Application Note

Critical RF Measurements in Cable, Satellite and Terrestrial DTV Systems

The secret to maintaining reliable and high-quality services over different digital television transmission systems is to focus on critical factors that may compromise the integrity of the system. This application note describes those critical RF measurements which help to detect such problems before viewers lose their service and picture completely.

Tektronix®

Modern digital cable, satellite, and terrestrial systems behave quite differently when compared to traditional analog TV as the signal is subjected to noise, distortion, and interferences along its path. Today s consumers are familiar with simple analog TV reception. If the picture quality is poor, an indoor antenna can usually be adjusted to get a viewable picture. Even if the picture quality is still poor, and if the program is of enough interest, the viewer will usually continue watching as long as there is sound.

DTV is not this simple. Once reception is lost, the path to recovery isn t always obvious. The problem could be caused by MPEG table errors, or merely from the RF power dropping below the operational threshold or the cliff point. RF problems can include any of the following: satellite dish or Low-Noise Block Converter (LNB) issues, terrestrial RF signal reflections, poor noise performance, or channel interference; and cable amplifier or modulator faults.

There are a couple of ways to solve DTV reception problems. One solution is to make set-top receivers more tolerant to degraded signals. A better solution is for the network to maintain a clean, high-quality RF signal.

To ensure this, Tektronix provides critical RF measurements for 8-VSB, 8PSK, QPSK, COFDM and QAM modulation schemes, integrated with real-time MPEG monitoring in a single instrument, the MTM400A. This instrument can be economically deployed at various points within the transmission chain from downlink and encoding, through multiplexing and remultiplexing to final delivery via uplink, head-end, and transmitter sites.

Using the MTM400A, an operator can make critical RF measurements at a fraction of the cost of dedicated RF test equipment.

Web-based remote control allows the correct measurements to be made at the appropriate signal layers throughout the transmission chain, thus ensuring that cost-effective results can be guaranteed.

The Key RF parameters

RF signal strength	How much signal is being received
Constellation diagram	Characterizes link and modulator performance
MER (Modulation Error Ratio)	An early indicator of signal degradation, MER is the ratio of the power of the signal to the power of the error vectors, expressed in dB
EVM (Error Vector Magnitude)	EVM is a measurement similar to MER but expressed differently. EVM is the ratio of the amplitude of the RMS error vector to the amplitude of the largest symbol, expressed as a percentage
BER (Bit Error Rate)	BER is a measure of how hard the Forward Error Correction (FEC) has to work $BER = \frac{\text{Bits corrected}}{\text{Total bits sent}}$
TEF (Transport Error Flag)	The TEF is an indicator that the FEC is failing to correct all transmission errors TEF is also referred to as “Reed-Solomon uncorrected block counts”

BER or Bit Error Rate

This is the ratio of bits in error to total bits delivered. Early DTV monitoring receivers provided an indication of bit error rate as the only measure of digital signal quality. This is simple to implement since the data is usually provided by the tuner demodulator chipset and is easily processed. However, tuners may often output BER after the Forward Error Correction (FEC) has been applied. It is better to measure BER before FEC (pre-Viterbi) so that an indication is given of how hard the FEC is working. After the Viterbi de-interleave process, Reed-Solomon (RS) decoding will correct errored bits to give quasi error-free signal at the output.

This is applicable when the transmission system is operating well away from the cliff point, where few data errors occur and pre-Viterbi bit error rates are near zero. As the system approaches the edge of the cliff, the pre-Viterbi BER increases gradually, the post-Viterbi more steeply, and the post-FEC (after RS) very steeply.

Therefore, FEC has the effect of sharpening the angle of the cliff. As a result, very sensitive bit error rate measurements do give a warning, but usually too late for any corrective action to be taken.

It is still useful to display BER to allow documentation and quantification of the signal quality being delivered. BER can also be used to log long-term system trends. It is best used to identify periodic, transient impairments.

BER measurements are usually expressed in engineering notation and are often displayed as an instantaneous rate and an average rate. Typical targets are: 1E-09, quasi error-free at 2E-04; critical BER: 1E-03; and out-of-service: greater than 1E-03.

How to Improve on BER — use MER

The TR 101 290 standard describes measurement guidelines for DVB systems. One measurement, Modulation Error Ratio (MER), is designed to provide a single figure of merit of the received signal. MER is intended to give an early indication of the ability of the receiver to correctly decode the transmitted signal. In effect, MER compares the actual location of a received symbol (as representing a digital value in the modulation scheme) to its ideal location. As the signal degrades, the received symbols are located further from their ideal locations and the measured MER value will decrease. Ultimately the symbols will be incorrectly interpreted, and the bit error rate will rise; this is the threshold or cliff point.

Figure 1 shows a graph, which was obtained by connecting the MER receiver to a test modulator. Noise was then gradually introduced and the MER and pre-Viterbi BER values recorded. With no additive noise, the MER starts at 35 dB with the BER near zero. Note that as noise is increased the MER gradually decreases, while the BER stays constant. When the MER reaches 26 dB, the BER starts to climb, indicating the cliff point is near. MER indicates progressive system degradation long before reaching the cliff point.

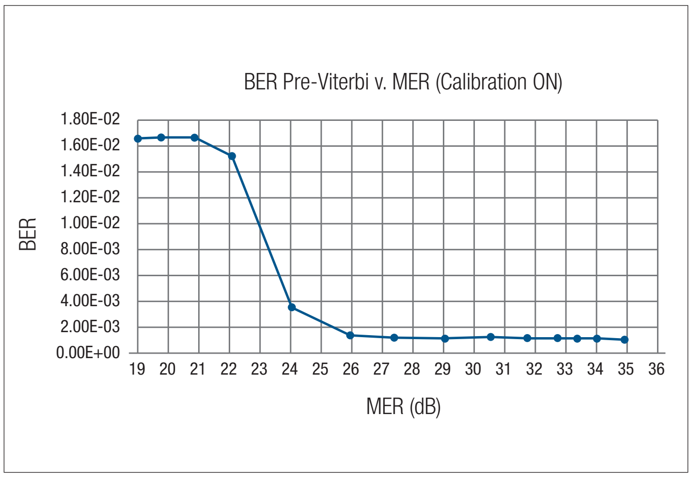

Figure 1. A 64-QAM receiver with MER measurement capability.

