Testing Digital Video on Cable TV Systems

Part 1: A Look at Measuring Power and Interference

Digital transmission is the key enabling technology that will allow cable systems to deliver a multitude of emerging services. High spectral efficiency, robust resistance to ingress, and high flexibility permit the installation of premium digital services, such as video-on-demand, PCS telephony, or commercial data transport. Subscribers will view these new capabilities with new expectations of high-value, dependable service. As telcos and cable companies compete to deliver digital services, a key differentiator will be the quality and reliability of service.

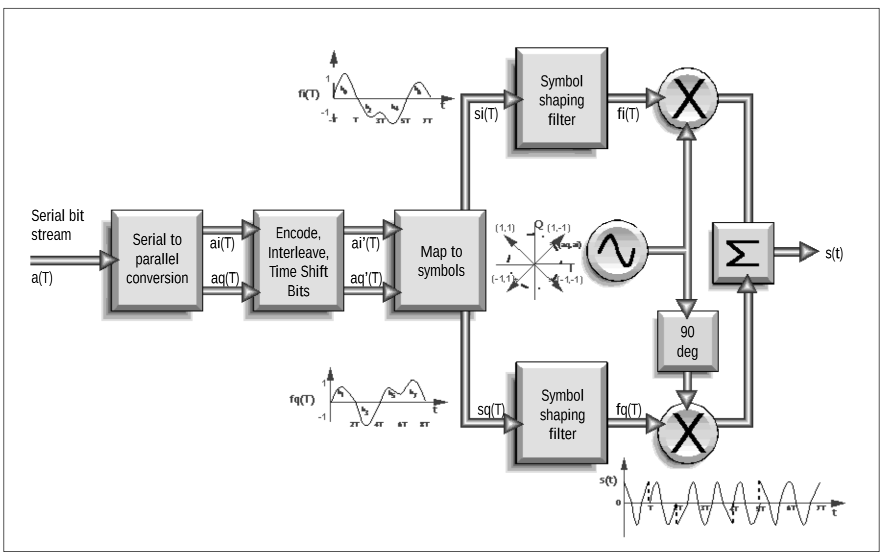


Figure 11.1 Block Diagram of Digital Modulator

Ensuring the quality of service requires testing digitally modulated signals. As in an analog cable TV system, power and interference measurements are essential to maintaining digital cable TV services. Although the effects are different from impairments on an analog television signal, amplifier compression and spurious interference will degrade digital video signals.

Evaluating the digital portions of a cable system will include extending the traditional tests of the analog television signal. In part one of this paper, we explore the key features of a digitally modulated signal, looking at basic characteristics in the time and frequency domains. These key characteristics define new considerations when measuring average power, peak power, and spurious interference of digital transmissions. Correctly measuring the power and spectrum of digital video and audio requires consideration of the features of digital modulation.

Forming a Digital Video Signal

All digital modulation formats define how bits correspond to carrier phase and amplitude, and how transitions between bits are made. Digital modulation formats often associated with cable systems are 16-VSB, 64QAM, QPR, and OQPSK. These formats share common characteristics in the time and frequency domains, driving common needs for measuring power and interference. A general block diagram for a digital modulator is shown in Figure 11.1. Example waveforms for Offset Quadrature Phase Shift Keying (OQPSK) are also shown in Figure 11.1 for each point in the modulator. Cable digital audio services are often delivered to the head-end using the OQPSK format.

A serial digital bit stream, a(T), contains digitized program information. In the first stage of the modulator, a(T) is split into parallel bit streams. For OQPSK, two parallel streams are formed, corresponding to 22 = 4 possible symbols. The two parallel bit streams, $a_i(T)$ and $a_q(T)$, may then be encoded, interleaved, and time shifted.

This data manipulation adds error correction, and influences the shape of the modulated signal spectrum. In OQPSK, the parallel bit streams are shifted by one bit period, limiting the maximum phase change of the carrier as the bits are transmitted. The one bit offset limits the OQPSK carrier phase to an increase or decrease of 90 degrees in each symbol period, limiting the spectral sidelobes of the signal. Next, the bit pairs, $a_{i'}(T)$ and $a_{q'}(T)$, are mapped to corresponding symbols in the inphase and quadrature (I/Q) plane. These vectors, $s_i(T)$ and $s_q(T)$, are the baseband inphase (I) and quadrature (Q) components of the digital modulation. At this point, the symbols are filtered with a shaping filter to control the spectrum of the modulated signal. Commonly used filters are raised cosine, root raised cosine, or Gaussian shapes. In vestigial sideband formats, such as 16 vestigial sideband (16-VSB), vestigial sideband filtering may be incorporated at this point. The filtered baseband I/Q signals, fi(T) and fq(T), are sent to a quadrature modulator and transmitted.

Key Features of Digital Modulation

In the frequency domain, digital modulation produces a noise-like spectrum whose bandwidth depends on the symbol rate, coding, and filtering used. Figure 11.2 shows the spectrum of unfiltered 64 Quadrature Amplitude Modulation (64QAM) at 4.167 Msymbols per second (25 Mb/s). After filtering with a raised cosine filter (alpha = 0.1), the spectral sidelobes are removed, as shown in Figure 11.3. The spectrum of the filtered 64QAM is restricted to about 4.5 MHz. Note that the broadband digital video signal is susceptible to spurious interference across the entire channel bandwidth, making control of analog and digital transmission spurs critical. Proper symbol filtering avoids spilling interference from a digital channel into adjacent video channels. Measuring spectral spillover into adjacent channels is a good way of confirming properly filtered digital modulation.

