QAM Overview and Troubleshooting Basics for Recently Digital Cable Operators

Digital quadrature amplitude modulation (QAM) signals are a complex challenge for the average cable technician. This article will examine QAM and will cover the basics for understanding QAM technology. We'll also discuss the kinds of failures that cause digital problems and explain what to look for when testing. Then we'll look at the tools that are used to find these faults.

How is QAM Created?

In a traditional voice modem, tones are used to represent ones and zeros. Low tones represent zeroes and high tones represent ones. In QAM, instead of tones, ones and zeroes are represented as the sum of two signals that are in- and out-of-phase with a clock. The two signals are called I (for in-phase) and Q (for quadrature). In QAM, the Q signal is 90 degrees out of phase with the clock. Both I and Q signals have different levels, each of their levels set by the bits as shown in Figure 1. Each clock cycle encodes 6 or 8 bits, 2^6 or 2^8, therefore 64 or 256 combinations are possible. Thus, unlike a traditional simple modem which encodes one bit per clock, QAM 64 encodes 6 bits per clock, and QAM 256 encodes 8 bits per clock. This technique allows for transmission of a lot more information in the same time frame.
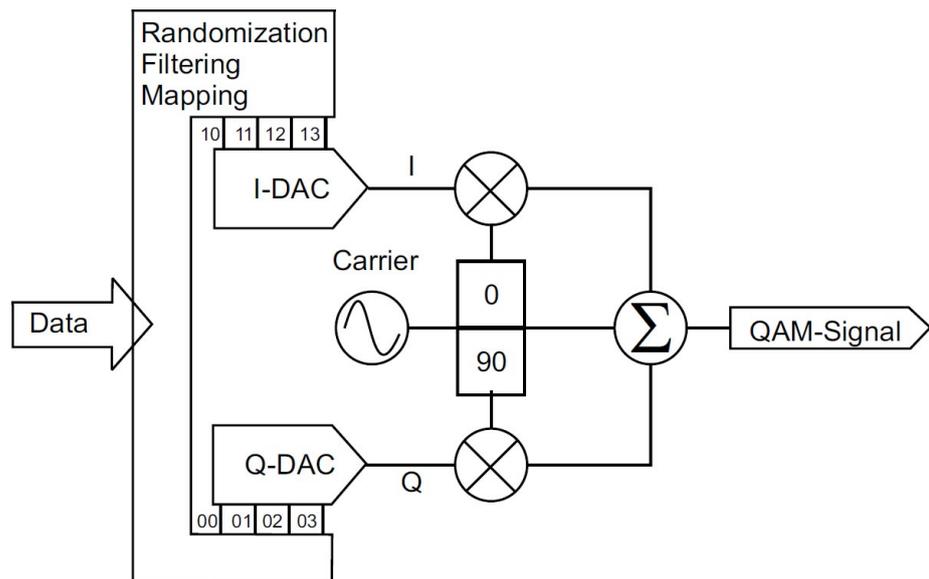

Figure 1. In 256 QAM, 8 bits set the level of I and Q for each clock cycle, with two of the bits setting a minus one multiplier. In 64 QAM, 6 bits are used.