The Importance of MER

Because Tektronix equipment can measure to a high value of ultimate MER (typically 38 dB in QAM systems, 37 dB in COFDM systems and 36 dB in 8-VSB systems), then monitoring equipment sited at the head-end modulator can provide early indication of signal degradation as the downstream MER reduction factor (safety margin) is known — or can be measured close to or at the subscriber site. Common set-top boxes may fail to correctly demodulate or drop out at 24 dB (for 64-QAM) and 30 dB (for 256-QAM). Other typical measuring equipment having a lower ultimate MER measurement will not give such an early warning of signal degradation.

Typical ultimate MER at a cable (QAM) head-end is 35 dB to 37 dB. A typical value of MER in an analog cable system is 45 dB. The difference between analog and digital levels is 10 dB, giving a digital MER in distribution systems of around 35 dB.

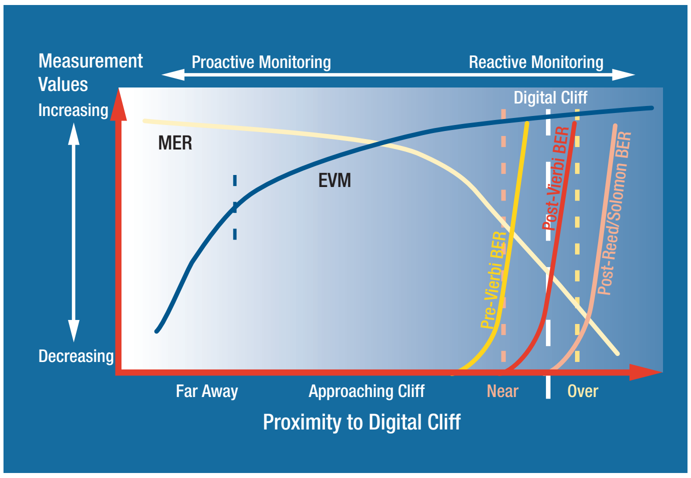

Figure 2. How MER and EVM can be used to predict how much safety margin the system has before BER rapidly rises and reception is lost.

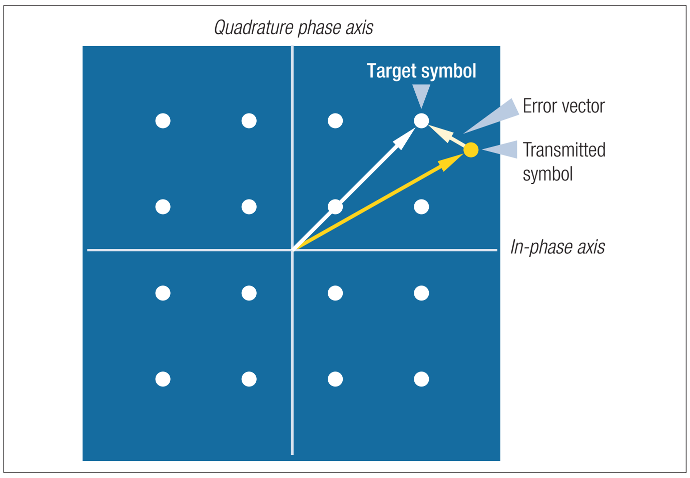

Figure 3. Error vector.

EVM or Error Vector Magnitude

EVM is a measurement similar to MER but expressed differently. EVM is expressed as the percentage ratio of the amplitude of the RMS error vector to the amplitude of the largest symbol. EVM increases as impairment increases, while MER decreases as impairment increases.

MER and EVM can be derived from each other. EVM is the distance that a carrier is detected on the IQ (in-phase and quadrature) constellation from the theoretical perfect landing point (Figure 3) and is the ratio of errored signal vectors to maximum signal amplitude and is expressed as an RMS percentage value. EVM is defined in an annex of TR 101 290. The Tektronix MTM400A provides both MER and EVM measurement capability.

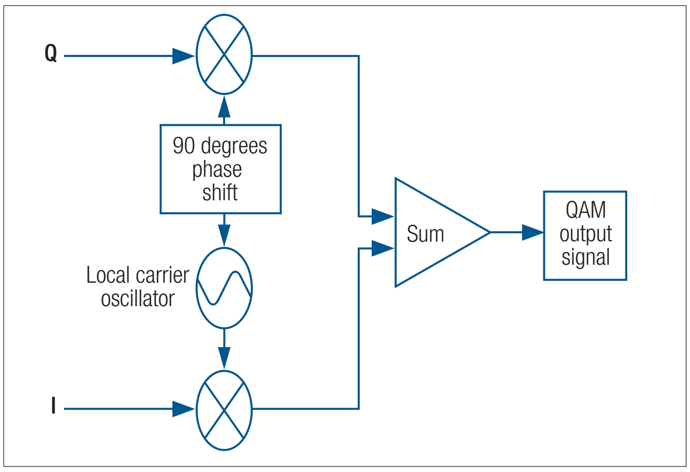

Figure 4. QAM modulator.

Modulation and System Variations

The signals used in satellite, cable, and terrestrial digital television transmission systems are modulated using quadrature modulation schemes, where phase and amplitude are modulated to represent data symbols. The most common modulation schemes used in digital television transmission are all variants of Quadrature Amplitude Modulation (QAM).

For example, in commonly used terrestrial digital modulation schemes, COFDM (as used in DVB-T transmissions) uses 16-QAM or 64-QAM and 8-VSB (as used in ATSC transmissions) uses an 8-column system. In satellite, the digital modulation scheme used is Quaternary or Quadrature Phase Shift Keying (QPSK), which is equivalent to 4-QAM. QPSK is a very robust modulation scheme, and has been in use for several years. QPSK is also used for contribution feeds and makes a more efficient use of the available bandwidth, but needs a better carrier-to-noise ratio.

Cable systems build on this, and have a wider range of schemes, which are still evolving. Additional modulation levels (16-QAM, 64-QAM, 256-QAM and 1024-QAM) improve spectral efficiency, thereby providing more channels within a given bandwidth.