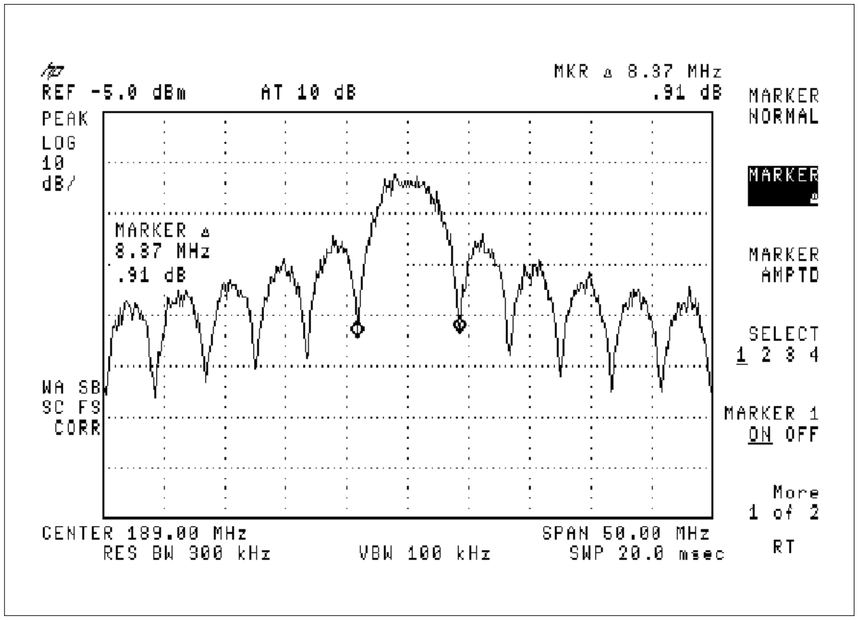


Figure 11.2: Unfiltered 64QAM at 4.17 MegaSymbols per Second

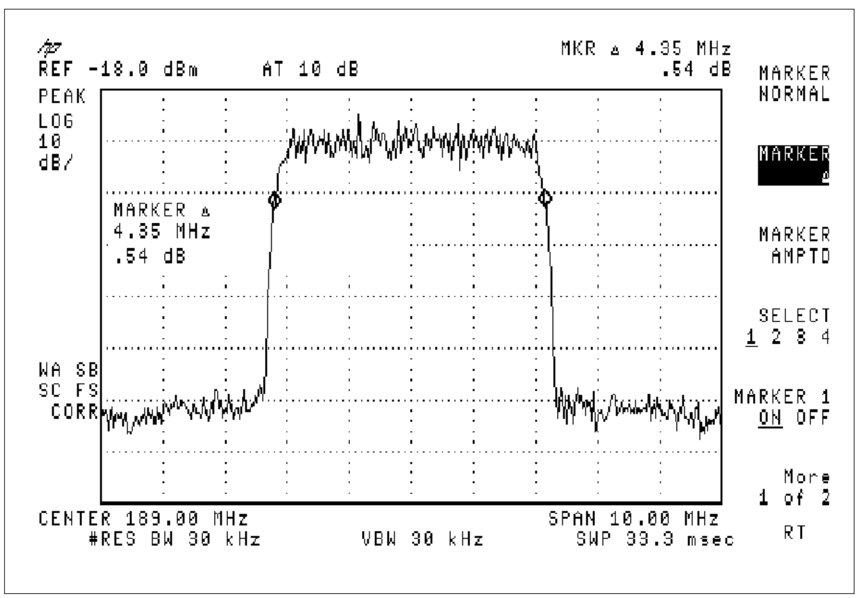


Figure 11.3: Spectral Sidebars Removed

In the time domain, digital modulation results in amplitude and phase variations that depend on the data sequence. Since the data is usually randomized, amplitude and phase changes are random. Figure 11.4 shows a time domain picture of a 16-VSB signal, showing the random occurrence of signal peaks over a 25 symbol transmission. Peak signal excursions are controlled by the format mapping and filtering. Interaction of the exact symbol sequence with the shaping filters often yields a peak amplitude that is much higher than the average amplitude. Peak power of digital transmissions can be 6 to 10 dB higher than the average power. Preventing amplifier compression, and the resulting intermodulation interference in the cable system, requires reducing the average transmission power to accommodate peak powers. Proper adjustment of signal levels requires measuring peak and average power.

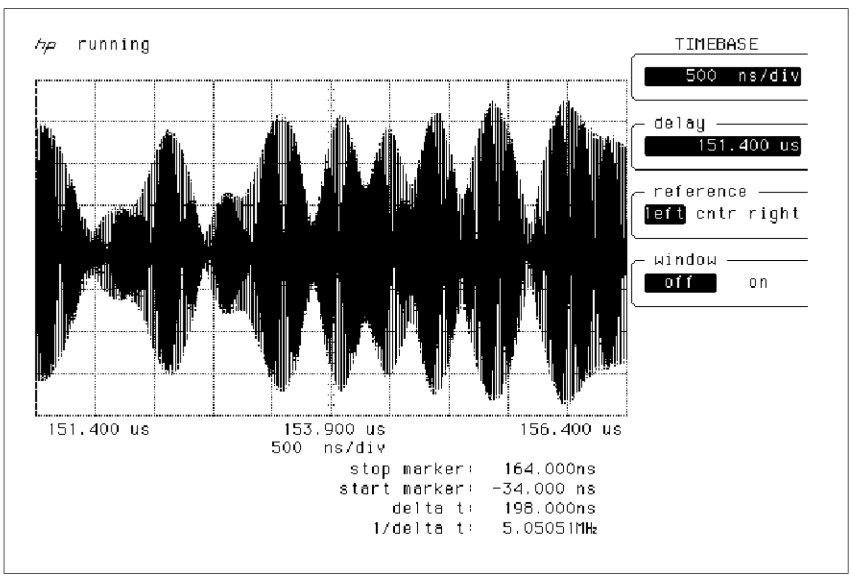


Figure 11.4: Time Domain Picture of 16-VSB Signal

Measuring Average Power

Maintaining the proper average transmission power is a key adjustment made in cable systems for digital as well as analog signals. Unlike the narrowband measurement of analog visual carrier level, testing average power of a digital transmission is a wide bandwidth measurement. One method of measuring average digital video power is to use a filter and a power meter. The filter must be flat across the entire channel bandwidth, 6 MHz wide in the United States. A sharp filter rolloff will remove undesired contributions from adjacent channels. Rejection in the stopband should be at least 50 to 60 dB. The digital video signal is applied to the filter and power sensor, reading the true average power. This method is accurate and inexpensive. Note that the power meter or signal level meter must have sufficient bandwidth and frequency range to handle 6 MHz wide signals at up to the highest carrier in the cable system, optimally up to a 1 GHz carrier frequency. One filter is required for each channel to be tested, unless a tunable channel filter is available.