A QAM signal at any given clock cycle is described by its amplitude and phase relative to the clock. The bits shown in Figure 1 are not necessarily b0=LSB (least significant bit) and b7=MSB (most significant bit). In fact, a considerable amount of scrambling, bit encoding, and data filtering occurs in a QAM modulator, which goes way beyond the scope of this paper. Before the bits are modulated to RF, I and Q are amplitude and phase modulated by the 6 bits (6 bits in QAM 64, 8 bits in QAM 256). The waveforms of clock, I and Q, at any given clock cycle, might appear similar to Figure 2.
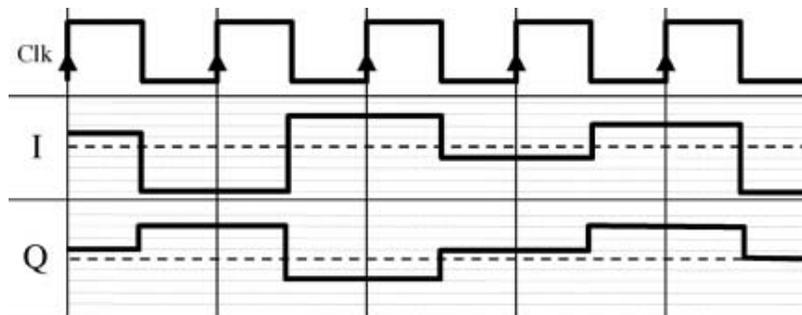
Figure 2. At each clock cycle, I and Q are summed and broadcasted to the receiver, where they are separated and then plotted on a grid (see Figure 3). Noise and impairments in the coax plant cause I and Q to wiggle and distort, among other things, causing errors in the receiver.

At the cable modem or digital television (DTV) set top box (STB), or instrument, the QAM signal must be demodulated and converted back into its I and Q components. To achieve this, the clock must be extracted (another subject beyond the scope of this paper). Once it is extracted, on each rising edge of the recovered clock, the I and Q are 'clocked' into a circuit performing the reverse of that shown in Figure 1, shown simply here in Figure 3.
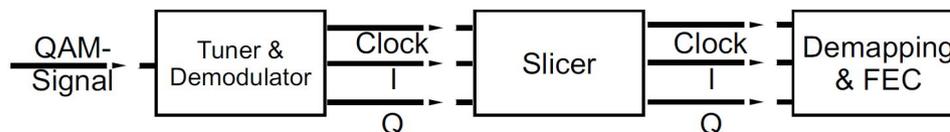

Figure 3. At the STB, cable modem, or test instrument, Clock, I and Q are recovered from the RF carrier. Further, slicing fixes moderate errors in I and Q signals.

The critical concept in Figure 3 is that this receiver circuit utilizes a slicing algorithm that attempts to clean up I and Q. The algorithm differs for the various QAM chip manufacturers. More discussion on this critical issue later.

Think of symbols, the collection of bits transmitted over the QAM signal, as falling into a grid of buckets. The I and Q assigns the symbol to a bucket when it gets transmitted from the headend and the receiving device places it in the correct bucket. For each clock cycle, one symbol is placed in a bucket. The grid of buckets is a running accumulation of clock cycles, and because I and Q are supposed to be discrete amplitudes (4 I and 4 Q levels in QAM 64, 4 levels in QAM 256), the first clock cycle would plot as the one shown in Figure 4.
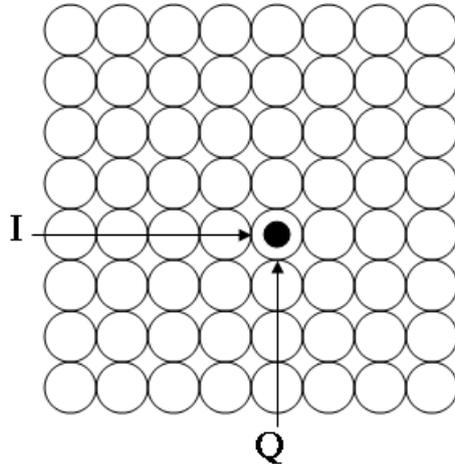
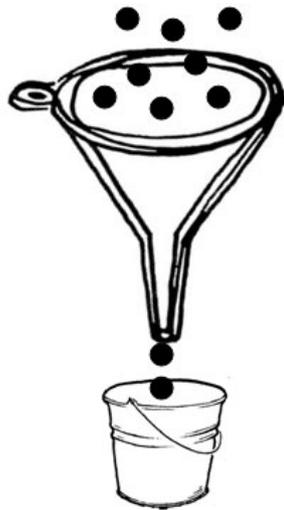Figure 4. Plotting a clock cycle into the appropriate bucket.

