays tell us about BER? Looking at the upper display, we see “Pre BER: 3.00E-05” and “Post BER: 2.00E-05”. The “Pre BER” says there were 3 errored bits received out of 100,000 transmitted, and the “Post BER” 2 errored bits received out of 100,000 transmitted. On the lower display we see “PRE 5.6E-5” and “POST 1.4E-7”. These tell us there were 56 errored bits received out of 1,000,000 bits transmitted and 14 errored bits received out of 100,000,000 bits transmitted respectively. More on how to interpret BER readings later.

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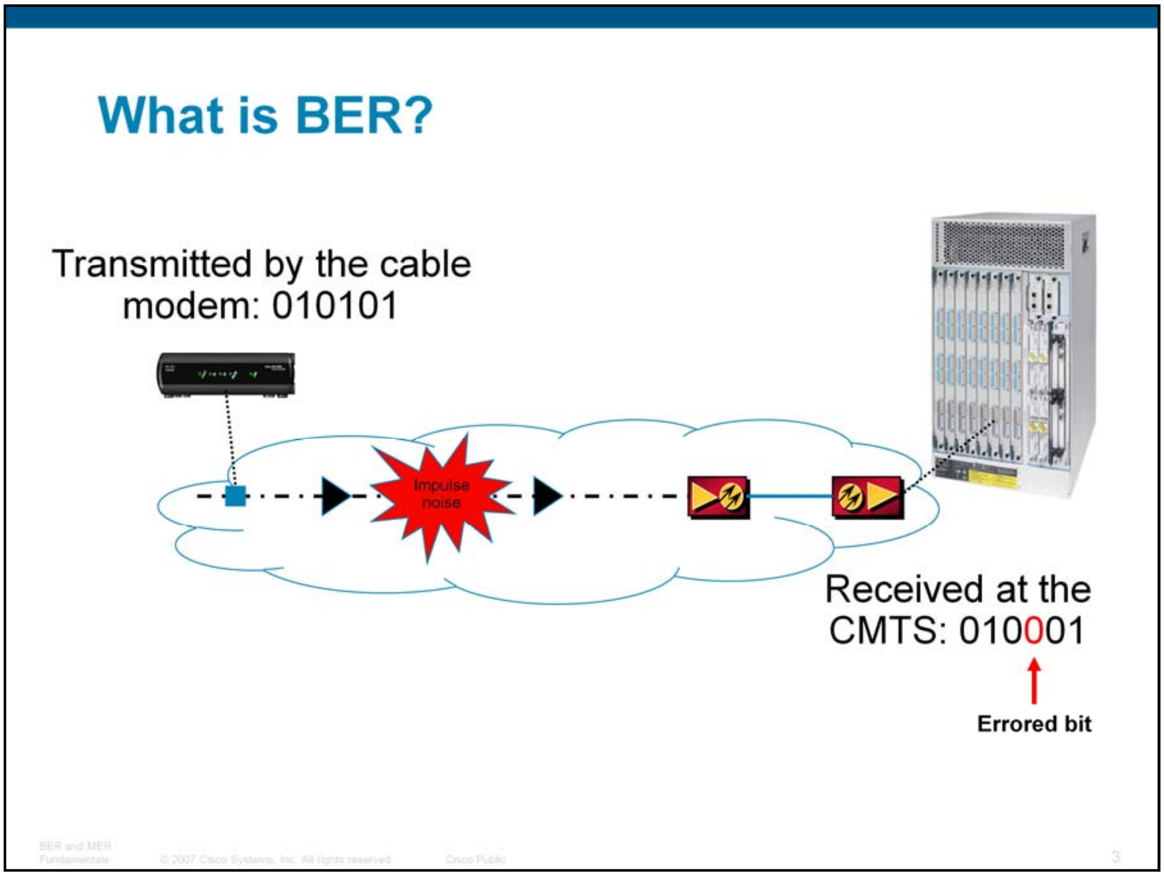

BER is the estimated probability that a bit transmitted through a device or network will be received incorrectly. For instance, if a 1 is transmitted and it's subsequently received as a 0, the result is a bit error. BER is measured or estimated by transmitting some number of bits, and comparing the number of incorrect or errored bits received at the other end to the total number of bits received.

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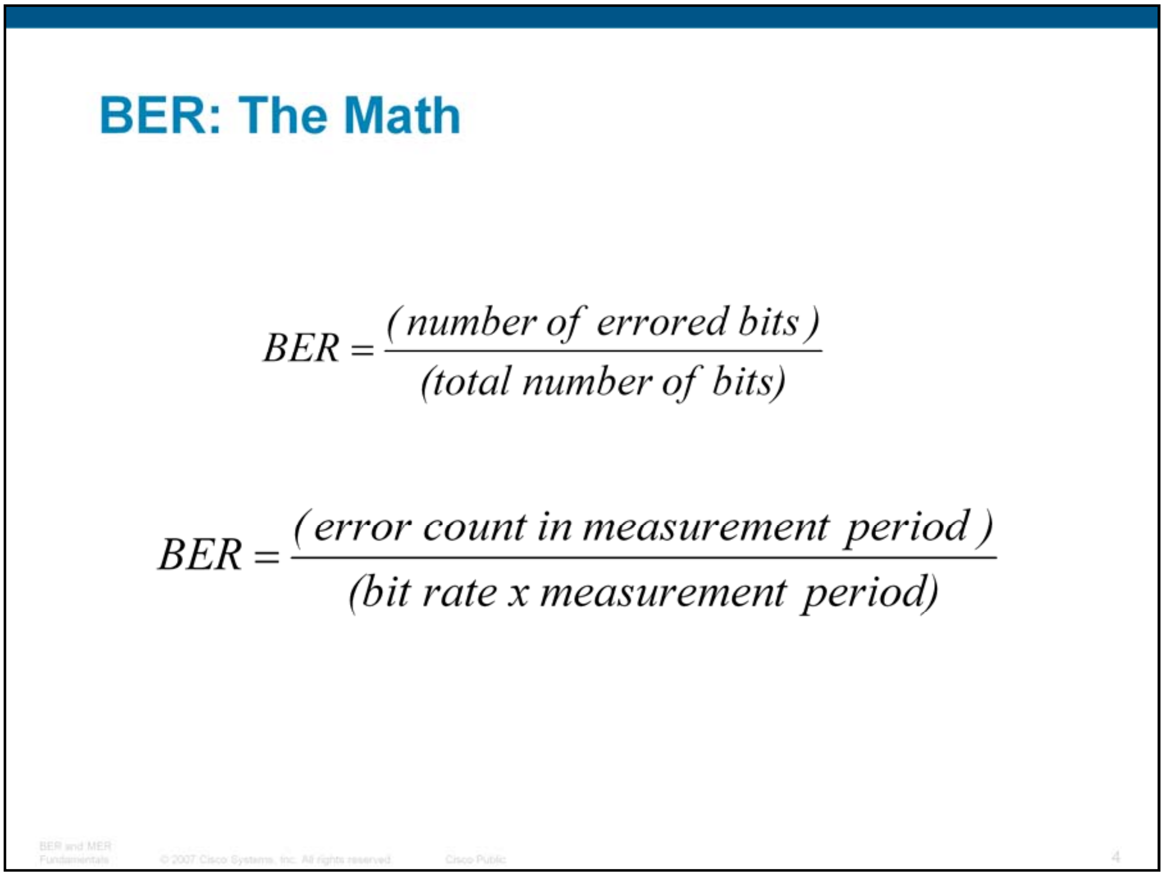

In general, BER is the ratio of errored bits to the total number of bits transmitted, received, or processed over a defined amount of time. Mathematically, two formulas are often used to describe BER:

BER = (number of errored bits)/(total number of bits)

BER = (error count in measurement period)/(bit rate x measurement period)

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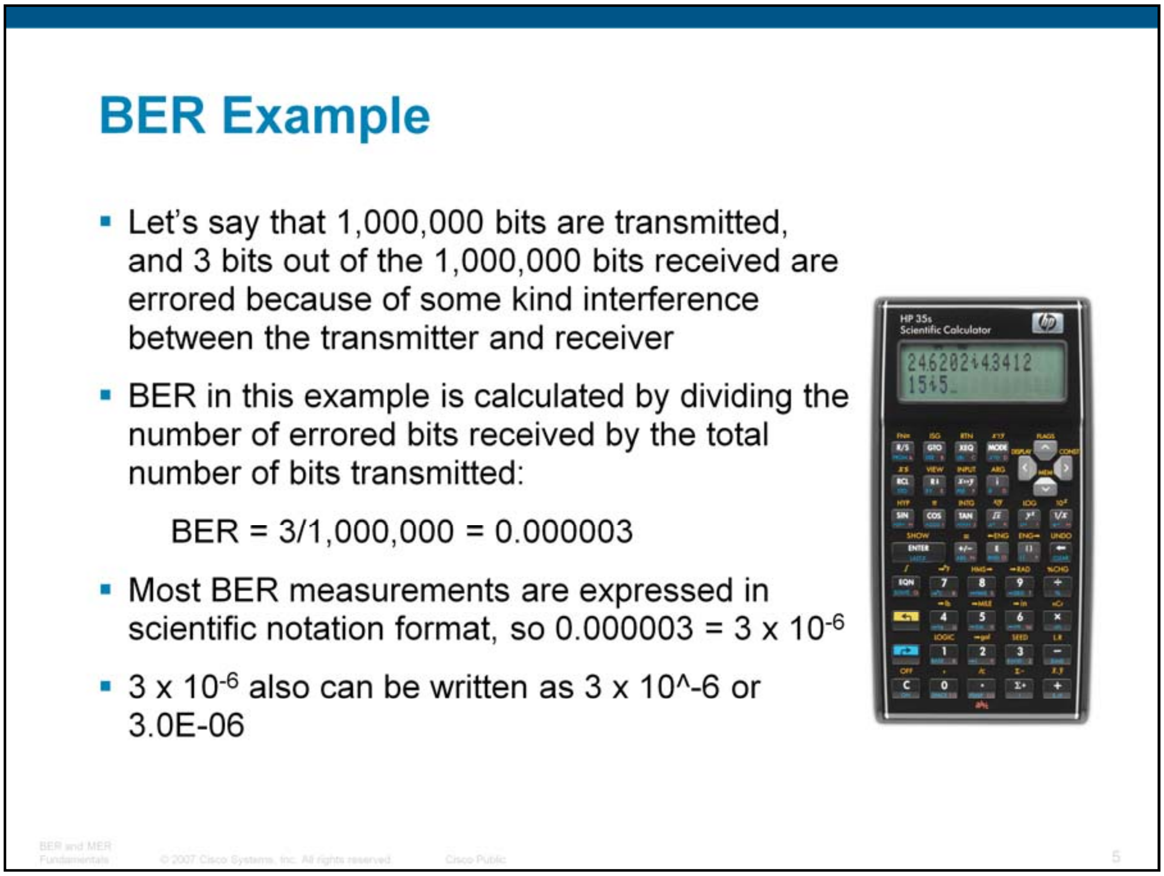

Here's an example of calculating BER using the first formula.

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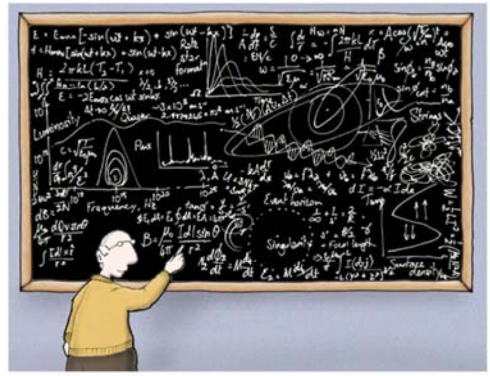
Scientific Notation



1,000,000 = 1 x 10^6 or 1.0E06
100,000 = 1 x 10^5 or 1.0E05
10,000 = 1 x 10^4 or 1.0E04
1,000 = 1 x 10^3 or 1.0E03
100 = 1 x 10^2 or 1.0E02
10 = 1 x 10^1 or 1.0E01
1 = 1 x 10^0 or 1.0E00
1/10 or 0.1 = 1 x 10^{-1} or 1.0E-01
1/100 or 0.01 = 1 x 10^{-2} or 1.0E-02
1/1,000 or 0.001 = 1 x 10^{-3} or 1.0E-03
1/10,000 or 0.0001 = 1 x 10^{-4} or 1.0E-04
1/100,000 or 0.00001 = 1 x 10^{-5} or 1.0E-05
1/1,000,000 or 0.000001 = 1 x 10^{-6} or 1.0E-06

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This table highlights several large and small numbers expressed in scientific notation format. For instance, 10,000 is 1 x 10^4 or 1.0E04, and 0.0001 is 1 x 10^{-4} or 1.0E-04.

Which of the following do you think represents a better BER: 1.6E-06 or 8.7E-06? Let's look at each value more closely, and see if we can discern which one means fewer bit errors. 1.6E-06, or 1.6 x 10^{-6} = 0.0000016, and 8.7E-06, or 8.7 x 10^{-6} = 0.0000087. In the case of the former, the stated BER tells us that there were 16 errored bits out of 10,000,000 bits: 16/10,000,000 = 0.0000016. The latter value is 87 errored bits out of 10,000,000 bits: 87/10,000,000 = 0.0000087. In this example, 1.6E-06 is the better BER.

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Pre- and Post-FEC BER

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In a typical QAM analyzer, pre-FEC (forward error correction) BER is estimated after the Trellis decoder, descrambler (derandomizer), and deinterleaver, but before Reed Solomon (RS) decoding. Post-FEC BER is after RS decoding. Pre-FEC BER states the estimated BER *before* FEC attempts to fix errored bits, and post-FEC BER is the estimated BER *after* the FEC fixes as many broken bits as it can.

Remember the two QAM analyzer displays earlier in this presentation (slide 2)? The reported BER values from the upper display was “Pre BER: 3.00E-05” and “Post BER: 2.00E-05”. The “Pre BER” says there were 3 errored bits received out of 100,000 transmitted. This is the pre-FEC BER, or the “raw” BER before FEC fixed the broken bits. The “Post BER” shows 2 errored bits received out of 100,000 transmitted, and is the post-FEC BER—that is, the BER after FEC fixed as many broken bits as it was able. On the lower display were “PRE 5.6E-5” and “POST 1.4E-7”. These tell us there were 56 errored bits received out of 1,000,000 bits transmitted—the pre-FEC BER before FEC fixed broken bits—and 14 errored bits received out of 100,000,000 bits transmitted—the post-FEC BER, after the FEC fixed as many broken bits as it could. Let’s work through the numbers:

3.00E-05 = 3×10^{-5} = 0.00003 = 3/100,000

2.00E-05 = 2×10^{-5} = 0.00002 = 2/100,000

5.6E-5 = 5.6×10^{-5} = 0.000056 = 56/1,000,000

1.4E-7 = 1.4×10^{-7} = 0.00000014 = 14/100,000,000

Pre- and Post-FEC BER

- Let's say that in our earlier example of 3 errored bits received out of 1,000,000 bits transmitted (BER = 3 x 10^{-6}), the receiver's FEC is able to fix only 2 of the 3 errored bits
- The pre-FEC BER is, of course, the "raw" BER of 3 x 10^{-6}
- The post-FEC BER is 1 x 10^{-6}, since there is still 1 errored bit remaining after the FEC did its magic and fixed the other 2 broken bits
- Most QAM analyzers would report these values as 3.0E-06 and 1.0E-06 respectively

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Here's a simplified explanation of pre- and post-FEC BER. Ideally there should be no pre- or post-FEC errors, so if they show up you need to find out why and fix the problem.

A Quick Side Note

In reality, a QAM receiver's Reed-Solomon decoder can easily fix the three bit errors in the previous example, although it is still a good illustration of the principle involved. In fact, the Reed-Solomon decoder in a DOCSIS cable modem can fix any three errored Reed-Solomon symbols in a codeword. This capability is commonly expressed as "t = 3". Each Reed-Solomon symbol is a group of seven bits. A Reed-Solomon codeword or block consists of 128 Reed-Solomon symbols, of which 122 are actual data symbols and six are "parity" symbols that allow for error correction. It doesn't matter to the decoder if one bit is wrong in a symbol or if all seven bits are wrong; the symbol is still considered wrong. So, in three errored Reed-Solomon symbols there can be anywhere from a total of three to 21 bit errors. Thus, the Reed-Solomon decoder can correct up to 21 bit errors in a codeword, depending how the bit errors are grouped.

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It is possible for the Reed-Solomon decoder to fail to decode. Let's say there are four input bit errors in a Reed-Solomon block, spread out with each bit error in a single Reed-Solomon symbol. This is more than t = 3, so the decoder can't correct the errors. It usually detects this condition, and outputs the data unchanged (the decoder should do it this way, depending on implementation). What does this mean? The output will include all four bit errors! If the decoder doesn't know it couldn't fix the block, it may try to fix it anyway, and output even more errors than four. This is less probable since most of the time the decoder can detect the errors. But for weak Reed-Solomon decoders—t = 3 is pretty weak, t = 8 is better and is more common—the probability of not detecting the error condition is not negligible. So, the Reed-Solomon decoder output may be bursty.

All of this makes BER more complicated than it needs to be when Reed-Solomon decoders are involved. Indeed, some prefer codeword error rate (CER) over BER in DOCSIS® high-speed data.

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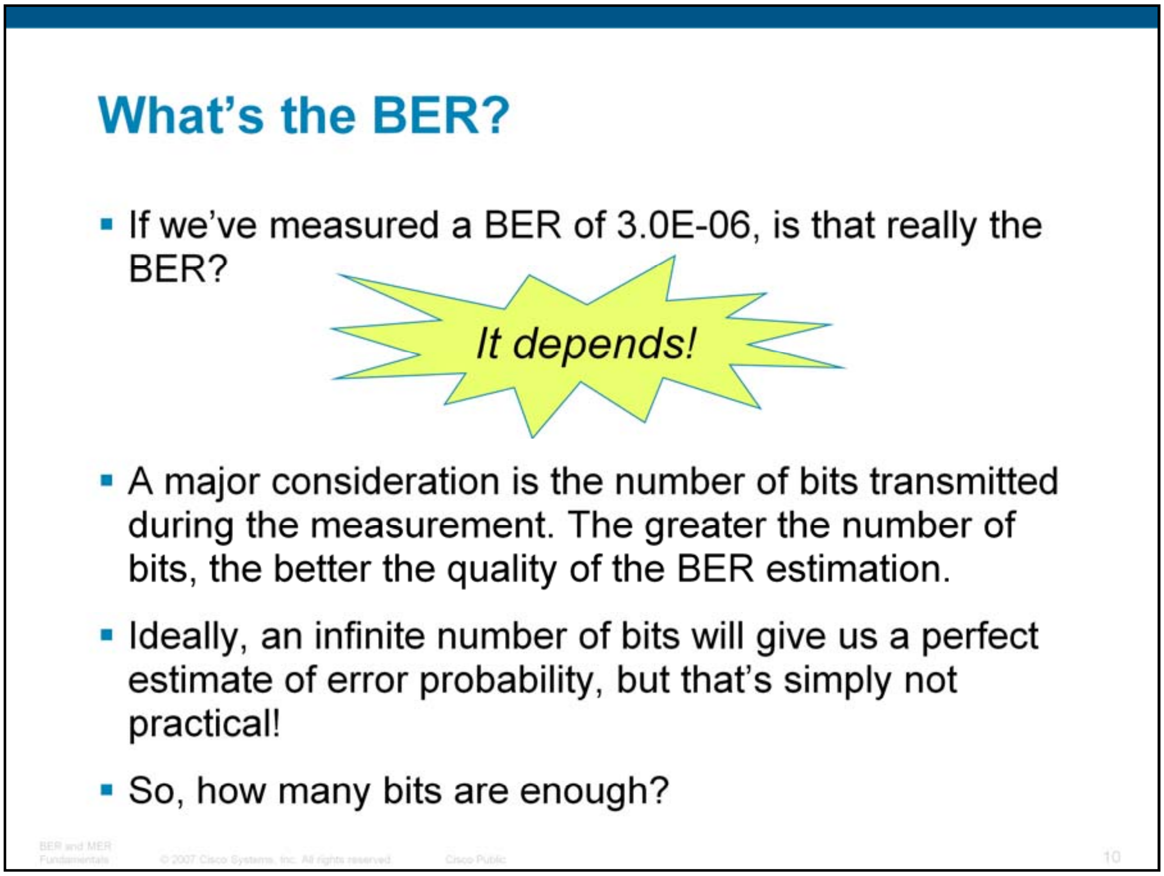

Here's where things get interesting. If we've measured a BER of 3.0E-06, is that really the BER? It's beginning to look as if the answer might fall into the category of "it depends."

First, would you expect a $40 cable modem to report BER as accurately as a $3,000 QAM analyzer? What about the QAM analyzer's accuracy compared to a $120,000 lab-grade BER test set? Clearly, receiver quality is important and may impact reported BER.

One major consideration is the number of bits transmitted during the measurement. The greater the number of bits, the better the quality of the BER estimation. Ideally, an infinite number of bits will give us a perfect estimate of error probability, but that simply isn't practical. Okay, how many bits are enough?

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How Many Bits are Enough?

- One rule of thumb is that transmitting 3 times the reciprocal of the specified BER without an error gives 95% confidence level that the device or network meets the BER spec.
- If one wants 99% confidence level, the multiplier is 4.61 rather than 3

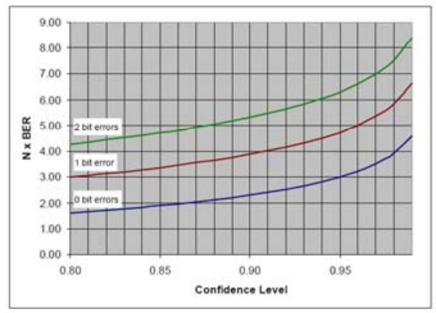
These multipliers are derived from some gnarly statistics mathematics involving binomial distribution function and Poisson theorem

$$C_{(n,k)} = \frac{n!}{k! * (n-k)!}$$

$$P_{tot} = C_{(n,k)} * [p^k * (1-p)^{(n-k)}]$$

$$CL = \text{PROB}\ [BER_T < R] \text{ given } E \text{ and } N$$

$$N = \frac{1}{BER}\left[-\ln(1-CL) + \ln\left(\sum_{k=0}^{E} \frac{(N \times BER)^k}{k!}\right)\right]$$



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One rule of thumb is that transmitting 3 times the reciprocal of the specified BER without an error gives 95% confidence level that the device or network meets the BER spec. If one wants 99% confidence level, the multiplier is 4.61 rather than 3. The multipliers are derived from some gnarly statistics math involving binomial distribution function and Poisson theorem. These numbers strictly apply to independent bit errors, and as we have seen previously, the errors at the output of a Reed-Solomon decoder are not independent. But they are still a good illustration of the concept involved.

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How Many Bits are Enough?

- Let's say we want to ensure the BER at a cable modem's input is 1×10^{-8} (1.0E-08), at a 95% confidence level.

  As mentioned previously, 95% confidence level requires transmitting 3 times the reciprocal of the specified BER without an error

- First, let's figure out the reciprocal of the BER in question:

  $1/(1 \times 10^{-8}) = 1/0.00000001 = 100{,}000{,}000$

- The required number of bits to be transmitted is 3 x 100,000,000 = 300,000,000

  300,000,000 bits is the same as 3×10^{8} bits

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Let's say we want to ensure the BER—bit error rate or bit error ratio—at a cable modem's input is less than 1×10^{-8}, also expressed as 1.0E-08. Recall that transmitting 3 times the reciprocal of the specified BER without an error gives 95% confidence level that the device or network meets the BER spec. If one wants 99% confidence level, the multiplier is 4.61 rather than 3. The reciprocal of 1×10^{-8} is $1/(1 \times 10^{-8}) = 1/0.00000001 = 100{,}000{,}000$, and 3 x 100,000,000 = 300,000,000. So, if we transmit 300 million bits and receive all 300 million bits without an error, the confidence level is 95% that we meet 1×10^{-8} BER.

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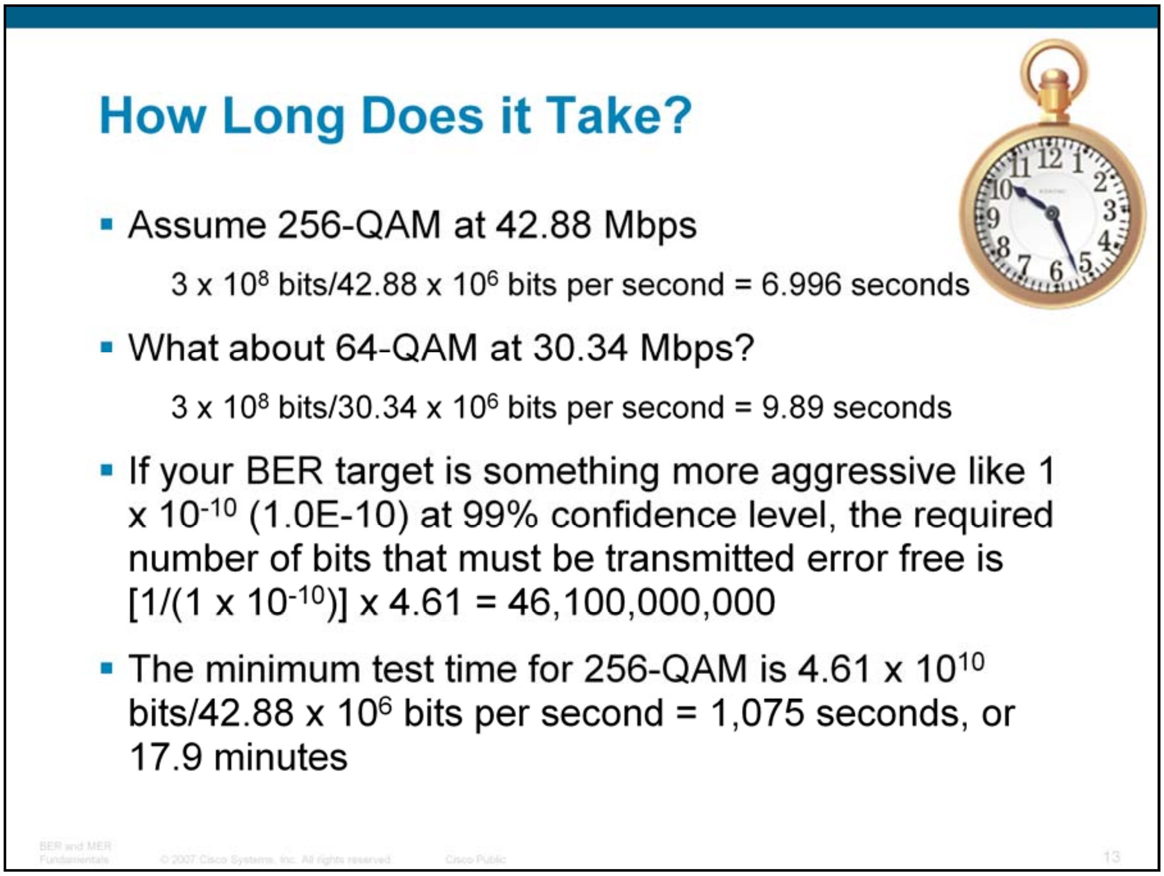

Another important factor in BER estimation is the duration of the measurement. Bit errors can be caused by all sorts of things—random noise, bursty or impulsive interference (laser clipping, sweep transmitter interference), etc. If one makes a brief BER measurement during an interval of time in which a particular intermittent interference is not occurring, the BER estimate won't accurately reflect what's really happening. One common question is "How long is long enough when performing a BER measurement?" The answer is "it depends." Clearly, the longer the measurement duration the better.