A second way of measuring average power uses a spectrum analyzer. Average channel power measurement begins with obtaining a swept trace of the spectrum, centered about the carrier frequency, a job the spectrum analyzer is optimized to perform. A spectrum analyzer trace is constructed from a series of readings of the power level at small discrete steps in frequency. Average power is calculated by averaging the power values at each frequency in the trace within the desired channel. Note that the spectrum analyzer may not have traditional square-sided, flat-topped filters used to measure noise-like

signals. The calculated average power must be corrected for the shape of the filters actually used in the analyzer. This is typically done automatically within the spectrum analyzer. Figure 11.5 shows an automatic average power measurement in a spectrum analyzer on a cable digital audio signal. Power readings in the portion of the trace between the two vertical lines at the bottom of the screen are used to obtain a true power average. Instrument software optimizes the accuracy of the measurement, adjusting the spectrum analyzer settings and applying the internal filter correction. This simple method of measurement can be used across the full frequency range of the spectrum analyzer over any desired bandwidth, eliminating the need for external channel filters.
The accuracy of the power reading can be optimized to within +/– 0.5 dB, slightly less accurate than a well calibrated power or signal level meter.

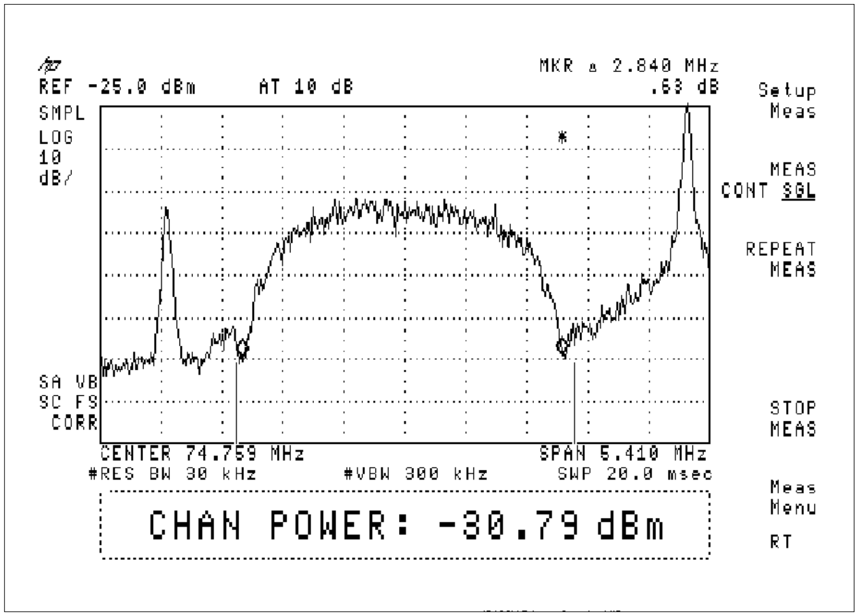


Figure 11.5: Automatic Average Power Measurement

Measuring Peak Power

Proper adjustment of a digital transmission system includes measuring both peak and average power. A good peak-to-average ratio is an indicator of accurate, linear digital modulation. Unlike the analog video horizontal sync tip, a digital video signal has random amplitude peaks of very short duration, depending on the symbol rate and data sequence. Measuring peak power on a digital transmission requires an instrument fast enough to accurately catch the signal peak. The measurement must be made over a relatively long time interval to be certain of catching intermittent peak power points. Testing peak power requires assessing the acceptable level of certainty that the measurement is long enough to catch signal peaks.

Peak power is typically measured using a peak power meter. The peak power meter samples the signal rapidly, repeatedly taking snapshots of the signal. The instrument sorts the samples, displaying the distribution of the amplitude variations of the digitally modulated signal. Figure 11.6 shows a high quality 16-VSB modulated signal measured on a peak power meter. The instrument displays the sampled snapshot in the upper window, and the accumulated power distribution over many snapshots in the lower window. The peak-to-average ratio is 7.015 dB, after acquiring 140,000 samples over four minutes. Figure 11.6 displays the same measurement on a slightly compressed 16-VSB signal.
The 5 dB of gain was added with an amplifier, yielding a 5 dB rise in the average power. The peak power rises only 4.64 dB due to compression of the signal peaks. Note the compression of the peak-to-average ratio to 6.744 dB, over a 4 minute measurement interval.

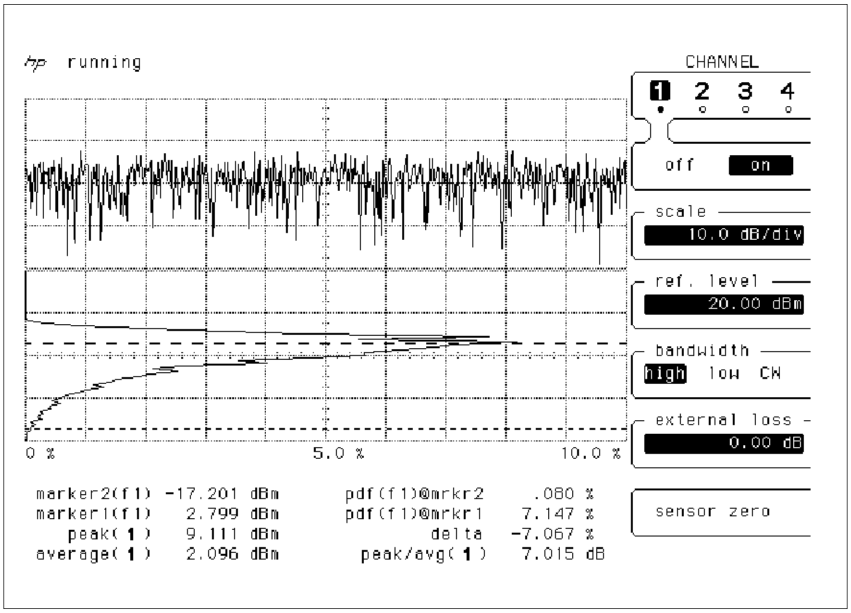


Figure 11.6: Peak Power Measurements

As the digital formats for cable transmission develop, the correct peak-to-average power ratio for each format will be defined. Choices on symbol shaping filters and clock/carrier synchronization strategies will affect the exact peak-to-average ratio for both 16-VSB and 64QAM formats. Cable operators will need this information to adjust amplifier cascades to accommodate digital video.