In U.S. systems, 64-QAM can transmit 27 Mb per second, allowing the transmission of the equivalent of six to 10 SD channels or 1 HD channel within a 6 MHz bandwidth. 256-QAM can transmit 38.8 Mbps or the equivalent of 11 to 20 SD channels or two HD channels within a 6 MHz bandwidth. New compression techniques can provide up to three HD channels over 256-QAM. In European systems, the 8 MHz bandwidth allows up to 56 Mb per second over 256-QAM.

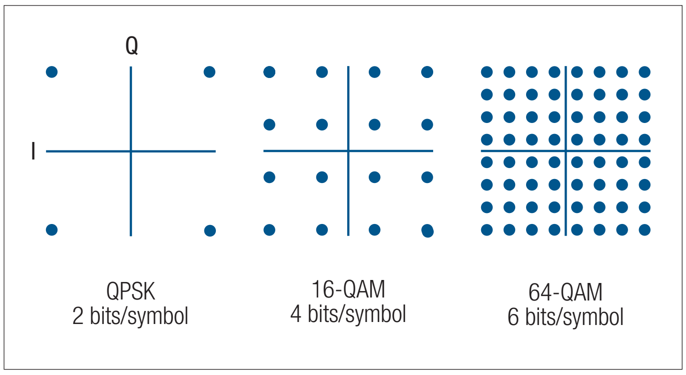

Figure 5. Modulation schemes.

Three regional QAM cable standards are specified in ITU.J83 as follows:

- Annex A — Europe
- Annex B — North America
- Annex C — Asia

The MTM400A has RF interface options and measurement capabilities for all the above QAM standards, as well as 8PSK & QPSK for satellite applications and 8-VSB & COFDM for terrestrial applications.

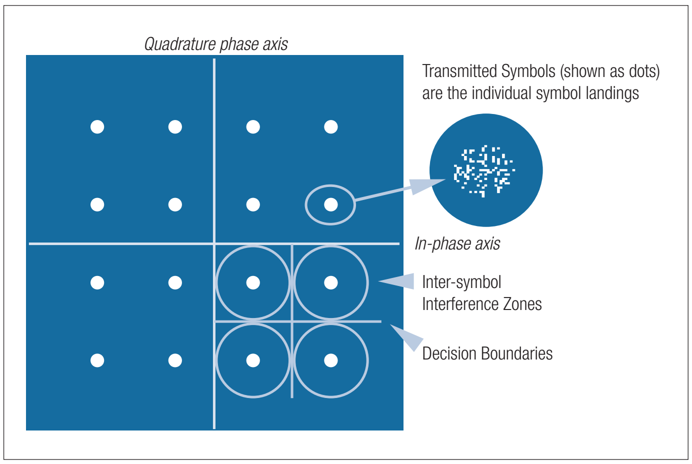

Figure 6. Constellation basics.

Constellation Displays

The constellation display is the digital equivalent of a vectorscope display, showing in-phase (I) and quadrature (Q) components of the QAM signal. A symbol is the smallest piece of information transmitted in a given modulation system.

For 64-QAM, a symbol represents 6 bits. This is then plotted as a single point. These symbol bits have been processed using a complex transcoding process from the original MPEG-2 transport stream. This involves Reed-Solomon encoding, interleaving, randomization, trellis for QAM Annex B systems and convolutional (Viterbi) encoding for QPSK systems. The idea is to protect and correct bit errors, provide immunity from burst noise, and spread energy evenly throughout the spectrum. After reversing these processes in the decoder, quasi error-free bitstreams must be restored. Because of this error correction, merely inspecting the transport stream will not provide any indication that channel or modulators and processing amplifiers are inducing errors, pushing the system closer to the digital cliff point.

Once Transport Error Flags (TEFs) start being reported in the MPEG stream, it is usually too late to take any corrective action.

The Constellation Diagram

This can be considered as an array of 2-D eye diagrams of the digital signal, with symbol landing points having acceptable limits or decision boundaries. The closer the points are together in the cloud of received symbols, the better the signal quality. Since the diagram maps amplitude and phase on the screen, the shape of the array can be used to diagnose and determine many system or channel faults and distortions, and help pin down the cause.

Constellation diagrams are useful for identifying the following modulation problems:

- Amplitude imbalance
- Quadrature error
- Coherent interference
- Phase noise, amplitude noise
- Phase error
- Modulation Error Ratio

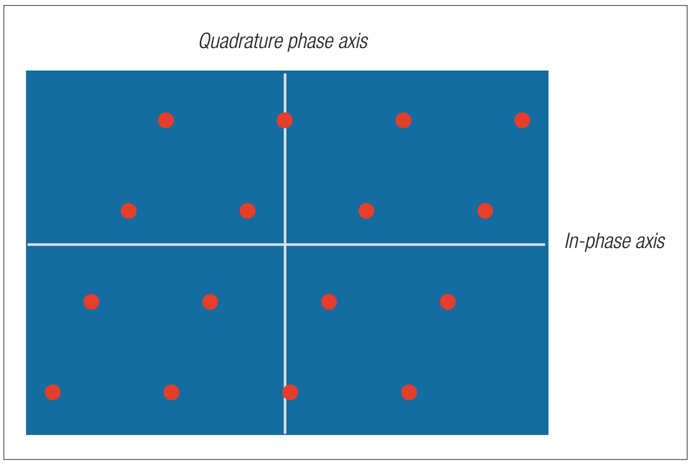

Figure 7. An error in quadrature between the in-phase and quadrature axes of the constellation shapes it into a diamond instead of a square.

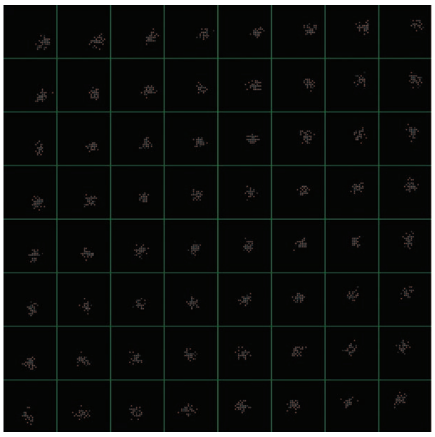

Figure 8. A screen capture from an MTM400A, showing quadrature error with IQ phase error of five degrees.