As mentioned previously, 95% confidence level for 1 x 10^{-8} BER requires that we transmit at least 300,000,000 bits without an error. How long does it take to transmit 300 million bits? Assuming 256-QAM at 42.88 Mbps, the minimum test time is 3 x 10^{8} bits/42.88 x 10^{6} bits per second = 6.996 seconds. For 64-QAM at 30.34 Mbps, the minimum test time is 3 x 10^{8} bits/30.34 x 10^{6} bits per second = 9.89 seconds. Of course, if your BER target is something more aggressive like 1 x 10^{-10} at 99% confidence level, the required number of bits that must be transmitted is [1/(1 x 10^{-10})] x 4.61 = 46,100,000,000. Here the minimum test time for 256-QAM is 4.61 x 10^{10} bits/42.88 x 10^{6} bits per second = 1,075 seconds, or 17.9 minutes. Keep in mind these minimum test times assume that all of the transmitted bits are received error-free.

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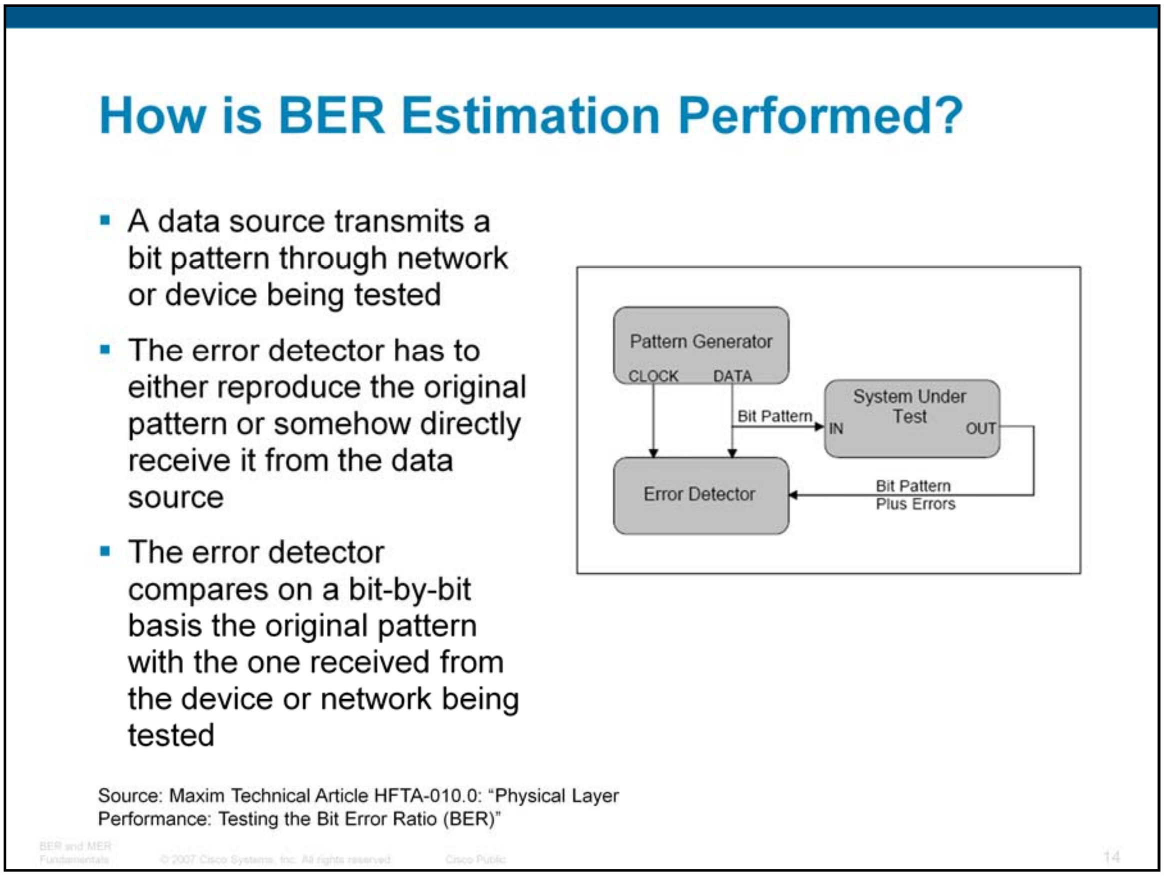

The way the BER estimation is performed is important. A true BER measurement involves a data source and error detector. The data source transmits a bit pattern through the device or network being tested, and the error detector has to either reproduce the original pattern or somehow directly receive it from the data source. Then the error detector compares on a bit-by-bit basis the original pattern with the one received from the device or network being tested. Any difference means one or more bit errors has occurred!

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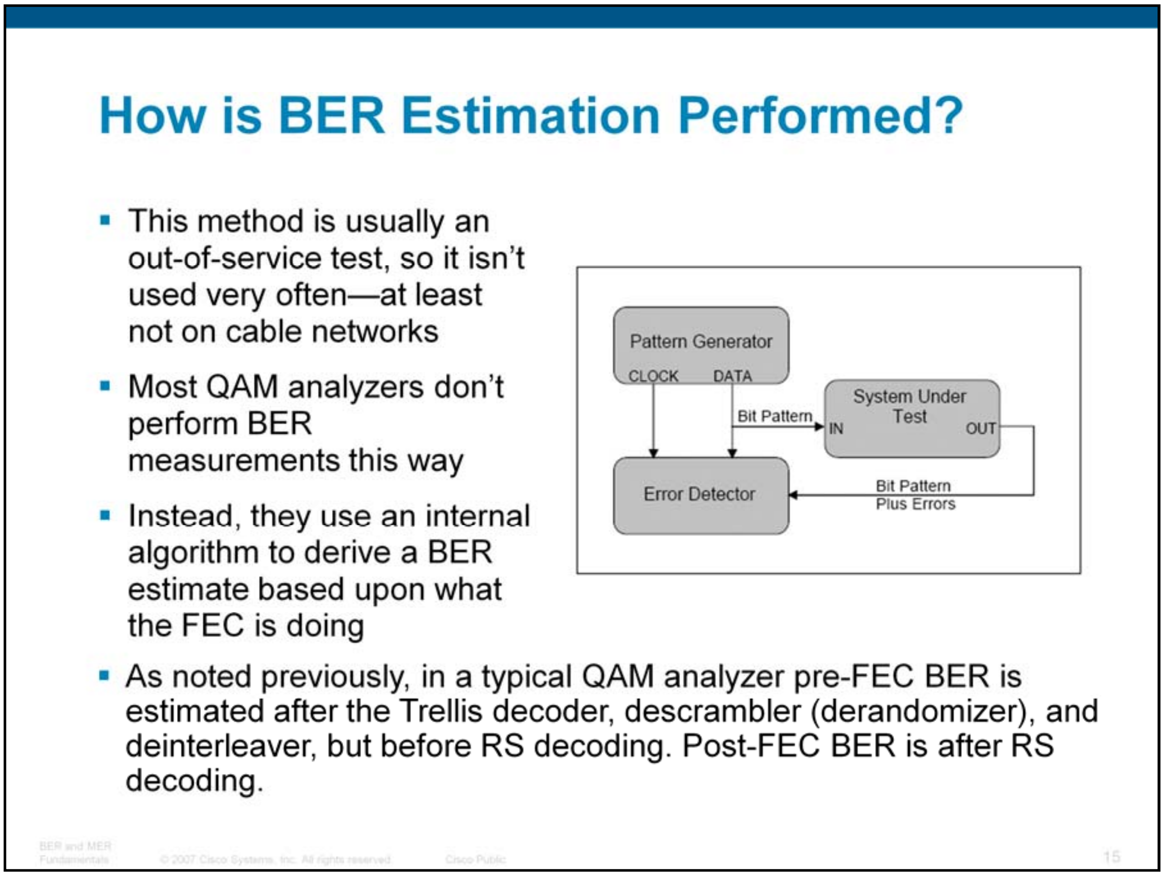

A true BER measurement is usually an out-of-service test, so it isn't used very often—at least not on cable networks. Most QAM analyzers don't perform BER measurements in this way. Instead, they use an internal algorithm to derive a BER estimate based upon what the forward error correction (FEC) is doing.

As noted previously, in a typical QAM analyzer pre-FEC BER is estimated after the Trellis decoder, descrambler (derandomizer), and deinterleaver, but before RS decoding. Post-FEC BER is after RS decoding.

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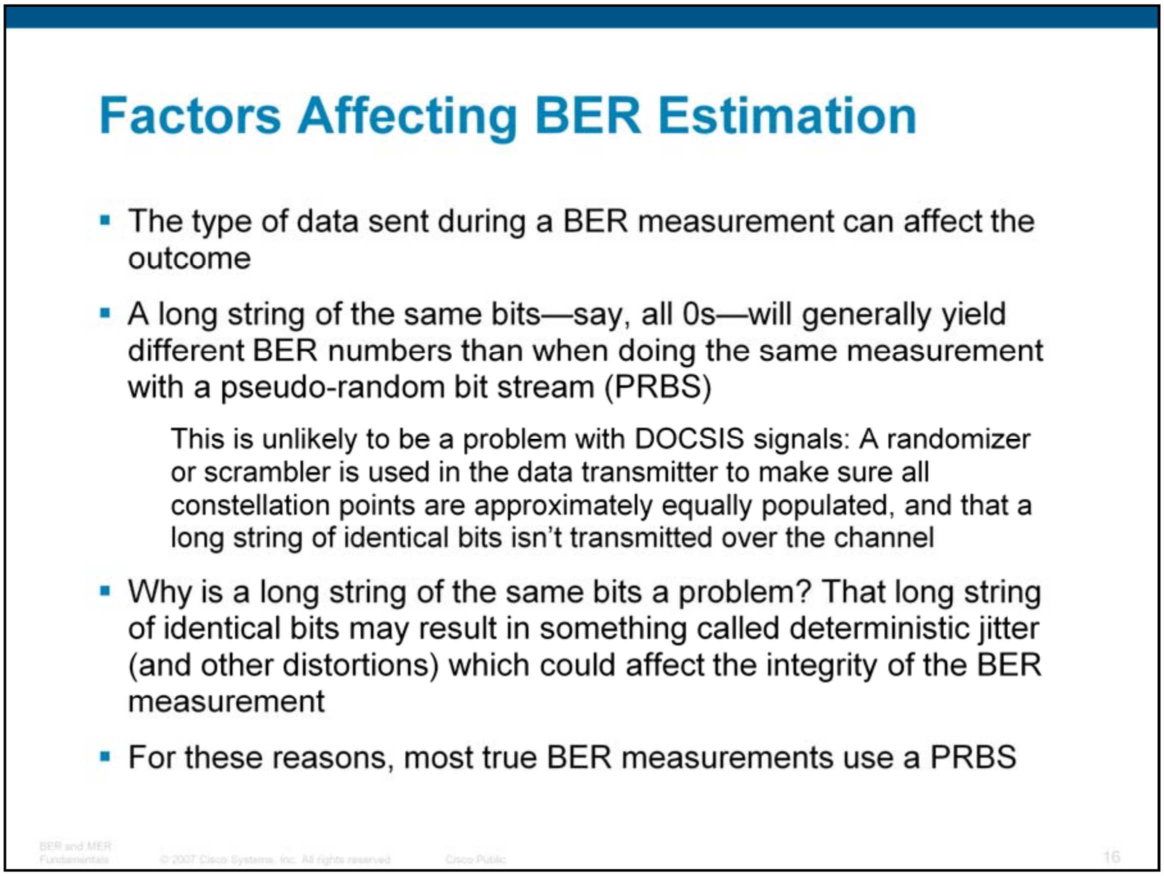

This in unlikely to be a problem when measuring BER on a DOCSIS digitally modulated signal. A randomizer or scrambler is used in the data transmitter to make sure that this sort of thing does not occur. The scrambler mixes the actual data stream with a pseudorandom sequence, so a long string of 0s or 1s will become randomized in the transmitted digitally modulated signal. At the receiver, the same pseudorandom sequence is used to descramble the data, giving back the original data.

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Avoid “False” BER

- Under some circumstances a QAM analyzer might incorrectly indicate the presence of bit errors
- Two typical scenarios are too much or too little RF input signal level
  - Too much input signal level may overload the QAM analyzer, which causes bit errors to be generated inside the analyzer
  - Too little input signal level means low carrier-to-noise ratio at the analyzer input, which also causes bit errors to be indicated
- Make sure the QAM analyzer’s RF input levels are within the range specified by the test equipment manufacturer

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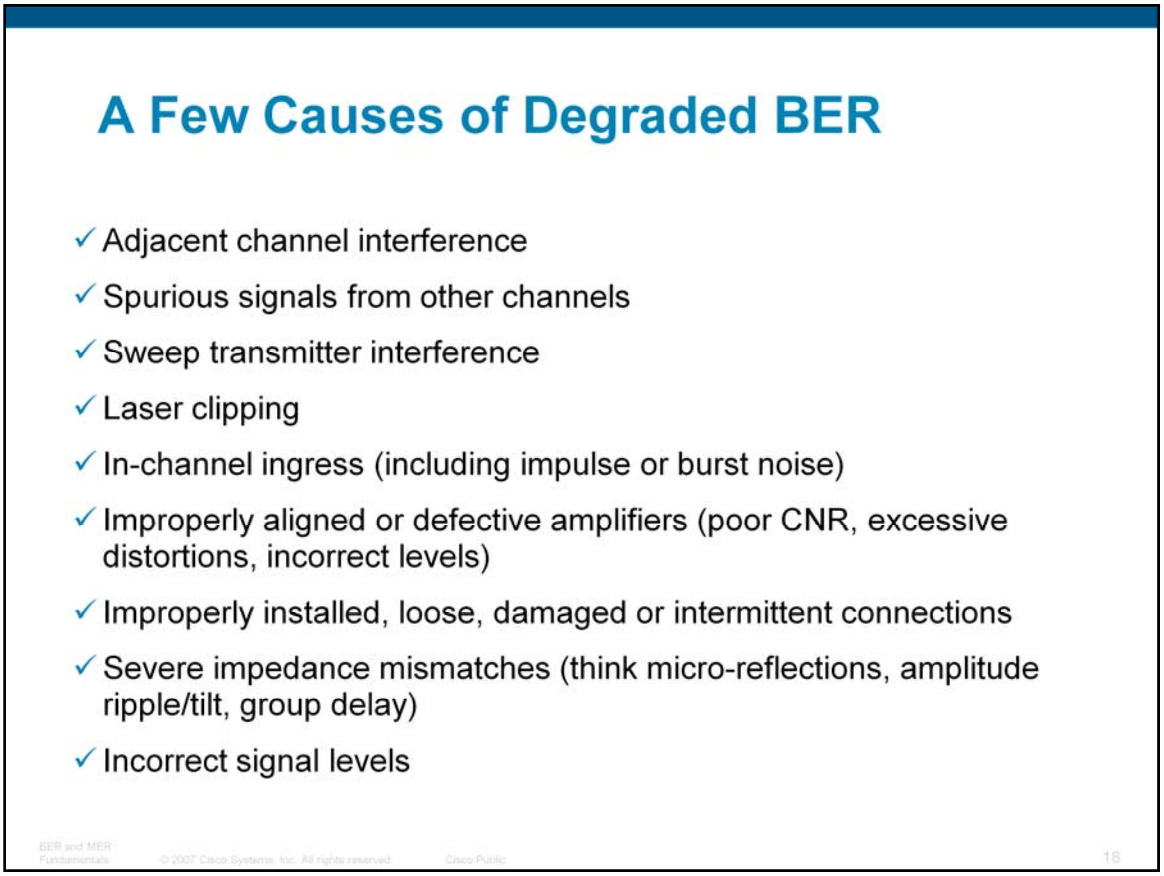

Here's a partial list of things that can cause bit errors in the hardline coax plant and subscriber drop. Use the divide-and-conquer technique to track down the location and cause of the problem.

At the customer premises, too much or too little signal can cause bit errors in the modem or set top box. In addition to measuring digital channel power on the QAM signal of interest, make sure that total power—the combined power of all downstream signals—is less than +30 dBmV.

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What About MER?

- To understand modulation error ratio (MER), we first need to understand the basics of digital modulation!
- Information such as sound (audio), images (video), and digital data can be transmitted from one point to another using radio waves
- This is done by modulating an RF signal—a carrier—with the information to be transmitted
- Modulation is the variation one or more properties of an RF signal to represent the information being transmitted: frequency, amplitude, phase

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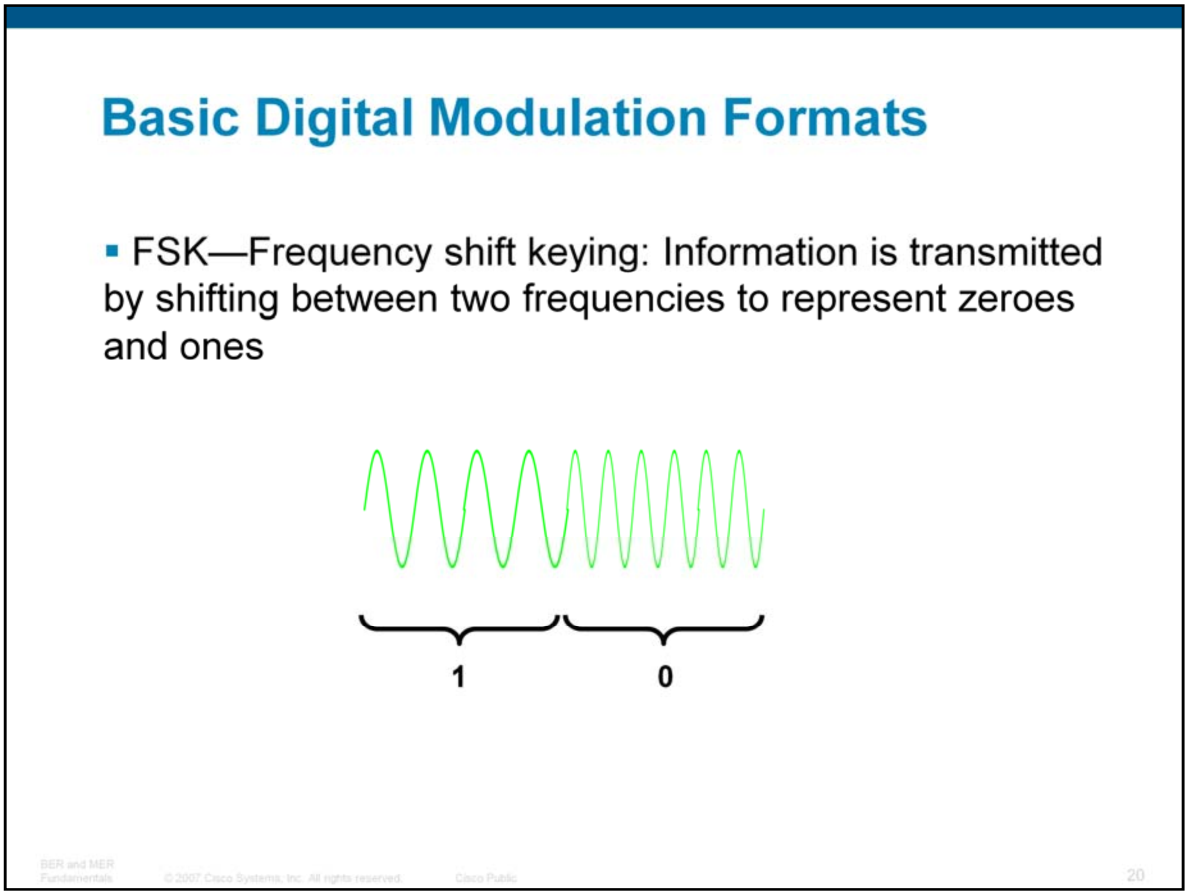

Frequency shift keying (FSK) involves varying the *frequency* of a carrier between different values to represent transmitted ones and zeros. In the example shown on the slide, a low frequency represents “1” and a slightly higher frequency represents “0”.

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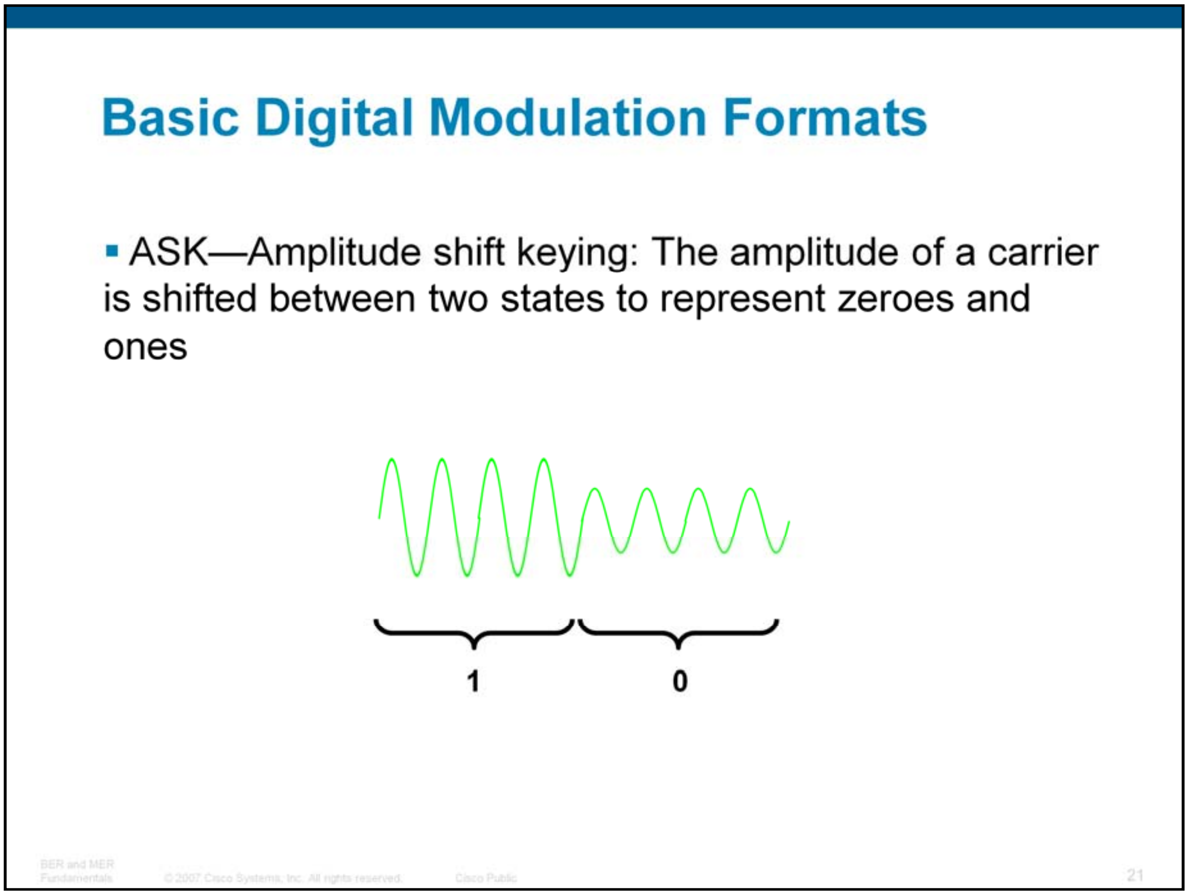

Amplitude shift keying (ASK) involves varying the *amplitude* of a carrier between different values to represent transmitted ones and zeros. In the examples shown on the slide, a high amplitude represents "1" and a low amplitude (or zero amplitude) represents "0".