Figure 5. Slicing conceptually shown as a funnel and a bucket. Dots, symbols, conceptually fall through the funnel and are 'snapped' to the center of the bucket. Problems exist with symbols that straddle adjacent funnels.

What Happens to I and Q?

As I and Q are modulated at the headend and then broadcast down the cable, faults in the plant cause them to deteriorate. As notch (suck-out), reflections, and other frequency-response-altering impairments occur, the receiver will rebuild the wrong amplitudes. The Adaptive Equalization (EQ) technique removes such types of interference. As ingress, coherent interference, and other modulating effects leak into the plant, the phase and amplitude of I and Q can wander or shift. Slicing corrects small variations in phase and amplitude; however, only within reason. Large variations that cannot be corrected cause the symbol to fall into the wrong bucket, causing bit errors.

Depending on the demodulator chip used, symbols that fall into the space between two funnels could be correctly identified and rerouted to the correct bucket, or they could be placed in the wrong bucket, thus causing bit errors. Bit errors over time are commonly referred to as bit error rate (BER) and can be corrected by the forward error correction (FEC) process, as long as the error is not too drastic. Bit errors occurring before FEC are called pre-BER errors and those occurring after the FEC are called post-BER.

What is BER and FEC?

BER is an age-old technique of characterizing the digital transmission medium. In the past, two components were used to measure BER, a transmitter and a receiver. The transmitter launched known bit patterns down the pipe to a receiver, which correlated the transmission errors into BER. These BER test systems were used to qualify a new pipe. BER systems were meant to sit online for days to determine the true BER. When digital signals first showed up in cable, operators saw BER as the way to characterize their pipe. Unfortunately, cable operators cannot take down a digital channel for days at a time to test its quality. So integrated circuit (IC) manufacturers built diagnostic tools into their chips to allow the reading of FEC statistics.
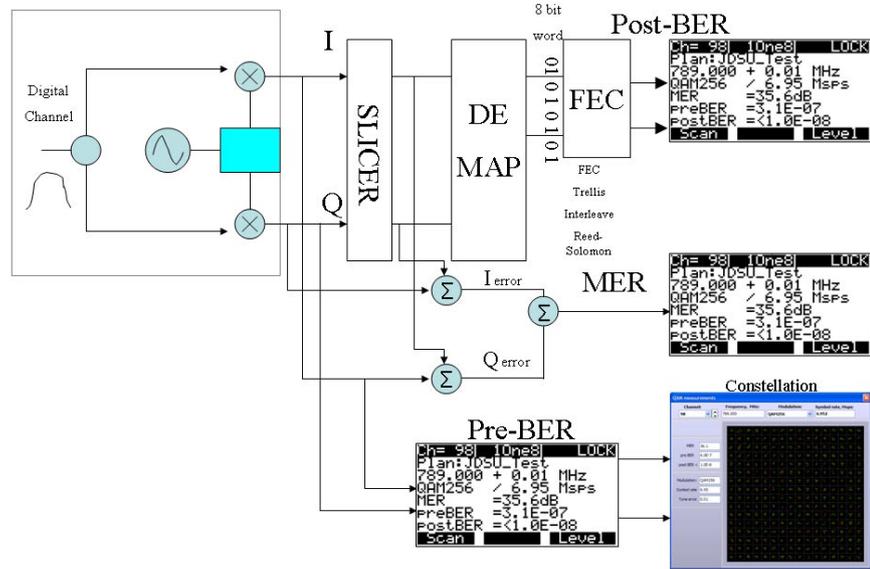
Figure 6. Concept of a QAM receiver shown with QAM test results shown on the MSQ.

In Figure 6, after the QAM signal is demodulated, the I and Q signals contain all of the information and errors generated through the transmission. The I and Q signals are routed through a slicer to make a hard decision on the symbol (recall the funnel in Figure 5). These post slicer or adjusted I and Q, I* and Q*, signals are then run through FEC. Recognizing that the hard decision removed all of the errors until an I and Q signal crosses a symbol boundary, tells us that FEC does not begin to work until modulation error ratio (MER) reaches fairly poor quality.