Amplitude Imbalance

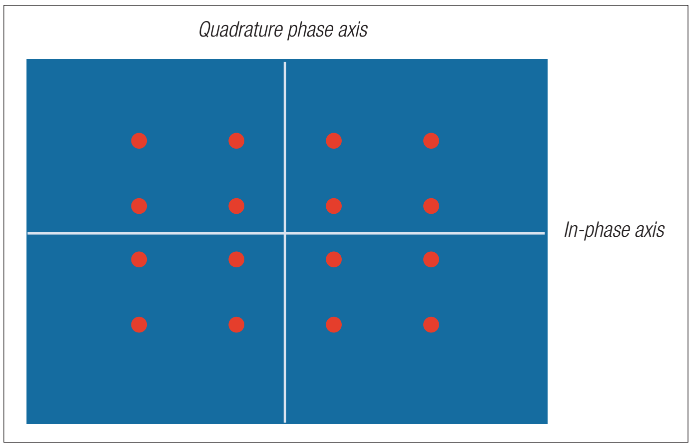

Figure 9. A difference in gain between the in-phase and quadrature components of the constellation shapes it into a rectangle instead of a square.

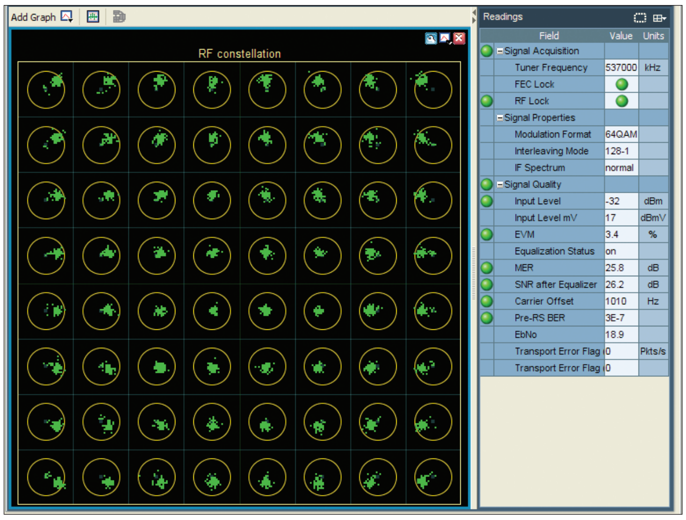

Figure 10. This MTM400A plot shows an IQ amplitude imbalance of 10%. The circles around each IQ sample represents the overall MER (25.8 dB).

Remote Constellation

The MTM400A uses Web-browser technology, so it is unique in that the constellation display can be viewed in a different location or even country to an unmanned test probe position using the Internet or a dedicated network. The user interface also has adjustable persistence so the spots can be made to fade away on older carriers received, like traditional instruments.

Note: The MTM400A screen shots below are all from instruments with tests set up so that MER and EVM are similar in all cases. Only the constellation shapes differ.

Quadrature Error

Quadrature error pushes symbol landing-points nearer to the boundary limits and therefore reduces noise margin. It occurs when I and Q are not spaced exactly 90 degrees apart. The result is that the constellation diagram loses its squareness and takes on the appearance of a parallelogram or rhombus (see Figures 7 and 8).

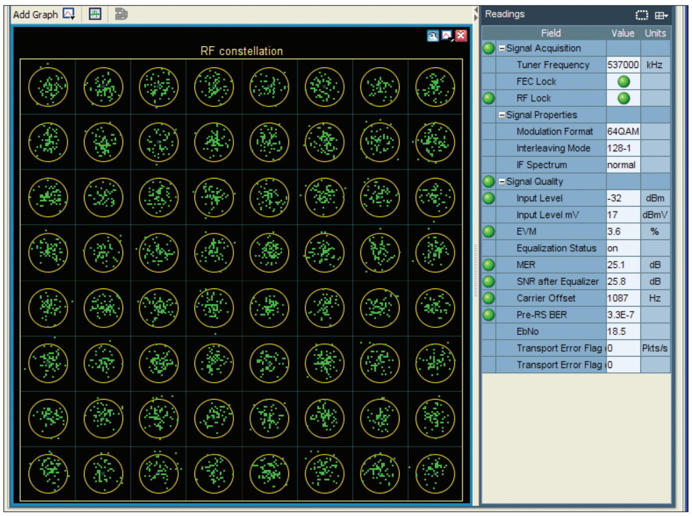

Figure 11. Noise error (64-QAM cable system).

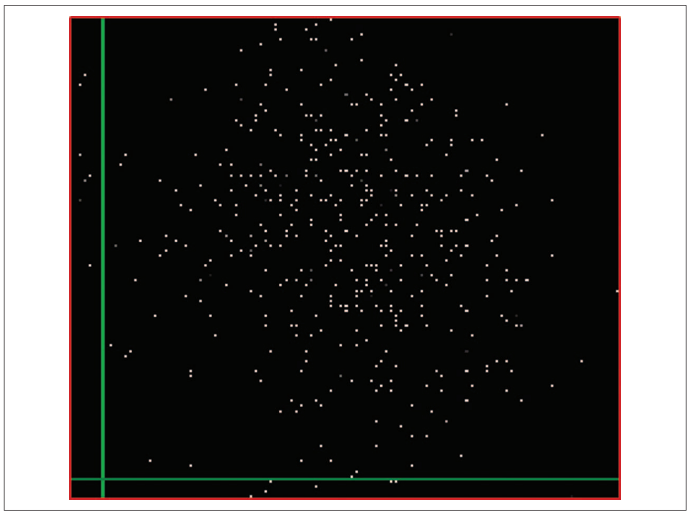

Figure 12. Noise error (QPSK satellite source).