Spurious Interference

Optimizing the cable system to serve the maximum number of subscribers usually means setting power levels to accept a known level of signal distortion. Analog video distortion yields intermodulation products, narrowband spurs spread across the cable channels. The digital video signal is sensitive to discrete spurs across the entire signal bandwidth, nearly 6 MHz. Spurs can add phase rotation to the digital modulation phase shifts, causing the demodulator to misinterpret the received phase, yielding symbol errors. The picture artifacts caused by spurious interference to a digital transmission depend on the exact format used. Traditional spurious tests, such as CSO and CTB, will be essential to maintaining a high quality environment for digital video transmissions.

If power levels are set to distort digital video signals, digital transmissions will spill noise-like interference into adjacent NTSC channels. The exact effect of this excess noise depends on the location of the noise relative to the visual and aural carriers. A weighting curve for digital interference across an analog channel must be developed to specify the acceptable level of digital spurious spillover. Experiments on perceptible digital noise levels at various locations in an NTSC channel can establish these test limits. Cable operators can then use these limits to adjust the digital video levels in their systems.

Measuring Adjacent Channel Power

The consequences of digital video distortion can be seen in the frequency domain. Very low distortion levels cause the spectrum of a digital video transmission to spill into adjacent channels, interfering with both digital and analog services. If the adjacent channel does not contain an active transmission, measuring out-of-channel interference can be a sensitive detector of low level distortion. Measuring out-of-channel power can be done using the same methods as those used in measuring average in-channel power. Adjacent channel power (ACP) is a measure of the amount of power spilled into adjacent channels. ACP can be measured either as a ratio to total average power, or as an absolute power level.

Use either the spectrum analyzer or a filter and power meter to measure the average power of the digital transmission. If the spectrum analyzer is used, the analyzer is then tuned to the upper or lower adjacent channel. If a power meter is used, the channel filter is exchanged for a filter centered about the upper or lower adjacent channels. The average power in the adjacent channel is obtained, and compared to the in-channel power. Figure 11.7 shows the ACP measurement of a slightly-compressed 64QAM signal using a spectrum analyzer. Note the graphical display of spillover in the adjacent channel. A weighting curve may be automatically applied in the analyzer to assess the real impact of digital noise on an adjacent transmission.

Conclusions

Testing cable TV digital transmissions is essential to realizing the benefits of the new services, regardless of the digital modulation formats used. Optimizing the cable plant to deliver reliable, high-quality digital service to the maximum number of subscribers requires the cable operator to accurately measure the characteristics of digital and analog signals. Average power and peak power tests must correctly measure digitally modulated signals. CSO and CTB measurements are used to assess analog to digital spurious interference. An adjacent channel power test can quantify digital to analog interference. The instruments used to measure analog signals can be adapted to digital video transmissions.

Providing emerging digital video services will require not only power and interference tests, but also direct measures of the integrity of the transmitted data.

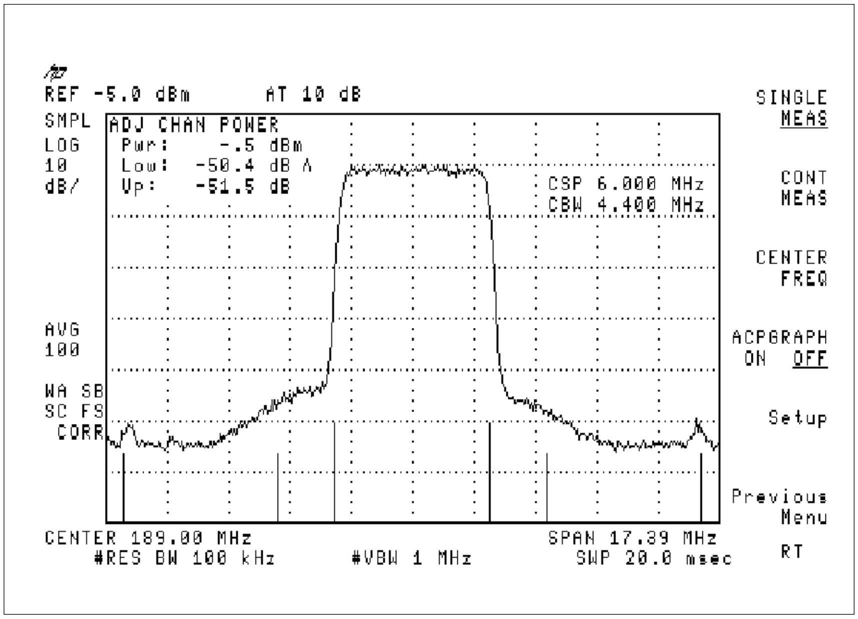


Figure 11.7: ACP Measurement of a Slightly-Compressed 64QAM Signal

New metrics such as bit error rate, modulation error vector measurement, or eye diagrams may become standard cable test strategy.

Part 2: New Measures of Signal Quality

In the first part of this paper, we saw that power and interference measurements are essential to both digital and analog cable systems. In addition to power and interference tests, digitally modulated cable transmissions create a need for new measures of signal quality. Emerging services, such as data transport and PCS telephony, depend on the integrity of the bits transmitted. Digital modulation formats employ multiple strategies to preserve the clarity of the data, such as adaptive equalization and error correction. When these strategies fail, digital services abruptly descend from acceptable quality to complete failure. New digital modulation tests must permit service providers to spot performance trends, and to prevent problems before they affect service delivery.

Digital video modulation measurements are very different from those used in analog video. Analog signal characteristics, such as FM deviation and chroma/luma delay, have proven over time to be practical tools for assessing the performance of the analog modulation system. Many digital modulation metrics could potentially be used in digital cable systems. The key digital tests will be determined in practice, as the setup and maintenance of digital cable systems increases. Several possible measurements are: bit error rate (BER), margin-to-critical BER, modulation error ratio (MER), and constellation/eye diagrams. In this article, we will define each measurement, and consider how to apply them to a digital cable TV plant. Using the right modulation tests at the right points in a digital cable system helps to ensure reliable service, a key competitive advantage.