FEC also works when the symbols are Gray coded, which means that any adjacent symbol will only change one bit value of the entire symbol once the MER reaches high enough to cross the boundary to the adjacent cell. Interleaving randomly distributes errors throughout the data transfer, so that if a block of errors occur, all data is not lost. After interleaving, the symbol is applied to Trellis Coding and Reed Solomon (R-S) FEC as shown in Figure 7. FEC can accommodate up to 3 symbols of error per block of 128.

Another method chip manufacturers use for improving signal reception is adaptive equalization (EQ). The EQ removes constant errors such as group delay and frequency response. Without EQ, the MER would be much worse and thus cause more bit errors. Because these errors are removed, it further enhances the ability to correct BER.
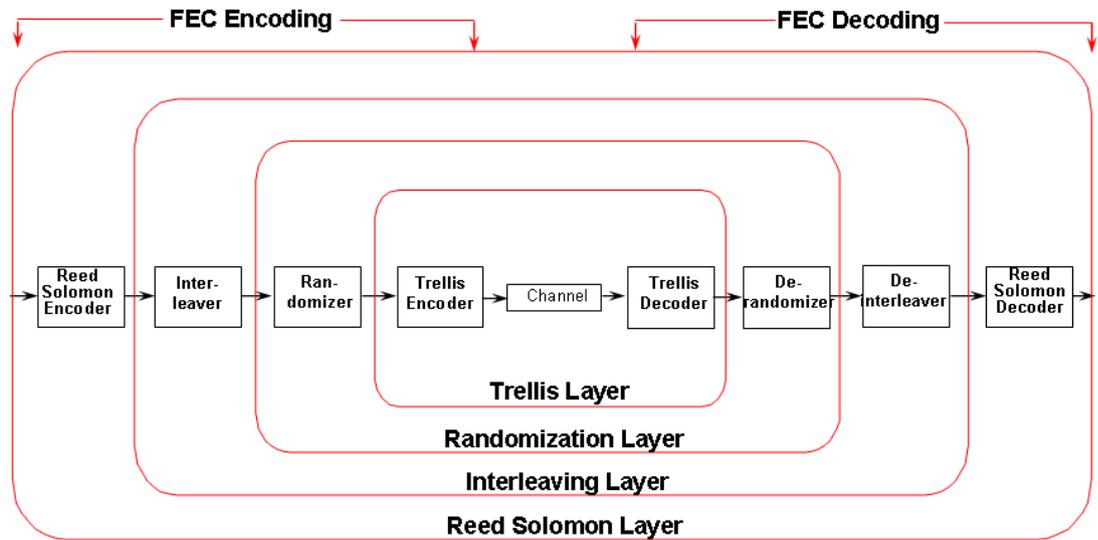
Figure 7. The processes involved with FEC encoding and decoding a QAM signal.

Understanding BER Testing

For a newer field technician, BER may seem difficult to understand. As Figure 8 shows, BER is displayed in scientific notation, such as 1E-06, which may seem counterintuitive as a lower number is better. Essentially this lower number, or higher negative number, means that for some number of bits tested fewer errors occurred. Where 1E-6 means 1 error occurred for every million bits tested (1E-06 = 1/1,000,000) and 1E-8 means only 1 error occurred for every 100 million bits (1E-08 = 1/100,000,000). Despite the initial complexity of BER to beginner cable technicians, BER has become one of the most mandated tests for certifying signal quality on QAM networks.

Figure 8. BER testing results shown in scientific notation.