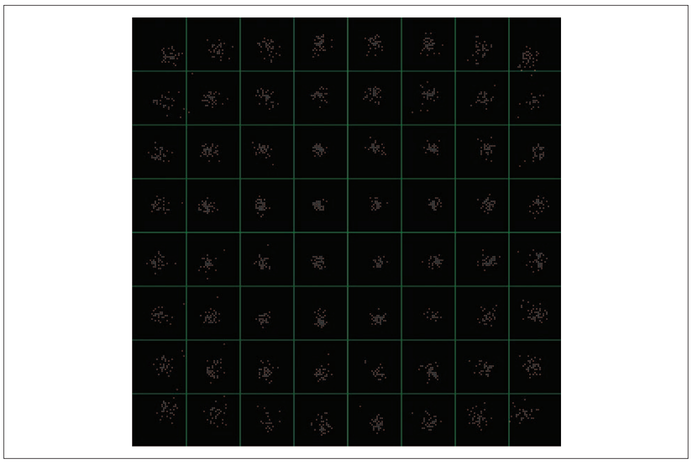

Figure 13. MTM400A plot shows gain compression.

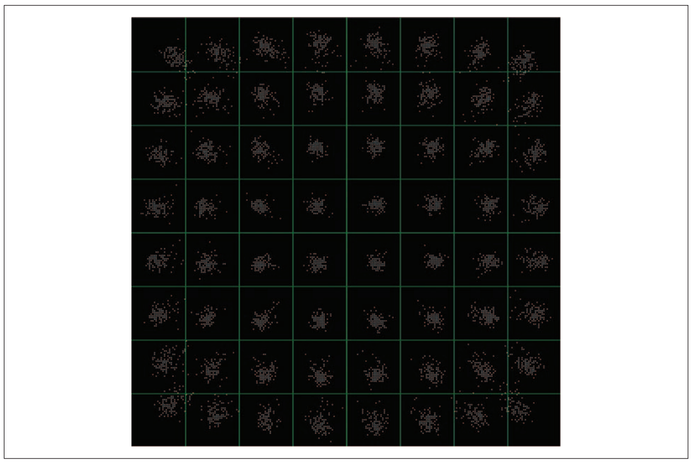

Figure 14. This plot is from a source with seriously errored gain compression.

Noise Errors

Noise is the most common and unavoidable impairment to any signal, including QAM. Additive White Gaussian Noise (AWGN) is the normal type of noise impairment. As it is white (flat power density function in frequency) and gaussian (mathematically normal amplitude density), it spreads the received symbols in a cluster around the ideal location.

Gain Compression

This MTM400A live signal display allows you to see gain compression, causing rounding of the corner edges, in both I and Q axes, but only where the modulator, or fiber transport system, is being driven to its limits. This is happening at higher amplitude levels, showing non-linearity. It appears as a spherical or fish-eye lens view.

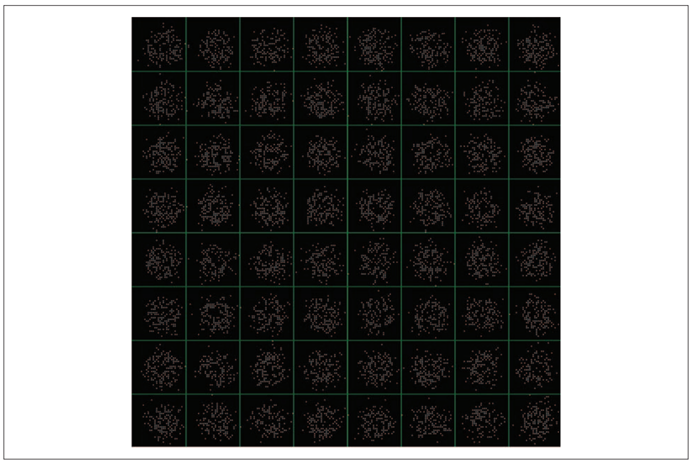

Figure 15. Coherent interference.

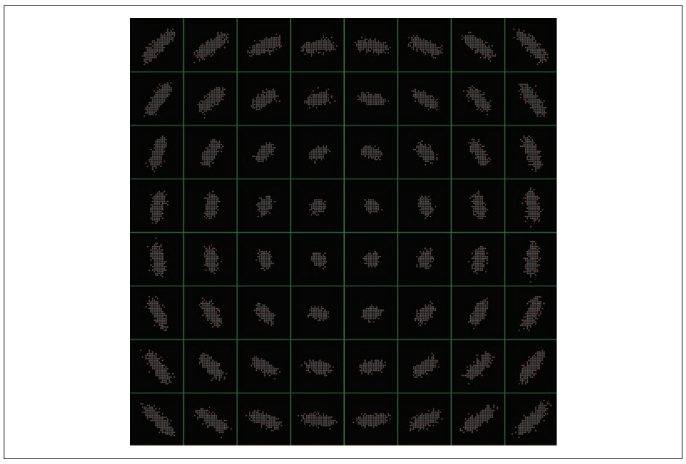

Figure 16. Phase noise (jitter in I and Q).

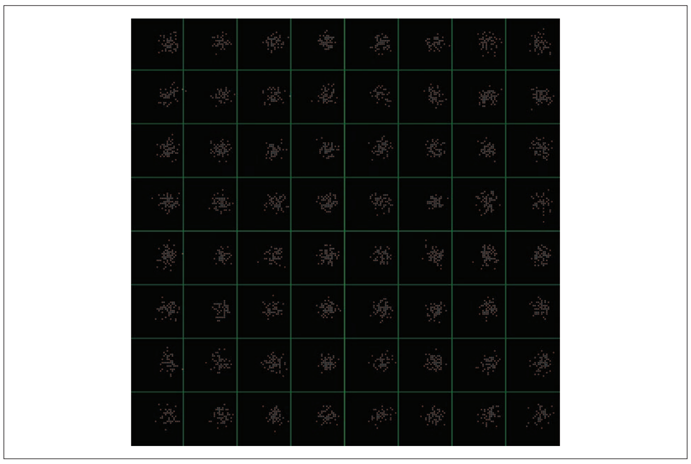

Figure 17. The effect of a DC offset on the In-phase axis, should the carrier be suppressed by 10%. The display is shifted to the right.

