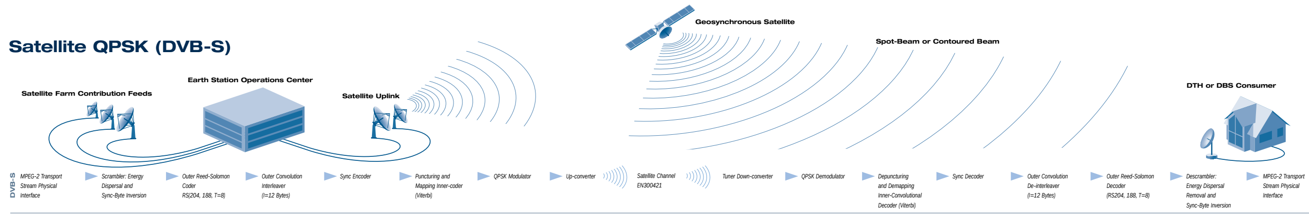
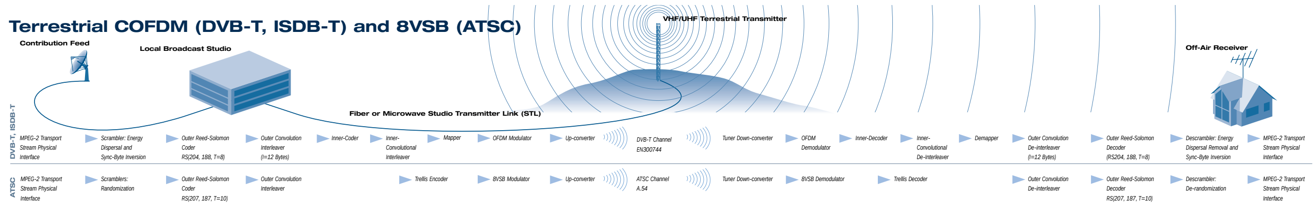
Delivering digital video to the home

Using MPEG-2 RF: DVB, ISDB, ATSC, and SCTE Standards

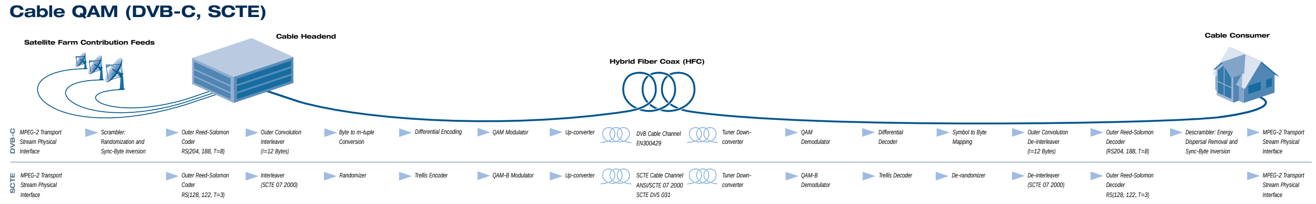
Satellite QPSK (DVB-S)



Terrestrial COFDM (DVB-T, ISDB-T) and 8VSB (ATSC)



Cable QAM (DVB-C, SCTE)



Error Vector Magnitude (EVM) and Modulation Error Ratio (MER)

The purpose of the Modulation Error Ratio (MER) measurement is to provide a single "figure of merit" analysis of the received signal. The calculated figure is to include the total signal degradation likely to be present at the input of a commercial receiver's decision circuits and so give an indication of the ability of that receiver to correctly decode the signal.

The method for calculating MER is as follows: The carrier frequency and symbol timing are recovered, which removes frequency error and phase rotation. Origin offset (e.g., caused by residual carrier or DC offset), Quadrature error, and amplitude imbalance are not corrected. The sum of the squares of the magnitudes of the ideal symbol vectors is divided by the sum of the squares of the magnitudes of the symbol error vectors. The result, expressed as a power ratio in dB, is defined as the Modulation Error Ratio (MER).

It should be considered that MER is just one way of computing a "figure of merit" for a vector modulated signal (see ETSI TR 101 290 IQ Signal Analysis).

Another "figure of merit" calculation is Error Vector Magnitude (EVM). It is also shown that MER and EVM are closely related and that one can generally be computed from the other.

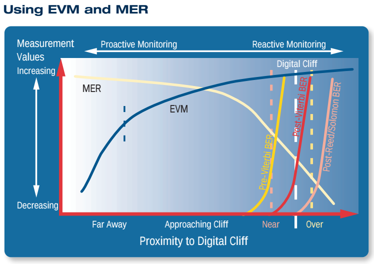
MER and EVM measure essentially the same quantity and easy conversion is possible between the two measures if the constellation is known. When expressed as simple voltage ratios, MER is equal to the reciprocal of the product of EVM and the peak-to-mean voltage ratio for the constellation.