Although it is a popular signal quality indicator, BER is commonly tested incorrectly. Because they require several million bits of data, BER tests take time to complete. The QAM (64/128/256) and the symbol rate used ultimately determine the length of time for BER testing. A more complex QAM results in more data transmitted in a given period of time, users must wait longer for a BER test to complete on QAM 64 than on QAM 256. Because standardized symbol rates exist for QAM Annexes B and C, it is easy to use them as examples. For QAM 64 Annex B the symbol rate is 5.0569 Msps (million symbols per second) and each symbol has 6 bits. Technicians who want to test for BER to 1E-8 (errors in 100 million bits) must wait for the STB or test equipment to receive 100 million bits. This is calculated from by dividing 100 million bits by its transmission rate of 30.34 Mb/s. The transmission rate is determined by its

symbol rate times the number of bits per symbol, in this case 5.0569 Msps times 6 bits per symbol, which means waiting approximately 3.3 seconds to perform the test properly. For QAM 256 Annex B, 5.3605 Msps times 8 bits/symbol equals 42.88 Mb/s, this wait time is decreased slightly to 2.3 seconds. Testing BER to 1E-9 increases wait intervals by 10 times to 33 seconds for QAM 64 and 23.3 seconds for QAM 256.

Individually testing several QAM channels in a typical channel lineup for the necessary testing periods can become very time consuming for technicians. Reducing the testing time can only be achieved through either lowering the BER thresholds on QAM channels or testing fewer channels. However, because BER issues between 1E-8 and 1E-9 can be well corrected through FEC, and because overall network health can be better determined by testing more channels, it is better to lower the thresholds than to reduce the number of channels tested.

Understanding Modulation Error Ratio

MER is the difference between the average symbol amplitude and the average error for the symbol. In cable terms, MER is the equivalent of signal to noise ratio (SNR). Like SNR, MER can be correlated to system distortions. However, unlike SNR, MER is not dependent on the content. Because the QAM signal is being modulated with a digital signal, the noise in the video is digitized prior to I and Q hitting the modulator. Technicians can then be sure that any distortion of MER measured in the field is caused by some component in the field.
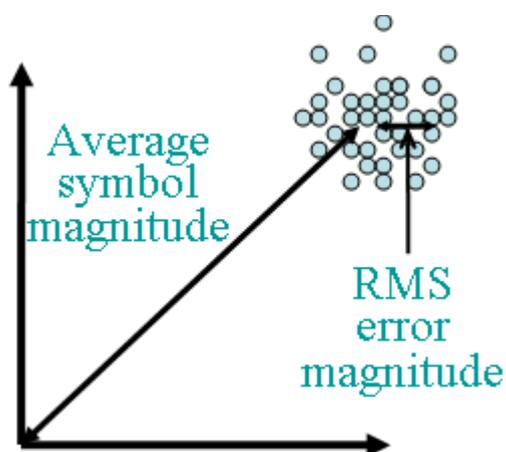

Figure 9. MER is the ratio of the error vector to the desired vector magnitude, which is determined by comparing raw I-Q values (errors) to I*-Q* values (desired).

Understanding MER Testing

Because MER is similar to SNR testing on the analog channel, technicians must also understand whether the issues seen with MER are actually caused by lower power levels. QAM signals will degrade as the power level of the signal degrades below a certain threshold. It is the limit where the receiver can no longer distinguish between QAM signal and Hybrid Fiber Coax (HFC) noise floor. To help distinguish between true impairments and power level issues technicians should perform an average digital level measurement as shown in Figure 10. Power levels at customer premises equipment should be around 60 dBµV (0dBmV). Technicians can be confident that something other than attenuation is causing the issues if the level is good but the MER remains poor.
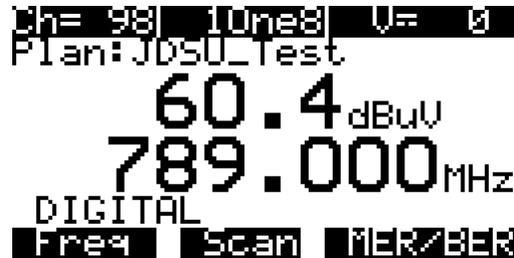
Figure 10. Because MER can be attributed to poor results based on power levels, technicians must verify that the QAM power level is sufficient before looking for other issues.