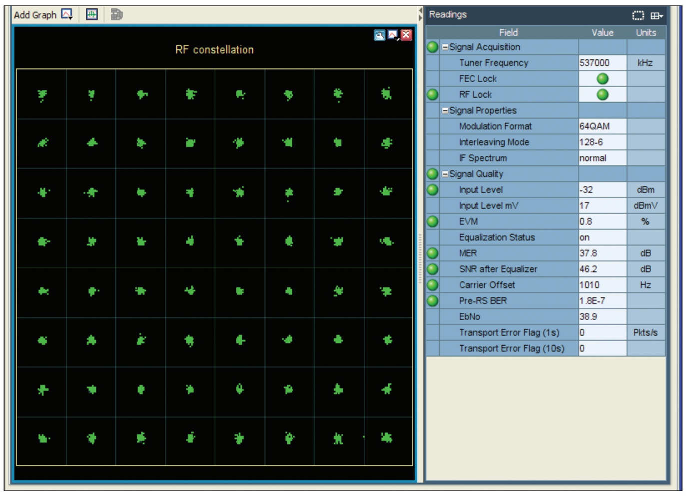

Figure 18. A correctly operating 64-QAM cable system.

Coherent Interference

Here a channel interferer or harmonic component happens to be phase-locked to the IQ signal. This results in an array of rings, or doughnuts.

Phase Noise (Jitter in I and Q)

Any carrier source or local oscillator in the signal chain has phase noise or phase jitter that is superimposed onto the received signal. Phase noise is displayed as concentric ring-arcs of carrier symbols.

Acceptable Signal

The IQ gain and phase errors are normally negligible in modern all-digital modulators. Such errors are not misalignment but rather equipment failure. Compression, on the other hand, can be generated in modulators, up-converters and transmission network.

Figure 18 shows what a normal signal looks like.

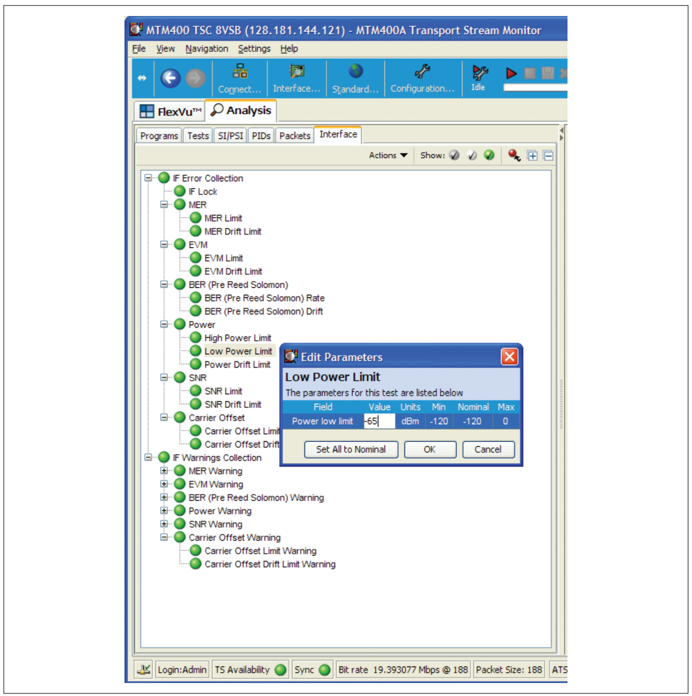

Figure 19. Test menu with Power Low Parameter set to -65 dBm.

RF Interfaces for the MTM400A

With the introduction of four new RF interface cards for the MTM400A, several new measurements and displays are now available. The.new cards include support for ITU-J83B (QAM-B) including Level-2 interleaving, ATSC 8-VSB, 8PSK (Turbo FEC, Broadcom BCM4500), and DVB-T COFDM.

The Input Power Level measurement is one of the many new parameters displayed to the right of each of the four new graphics displays. Along with the new measurements is the ability to set limits to determine when a measurement range has been exceeded. Figure 19 shows the Test menu along with the default Power Low parameter being changed from -120 dBm to -65 dBm.

The new QAM-B RF interface supports level-2 interleaving as well as auto-detection of 64 or 256 QAM, and Interleaving mode. Figure 20 shows a 256-QAM constellation in the 128-1 level-2 mode. The lower right corner of the GUI shows that the Modulation Format and the Interleaving Mode are set to Auto. Simply entering a new frequency will auto-detect the format and mode.

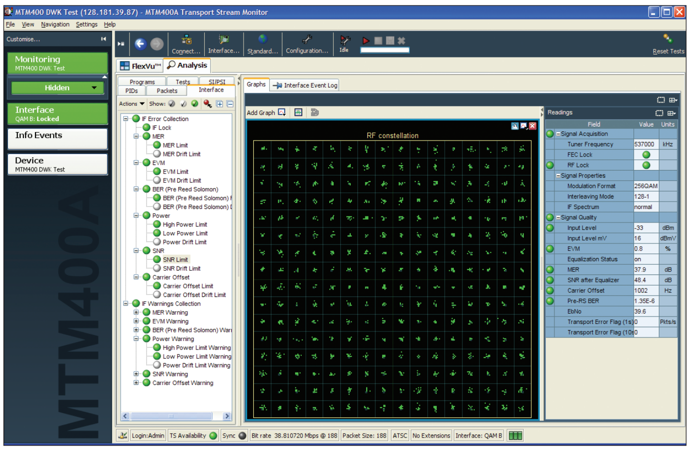

Figure 20. 256-QAM-B constellation with detailed measurements.

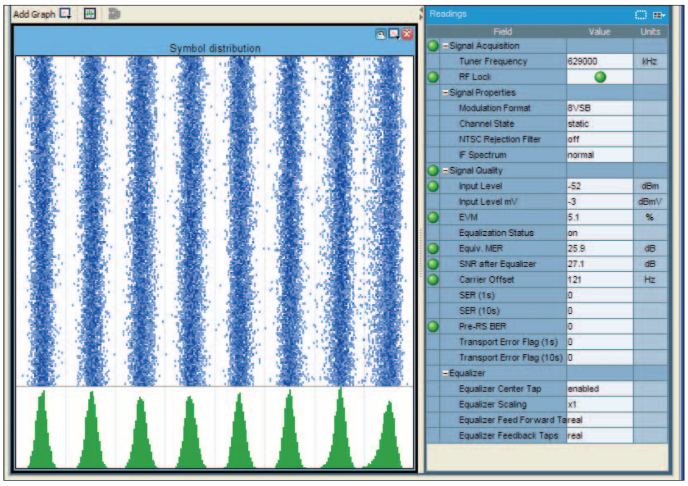

Figure 21. ATSC 8-VSB Symbol Distribution, Histogram, and RF measurements.