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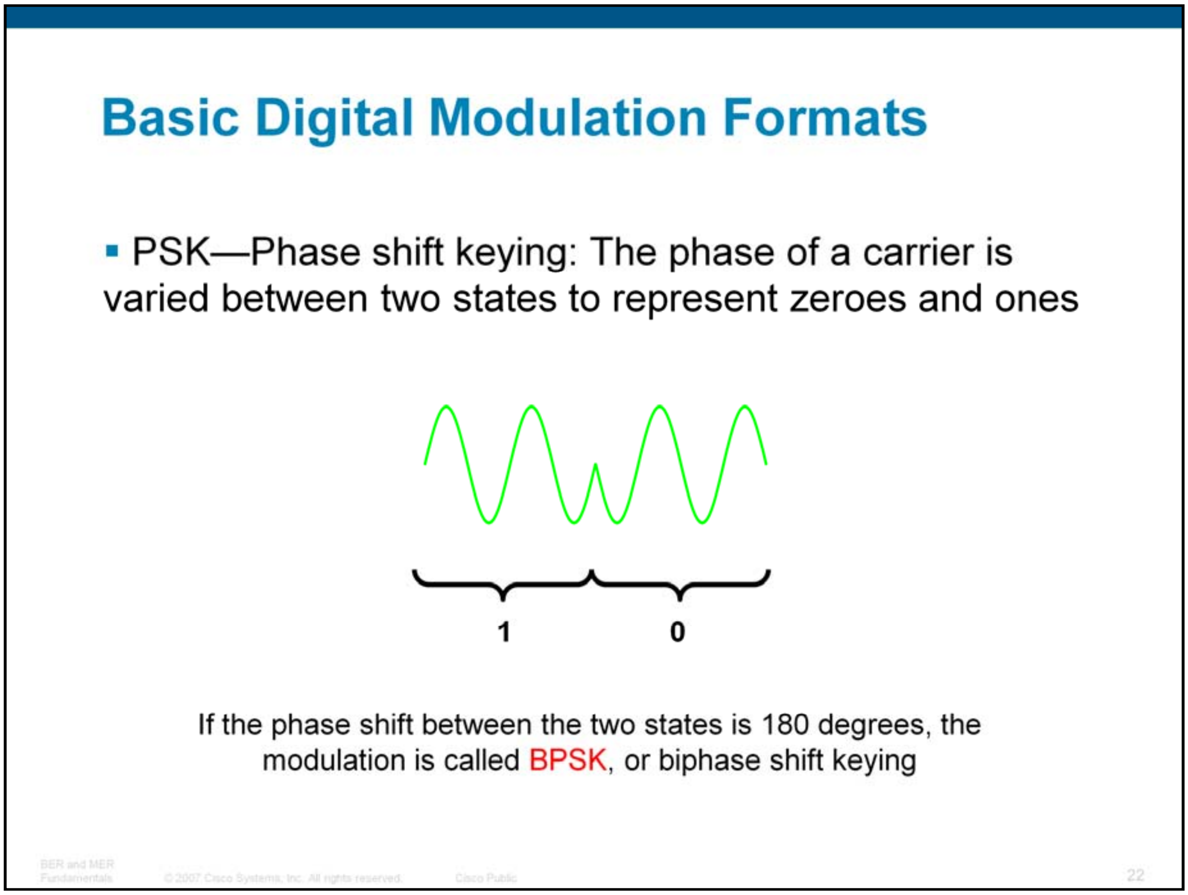

Phase shift keying (PSK) involves varying the *phase* of a carrier between different values to represent transmitted ones and zeros. In the example shown on the slide, one phase represents “1” and another phase—in this case different from the first phase by 180 degrees—represents “0”. When the phase shift is 180 degrees as shown, the modulation is known as biphase shift keying (BPSK).

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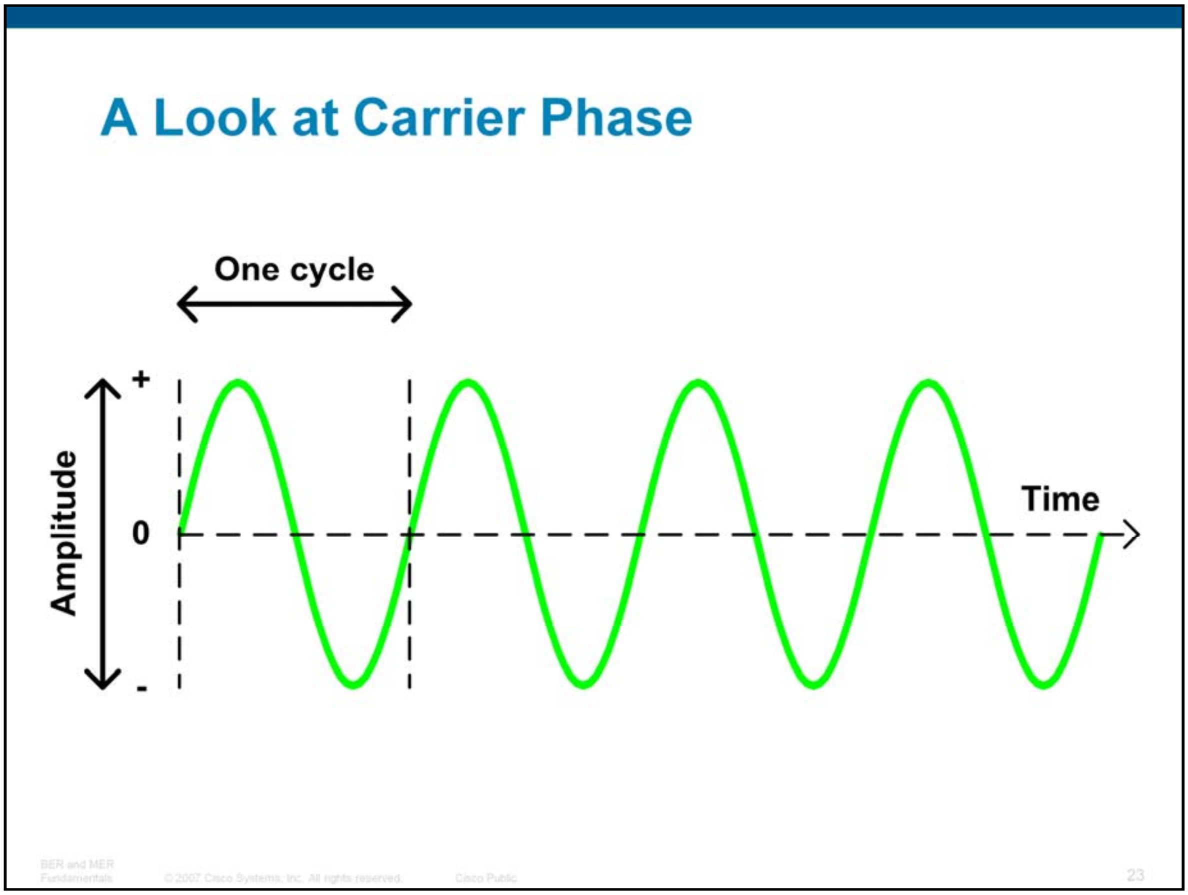

This slide illustrates a sine wave (unmodulated carrier) in the time domain, as might be seen on an oscilloscope. The vertical axis is amplitude and the horizontal axis is time.

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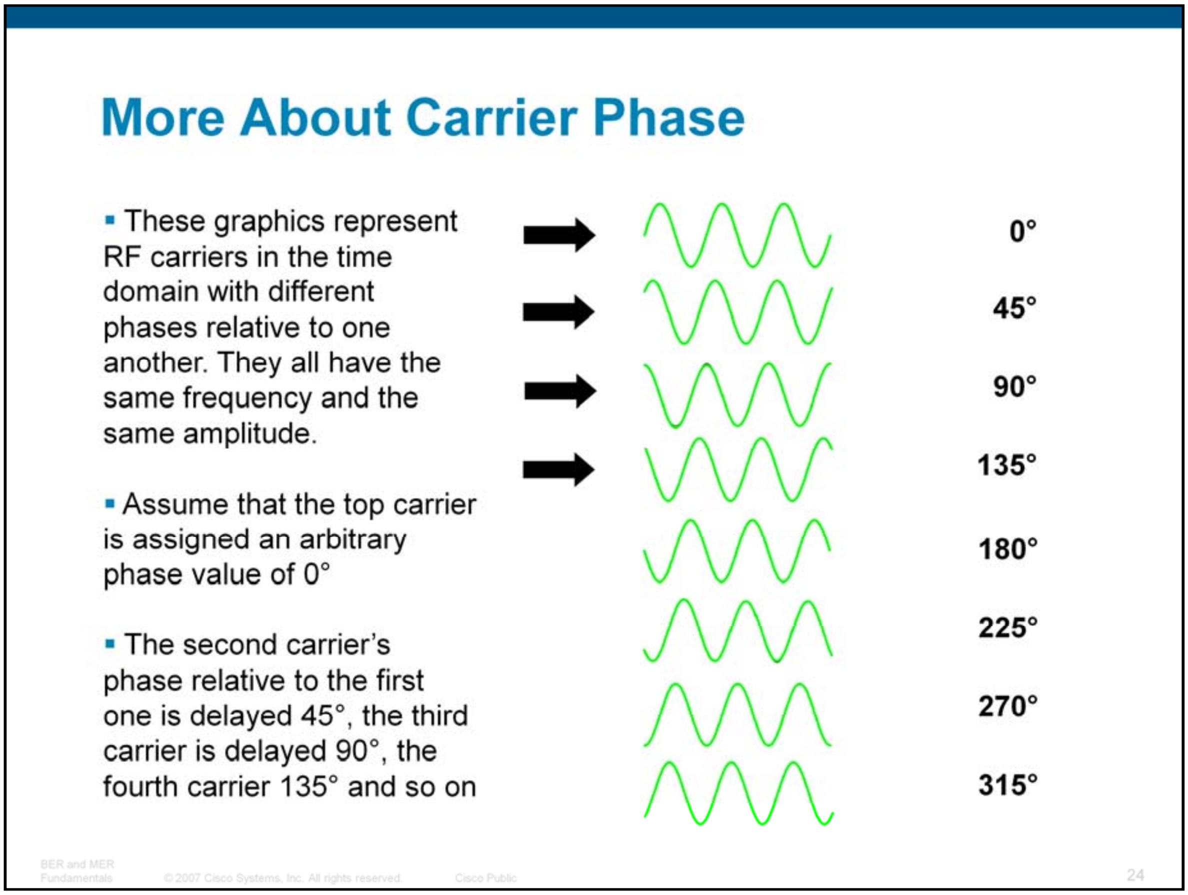

The sine wave graphics on the slide represent RF carriers in the time domain with different phases relative to one another. They all have the same frequency and the same amplitude. Assume that the top carrier is assigned an arbitrary phase value of 0°. The second carrier's phase relative to the first one is delayed 45°, the third carrier is delayed 90°, the fourth carrier 135° and so on.

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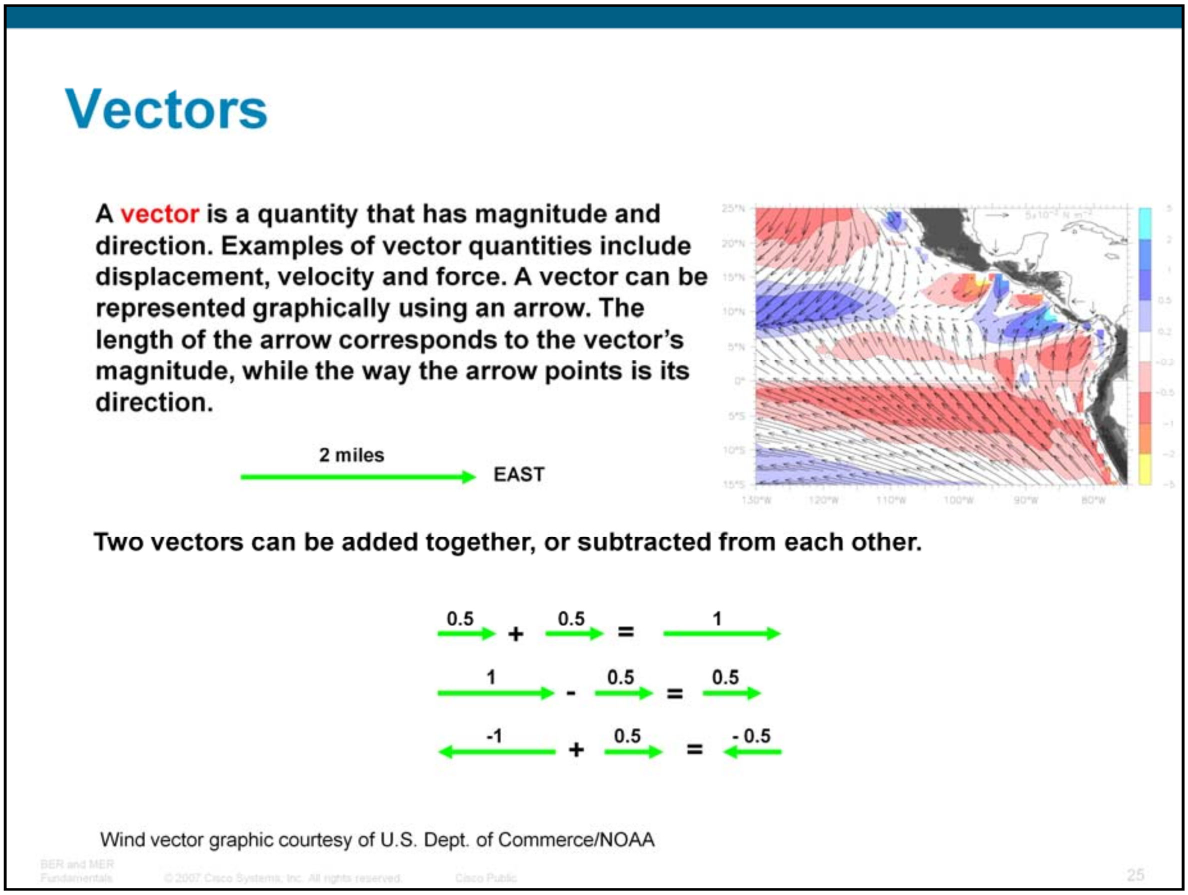

Understanding data constellations, and eventually MER, is much easier if one understands vectors.

We can also perform math with vectors. As shown on the slide, two vectors can be added together or subtracted from each other.

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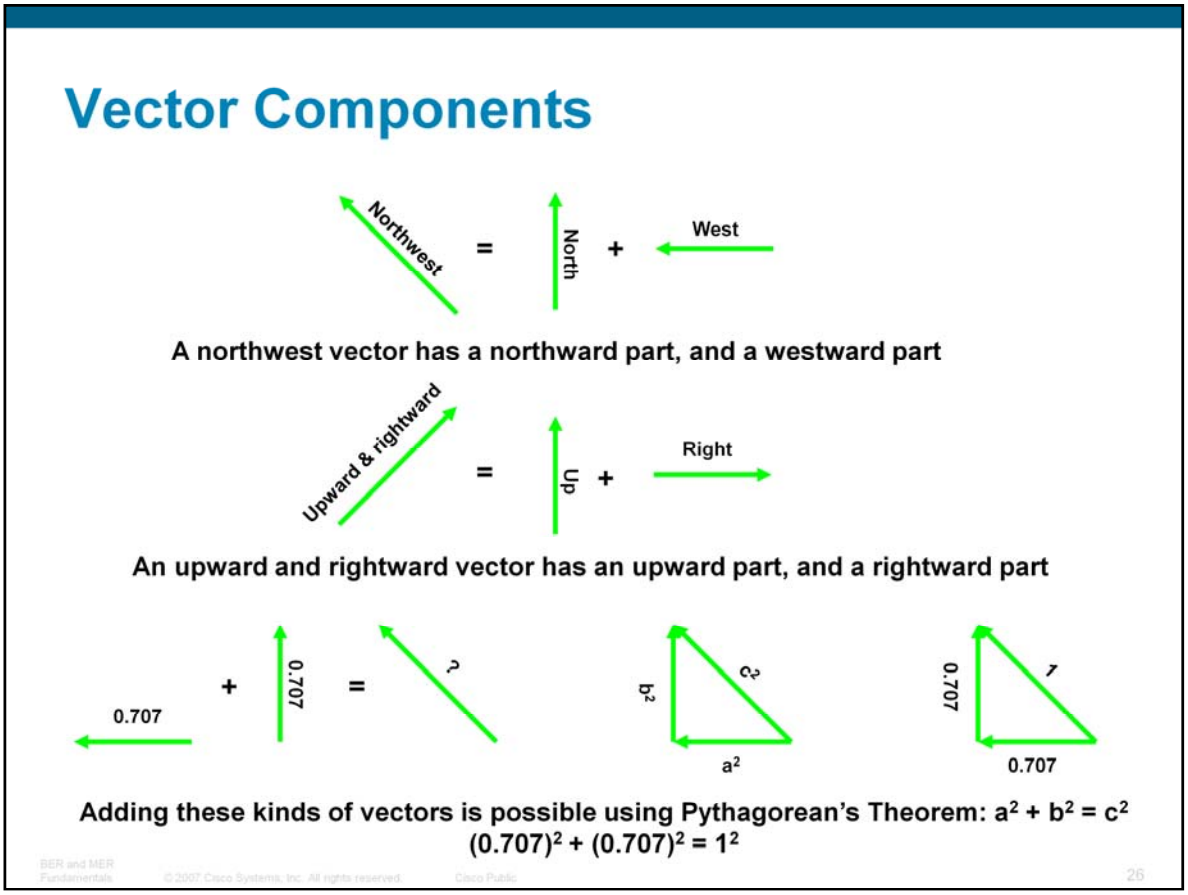

Vectors can have components, too. For example, a northwest vector has a northward part and a westward part. Likewise, an upward and rightward vector has an upward part and a rightward part. Adding the components of a vector together is possible using Pythagorean's Theorem: $a^2 + b^2 = c^2$.

In the example shown at the bottom of the slide, summing a leftward vector whose length is 0.707 and a northward vector whose length also is 0.707 gives us a northwest vector whose length is 1. This is basic geometry with right triangles: $(0.707)^2 + (0.707)^2 = 1^2$

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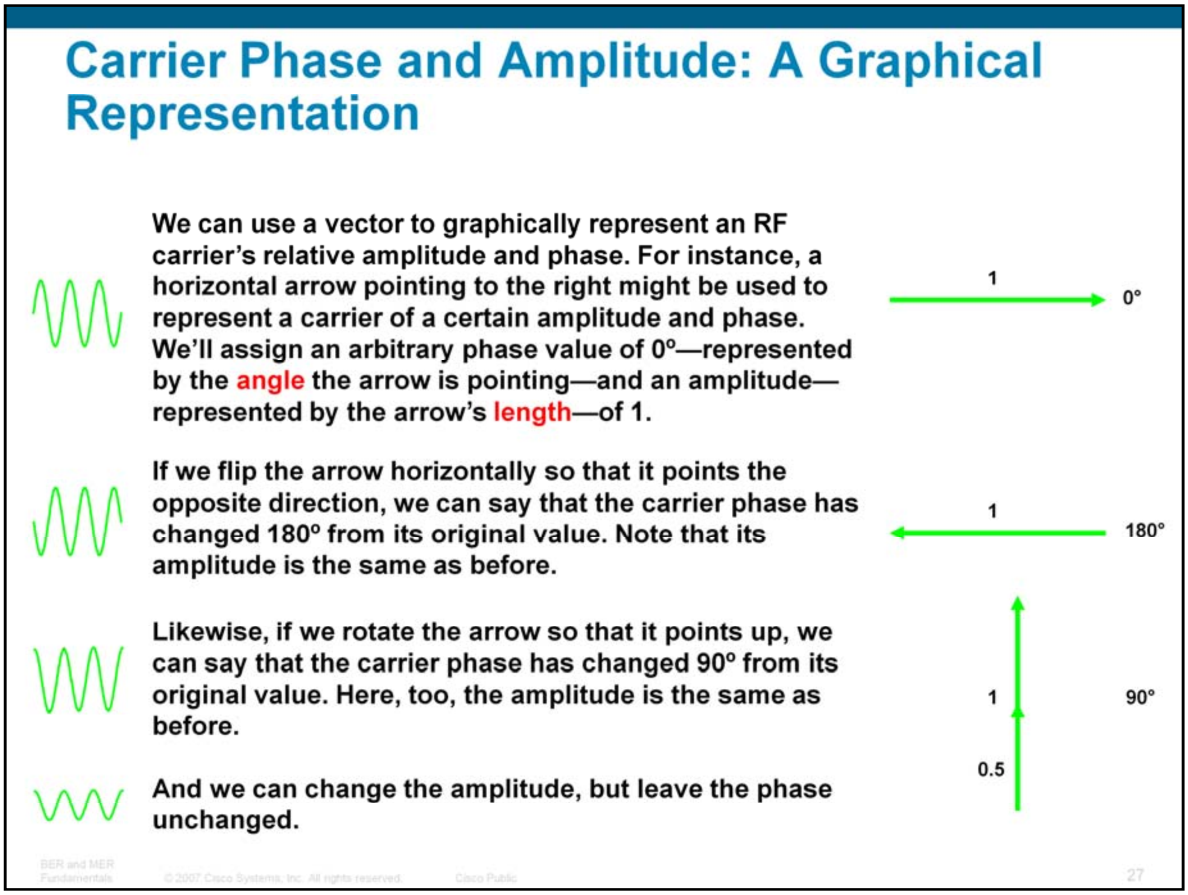

Vectors can be used to graphically represent an RF carrier, where the vector's length corresponds to the carrier's amplitude, and the direction the vector is pointing corresponds to the carrier's relative phase.

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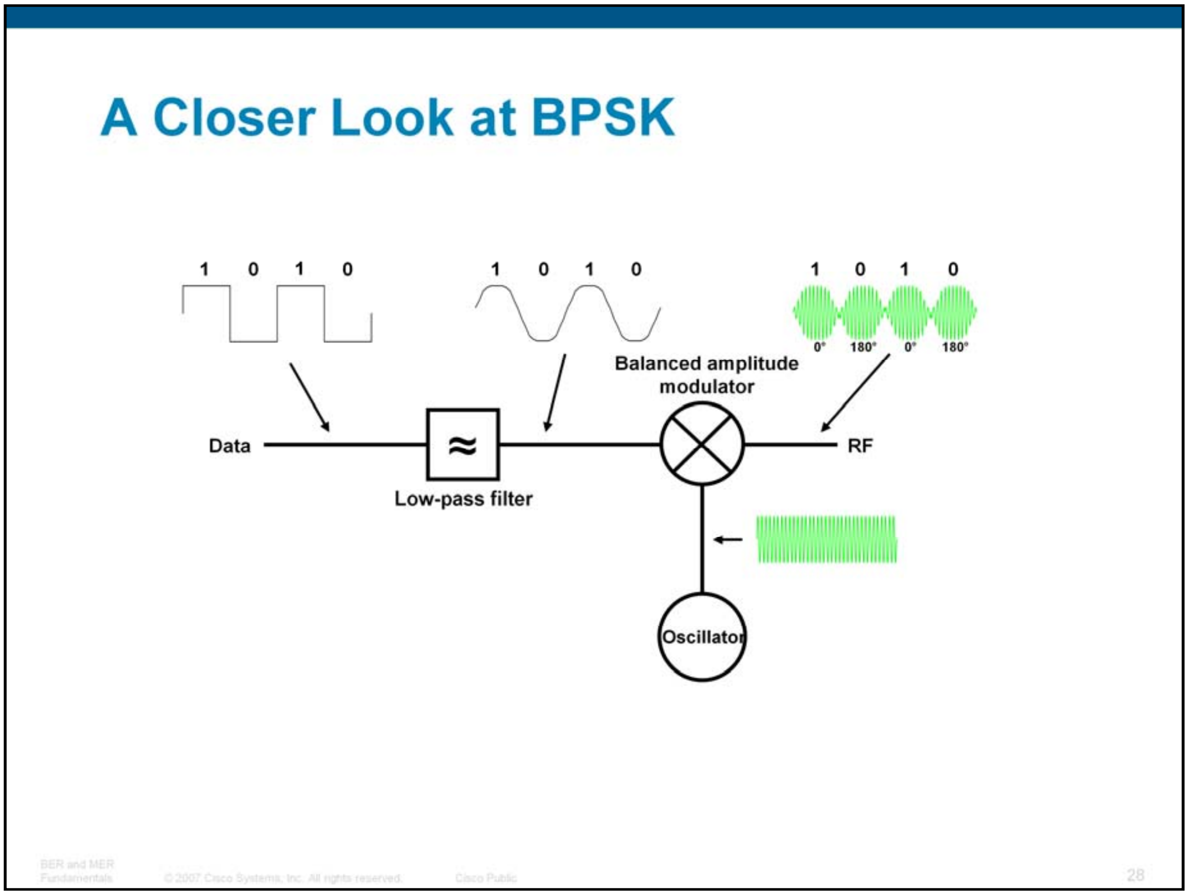

This slide illustrates a simple BPSK data modulator. The NRZ* data passes through a low-pass filter to remove higher order harmonics, then is applied to a balanced amplitude modulator. The filtered data amplitude modulates the RF signal from the oscillator, resulting in a double sideband, suppressed carrier RF signal. The modulated signal has one phase for a 1, and the opposite phase for a 0. Note that the carrier envelope drops to zero amplitude during the transitions between 1 and 0, a direct result of the low pass filter's action on the baseband signal.

*NRZ, or non-return-to-zero data, simply means a logic "one" is defined as a high voltage state, while a logic "zero" is defined as a low voltage state.

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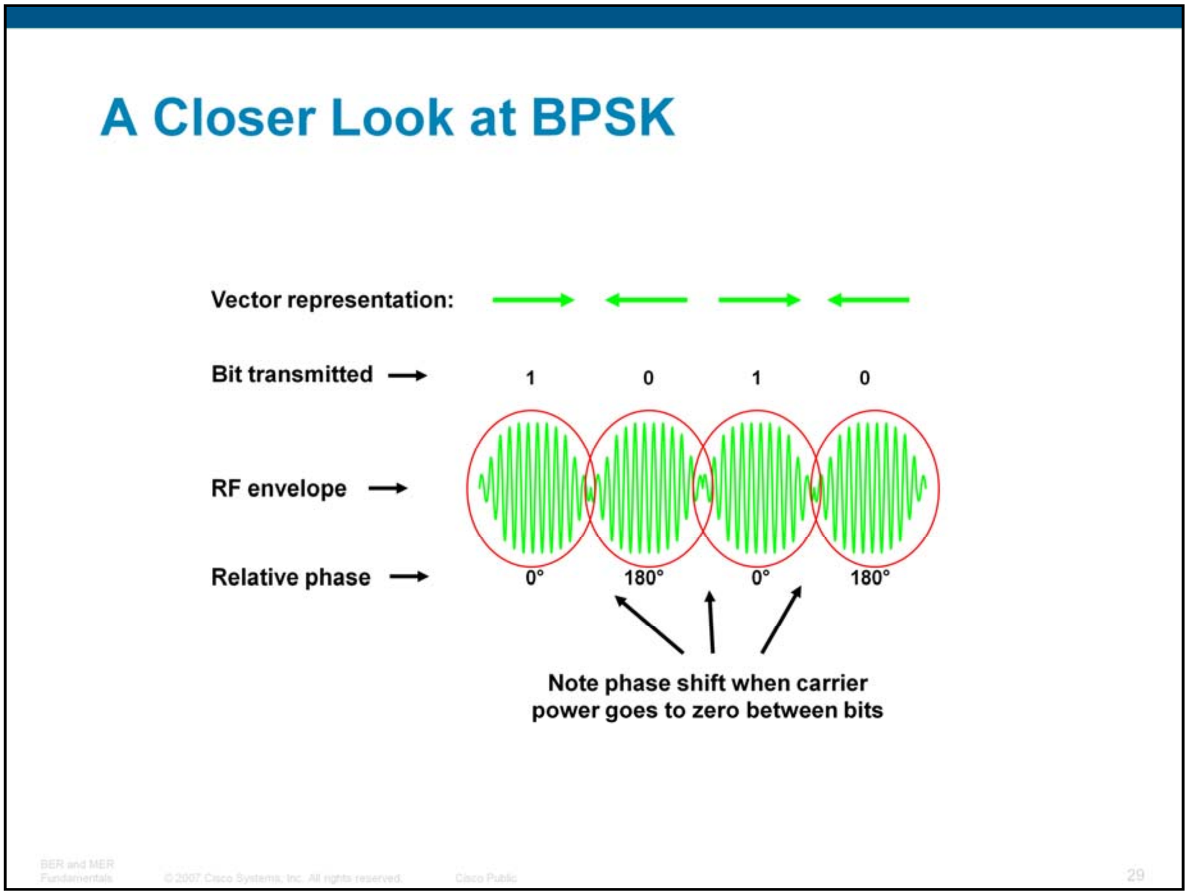

Here is a closer look at the BPSK signal's RF envelope. Note the phase shift when the carrier envelope goes to zero amplitude between bits. The arrows above the carrier envelope are vectors that represent the modulated signal's amplitude and phase.