MER is the preferred measurement for the following reasons:

- The sensitivity of the measurement, the typical magnitude of measured values, and the units of measurement combine to give MER an immediate familiarity for those who have previous experience of CN or Signal-to-Noise Ratio (SNR) measurement.
- MER can be regarded as a form of SNR measurement that will give an accurate indication of a receiver's ability to demodulate the signal, because it includes not just Gaussian noise, but all other uncorrectable impairments of the received constellation as well.

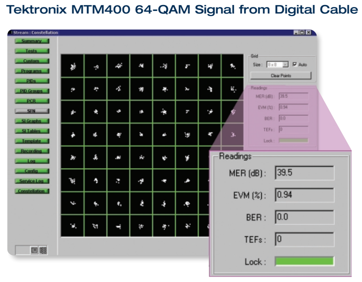
If the only significant impairment present in the signal is Gaussian noise then MER and SNR are equivalent.

Using EVM and MER



Monitoring MER and EVM is critical to maintaining a high-quality MPEG-2 RF transmission link. The MER and EVM results help to estimate the proximity of the digital cliff. The digital cliff is the point at which the received signal has degraded so much that the protection layers of Forward Error Correction (FEC) and Reed-Solomon are not enough to recover the many errored bits. The graph above shows that EVM continues to increase while MER continues to decrease as the signal continues to degrade (even during good video and audio quality). But, once the MER begins to reach its minimum value (and EVM begins to reach its maximum value), the BER of the received signal is so great, that the quality of the picture and sound becomes unusable. Since MER and EVM can be used to detect a degrading signal, it is important to monitor well before the picture and sound go away. For this reason, understanding and monitoring MER and EVM will help in proactively maintaining the digital RF transmission link.

Tektronix MTM400 64-QAM Signal from Digital Cable

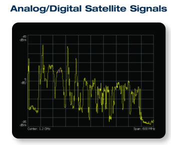


When measuring the quality of digital RF signals, it is very useful to see the graphical representation of the constellation. The constellation display shows both the I (In-phase component) and Q (Quadrature component) values. Each location on the constellation is framed by decision boundaries. If the signal falls within these boundaries, the correct data will be received. The data is in error if it falls outside of its boundaries into an adjacent location such as when the signal is affected by noise or other interference. Significant degradations in the signal can be identified including noise, coherent interference, and transmission distortions, as well as modulator impairments such as IQ imbalance or Quadrature error. Understanding the constellation display can help in quickly troubleshooting problems by allowing the operator to identify the type of impairment and isolate the source. Following installation and adjustment of modulators, amplifiers, and splitters, modulation impairments can appear due to various I and Q vectors being distorted in amplitude or phase.

RF Spectrum

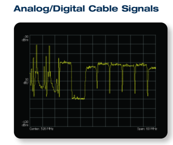
Spectrum analyzers provide help in troubleshooting RF problems. RF power measurements and frequency spectrum measurements are very important in delivering digital video to the home. Diagnosing carrier modulation problems will require a demodulator specific to a modulation type.

Analog/Digital Satellite Signals



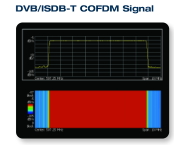
Ku-Band (10-12 GHz) and C-Band (4-6 GHz) satellite feeds are downconverted to L-Band (950-2250 MHz) using a Low Noise Block (LNB). The L-Band example above shows several analog NTSC transponders along with several MPEG-2 QPSK transponders.

Analog/Digital Cable Signals



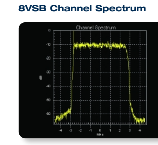
Cable delivery systems commonly provide both analog and digital carriers. This spectrum analyzer display shows three analog NTSC carriers (Ch 69, 70 and 71) and several digital QAM carriers (Ch 72-79). This example shows that channel 72 is currently inactive.

DVB/ISDB-T COFDM Signal



DVB-T defines either 2k or 8k low-frequency QAM or QPSK carriers within the 6, 7, or 8 MHz carrier. ISDB-T allows for 2k, 4k, or 8k. The example above shows several thousand low-frequency carriers all within an 8 MHz band.

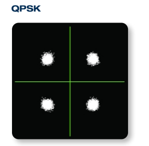
8VSB Channel Spectrum



This 8VSB display shows the dynamic range of the 6 MHz carrier as well as the pilot carrier on the leading edge. ATSC has chosen 8VSB as its modulation scheme and is common to the U.S., Korea, and Taiwan.