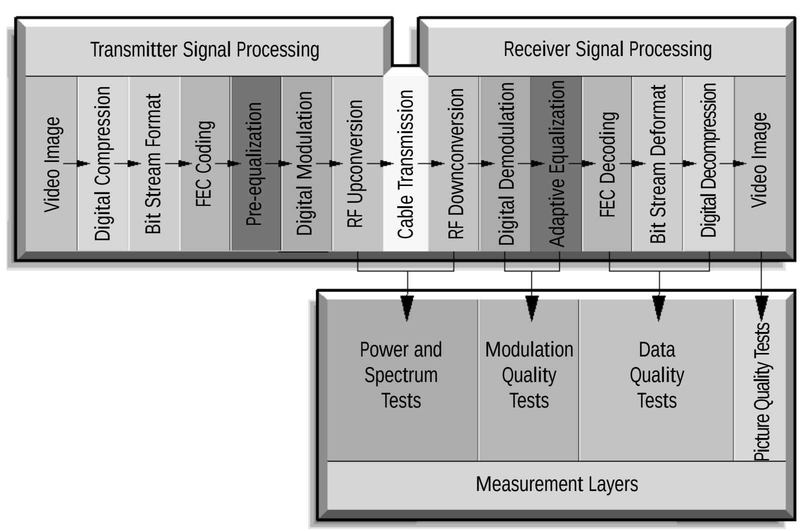


Figure 11.8: Layered Signal Processing in Digital Transmissions

Probing Layers of Digital Signal Processing

Every digital cable format is designed to maximize the transportation of data through the linear and non-linear distortions of the transmission channel. Figure 11.8 shows the layers of signal processing in a digital transmitter and receiver. The video image is digitized and compressed to form a bit stream. Forward error correction coding and pre-equalization may be applied to protect the data from corruption due to impairments in the transmission channel. The bit stream then enters a digital modulator, such as a 16-VSB or 64QAM modulator. The resulting baseband digitally modulated signal is upconverted to the desired RF carrier frequency. Each successive layer of processing transforms the signal, hiding the information of previous layers.

To recover the information hidden by the transmitter signal processing, the receiver must undo each level of concealment. The quality of the data bits retrieved by the receiver depends on how channel distortions have affected each layer of the transmission. To measure the transmission quality, a test instrument must recover the signal at the correct layer for testing. Each level of signal recovery holds a different view of the performance of the system. Figure 11.8 shows how each type of measurement corresponds to a signal recovery layer. As we have seen, power and interference tests are applied to digitally modulated RF transmissions. The next layers of measurement are modulation and data quality tests.

Navigating Test Points in a Digital Cable System

Choosing test points in the cable system requires considering what layers of signal processing are present in the signal, and how much signal processing the test equipment must apply. Navigating the layers of signal processing in the digital cable plant is essential to any test plan. Figure 11.9 is a block diagram of the components of a digital cable system, highlighting possible test points.

In the transmitter, bits are processed into digital transmission formats. Forward error correction (FEC) coding is often applied to the symbol stream. FEC adds redundancy to the bitstream, making the correct data sequence recognizable even with one or more bit errors. The FEC is unique to each digital transport format. In the European 64QAM digital video cable standard, a Reed-Solomon t=8 (204,188) error correction code is used. This 64QAM code adds sixteen Reed-Solomon parity bytes to 188 bytes of data, yielding 204 bytes of data to be transmitted. This code can correct up to eight byte errors. In the quadrature modulator, the coded data is mapped to I/Q values (symbols), and filtered by a shaping filter to control the spectrum of the RF transmission. At a test point attached to the output of the head-end modulator (A), the original bit stream is buried in the effects of the FEC, the digital shaping filter, and the digital modulator.

The transmission channel imposes linear and nonlinear distortion. Linear distortions include group delay, and amplitude ripple. Nonlinear distortion can result from amplitude compression, and spurious interference due to ingress or intermodulation distortion products.

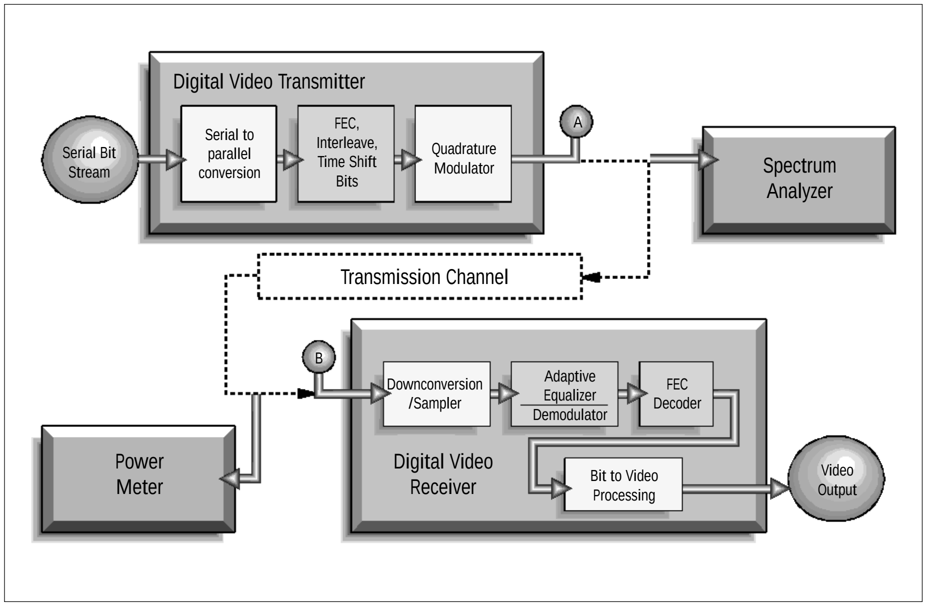


Figure 11.9: Digital Cable System Test Points

Noise may be added. The impaired RF signal is probed at test point B in Figure 11.9.