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I/Q Modulation

- Amplitude and phase can be modulated simultaneously and separately to convey more information than either method alone, but is difficult to do
- An easier way is to separate the original signal into a set of independent components or channels: I (In-phase) and Q (Quadrature)
- The I and Q components are considered orthogonal or in quadrature because their phases are separated by 90 degrees
- The I and Q components are summed in a modulator circuit

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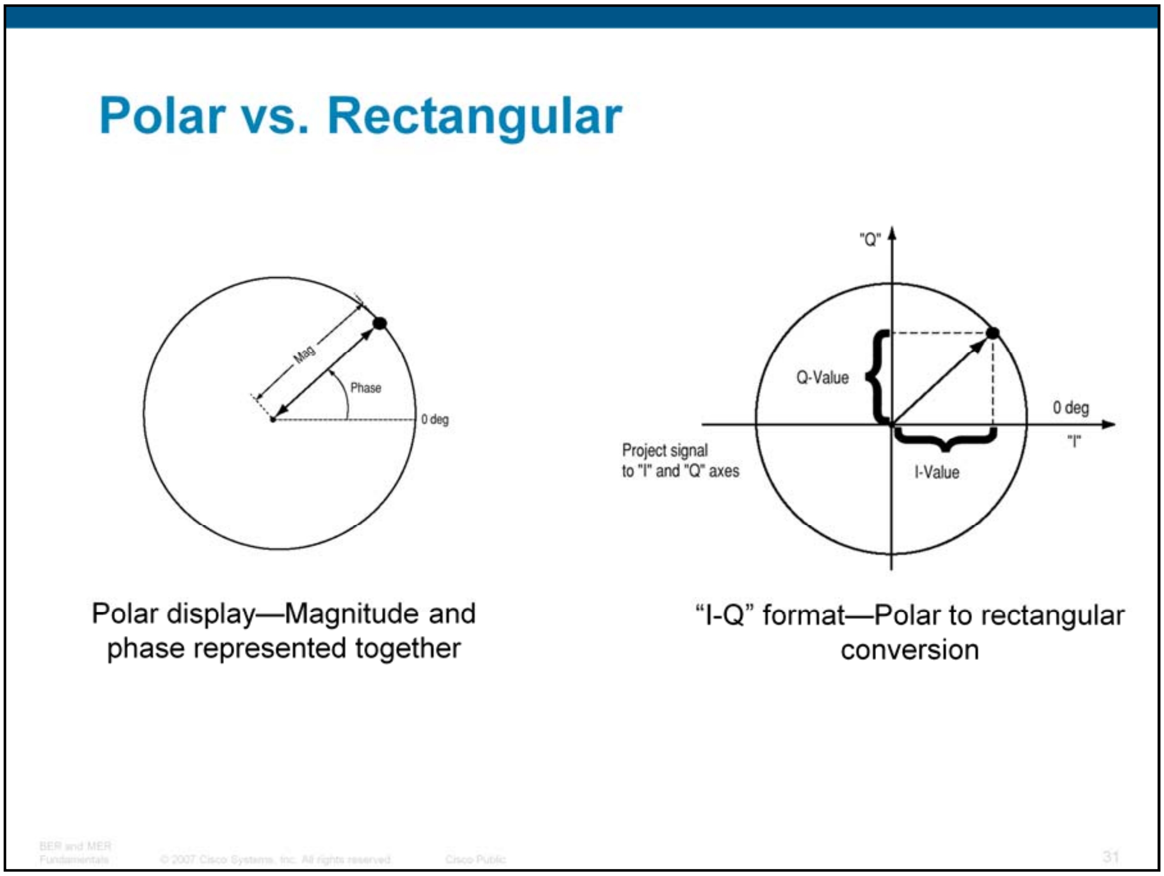

The left graphic shows a polar display of a point on a circle defined in terms of magnitude and phase. This is known as the polar coordinate system, a two-dimensional coordinate system in which a point is determined by angle and distance.

The right graphic shows the same point represented by the rectangular or Cartesian coordinate system. The point is defined in terms of an x-axis value (the I value) of a certain magnitude and y-axis value (the Q value) of a certain magnitude.

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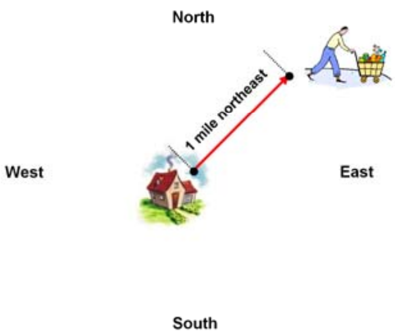
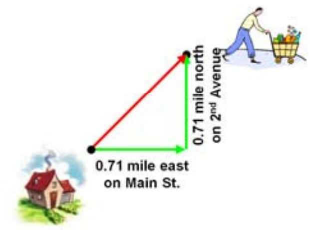
Polar vs. Rectangular: An Analogy





Polar display—Magnitude and phase represented together

"I-Q" format—Polar to rectangular conversion

The relationship between polar and rectangular might be considered analogous to directions to get from one's house to the grocery store. In polar representation, one could say that the grocery store is "1 mile northeast of the house." A rectangular representation would describe the store's location as "0.71 mile east on Main St., then 0.71 mile north on 2nd Avenue."

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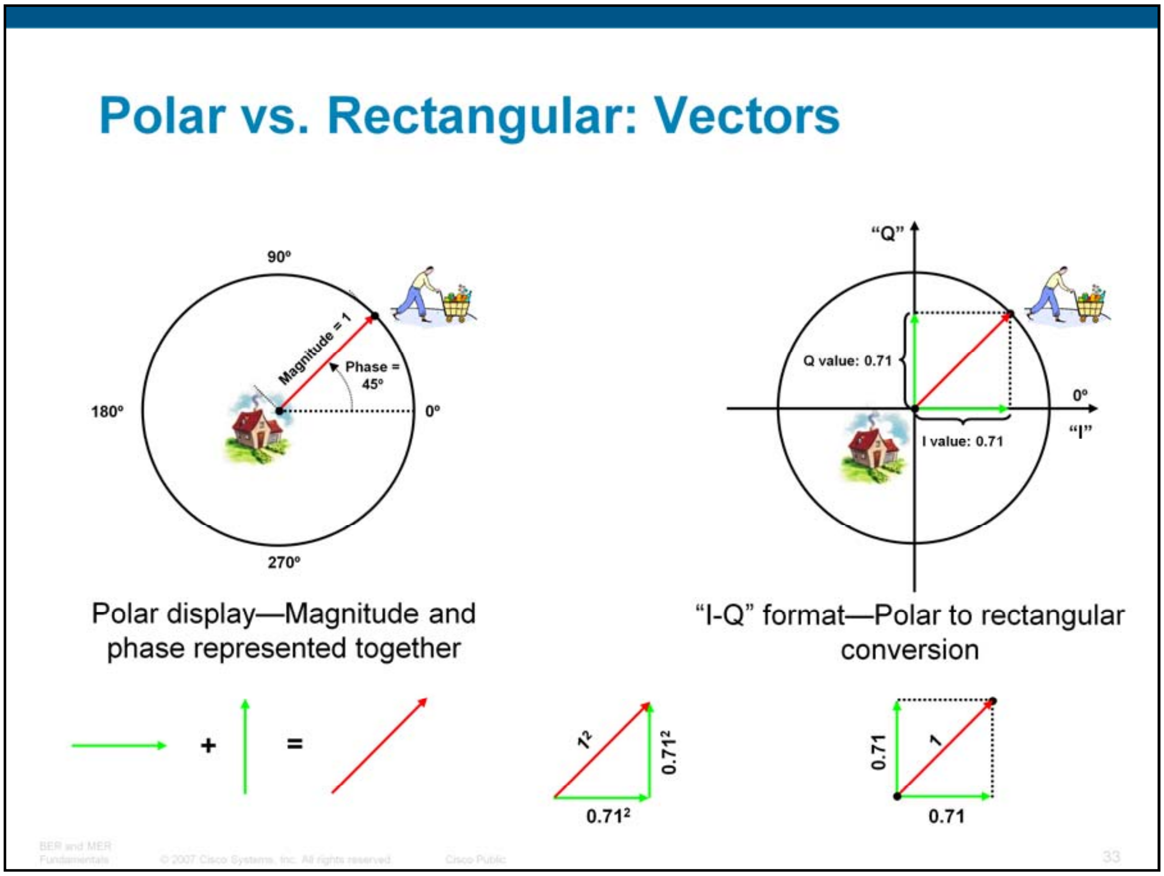

Vector addition using Pythagorean's Theorem allows us to sum the I and Q values. Adding the "north" or 90° vector (Q) and "east" or 0° vector (I) gives us the vector sum of the two vectors: $(0.71)^2 + (0.71)^2 = 1^2$. That is, the vector sum of a 0.71 magnitude 90° vector and a 0.71 magnitude 0° vector equals a vector whose magnitude is 1 and direction is 45°. We'll apply this concept to RF signals later.

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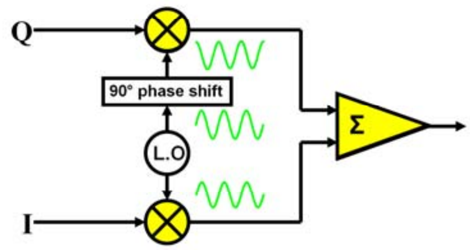
I/Q Modulator

- A single carrier generated by a local oscillator (L.O.) circuit is split into two paths.
- One path is delayed by an amount of time equal to ¼ of the carrier's cycle time, or 90 degrees.
- The second path has no phase shift.
- The two carriers are amplitude modulated—one by the *I* signal, the other by the *Q* signal.
- The two modulated carriers are combined in a summing circuit.
- The output is a digitally modulated signal that is the vector sum of the amplitude modulated *I* and *Q* signals. The output signal contains amplitude and phase variations.



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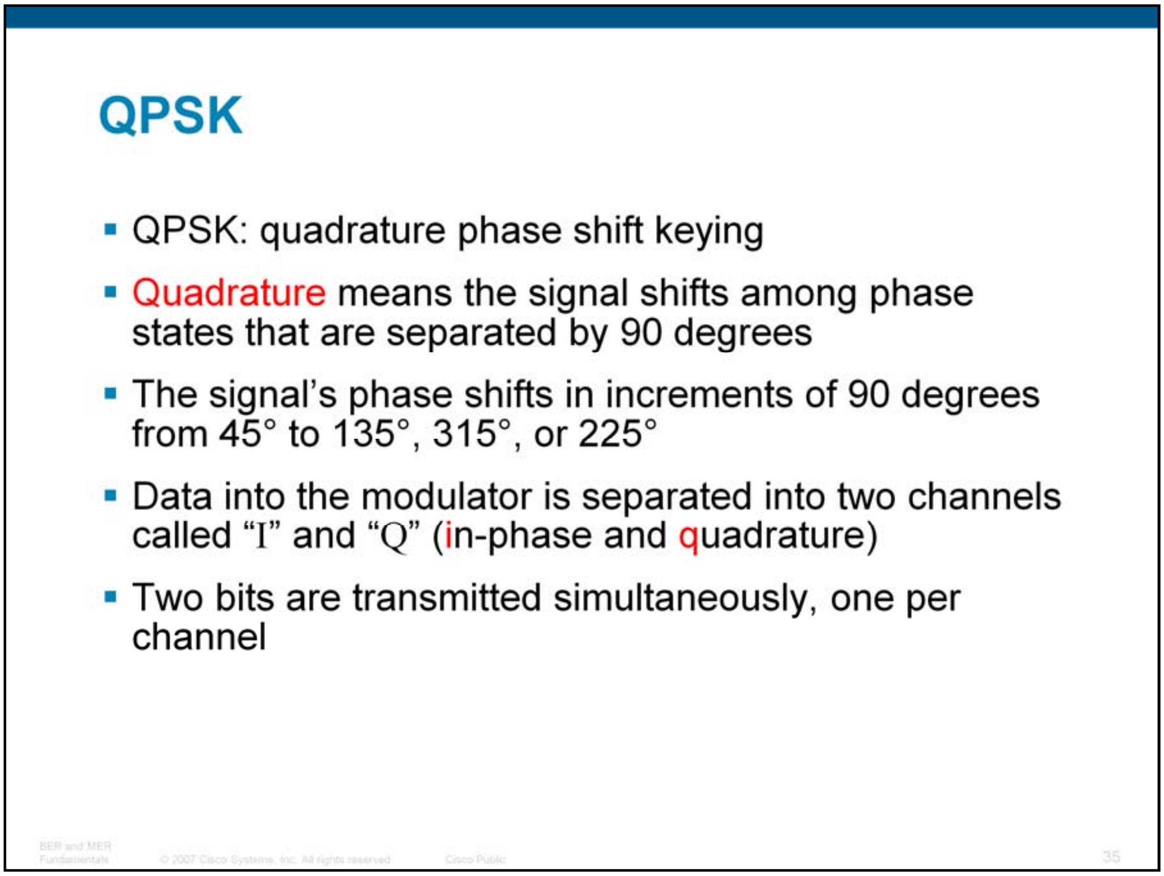

One of the modulation formats supported in DOCSIS networks is quadrature phase shift keying (QPSK), also known as 4-QAM.

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QPSK

- Each channel amplitude modulates a carrier

  The two carrier frequencies are the same, but their phases are offset by 90 degrees—that is, they are "in quadrature"

- The two amplitude modulated carriers are combined and transmitted
- The resulting RF signal is a double-sideband, suppressed carrier signal, and is the vector sum of the original two "I" and "Q" carriers
- QPSK has four states because $2^2 = 4$

  2^n is the total number of symbol states required to represent all possible bit combinations (n = number of bits/symbol)

- Theoretical bandwidth efficiency is two bits/second/Hz

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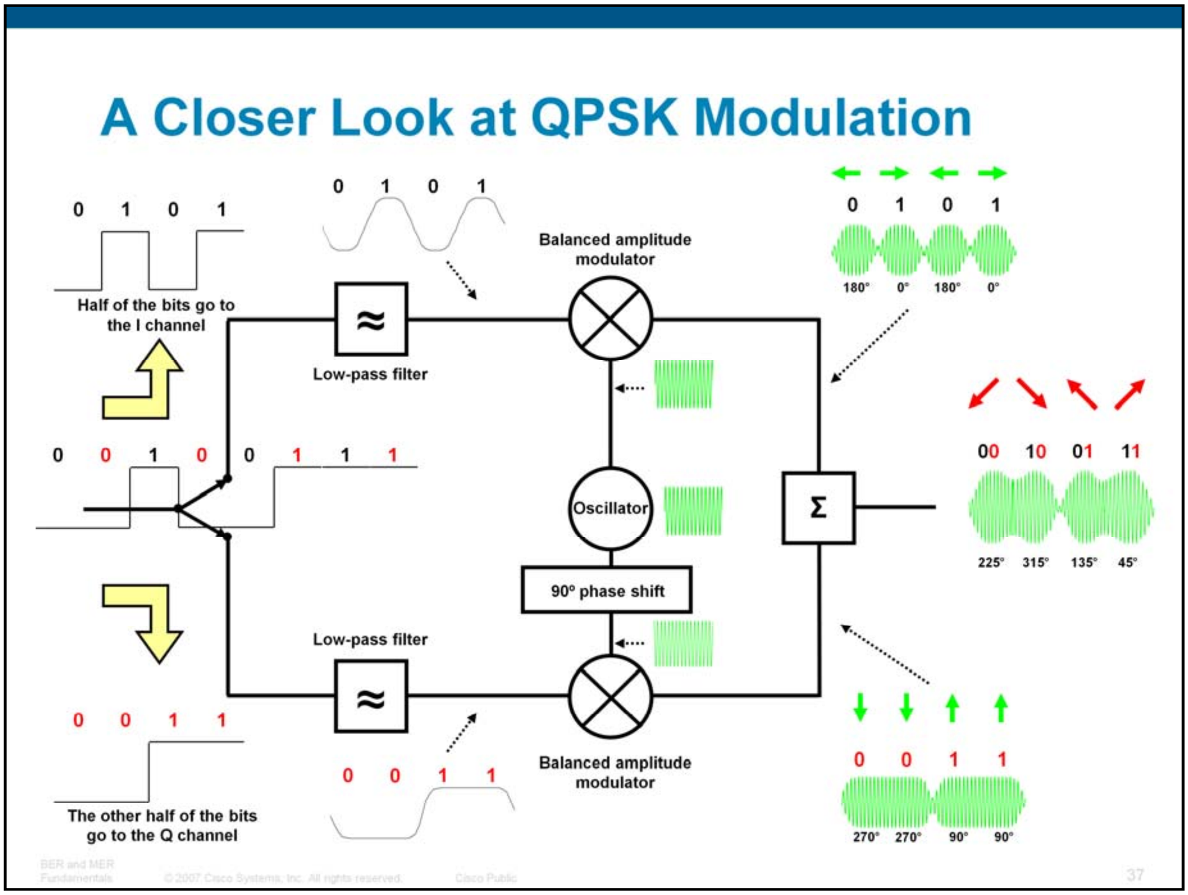

This slide shows a basic QPSK modulator. Half of the input bits go to the *I* channel, and the other half of the bits go to the *Q* channel. After passing through a low-pass filter, the data in each channel amplitude modulates a carrier (same frequency and amplitude carrier in each channel, but the *Q* channel carrier is delayed 90° prior to the balanced amplitude modulator). The two amplitude modulated carriers are combined in a summing circuit. The modulated output RF signal is a double sideband, suppressed carrier signal that is the vector sum of the two amplitude modulated *I* and *Q* signals. Technically speaking, the output signal can be one of four phase and amplitude values (the amplitude value during each transmitted symbol is ideally the same value for all four phase states), where each phase/amplitude combination represents a data symbol. Each symbol in QPSK represents two bits.

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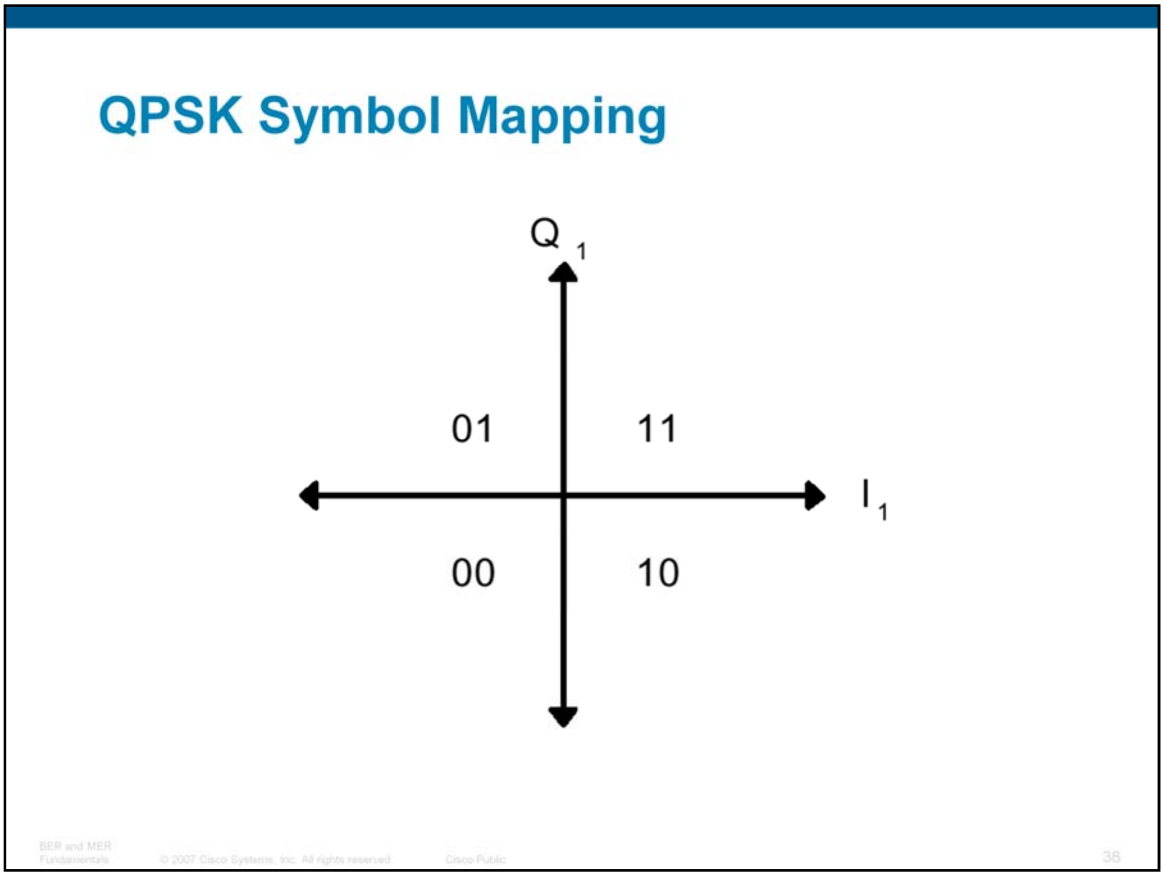

This constellation diagram shows QPSK bit-to-symbol assignments, also known as a bit-to-symbol map. That is, each pair of bits is mapped to one of four QPSK symbols. With differential QPSK, the bits are mapped to phase changes rather than to an absolute transmitted phase values.

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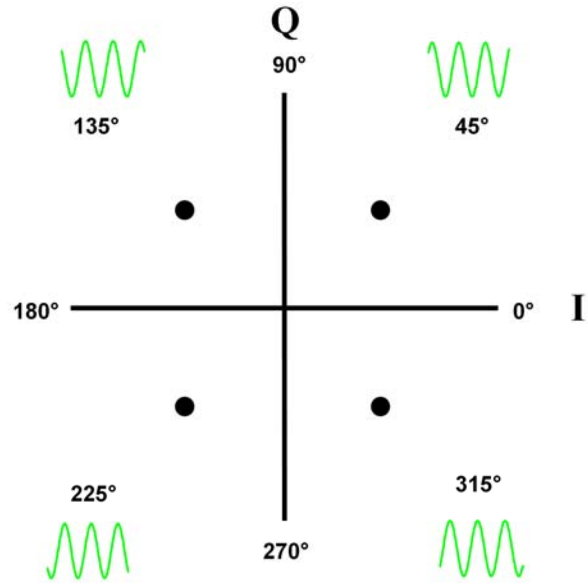
QPSK Constellation

Symbol Transmitted	Carrier Envelope Phase	Carrier Envelope Amplitude
00	225°	1.0
01	135°	1.0
10	315°	1.0
11	45°	1.0



Here we can see where the absolute phase of the modulated signal’s envelope represents a transmitted symbol. This is known as coherent QPSK, requiring the receiver to compare the received phase to a reference signal of some sort. As mentioned previously, when differential QPSK is used, a phase *change* rather than an *absolute phase value* represents the transmitted symbol.