Also MER, similar to BER, can vary between various demodulator chipsets, which is because IC manufacturers have improved over the years with noise canceling algorithms and increasing the number of taps used in the demodulation of the QAM signal. The chips with the most noise cancelation and lowest noise floors provide operators with the highest MER values, which does not mean that it is unnecessary to test MER; on the contrary, MER serves as a very good indicator of continuous issues in the QAM path regardless of the complex methods used to remove noise from the video. MER is primarily useful for identifying noise under the QAM carrier that is steadily interfering with the signal. As Figure 11 shows, MER is an average measurement that has a tendency to eliminate impulse noise impairments from its measurement; however, a consistent noise source, such as an off-air carrier, can cause MER values to degrade.

$$MER(dB) = 20 \times log \left[\frac{RMS\ error\ magnitude}{average\ symbol\ magnitude} \right]$$

Figure 11. MER is calculated as an average measurement, which is best for revealing consistent noise sources

A nominal QAM modulator has an inherent MER greater than 37 dB. The output of a fiber node should maintain that signal quality. Figure 12 shows typical MER values to try to achieve in your system. Based on carrier-to-noise ratio (CNR) values on analog channels of 47 dB at the terminator, with a 10 dB differential between the analog and QAM channels, the MER should be >37 dB. When testing in the field, it is good to know what MER levels to expect. As a rule, 64 QAM will stop working at around 22 dB MER, and 256 QAM requires at least 28 dB. To ensure that digital services will work over temperature and time, technicians should account for enough margin for drift to avoid future service calls on extremely cold or hot days.

Digital Video		MER				Pre FEC BER (Pre-BER)	Post FEC BER (Post-BER)
		QAM 64		QAM 256			
Node	Excellent	34	dB	35	dB	0.0 E -0	0.0 E -0
	Acceptable	31	dB	34	dB	<1.0 E -8	<1.0 E -8
	Marginal	28	dB	30	dB	<1.0 E -7	<1.0 E -8
Amp	Excellent	33	dB	35	dB	0.0 E -0	0.0 E -0
	Acceptable	30	dB	32	dB	<1.0 E -8	<1.0 E -8
	Marginal	25	dB	27	dB	<1.0 E -7	<1.0 E -8
Tap	Excellent	32	dB	35	dB	<1.0 E -8	0.0 E -0
	Acceptable	28	dB	31	dB	<1.0 E -7	<1.0 E -8
	Marginal	24	dB	28	dB	<1.0 E -6	<1.0 E -8
Set-top	Excellent	32	dB	35	dB	<1.0 E -8	0.0 E -0
	Acceptable	27	dB	31	dB	<1.0 E -7	<1.0 E -8
	Marginal	23	dB	27	dB	<1.0 E -6	<1.0 E -7

Figure 12. Recommended MER and BER test results based on test location for digital video.

Conclusion

Key concepts to remember concern understanding what QAM signals really are and how to determine the quality of the QAM:

- BER is a certification test that can be corrected with FEC when issues occur in the QAM signal. BER can have slightly different values based on various chipsets and the algorithms used in them to correct I and Q values. Realize that pre-BER is primarily a raw indication of HFC performance and post-BER indicates the level at which FEC is working to correct issues. Remember that BER is not a test that can be performed quickly similar to level or even MER measurements, and they can vary based on QAM type and symbol rates used.

- MER is useful in identifying continuous noise in the coax path, whether as a result of low power levels, off-air carriers, or consistent electric motor interference. Acceptable MER values depend on the type of QAM used. Higher modulated QAM signals require higher levels of MER to operate effectively.

Most digital interference or distortion patterns can be diagnosed and fixed when using tools that measure QAM channels with average digital level measurements, MER, and BER such as an MSQ or DSAM offered by JDSU.