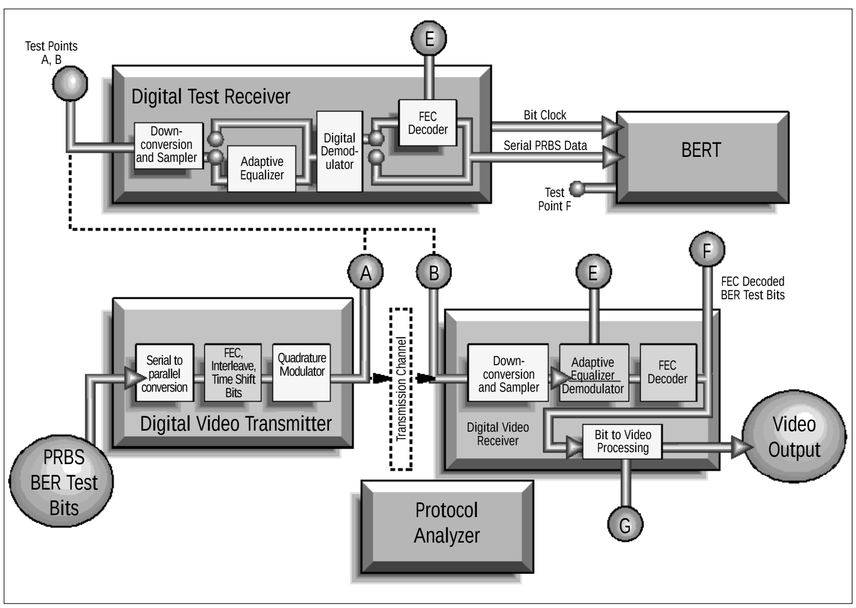
In the receiver, the digitally modulated signal is downconverted and sampled. Digital transport systems often include an adaptive equalizer to remove the linear distortions of the transmission channel. An adaptive equalizer is a digital filter that continuously reprograms phase and amplitude characteristics to exactly compensate for the phase and amplitude distortions of the transmission channel. The 16-VSB digital cable format uses a two part adaptive equalizer: a feed forward transversal filter followed by a decision feedback filter. Test point D allows probing the received symbols after the adaptive equalizer. The equalized I/Q symbol vectors are demodulated to recover the coded symbol stream. FEC is decoded to recover the original data bits. Test point F permits examination of the corrected bit stream. Test points C and E represent information that can be made available from the adaptive equalizer and FEC chips.

Digital video metrics must be matched to the correct test point, optimizing the value of the measurement. First, we look at the overall quality checks provided by assessing the quality of the received data. Next, sensitive troubleshooting measurements of modulation quality will be examined.

Testing Data Quality: Bit Error Rate

Bit error rate (BER) is an overall measure of the quality of the received bit stream. BER is the ratio of the number of bit errors to the total number of bits sent in a given time interval.

Measurements derived from BER provide a distant reflection of picture quality, separated from direct picture quality metrics by several layers of signal processing. Note that accurate measurement of BER requires long measurement times. For example, a BER of 1 x 10-8 in a digital video system with a bit rate of 30 Mb/s will experience a bit error every 3.3 seconds, on the average. Gathering enough bit errors to form a statistically accurate BER can take many minutes, or even hours, at low BER.



Bit error rate is typically an end-to-end system measurement that includes the error correction processing of the FEC. Figure 11.10 shows a block diagram of an intrusive BER test. A known bit stream is injected into the data to be transmitted. Standard pseudorandom bit sequences (PRBS), such as CCITT 2-23-1, are often used. In the simplest version of BER test, the known bit stream passes through the transmitter FEC and the shaping filter. A bit error rate tester (BERT) measures the received bit stream after shaping filter compensation, adaptive equalization, digital demodulation, and FEC decoding in the digital cable receiver in the settop box. BERT input comes from test point F. Note that either the known bit stream must be transmitted on a separate channel, or the BERT must know how to extract the known bit sequence from the program data stream. Since the known bit stream displaces cable TV program data, this is an intrusive test.

Measuring BER at intermediate test points (A and B) in the digital cable system requires more complexity in the test equipment. As shown in Figure 11.10, a digital test receiver performs a high-quality downconversion and demodulation of the digitally modulated signal to recover the symbol stream. The test receiver selectively applies the desired signal processing layers to reveal the bit stream. A BERT can then measure BER from the data output of the test receiver. Note that the BER reading will be different depending on whether the adaptive equalization and the FEC are applied in the test receiver. A cable operator must know what layers of processing are included in his test receiver. The test receiver may have to include an adaptive equalizer and FEC decoder for every format to be tested in the digital cable system.

Alternatively, a non-intrusive BER test can be done using the error information in the forward error correction chip, using test point E. The FEC decoder recognizes bit errors and corrects them. The decoder can also count and record the number of bit errors that have been corrected. If the pathway to read this information is available, the FEC chip can supply an accurate BER without injecting a known bit stream. This non-intrusive BER depends on the power of the FEC to detect bit errors. Different FEC codes have different error detection sensitivities. A Reed-Solomon code, for example, can correct bursts of bit errors, as well as single bit errors. If the BER exceeds the error correction power of the FEC, the error statistics will not accurately reflect the true BER. Applying this method requires understanding the FEC limits.

BER reflects only modulation impairments severe enough to cause bit errors, remaining insensitive to subtle trends in the digital modulation. A good BER indicates proper service delivery. A bad BER highlights impaired service, but does not identify the cause of the problem.

Pushing Limits: Margin-to-Critical BER

A single BER measurement is a performance measure of the digital cable system at its current operational level, giving no indication of how close the system may be to critical BER. At critical BER, the subscriber encounters severe impairments, such as freeze-frame of the received video. A margin-to-critical BER combines signal-to-noise (SNR) measurements with BER measurements to test the robustness of the digital cable system. Margin-to-critical BER, or margin test, is a stress test of the digital TV system.