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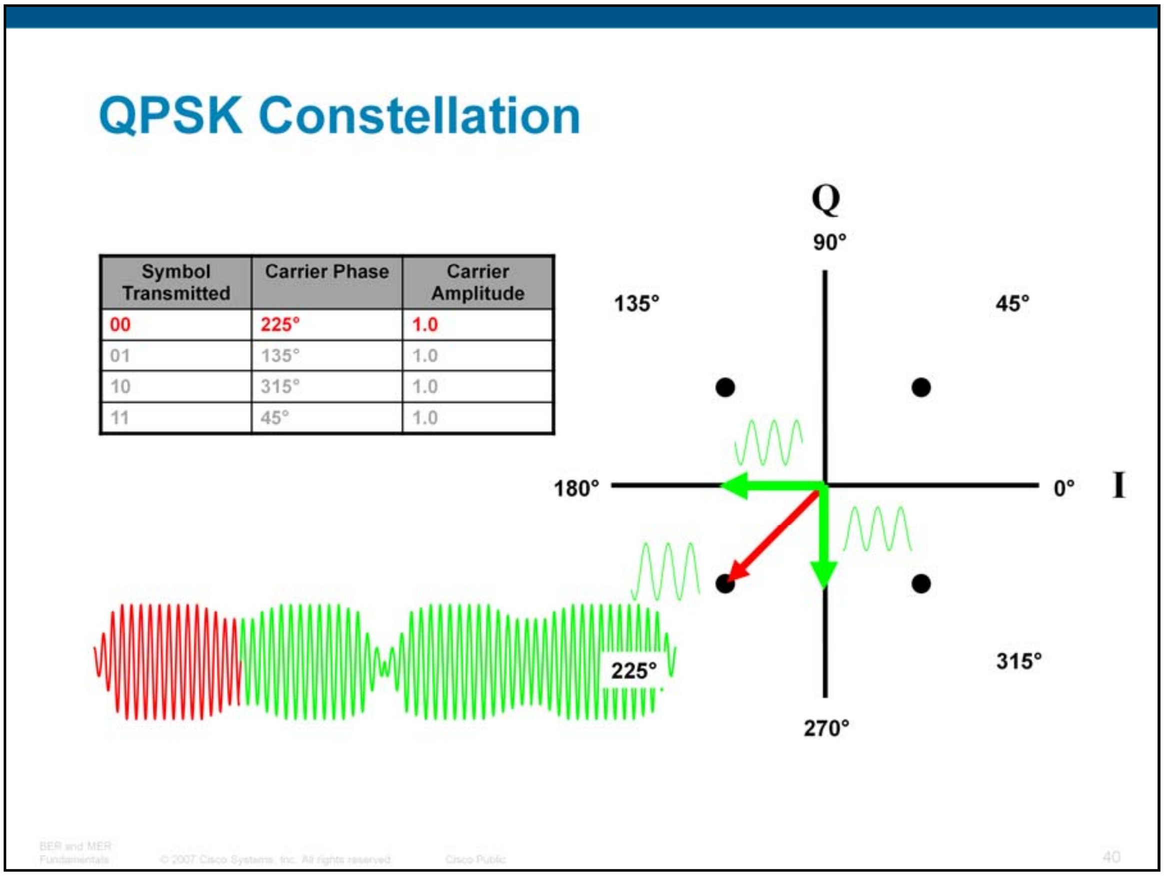
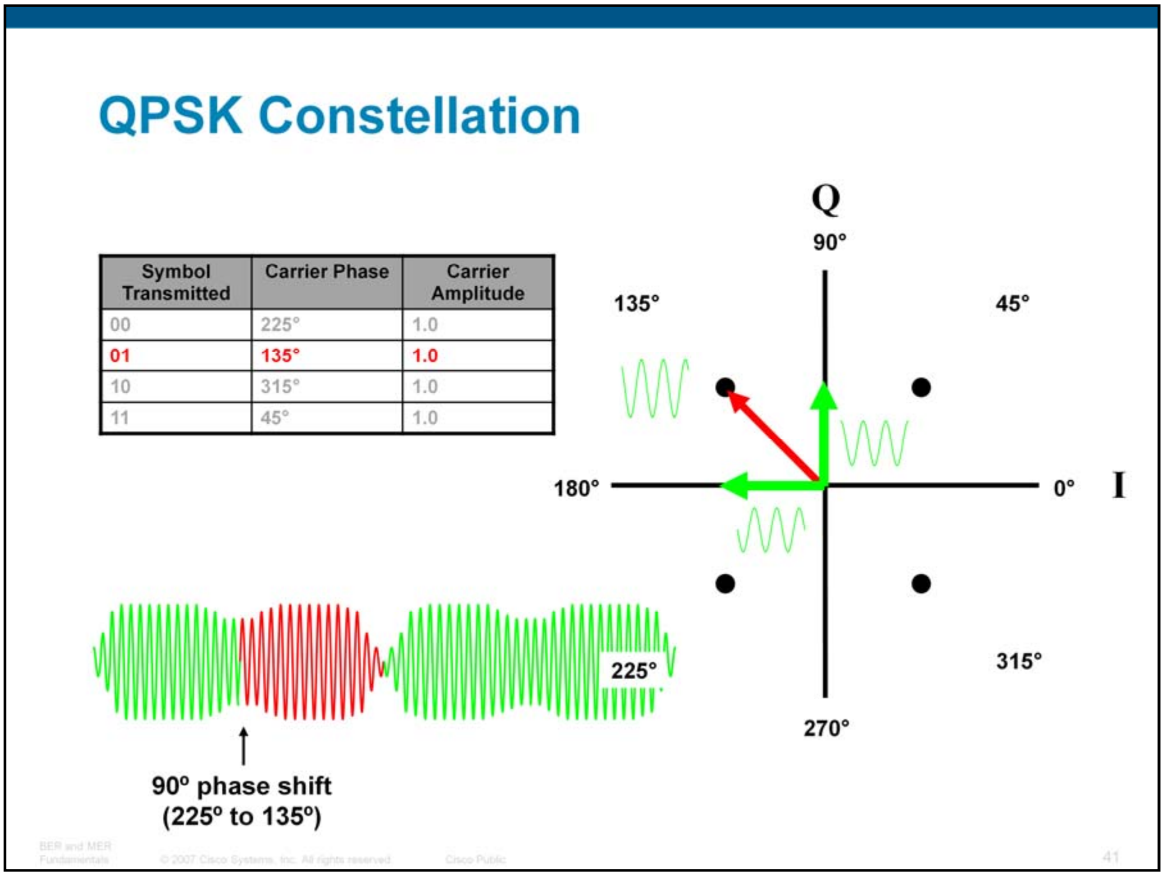


Here the transmitted symbol “00” is represented by a modulated signal phase of 225° and a normalized amplitude of 1. The modulated RF signal is the vector sum of a I channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 180°, and a Q channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 270°.



Here the transmitted symbol “01” is represented by a modulated signal phase of 135° and a normalized amplitude of 1. The modulated RF signal is the vector sum of a I channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 180°, and a Q channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 90°.

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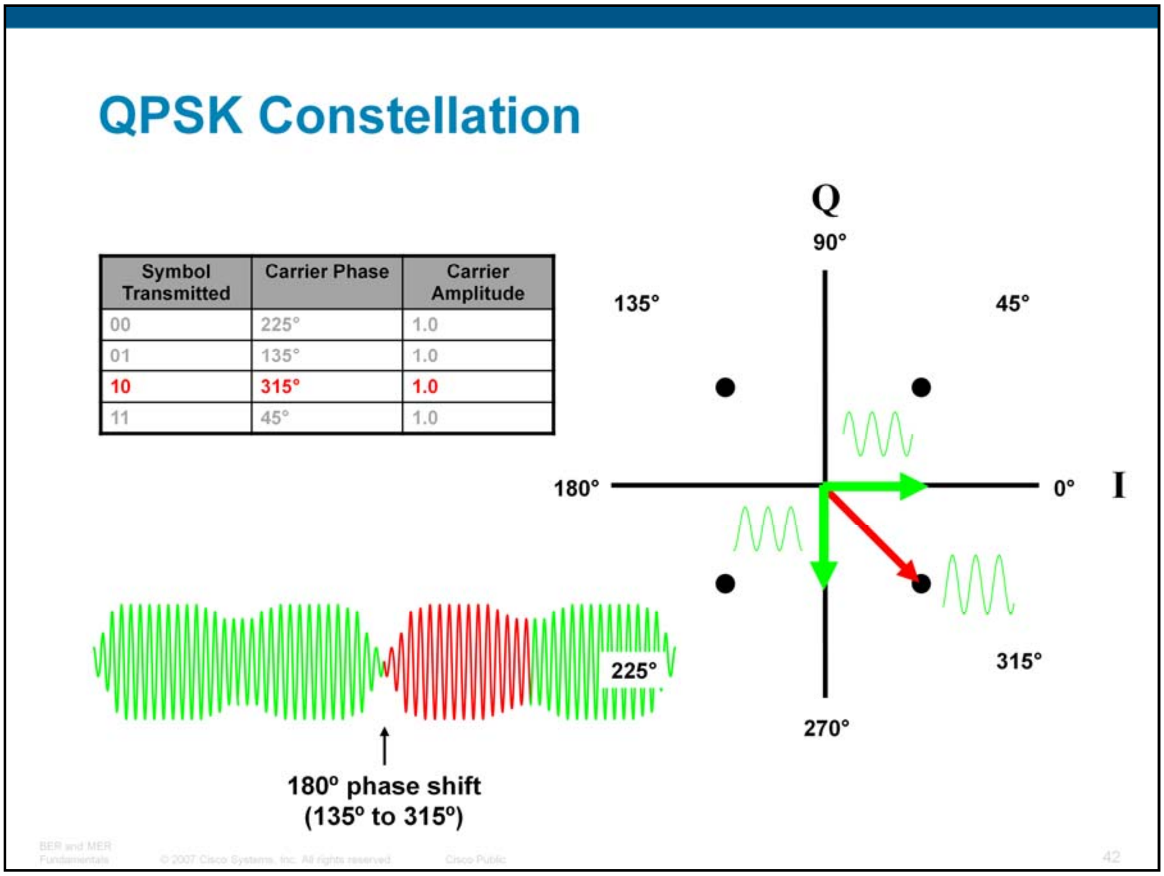

Here the transmitted symbol "10" is represented by a modulated signal phase of 315° and a normalized amplitude of 1. The modulated RF signal is the vector sum of a I channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 0°, and a Q channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 270°.

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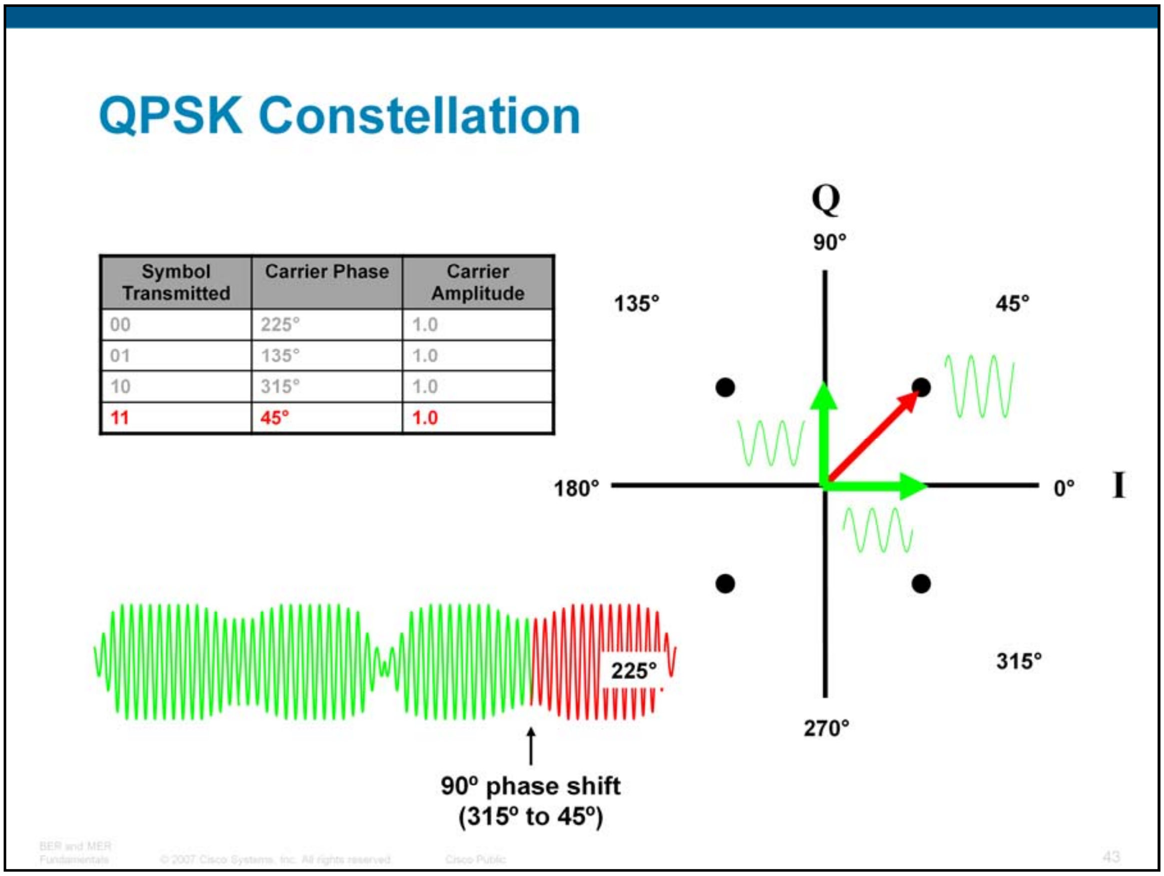

Here the transmitted symbol "11" is represented by a modulated signal phase of 45° and a normalized amplitude of 1. The modulated RF signal is the vector sum of a I channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 0°, and a Q channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 90°.

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16-QAM

- 16-QAM: 16-state quadrature amplitude modulation
- Four *I* values and four *Q* values are used, yielding four bits per symbol
- 16 states because $2^4 = 16$
- Theoretical bandwidth efficiency is four bits/second/Hz

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Another modulation format supported in DOCSIS is 16-state quadrature amplitude modulation, or 16-QAM. Four *I* values and four *Q* values are used, yielding four bits per symbol. There are 16 states because $2^4 = 16$. The theoretical bandwidth efficiency is four bits/second/Hz. In the RF domain, visualize 16 different combinations of amplitude and phase representing the 16 different symbols that can be transmitted.

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16-QAM

- Data is spit into two channels, I and Q
- As with QPSK, each channel can take on two phases. However, 16-QAM also accommodates two intermediate amplitude values!
- Two bits are routed to each channel simultaneously
- The two bits to each channel are added, then applied to the respective channel's modulator
- Each channel uses amplitude modulation
- The resulting RF signal is a double-sideband, suppressed carrier signal. It is the vector sum of the original two carriers, and has phase and amplitude variations.

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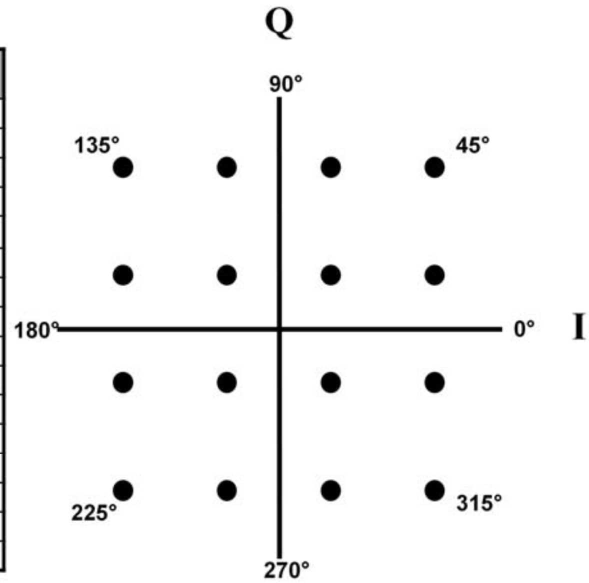
16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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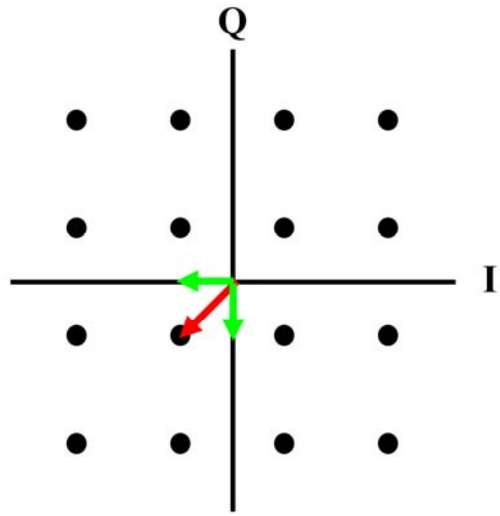
Here we can see where the absolute phase and amplitude of the modulated signal's envelope represents a transmitted symbol.

16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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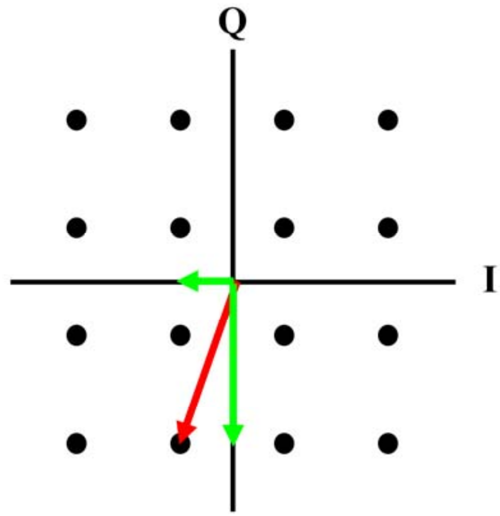
Here the transmitted symbol “0000” is represented by a modulated signal phase of 225° and a normalized amplitude of 0.33 (the four outer corners of the constellation have a normalized amplitude of 1). The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 180°, and a Q channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 270°.

16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	**255°**	**0.75**
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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Here the transmitted symbol “0001” is represented by a modulated signal phase of 255° and a normalized amplitude of 0.75. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 180°, and a Q channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 270°.

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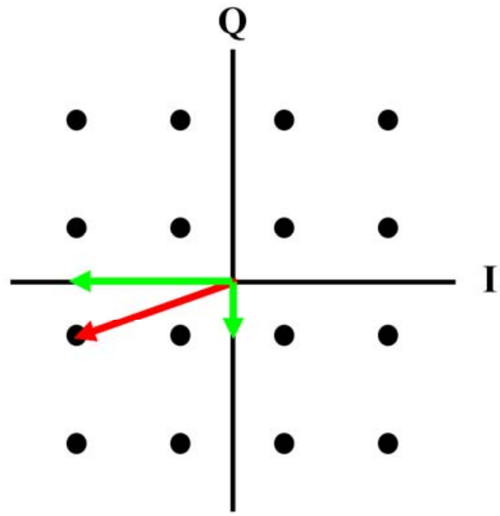
16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	**195°**	**0.75**
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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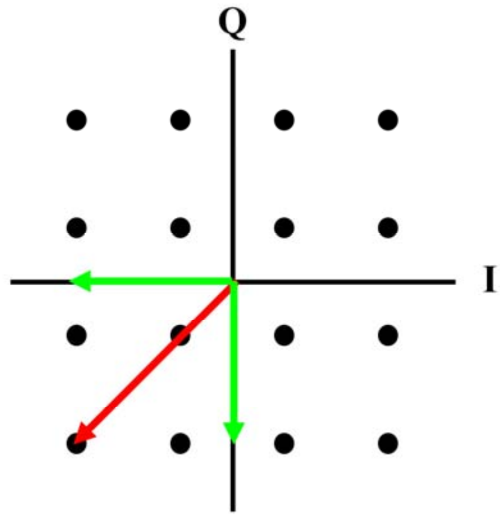
Here the transmitted symbol “0010” is represented by a modulated signal phase of 195° and a normalized amplitude of 0.75. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 180°, and a Q channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 270°.

16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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Here the transmitted symbol "0011" is represented by a modulated signal phase of 225° and a normalized amplitude of 1. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 180°, and a Q channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 270°.

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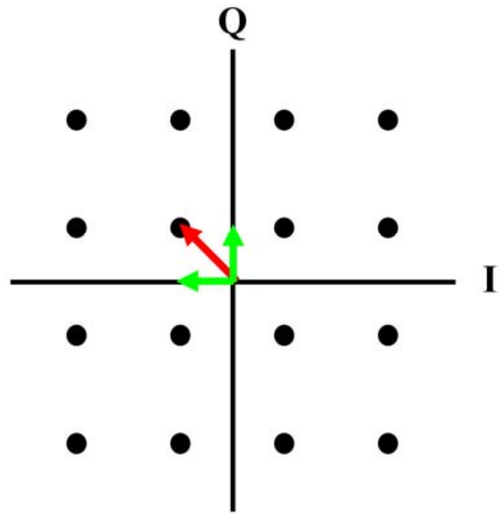
16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	**135°**	**0.33**
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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Here the transmitted symbol “0100” is represented by a modulated signal phase of 135° and a normalized amplitude of 0.33. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 180°, and a Q channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 90°.

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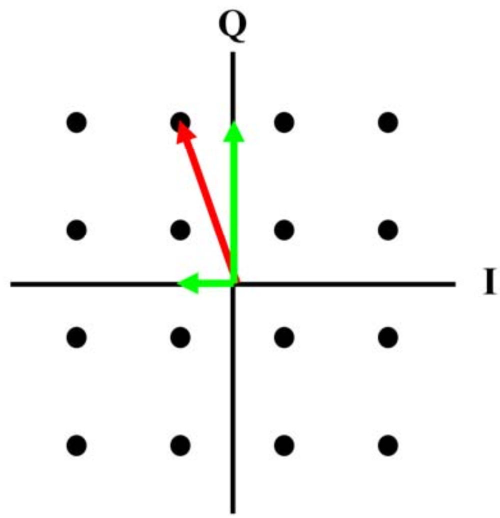
16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	**105°**	**0.75**
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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Here the transmitted symbol "0101" is represented by a modulated signal phase of 105° and a normalized amplitude of 0.75. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 180°, and a Q channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 90°.

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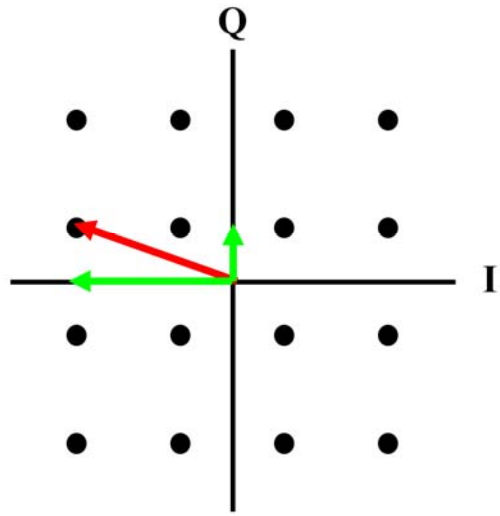
16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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Here the transmitted symbol "0110" is represented by a modulated signal phase of 165° and a normalized amplitude of 0.75. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 180°, and a Q channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 90°.

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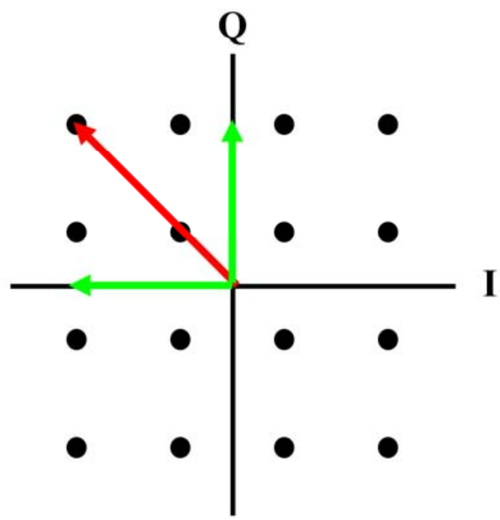
16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	**135°**	**1.0**
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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Here the transmitted symbol "0111" is represented by a modulated signal phase of 135° and a normalized amplitude of 1. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 180°, and a Q channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 90°.

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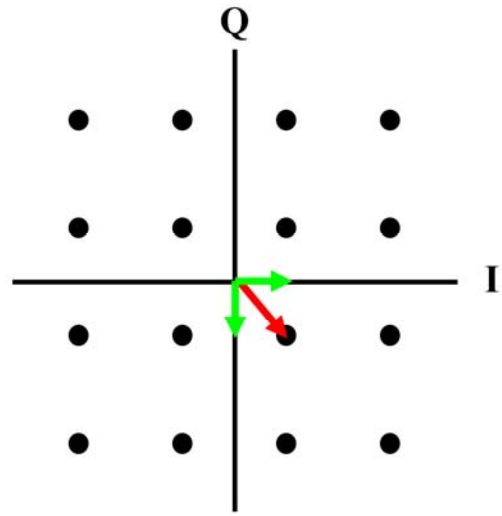
16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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Here the transmitted symbol “1000” is represented by a modulated signal phase of 315° and a normalized amplitude of 0.33. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 0°, and a Q channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 270°.

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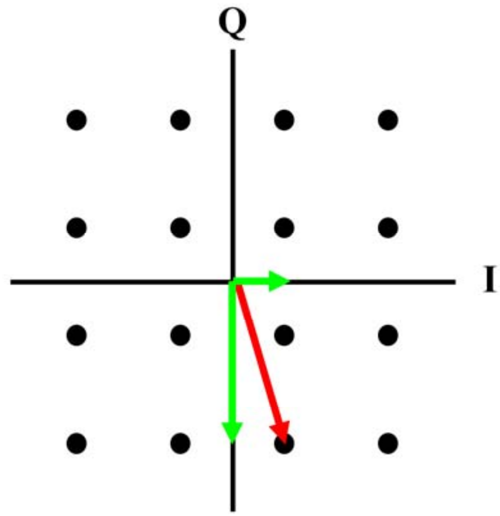
16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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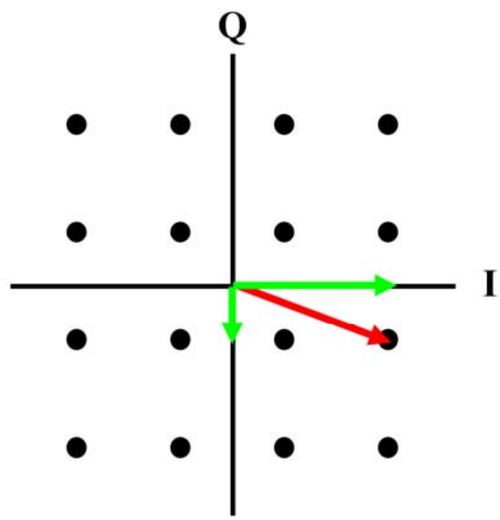
Here the transmitted symbol "1001" is represented by a modulated signal phase of 285° and a normalized amplitude of 0.75. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 0°, and a Q channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 270°.

16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	**345°**	**0.75**
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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Here the transmitted symbol "1010" is represented by a modulated signal phase of 345° and a normalized amplitude of 0.75. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 0°, and a Q channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 270°.

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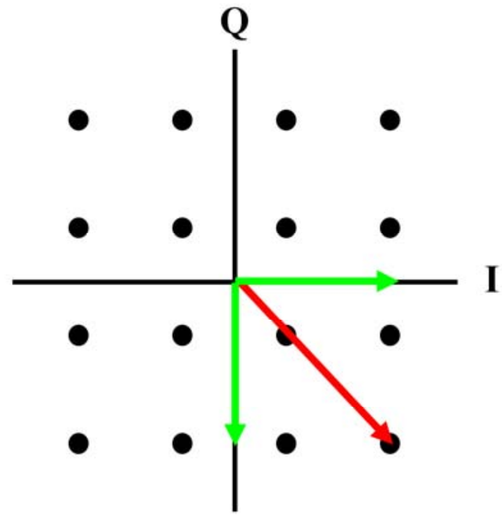
16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	**315°**	**1.0**
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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Here the transmitted symbol "1011" is represented by a modulated signal phase of 315° and a normalized amplitude of 1. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 0°, and a Q channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 270°.