The new ATSC 8-VSB RF interface card is sensitive enough to receive low-power RF signals from an off-air antenna. The received power level is displayed to the right of the symbol distribution along with SNR, MER, EVM, and other important RF measurements. The vertical bands are a waterfall display represent each of the 8 possible symbols (see Figure 21). All of the distribution data is summed at the bottom of the display and represented by a histogram. A wide series of bands indicates poor signal quality, while narrow bands indicate clean symbol reception.

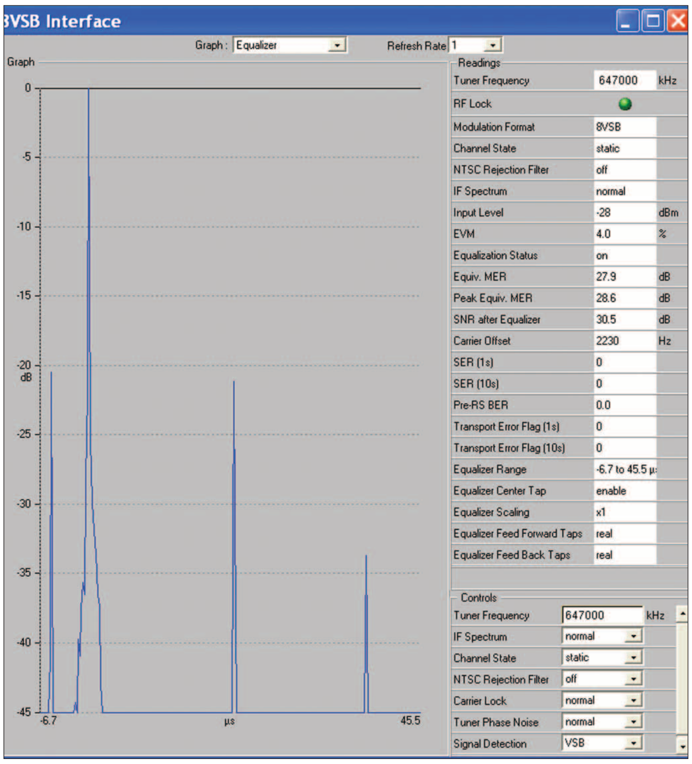

Figure 22. ATSC 8-VSB carrier at 647 MHz with several ghosts.

Multipath or ghost signals can be quantified within the 8-VSB signal by viewing the Equalizer tap graph. The x-axis starts with 6.7 s of pre-ghost information and ends at 45.5 s. The example shown in Figure 22 includes several ghosts or multipath signals on the same frequency. The first ghost is down 21 dB at 5.5 s before the carrier, another down 21 dB at 20 s after the carrier, and the last ghost down 34 dB at 38 s after the carrier.

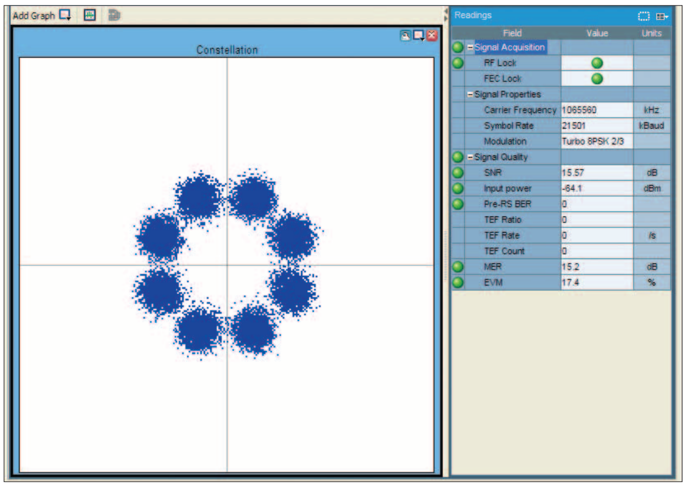

Figure 23. 8PSK constellation display with RF measurements.

DVB-S bandwidth has been expanded through the use of the 8PSK modulation scheme. This increased bandwidth allows for multiple HD channels on a single satellite transponder. Figure 23 shows an 8PSK signal being received from a live satellite feed. Several different 8PSK modulation schemes exist, and the MTM400A uses the Turbo 8PSK support by the BCM4500 demodulator.

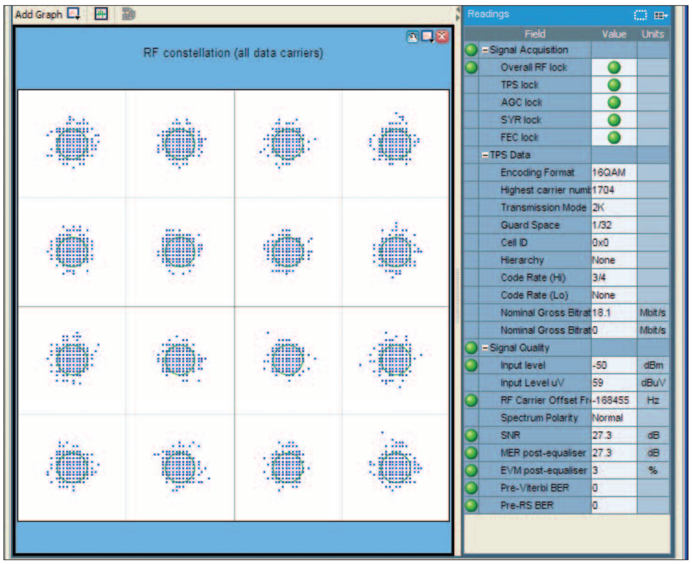

Figure 24. COFDM 16-QAM constellation and RF measurements.