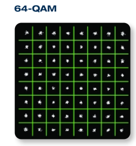
Digital Modulation Techniques

QPSK



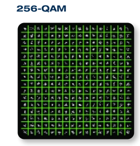
QPSK signals are commonly found is DVB-S digital satellite systems. They are used in Digital Signal News Gathering (DSNG), as well as in DTH and DBS. QPSK signals are susceptible to atmospheric conditions such as rain and snow storms. See ETSI EN 300 421 for a complete description of the DVB-S signal.

64-QAM



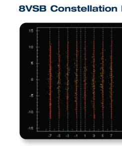
IQ constellations of 64-QAM can be found in both DVB-C and ANSI/SCTE 07 2000 (previously SCTE DVS 031, also known as ITU J.83 Annex B) digital cable systems. 64-QAM signals can also be found in DVB-T and ISDB-T terrestrial systems.

256-QAM



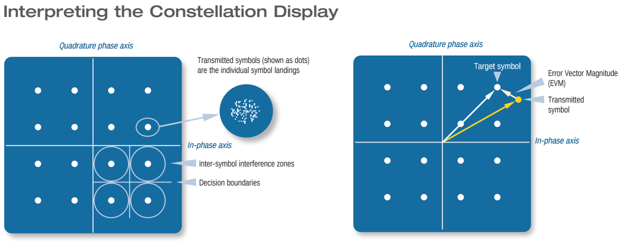
IQ constellations of 256-QAM can be found in both DVB-C and ANSI/SCTE 07 2000 digital cable systems. 256-QAM will carry more bits per symbol when compared to 64-QAM and QPSK, but is more susceptible to errors in the midst of modulation impairments.

8VSB Constellation Display

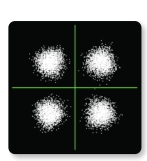


The 8VSB constellation display is created from its eight unique levels per symbol. MER and EVM measurements are derived from the samples and their proximity to each of the eight levels. Constellation problems such as noise, phase error, phase noise, and amplitude imbalance can be seen on an 8VSB constellation display.

Interpreting the Constellation Display

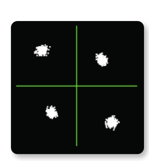


Typical IQ Constellation Impairments



System Noise (Non-coherent Interference)

System noise appears as a cloud around the ideal point. The cloud density lightens as it expands away from the center. The display is considered Gaussian if it is representative of noise in a communication system. The Gaussian "standard" bell shape distribution curve can be used to predict the probability that the noise will exceed a given amplitude or threshold. The broader the cloud or Gaussian distribution, the higher the probability that a boundary adjacent to a symbol will be crossed. The example above shows several samples that have either crossed the decision boundary, or almost crossed the boundary.

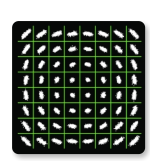


Quadrature Error (Phase Error)

An error in the quadrature between the In-phase and Quadrature axes of the constellation changes the ideal square shape into a diamond or parallelogram. The placement of each symbol is displaced along the I and Q axes in proportion to its distance from the central axis. This creates an error vector in each axis for each symbol.

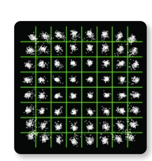
With an IQ phase error of 2 degrees, each axis is shifted by 1 degree toward each other or away from each other.

An error of 1 degree causes a error vector of: tangent 1 degree = 0.017 or 1.7%. This is also one of the power components of MER measurement.



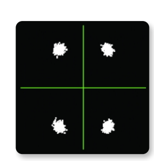
Phase Jitter (Phase Noise)

A phase noise display resembles a crescent shape for each constellation point. The shape is more apparent at the outer edges of 16-QAM, 64-QAM, and 256-QAM constellation displays (less near the center). This effect is from the angular shift of the signal. All local oscillators or carriers add phase noise to the received signal. Phase noise is cumulative through the network. A QPSK or QAM demodulator can track the signal using a PLL. The PLL can act as a high pass filter and thereby reduce the phase noise at low frequencies, but letting through high-frequency phase noise. Therefore, the MER measurement due to phase noise is multiplied by the amplitude response of the QPSK or QAM PLL.