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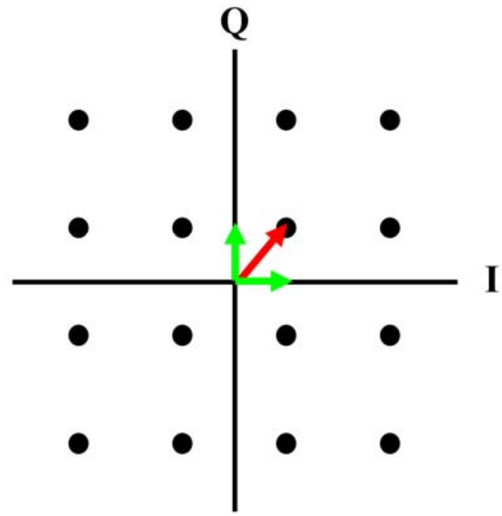
16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	**45°**	**0.33**
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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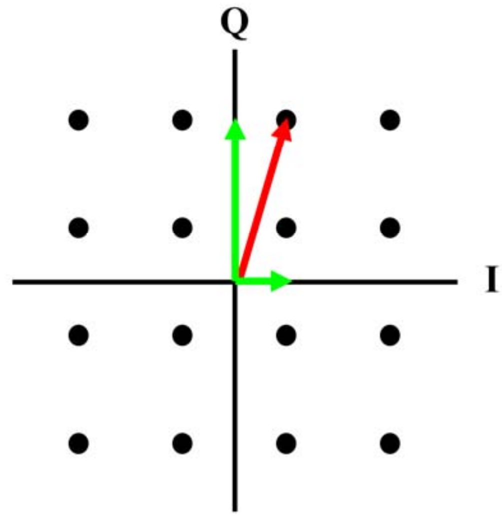
Here the transmitted symbol “1100” is represented by a modulated signal phase of 45° and a normalized amplitude of 0.33. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 0°, and a Q channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 90°.

16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0



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Here the transmitted symbol "1101" is represented by a modulated signal phase of 75° and a normalized amplitude of 0.75. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 0°, and a Q channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 90°.

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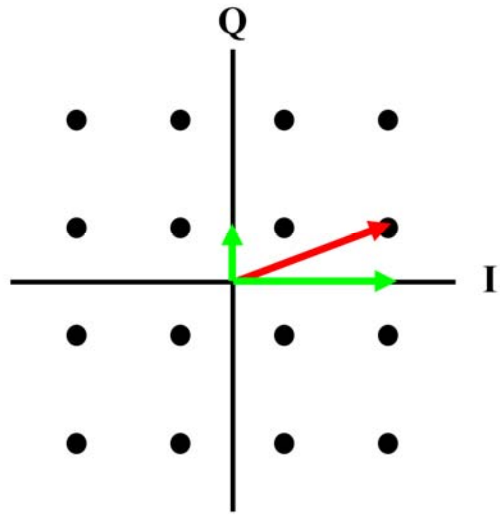
16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	**15°**	**0.75**
1111	45°	1.0



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Here the transmitted symbol “1110” is represented by a modulated signal phase of 15° and a normalized amplitude of 0.75. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 0°, and a Q channel signal whose amplitude is a normalized value of 0.23 with a relative phase of 90°.

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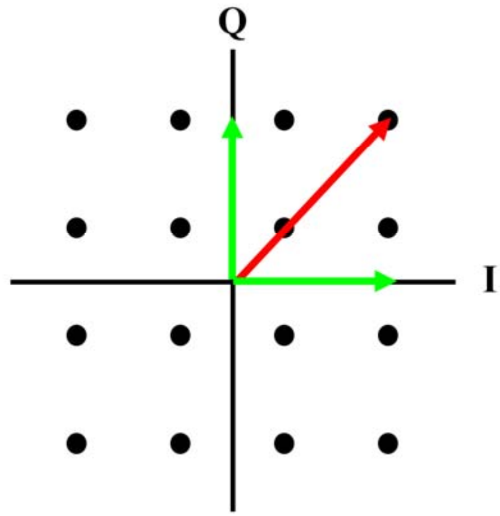
16-QAM Constellation

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	**45°**	**1.0**



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Here the transmitted symbol "1111" is represented by a modulated signal phase of 45° and a normalized amplitude of 1. The modulated RF signal is the vector sum of an I channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 0°, and a Q channel signal whose amplitude is a normalized value of 0.707 with a relative phase of 90°.

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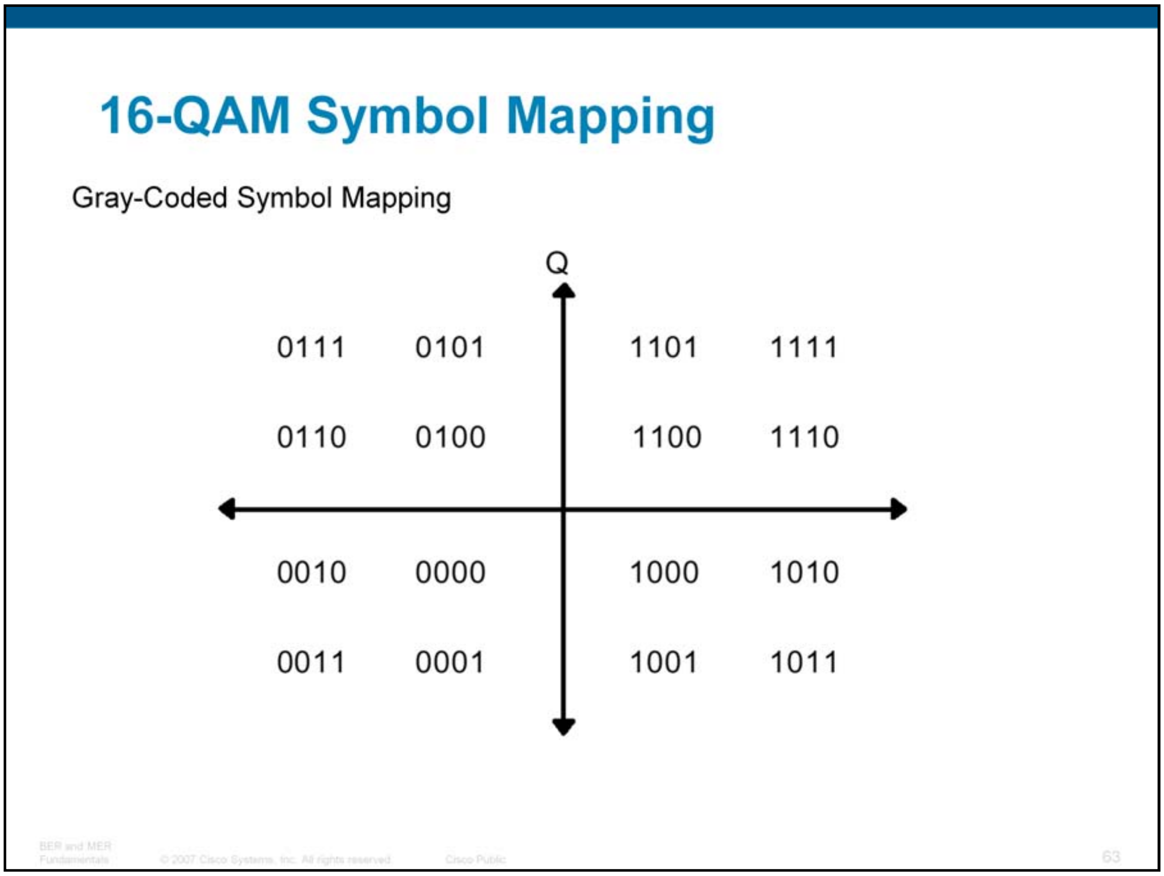

With Gray-Coding, the bit-to-symbol mapping is such that the bit patterns represented by adjacent constellation symbol points differ by only one bit. When used in conjunction with suitable forward error correction, the receiver can correct transmission errors that cause a constellation's symbol point to "land" in the area of an adjacent symbol point. This makes the data transmission more robust.

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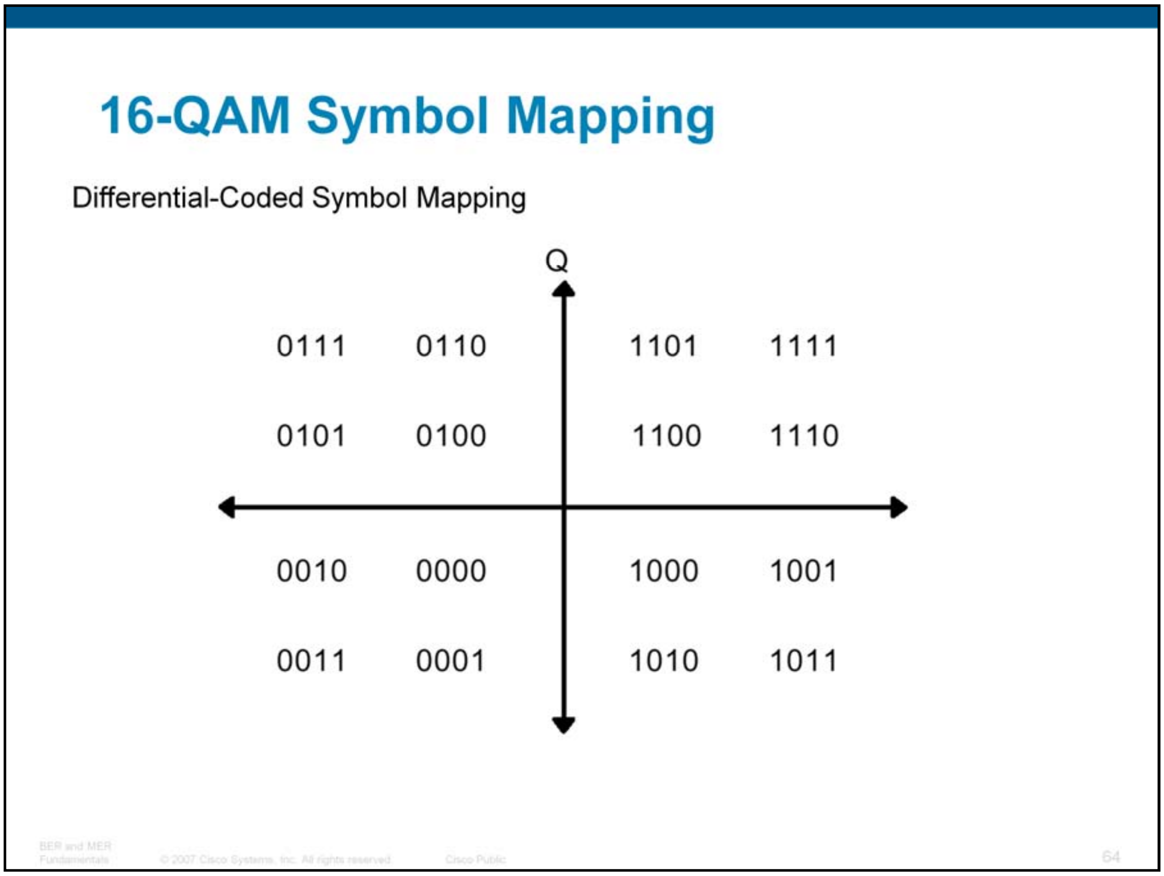

Generally speaking, *differential coding* produces an output in which the information is contained in the differences between successive symbols. As applied to differential modulation, it represents the change in the quadrant since the last symbol. For example, if a given symbol has the same quadrant as the last symbol, the most significant bits are set to 00. If the quadrant of this symbol is 90 degrees clockwise from the previous quadrant, the MSBs (Most Significant Bit) are set to 01. If the quadrant of this symbol is 90 degrees counterclockwise from the previous quadrant, the MSBs are set to 10. And if the quadrant of this symbol is 180 degrees from the previous quadrant, the MSBs are set to 11. [These are example codes and may not represent DOCSIS.]

If the waveform has known reference bits, such as a header, sync byte, or training sequence, then differential modulation is not necessary. But in the absence of a reference signal, differential modulation permits the receiver to lock up its phase tracking loop in any one of four different phases, corresponding to the four quadrants. From then on, it doesn't matter what the original quadrant was, just the *difference* between quadrants. The penalty is that if the receiver makes an error on the MSBs and chooses the wrong quadrant, it affects not just that symbol but the next one as well, and causes error extension.

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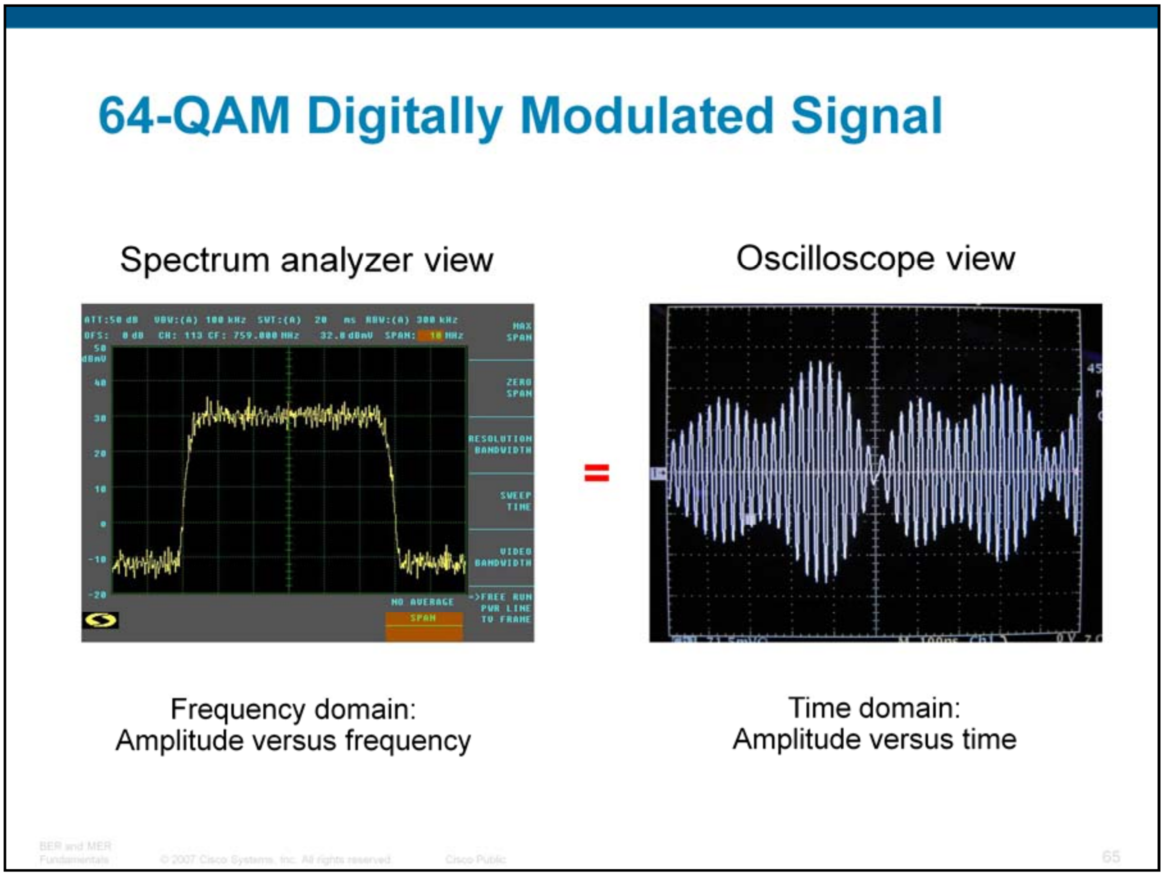
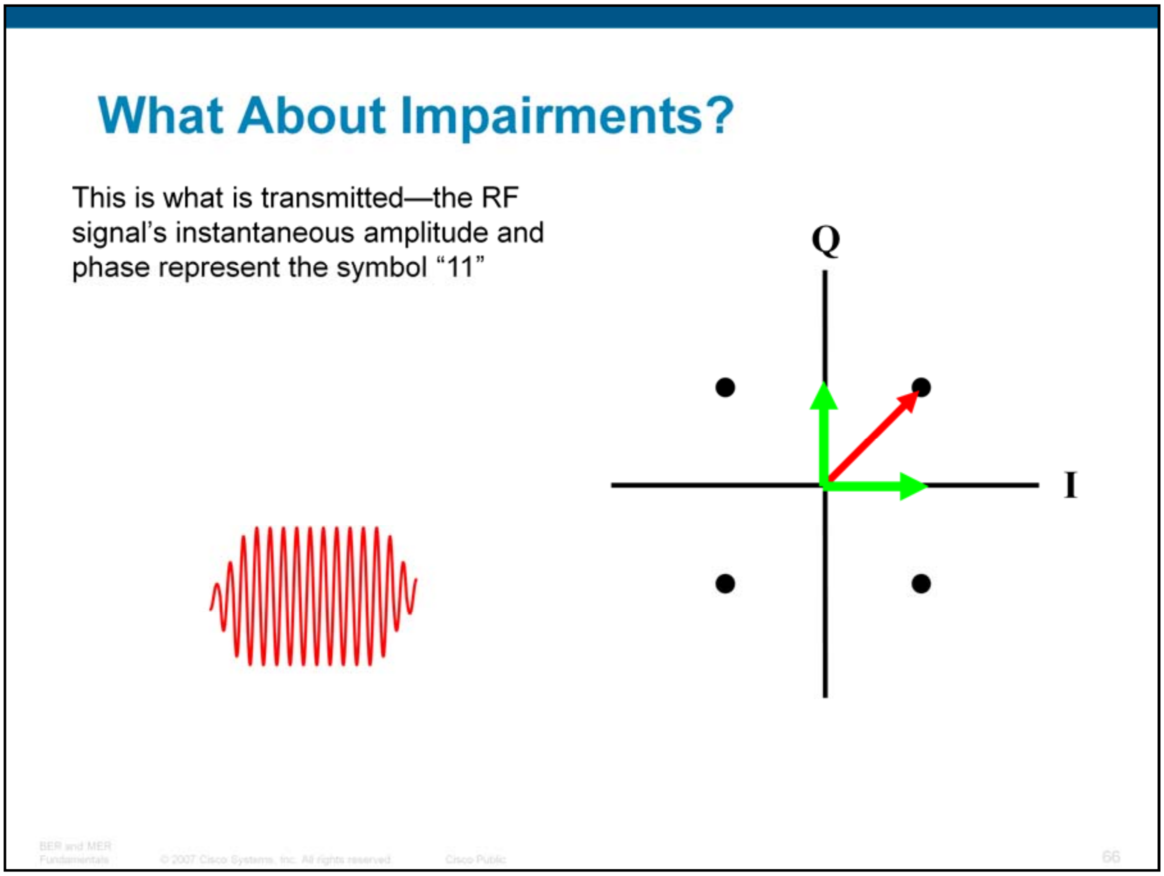


The spectrum analyzer screen shot on the left shows a 64-QAM signal in the frequency domain—what we sometimes call a "haystack." The oscilloscope display on the right is the same 64-QAM signal in the time domain. Note the amplitude and phase changes that correspond to different transmitted symbols.



Let's look at what happens when impairments affect a transmitted QPSK signal. This slide shows the transmitted symbol "11" at the transmitter output. We'll assume the signal is perfect at this point.

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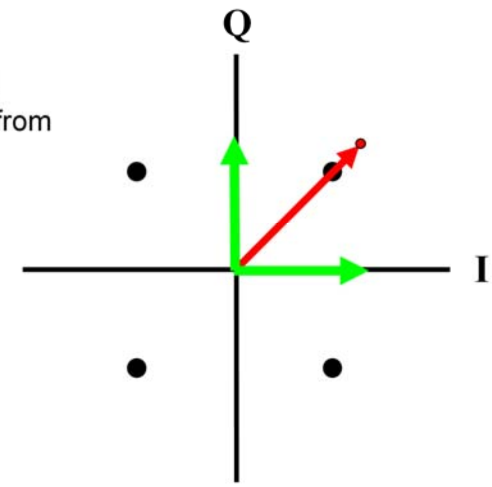
What About Impairments?

This is what is received after noise randomly mixes with the transmitted signal somewhere in the transmission path. Because the received RF signal's phase and amplitude didn't change very much from what was actually transmitted, the data receiver interprets the signal as "11".



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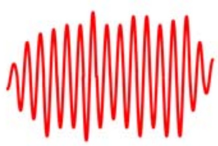
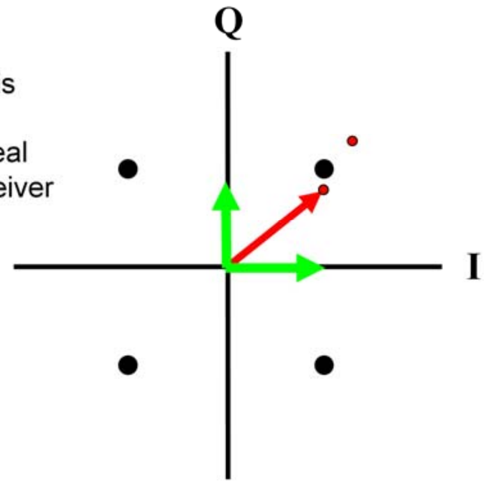
What About Impairments?

The next time the symbol “11” is transmitted, the RF signal randomly mixes with noise again. But this time the received signal’s amplitude is a little lower, and the phase is shifted slightly. The received phase and amplitude are still close enough to the ideal position to be interpreted by the data receiver as “11”.





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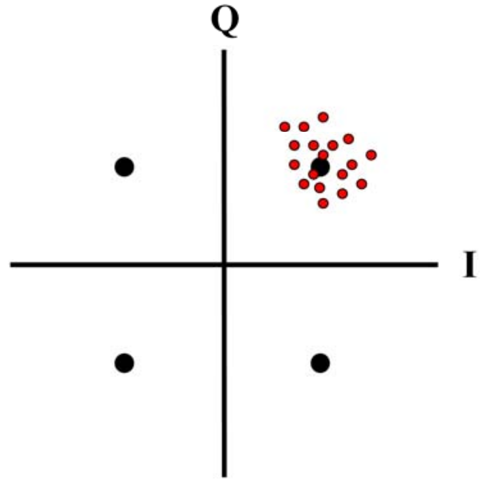
What About Impairments?

The same symbol transmitted multiple times mixes randomly each time with noise in the transmission path. As a result, each received symbol's plotted position on the constellation is slightly different. In this example, all of the received signals' phases and amplitudes are able to be interpreted as "11".



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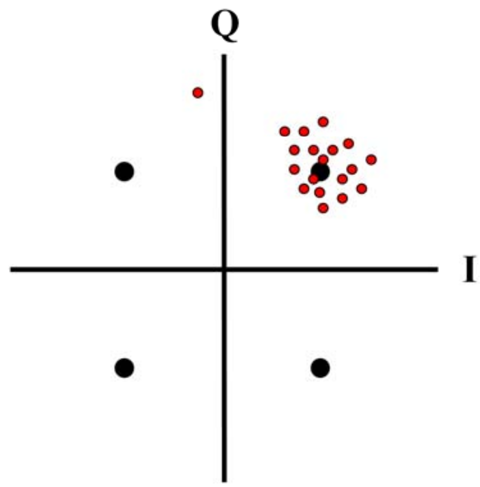
What About Impairments?

Here a large burst of noise mixes with the RF signal, causing the received phase and amplitude to be outside of the “decision boundary” for the desired symbol. The data receiver is not able to correctly interpret the received signal as “11”, so an error occurs. As we shall see, this generally does not affect MER!



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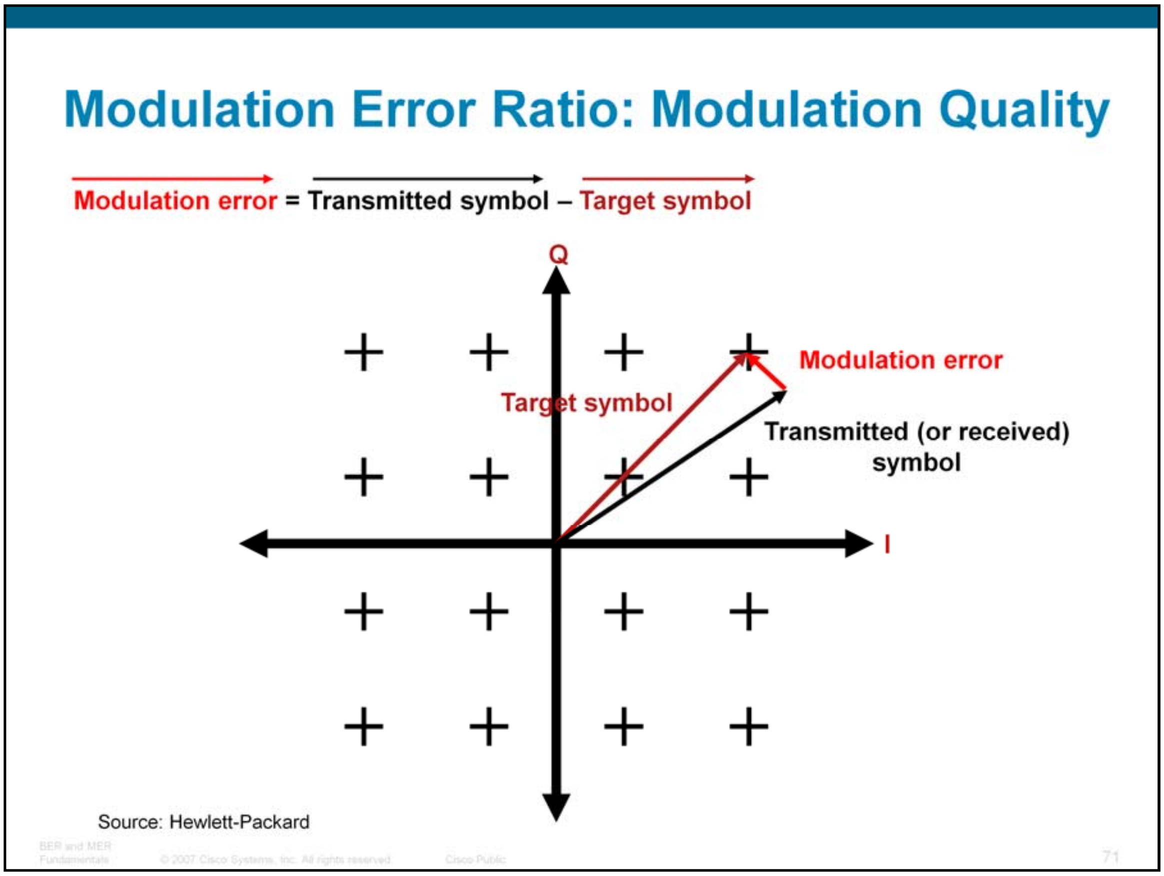

This slide illustrates a 16-QAM constellation. A perfect, unimpaired 16-QAM digitally modulated signal would have all of its symbols land at exactly the same 16 points on the constellation over time. Real-world impairments cause most of the symbol landing points to be spread out somewhat from the ideal symbol landing points. The slide shows the vector for a *target symbol* – the ideal symbol we want to transmit or receive. 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, modulation error vector = transmitted symbol vector – target symbol vector.