COFDM is the modulation scheme used by DVB-T for terrestrial transmission. COFDM allows for QPSK, 16-QAM and 64-QAM formats. It allows for a hierarchical mode that can transmit one or two transports at the same time. Each carrier is divided into 2k or 8k smaller carriers. These lower data rate carries virtually eliminate Multipath from the signal. Figure 24 shows a 16-QAM COFDM signal measured from an off-air signal.

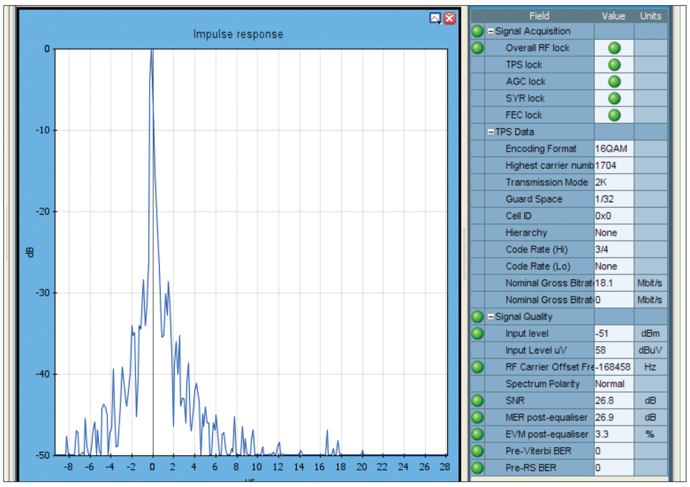

Figure 25. COFDM Impulse Response.

Figure 25 shows an Impulse Response graph that plots the magnitude of similar COFDM carriers at the same frequency at different arrival times (multipath).

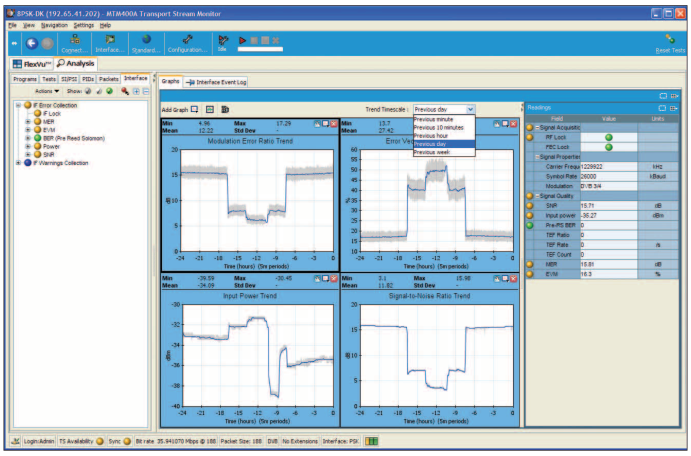

Figure 26. Long-term trend plots showing MER, EVM, Power, and SNR over an entire day (Blue=Avg, Gray=min/max pairs).

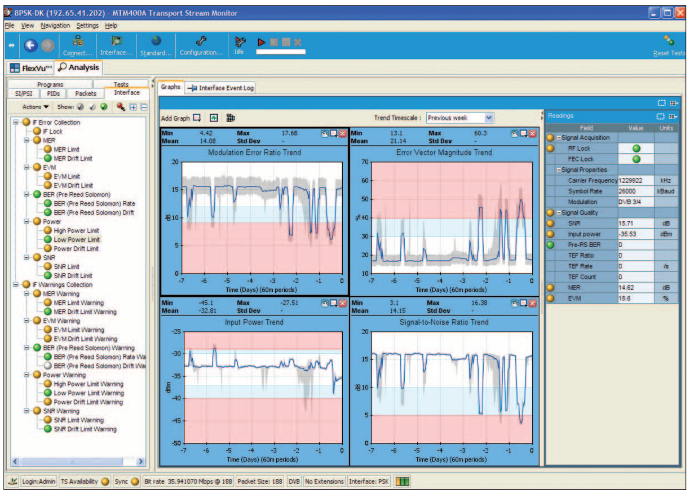

Figure 27. Long-term trend plots showing an entire week, along with blue warning limits and red error limits.

Trends over time

As the RF signal deteriorates over time, it becomes increasingly important to contrast measurements and problems against other measurements. Looking at a live set of measurement parameters is important, but plotting long-term history across several different measurements allows one to see the relationship one impairment has on another measurement (e.g., drop in power affects SNR and MER). Problems can creep into the signal from many different outside sources such as wind on the dish or LNB, temperature, RF noise, atmospheric problems such as heavy rain storms, etc. Figure 26 shows four different measurements over 24 hours. The bold blue line denotes the average measurement, and the gray band denotes the min/max pairs over each sample. Figure 27 shows a similar graph but includes seven days of history. The blue band shows the limit-line for triggering a warning-alarm, and the red band shows the limit-line for triggering an error-alarm.

Conclusions

It is better to predict system problems long before critical revenue earning services go off the air, rather than cure them.

MER measurements are able to measure small changes in transmitter and system performance and are one of the best single figures-of-merit for any cable and satellite transmissions system. EVM and more traditional BER are useful for standard cross-equipment checks and as an aid to identify short-term signal degradation.

Constellation displays help provide a reliable health check for RF transmission systems by indicating artifacts, distortion, or equipment drift.

By combining these critical RF measurements with comprehensive MPEG transport stream monitoring and alarming in a single probe, system problems can be detected at an early stage, before viewers are affected.

With the MTM400A, Tektronix is able to provide all the critical RF measurements and interfaces, integrated with MPEG measurements in a single cost-effective monitoring probe.

References

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ATSC Recommended Practice A/54A: Guide to the Use of the ATSC Digital Television Standard.

Measurement Guidelines for DVB systems, ETSI Technical Report, TR101 290 V1.2.1 (2001-05) Digital Video Broadcasting (DVB); European Telecommunications Standard Institute.

Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for cable systems EN 300 429 V1.2.1 (1998-04) European Standard (Telecommunications series).

Broadcom BCM4500 Advanced Modulation Satellite Receiver: supporting QPSK and 8PSK with turbo code FEC, as well as DVB-S, DirecTV, and Digicipher-II QPSK systems.

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