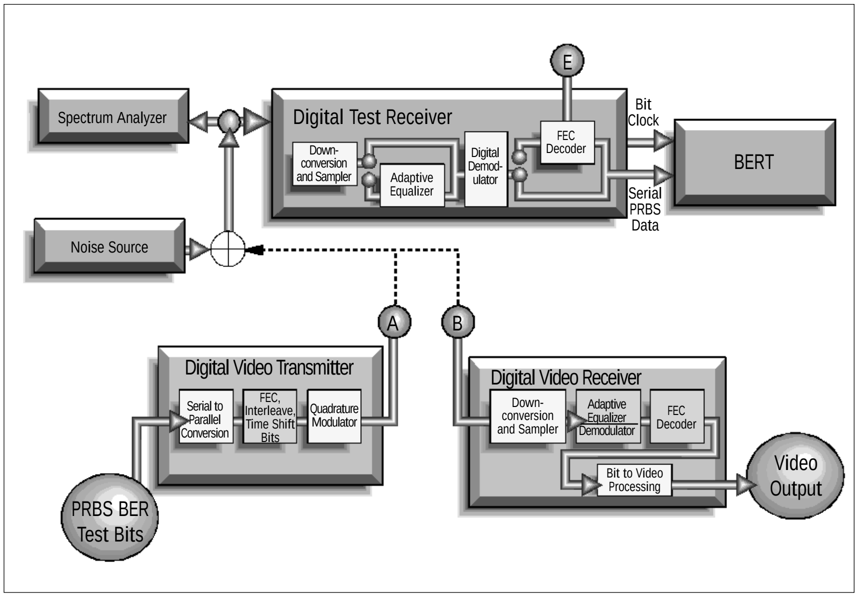


Figure 11.11: Transmitter Margin Test Setup

Figure 11.11 shows a block diagram for margin test. In addition to the test receiver and BERT required for BER measurement, a spectrum analyzer and calibrated noise source are added. Margin measurement begins with obtaining the BER at the current operating point. The signal-to-noise ratio (SNR) is measured with the spectrum analyzer. Next, measured levels of white noise are then added using a calibrated noise source. The noise level is increased while the BER and corresponding SNR are measured. Noise obscures the bits recovered at the test receiver demodulator, degrading BER as noise is increased. When critical BER is reached, the signal-to-noise ratio at critical BER is recorded. Margin-to-critical BER can then be calculated.

Margin-to-critical BER = S/Noperational – S/Ncritical

Critical BER must be separately defined for each digital cable format. Margin-to-critical BER indicates the amount of additional noise that can be tolerated by the digital cable system.

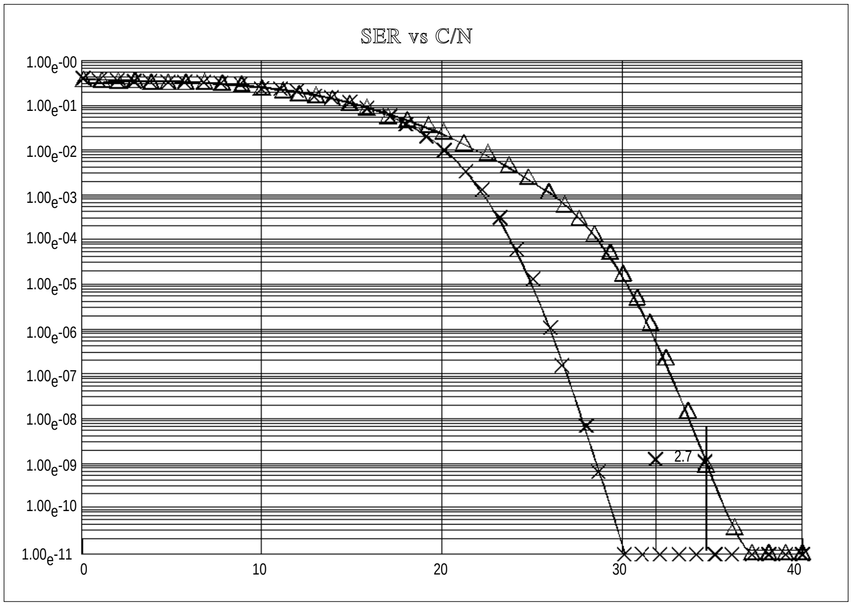


Figure 11.12: 64QAM Margin-to-Critical BER Test

Figure 11.12 shows a margin test on a 64QAM transmitter, performed at the output of the transmitter without adaptive equalization or FEC. The operating BER is 1x10-9. 2.7 dB of noise could be added to reach a critical BER at 1x10-6. Margin results must state which layers of signal processing are included. The adaptive equalization filter alters both the BER and the noise bandwidth. The FEC improves the measured BER, changing the margin test result.

Margin measurement offers an indication of the robustness of the digital cable system to noise and ingress. Margin test does not, however, give a calibrated picture of the quantity of spurious or compression impairments that might be tolerated. In addition, this test is cumbersome to perform, requiring multiple test instruments. Since several accurate BER measurements must be made, measurement time is long. Margin test is perhaps best suited to qualifying the performance of new digital cable installations.

Viewing Digital Modulation: Constellation and Eye Diagrams

When using digital modulation to transport video, signal impairments do not affect the picture quality unless they cause uncorrectable bit errors. The error retrieval power of the adaptive equalizer and the FEC masks modulation distortion problems. BER tests will not expose digital modulation impairments. Direct measurement of the quality of the baseband digital modulation, however, permits the cable operator to assess the magnitude of the distortion being concealed by equalization and error correction. Understanding the source of the degradation of the digital modulation allows the problem to be repaired before the BER is affected.

Eye diagrams and constellation plots are graphical views of baseband digital modulation. RF downconversion, digitizing, digital demodulation and adaptive equalization are applied to the RF transmission to expose the baseband modulation layer for measurement. A constellation plot displays the modulation phase and amplitude points that correspond to bits in a digital modulation format. For example, a bit stream passed into a 16QAM modulator is first grouped into sets of four bits. Each set of four bits is a symbol, creating 24=16 possible symbols. Each symbol is mapped into a phase/magnitude, or I/Q plane position to be modulated onto an RF carrier. I/Q position is related to the modulation phase and magnitude by:

The constellation plot shows the actual I/Q modulation values that were sent. An eye diagram, shows the how either the I or Q modulation component changes over time, superimposing segments of I or Q trajectory. Figure 11.13 shows 16QAM constellation plots and eye diagrams.

The constellation plots of the left side of the picture show the sixteen target phase magnitude states of 16QAM. The eye diagrams on the right side of the picture show the four amplitude levels of the Q component of the baseband modulation, and the transitions between amplitude levels.
In the upper section of the display, no impairments are seen in the diagrams. In the lower section of the display, a spur 35 dB below the average signal power level has been added at a frequency 1.5 MHz higher than the 16QAM carrier. The spur disturbs the modulation phase, causing the transmitted states to form rings on the constellation diagram and closing the eye.