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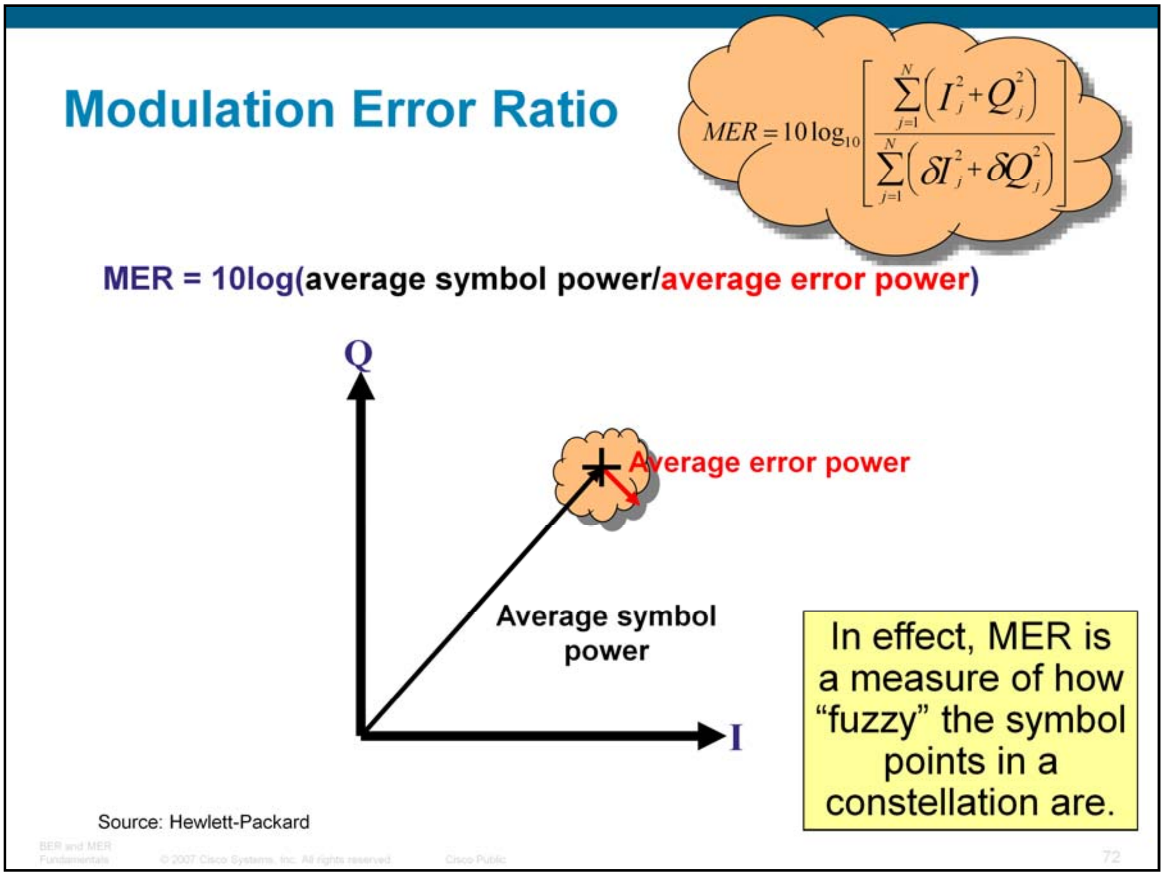

If a constellation diagram is used to plot the landing points of a given symbol over time, the resulting display forms a small "cloud" of symbol landing points rather than a single point. MER is the ratio of average symbol power to average error power:

MER(dB) = 10log(average symbol power ÷ average error power)

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

Mathematically, a more precise definition of MER (in decibels) is shown in the upper right corner of the slide. In that formula, *I* and *Q* are the real (in-phase) and imaginary (quadrature) parts of each sampled ideal *target symbol* vector, and δ*I* and δ*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.

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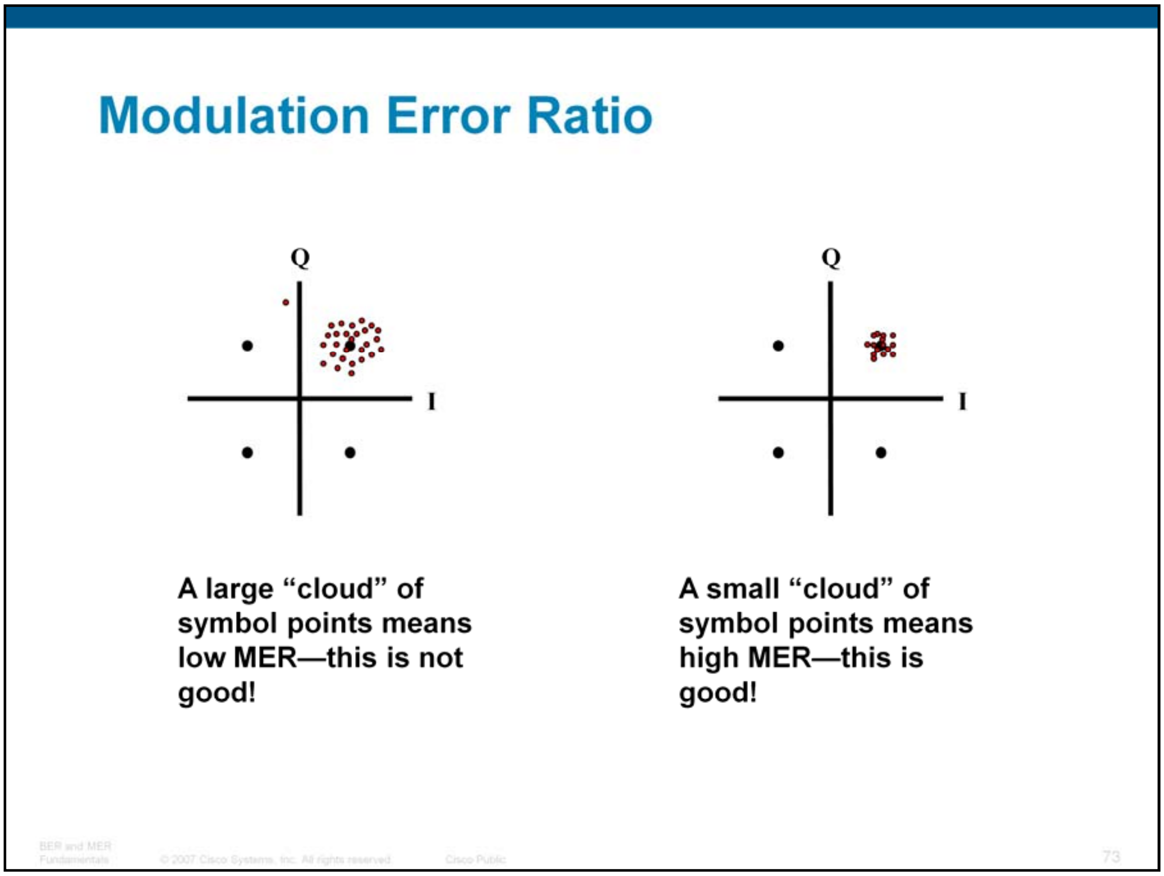

A large "cloud" of symbol points equates to low MER, which is not good. What we want is what's shown on the right—a small cloud of symbol points, which gives us high MER. Because MER is in effect a measure of the fuzziness of the cloud of symbol points, the occasional stray symbol point (as seen on the left graphic) will have little or no impact on MER. This means that one can have good MER, even in the presence of degraded BER. This is particularly true when bursty or intermittent interference is occurring. The MER will often be fine, while the BER is not.

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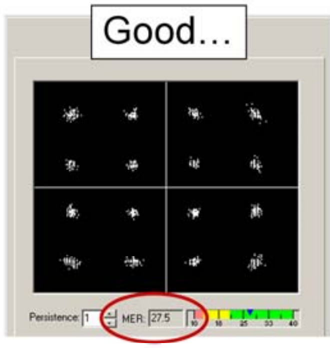
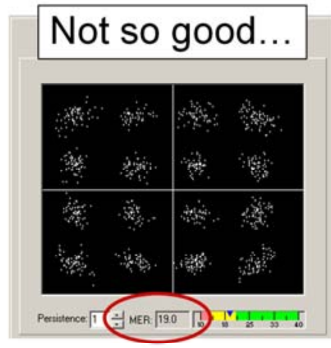
MER Measurements

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





Graphics courtesy of Filtronic Sigtek

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The table 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.

Good engineering practice suggests keeping MER in an operational system at least 3 to 6 dB or more above the lower E_S/N_0 threshold. This guideline will accommodate temperature-related signal-level variations in the coaxial plant, amplifier, and optoelectronics misalignment; test equipment calibration and absolute amplitude accuracy; and similar factors that can affect operating headroom. The lower E_S/N_0 threshold can be thought of as an “MER failure threshold” of sorts.

The constellation displays show an upstream 16-QAM digitally modulated signal. The left constellation’s unequalized MER is 27.5 dB, a value that is well above the failure threshold for 16-QAM. The right constellation’s unequalized MER is 19 dB, which is at or near the failure threshold for 16-QAM. Note that it is not possible to discern the reason for the low MER in the right constellation—it could be caused by poor CNR, or the presence of linear or non-linear impairments.

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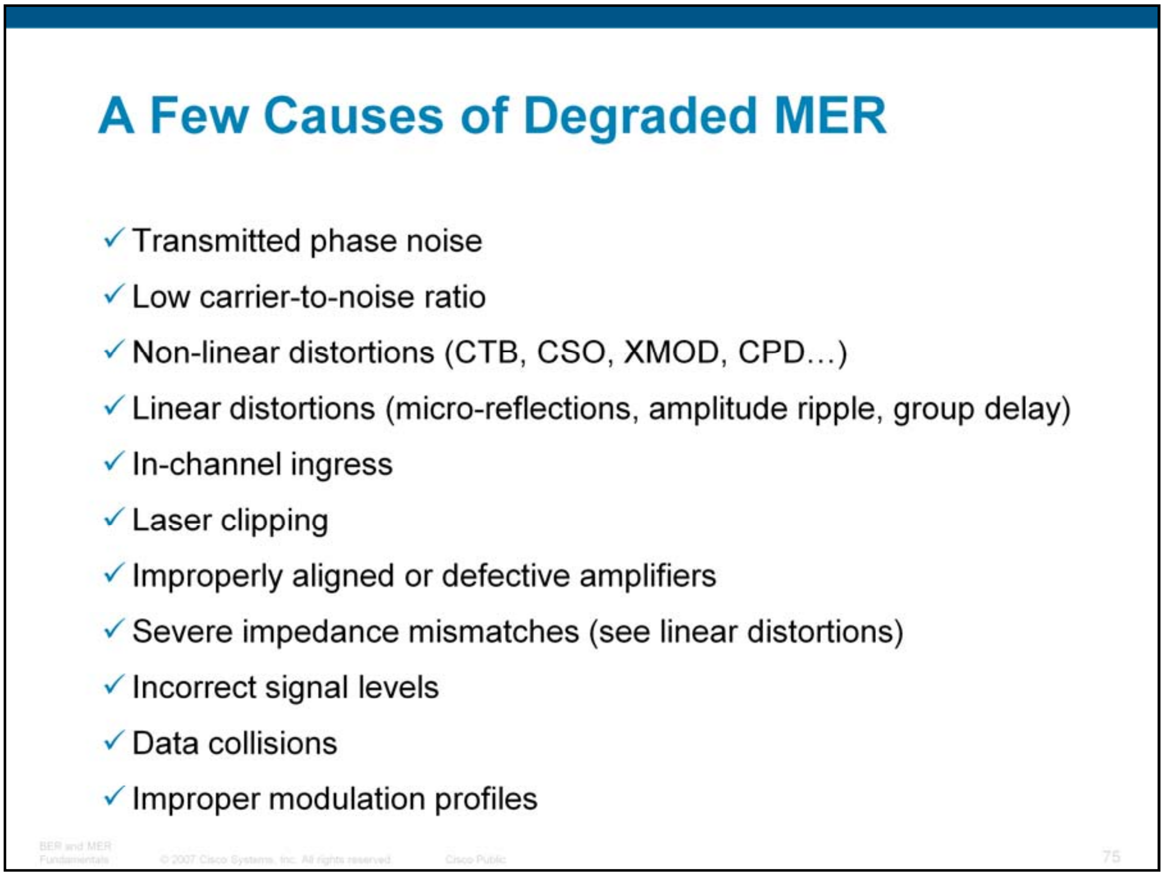

Here's a partial list of things that can degrade MER. Use the divide-and-conquer technique to track down the location and cause of the problem.

At the customer premises, too much or too little signal can affect MER ("SNR") reported by the modem or set top box. In addition to measuring digital channel power on the QAM signal of interest, make sure that total power—the combined power of all downstream signals—is less than +30 dBmV.

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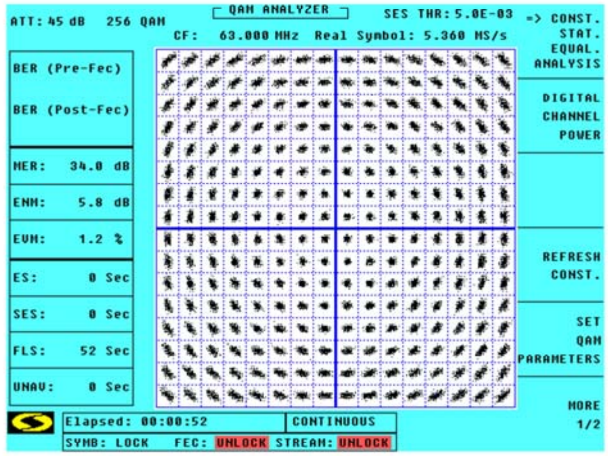
A Few Causes of Degraded MER

Transmitted phase noise



Graphic courtesy of Sunrise Telecom

Phase noise causes the constellation symbol points to smear in a circular pattern, almost like the display is rotating. Excessive phase noise usually occurs in a frequency conversion device such as an upconverter, but also can occur in the data modulator itself.

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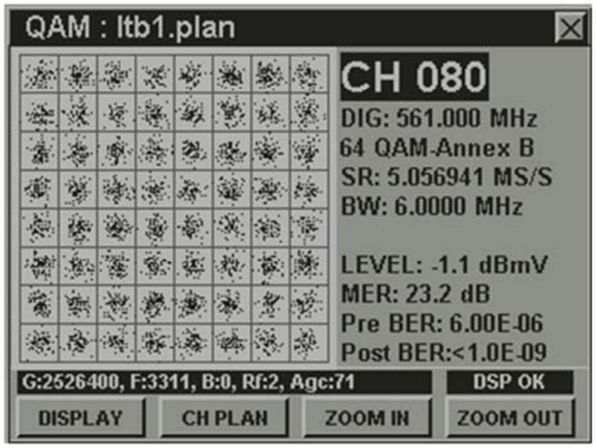
A Few Causes of Degraded MER

Low carrier-to-noise ratio



Graphic courtesy of Trilithic

The constellation symbol points in this screen shot are fuzzy and spread out, typical of low carrier-to-noise ratio and/or low MER (make certain that the signal level at the QAM analyzer input is adequate before assuming an external problem exists), or perhaps a problem with composite triple beat (CTB), composite second order (CSO) or other non-linear distortions. Note that pre- and post-FEC BER are degraded, too. If carrier-to-noise and carrier-to-distortion ratios are found to be acceptable, low MER caused by *linear* distortions such as a severe micro-reflection, amplitude ripple or group delay may be the culprit. The QAM analyzer's adaptive equalizer graph, in-channel frequency response and group delay measurement functions can be used to identify linear distortions.

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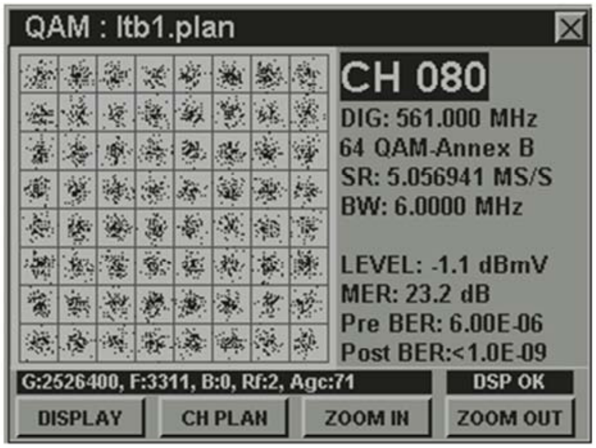
A Few Causes of Degraded MER

Non-linear distortions (CTB, CSO, XMOD, CPD…)



Graphic courtesy of Trilithic

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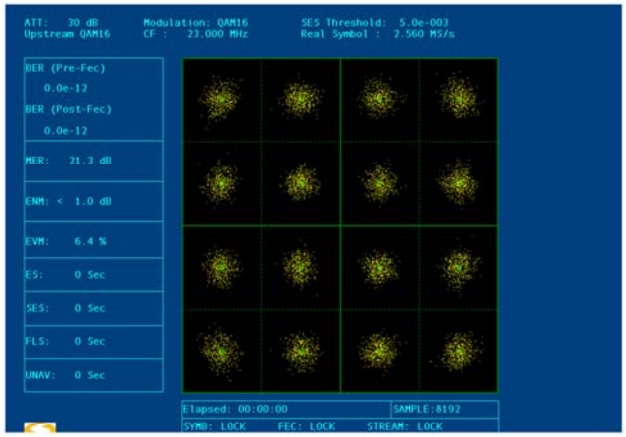
Is this a low carrier-to-noise ratio problem, or perhaps a problem with distortions? As before, make certain that the signal level at the QAM analyzer input is adequate before assuming an external problem exists. Composite triple beat (CTB), composite second order (CSO) or other composite distortions generally spread the constellation points out as shown here. Composite distortions won't create a donut-like pattern on a QAM analyzer—it will be more noise-like and spread the symbol points similar to low CNR.

A Few Causes of Degraded MER

Linear distortions (micro-reflections, amplitude ripple, group delay)



Graphic courtesy of Sunrise Telecom

Linear distortions such as micro-reflections, amplitude ripple/tilt, and group delay will, if severe enough, result in degraded MER. This screen shot shows an upstream 16-QAM signal whose unequalized MER is about 21 dB, just a dB or so above the MER failure threshold for 16-QAM. Note that the constellation's symbol points are spread out and fuzzy as if the carrier-to-noise ratio were low. In this particular case, the CNR actually was about 37 dB! The degraded constellation and MER were caused by a severe impedance mismatch about 1100 feet from the node. The resulting micro-reflection caused substantial amplitude ripple ("standing waves") and group delay ripple, neither of which could be seen on a spectrum analyzer.

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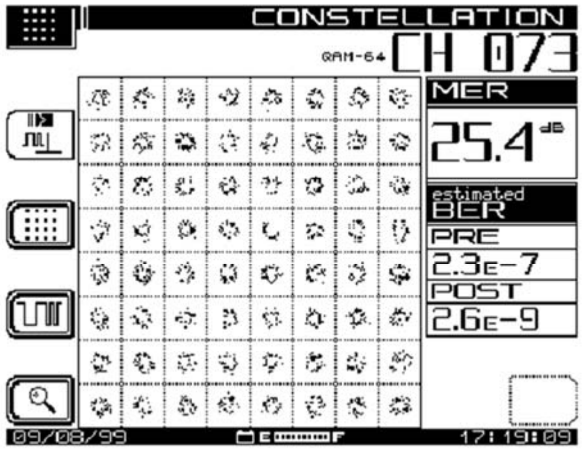
A Few Causes of Degraded MER

In-channel ingress



Graphic courtesy of JDSU

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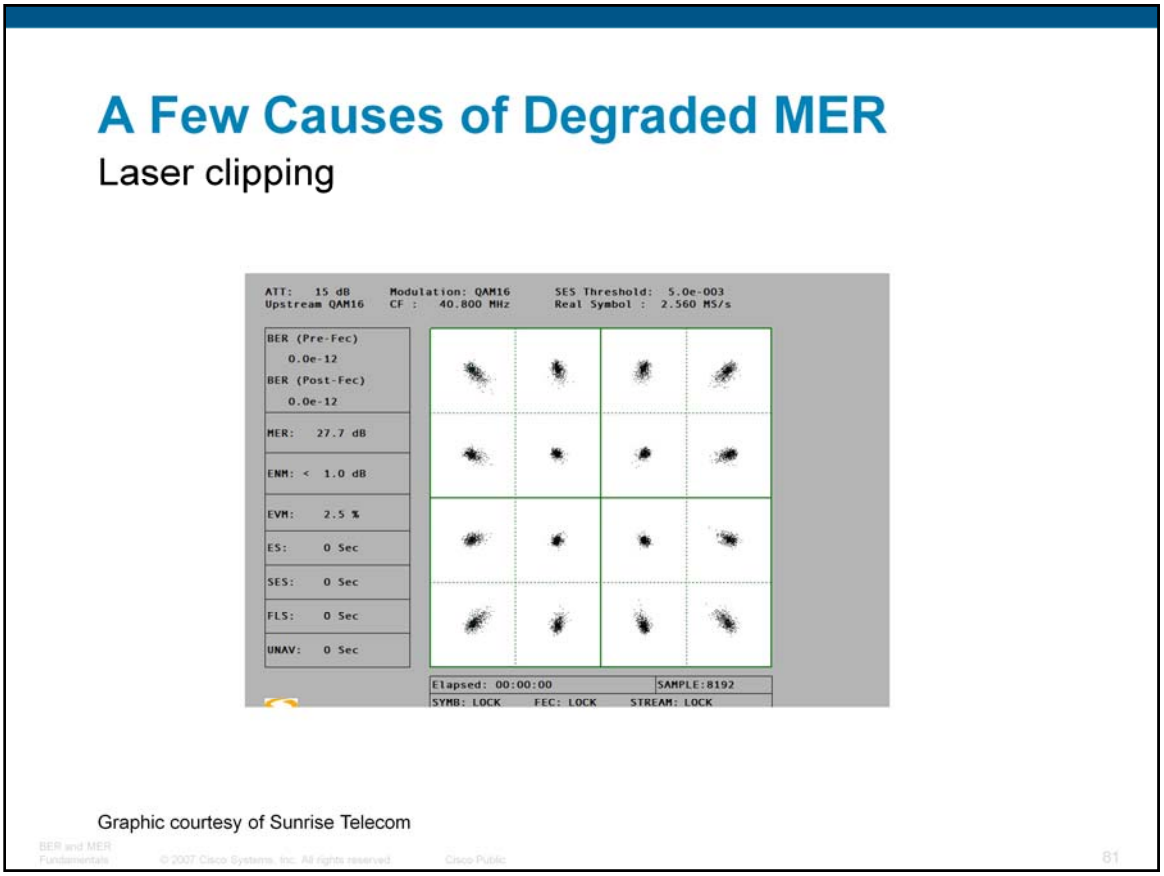
Coherent interference causes the constellation symbol points to resemble small donuts. In-channel ingress, discrete intermodulation distortion or spurious signals are the most common impairments that cause this. Composite distortions such as CTB and CSO generally won't create a donut-like pattern on a QAM analyzer—it will be more noise-like and spread the symbol points similar to low CNR. The donut-like pattern is fairly easy to see in a 64-QAM constellation, as shown here. The symbol points are much closer together in a 256-QAM constellation, and by the time an in-channel interfering signal is high enough amplitude to create the donuts, 256-QAM will in most cases have stopped working altogether.



This slide shows an example of the onset of upstream laser clipping and the effect it has on a 16-QAM signal. Note that the clipping isn't quite severe enough to cause BER problems, but equalized MER has started to degrade. This optical link has perhaps another dB or so of headroom before performance becomes unacceptable.