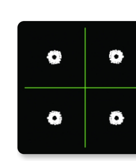
Gain Compression

Signal amplifier compression can be seen as a shift of the outer points toward the center of the display (i.e., pincushion). This is because it is more severe on the larger amplitudes (not detectable on QPSK and 4-QAM signals). This compression is non-linear and can be most easily seen in the corners of the constellation display where the amplitude is the largest. The effect is not seen on IQ samples near the center of the constellation display because the amplitude is the smallest. In a 256-QAM example with 1% compression, 4 symbols (in the corners) at 1% or 0.0001 power, 8 symbols get 0.5% compression or 0.000025 power, and 12 symbols get 0.25% compression or 0.00000625 out of all 256 symbols.



Amplitude Imbalance (Gain Error)

Amplitude imbalance can be seen when the difference in the gain between the In-phase and Quadrature components of the constellation looks more like a rectangle than a square. Each symbol is offset toward one axis and away from the other axis in the same proportion. This creates an error vector in each axis for each symbol. The difference in an IQ gain of 4% (0.34 dB) causes 2% error in I and 2% error in Q. Therefore, each symbol is associated with a 2% error vector. The relative power is -34 dB. The average power resulting to an IQ gain error is 34 dB below the signal power. IQ gain error is one of the power components of MER measurement.



Coherent Interference

Coherent distortion creates doughnut-shaped constellation points. This is because of the sum of different frequency vectors. Introducing a CW interference to a QPSK or QAM signal will introduce an error vector that will rotate when compared to the received symbols at a difference in frequency between the carrier and the interferer. The result is a doughnut-shaped distortion within the constellation. The amplitude of the interferer is the amplitude of the error vector. The relative power of the interference is a power component of MER measurement.

Abbreviations

ATSC Advanced Television Systems Committee
BER Bit Error Rate
COFDM Coded Orthogonal Frequency Division Multiplexing
CW Continuous Wave
DBS Direct Broadcast Satellite
DSNG Digital Signal News Gathering
DTH Direct To Home (satellite delivery)
DVB Digital Video Broadcasting
DVB-C Digital Video Broadcasting baseline system for digital cable television (ETS 300 429)
DVB-S Digital Video Broadcasting baseline system for digital satellite television (ETS 300 421)
DVB-T Digital Video Broadcasting baseline system for digital terrestrial television (ETS 300 744)
EB Errored Block
ETR ETSI Technical Report
ETS European Telecommunication Standard
EVM Error Vector Magnitude
FEC Forward Error Correction
ICI Inter-Carrier Interference
IF Intermediate Frequency
IQ In-phase/Quadrature components
IRD Integrated Receiver Decoder
ISDB Integrated Service for Digital Broadcast
ISO International Organization for Standardization
ITU International Telecommunication Union
LO Local Oscillator
MER Modulation Error Ratio
MPEG Moving Picture Experts Group
NTSC National Television System Committee
OFDM Orthogonal Frequency Division Multiplex
PE Phase Error
PID Packet Identifier
PJ Phase Jitter
PLL Phase Locked Loop
PRBS Pseudo Random Binary Sequence
PSI MPEG-2 Program Specific Information (as defined in ISO/IEC 13818-1 [1])
QAM Quadrature Amplitude Modulation
QE Quadrature Error
QEF Quasi Error Free
QEV Quadrature Error Vector
QPSK Quaternary Phase Shift Keying
RF Radio Frequency
RMS Root Mean Square
RS Reed-Solomon
RTE Residual Target Error
SCTE Society of Cable Telecommunications Engineers
SER Symbol Error Rate
SFN Single Frequency Network
SI Service Information
SMATV Satellite Master Antenna TeleVision
SNR Signal-to-Noise Ratio
STD System Target Decoder
TEV Target Error Vector
TS Transport Stream
TV TeleVision
VSB Vestigial Sideband Modulation
UI Unit Interval

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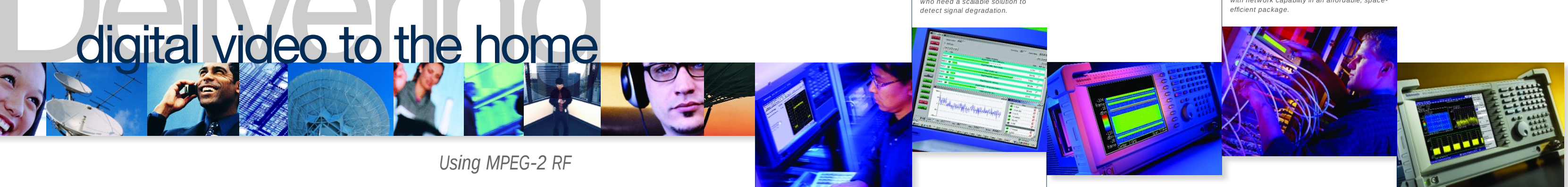

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