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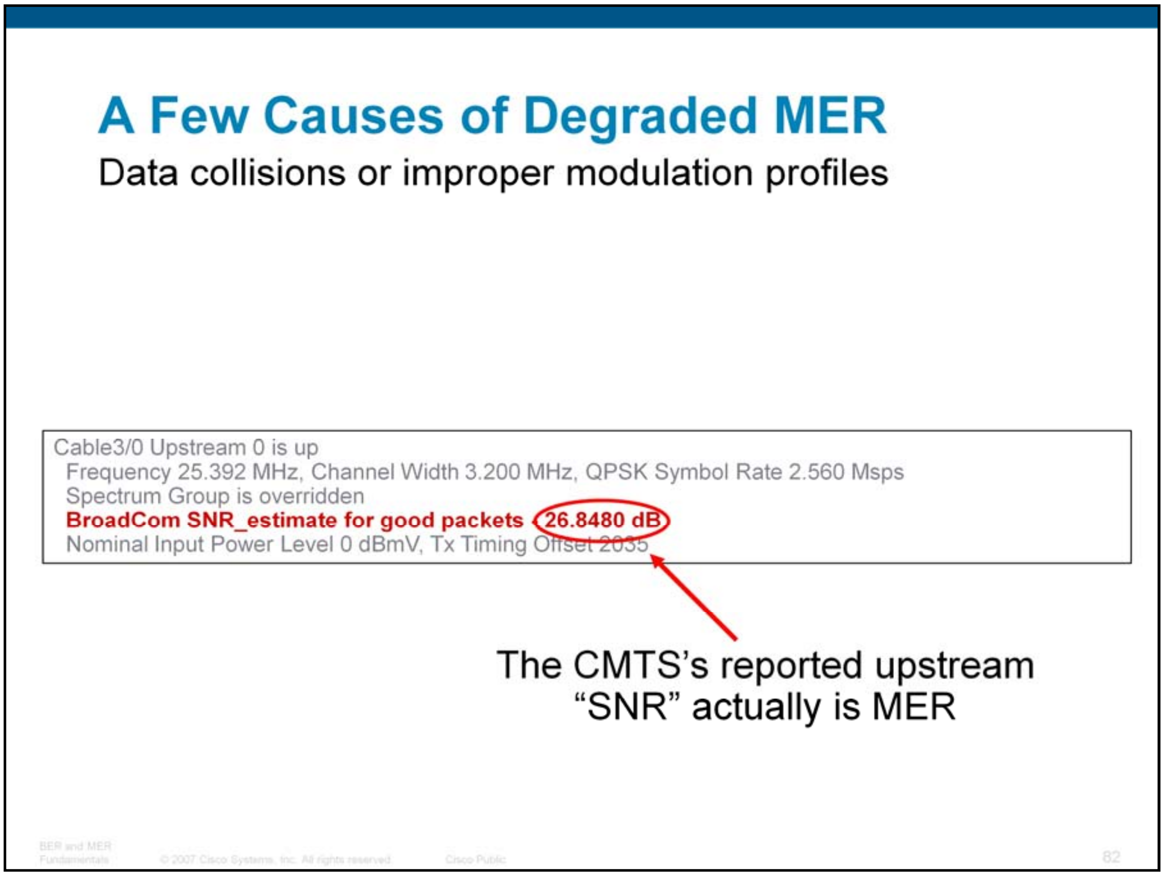

Data collisions and improper modulation profiles are two factors that can affect a CMTS's reported "upstream SNR" (MER), and in some cases cause packet loss. Ensure that the modulation profile in use is optimized for the modulation type.

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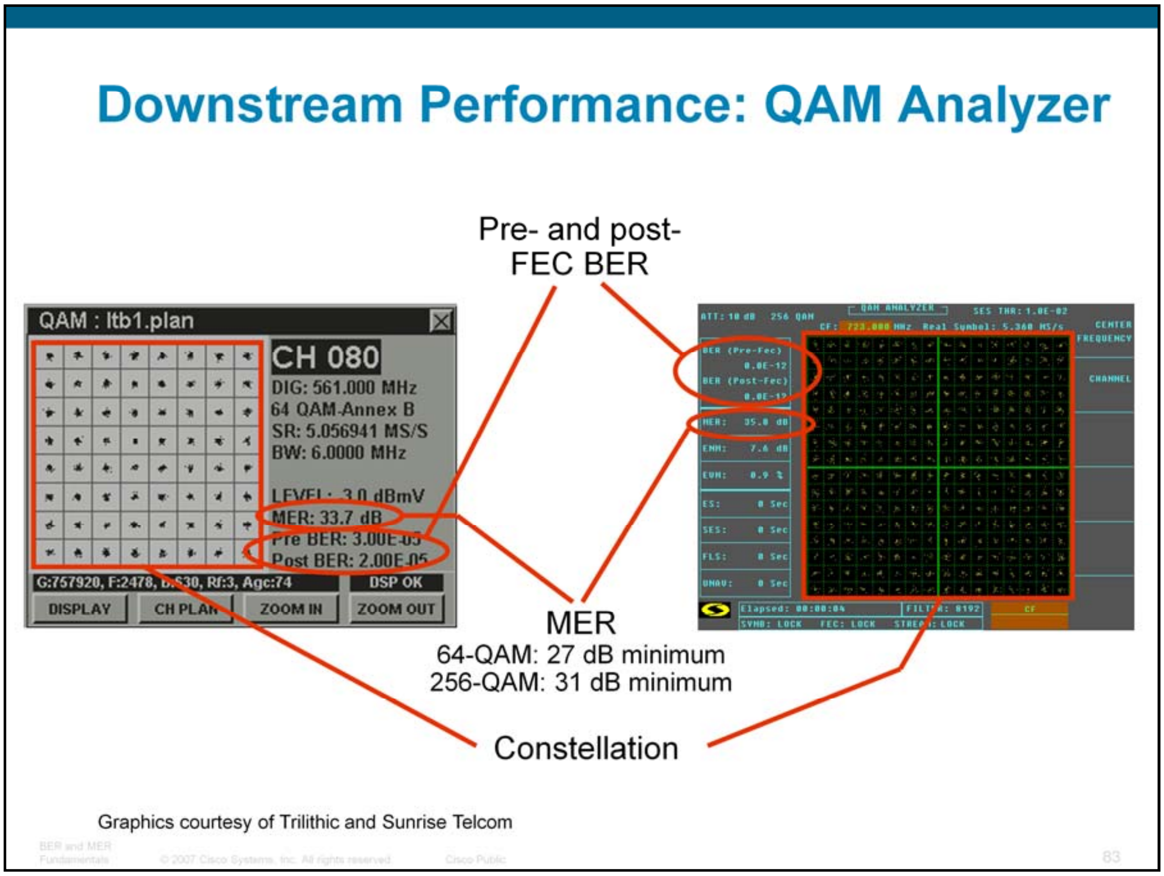

These two screen shots show examples of downstream 64-QAM (left) and 256-QAM (right) digitally modulated signals.

- The 64-QAM signal's digital channel power is -3 dBmV, an acceptable value. The constellation has tight symbol points, an overall square shape, and shows no signs of visible impairments such as phase noise or coherent interference. Equalized MER is 33.7 dB. But pre- and post-FEC bit error rate are much higher than they should be, with values of 3.00E-05 (3×10^{-5}) and 2.00E-05 (2×10^{-5}) respectively. This screen shot illustrates the importance of evaluating multiple parameters on a QAM analyzer. In this case the digital channel power, MER and constellation are fine, but the bit error rate indicates a problem—perhaps sweep transmitter interference, downstream laser clipping, an upconverter problem in the headend, or a loose connection.
- The 256-QAM signal's constellation has tight symbol points, an overall square shape, and no signs of visible impairment. MER is 35.8 dB. There are no pre- or post-FEC bit errors. This is a problem-free signal.

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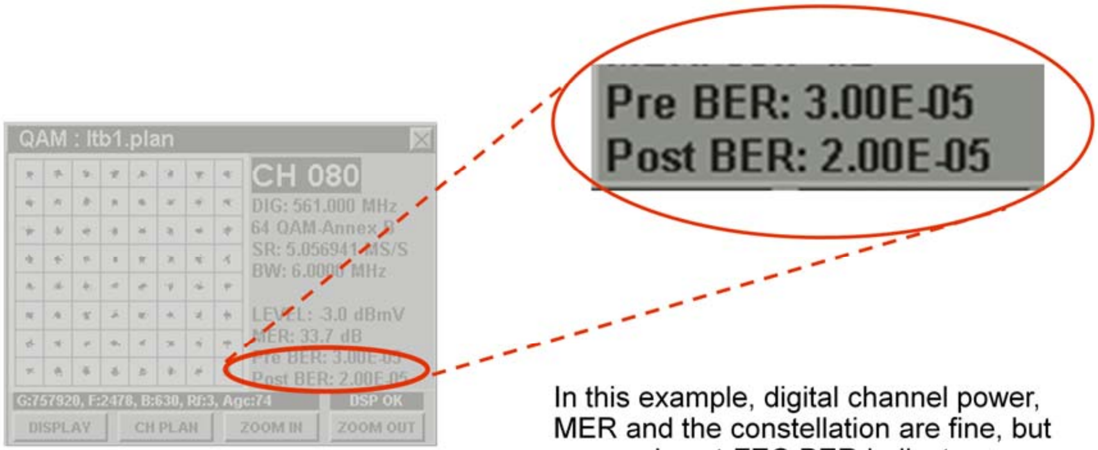
Pre- and Post-FEC BER



In this example, digital channel power, MER and the constellation are fine, but pre- and post-FEC BER indicate a problem—perhaps sweep transmitter interference, downstream laser clipping, an upconverter problem in the headend, or a loose connection.

Graphic courtesy of Trilithic

There should be no pre- or post-FEC bit errors in the headend or the node's downstream output. Ideally there should be no bit errors at the customer premises, either, although the DOCSIS Radio Frequency Interface Specification states that post-FEC BER at the cable modem input shall be 1.0E-08 or less at specified signal levels and carrier-to-noise ratios. In this screen shot, all parameters *except* pre- and post-FEC BER are fine.

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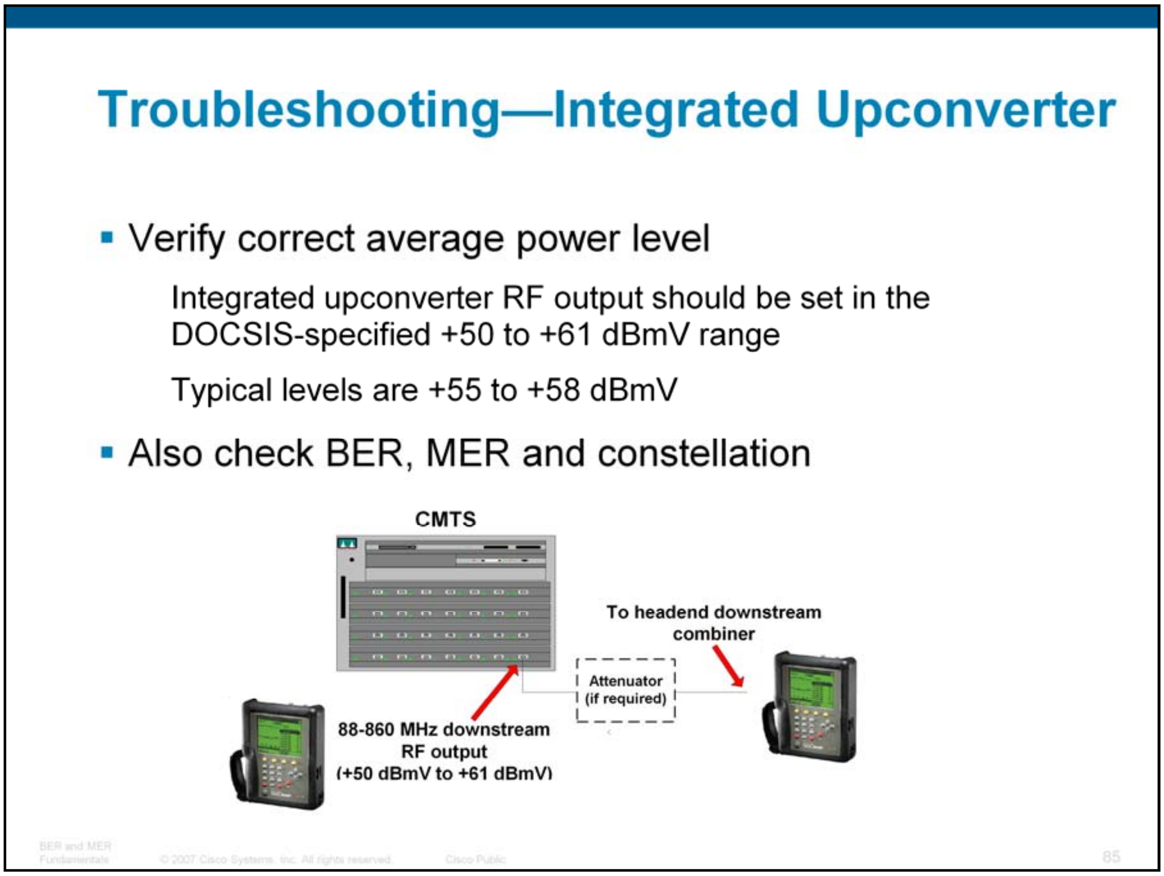

When troubleshooting a problem that affects a large number of customers, start at the source: The CMTS or QAM modulator output. This slide shows a CMTS with an integrated upconverter. Verify that the output level is within the specified or desired range: +50 to +61 dBmV in this example, although +55 to +58 dBmV is fairly typical. Check pre- and post-FEC BER; there should be no bit errors here. MER should be as high as the QAM analyzer is capable of measuring, generally in the mid to high 30s. The constellation should show no signs of visible impairment, and should have an overall square shape. In-channel frequency response should be essentially flat, and group delay no worse than a few tens of nanoseconds.

Ensure that the digital channel power is sufficient so that the digitally modulated signal is 6 dB to 10 dB lower than what an analog TV channel's signal level would be on the same frequency. This may require an in-line attenuator between the CMTS or QAM modulator output and headend combiner input, depending on headend configuration.

Repeat all of these measurements at the headend combiner test point and downstream laser input to ensure that the signal is not being impaired by a problem between the CMTS or QAM modulator output and the combiner or laser.

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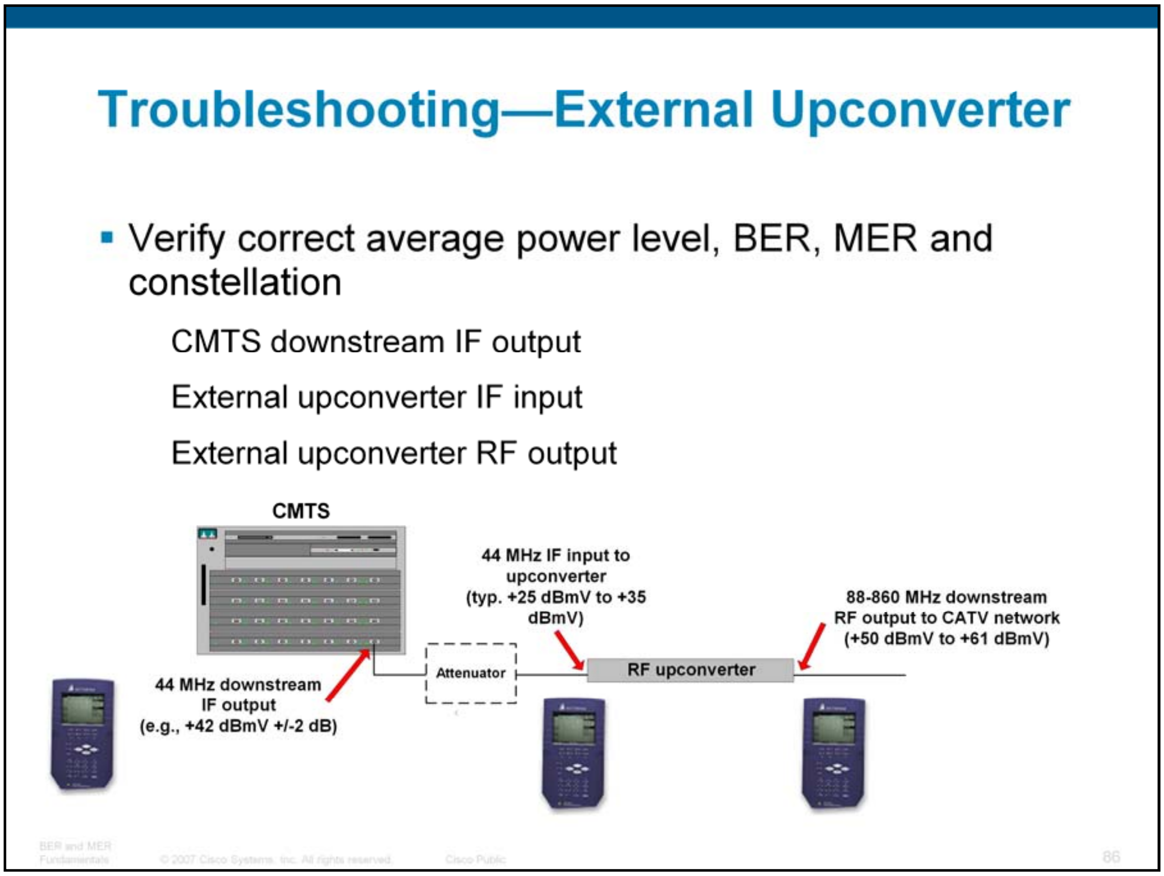

As before, when troubleshooting a problem that affects a large number of customers, start at the source: The CMTS or QAM modulator output. This slide shows a CMTS with an external upconverter. Verify that the CMTS or QAM modulator IF output level is within the specified or desired range: +42 dBmV, +/-2 dB in this example. Check pre- and post-FEC BER; there should be no bit errors here. MER should be as high as the QAM analyzer is capable of measuring, generally in the mid to high 30s. The constellation should show no signs of visible impairment, and should have an overall square shape. In-channel frequency response should be essentially flat, and group delay no worse than a few tens of nanoseconds. Repeat these measurements at the upconverter IF input, and make certain that the upconverter is not being overdriven by too much signal. In most cases an in-line attenuator is recommended at or near the upconverter input.

Verify the external upconverter's RF output level is within the specified or desired range: +50 to +61 dBmV in this example, although +55 to +58 dBmV is fairly typical. Repeat the previous measurements of pre- and post-FEC BER and MER, and look at the constellation for signs of impairment. The signal quality should be more or less the same as what was measured at the upconverter input.

Ensure that the upconverter's output digital channel power is sufficient so that it is 6 dB to 10 dB lower than what an analog TV channel's signal level would be on the same frequency. This may require an in-line attenuator between the upconverter RF output and headend combiner input, depending on headend configuration.

Repeat all of these measurements at the headend combiner test point and downstream laser input to ensure that the signal is not being impaired by a problem between the upconverter RF output and the combiner or laser.

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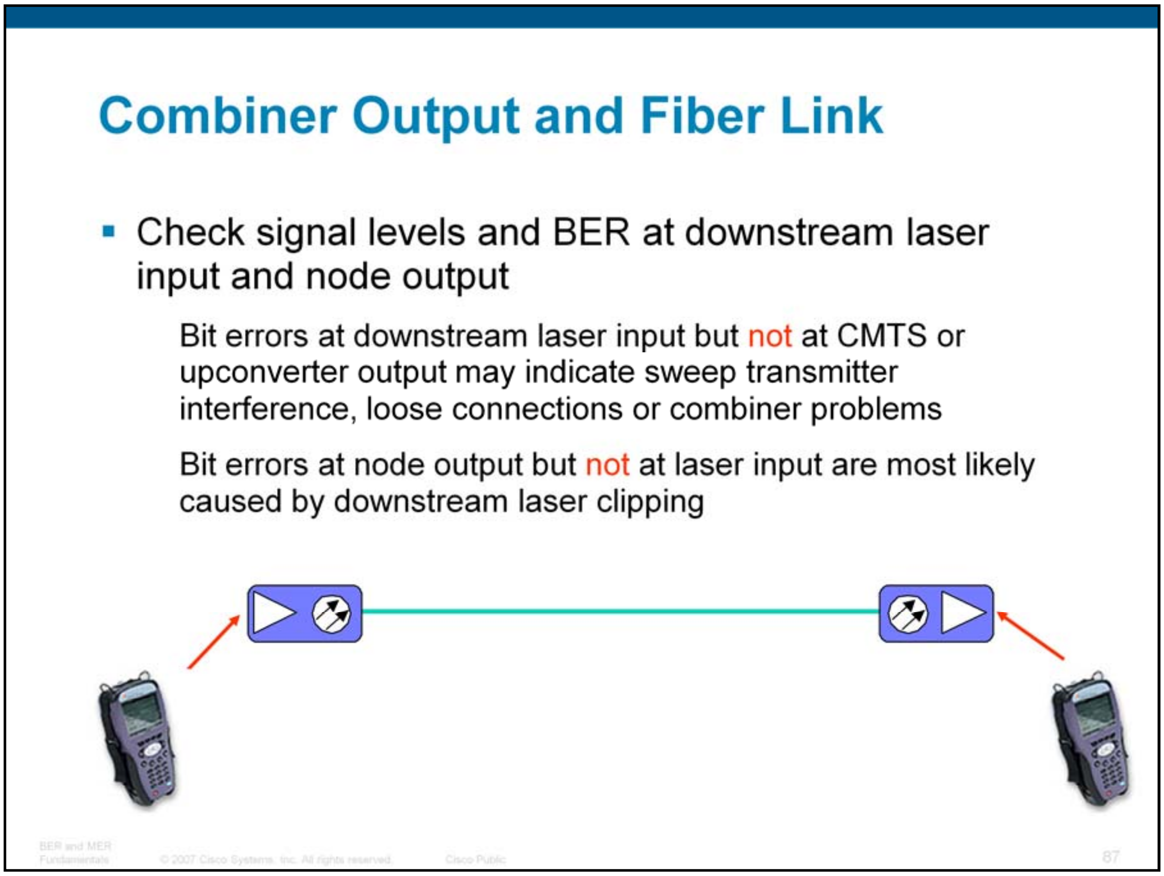

At the points shown, measure downstream digitally modulated signal average power, pre- and post-FEC bit error rate and MER. Evaluate the constellation for visible signs of impairment.

For more information on this, see the article “Those Pesky Bit Errors” in the January 2006 issue of *Communications Technology* magazine.

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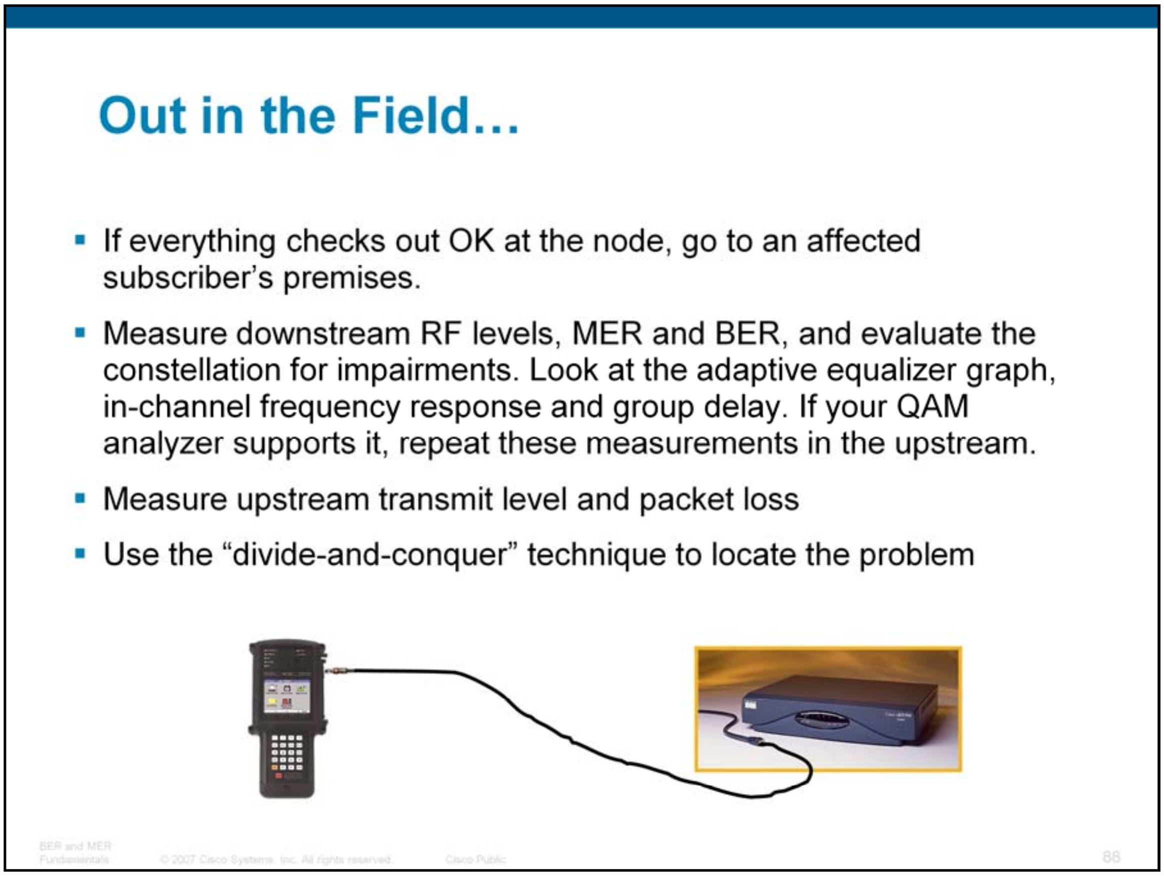

Go to an affected subscriber's premises. Measure the digitally modulated signal's RF level, MER, pre- and post-FEC BER, and evaluate the constellation for impairments. Look at the equalizer graph for evidence of micro-reflections. Also check in-channel frequency response and group delay. If the QAM analyzer supports it, repeat these measurements in the upstream.

Be sure to measure upstream transmit level and packet loss.

If upstream transmit level is at or near the maximum (+58 dBmV for QPSK, +55 dBmV for 16-QAM), the most likely culprit is one or more drop problems. In typical installations, cable modem upstream transmit levels will be in the +30 to +45 dBmV range—give or take a bit—although there can be exceptions.

Upstream packet loss should not exceed about 1% for conventional high-speed data service, and 0.1% to 0.5% for reliable voice service.

Consider a hypothetical downstream problem. Assuming that signal quality at the node is OK, and a problem has been identified at the customer premises, first check at the tap port to make sure the problem isn't occurring somewhere in the drop. If the impairment exists at the tap, use the "divide-and-conquer" technique to locate the problem. That is, go to a location that is about halfway between the node and affected subscriber, and see if the problem is there. If it is, it's occurring somewhere between the node and this first "halfway" test point. Choose a test location about halfway between this location and the node, and check there. Continue the divide and conquer routine until the location of the problem has been identified.

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What's Good?

- BER: Ideally, there should be no measurable bit errors shown on the QAM analyzer, anywhere in the system!

  DOCSIS assumes a worst-case post-FEC BER at the cable modem input of 1×10^{-8} (1.0E-08) at specified RF input levels and carrier-to-noise ratios

- MER: The higher the better!

  Good engineering practice says to keep unequalized MER 3 to 6 dB above the unequalized MER "failure threshold" for the modulation type in use

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

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The Takeaway?

- BER and MER are not the same thing!
- BER is an estimation of the ratio of the number of errored bits to the total number of bits, typically expressed in scientific notation.
- MER is, in effect, a measure of the "fuzziness" of a data constellation's symbol landings, and is expressed in dB. MER is somewhat analogous to baseband signal-to-noise ratio.
- Both BER and MER should be measured. The two together tell a more complete story than either by itself.

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