Figure 11.14 shows a test setup for obtaining these diagrams. A test receiver with a digital modulation analyzer, or a high-speed oscilloscope may be used. Eye diagram and constellation plots require signals with low distortion to produce defined graphical plots. Measurements done at the output of the head-end (A) give a quick check on the quality of the digital video transmitter before cable channel distortions. If the test receiver can apply adaptive equalization, the linear distortion of the channel can be removed, permitting clearer views of baseband modulation impairments due to noise, compression and spurs at the settop receiver (B). Note that these graphical diagrams are limited by the display hardware resolution in the test equipment. A 64QAM or 16-VSB eye diagram has many finely spaced levels, requiring a very high resolution display for quantitative measurements.

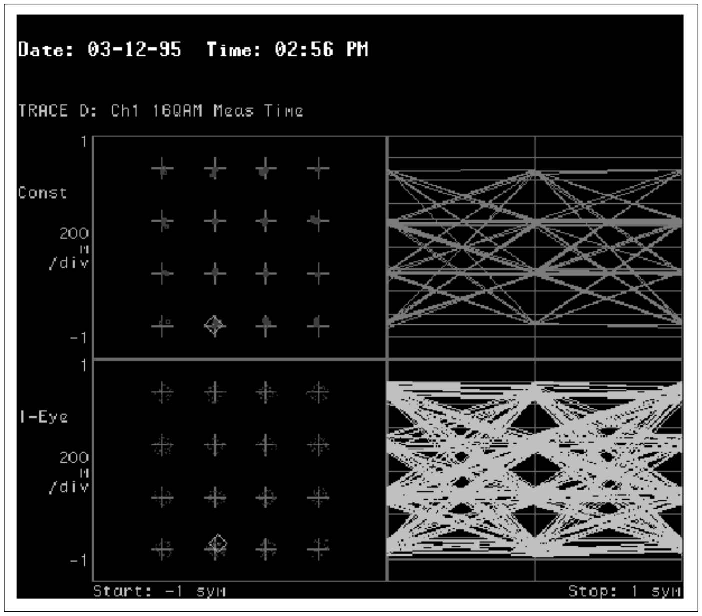


Figure 11.13: 16QAM Constellation Plot & Eye Diagram

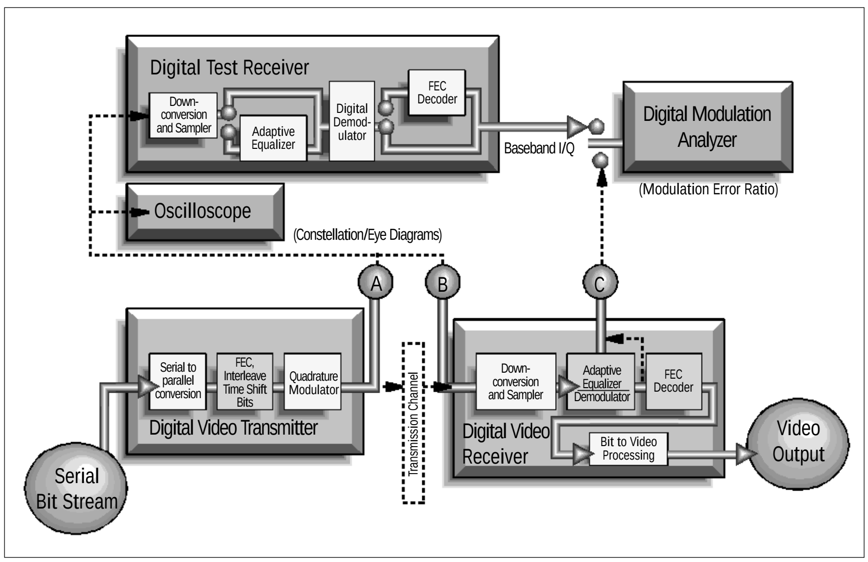


Figure 11.14: Modulation Metrics Test Setup

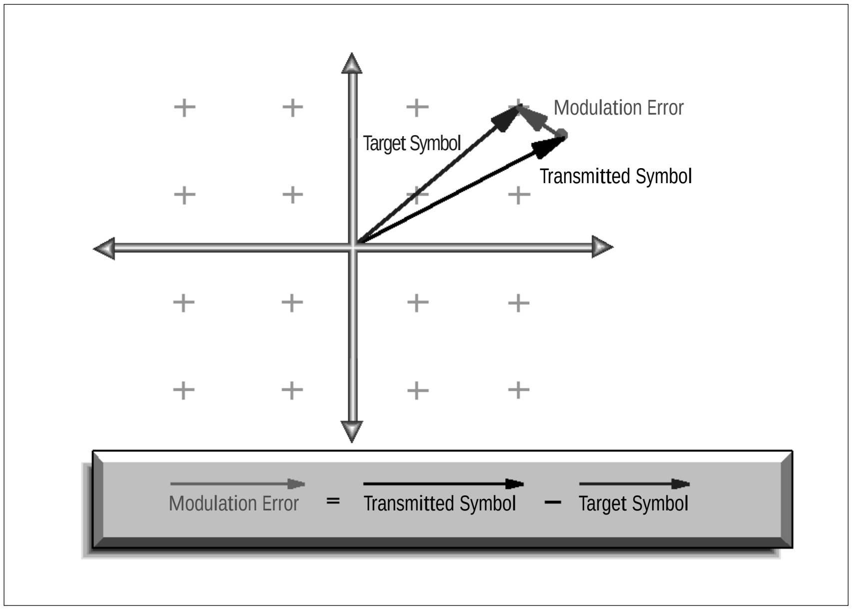


Figure 11.15: QAM Modulation Error

Eye diagram and constellation plots are most useful as fast, qualitative indications of modulation problems. Noise, group delay distortion, compression, and spurious interference each have a characteristic effect on the eye and constellation. Recognizing these display effects can help the service provider identify and troubleshoot a problem.

Testing Modulation Quality: Modulation Error

Assessing the quality of digital video requires not only qualitative views of the modulation, but also quantitative modulation metrics. Modulation error is a measure of the digital modulation impairments that obscure the transmitted data. Modulation error measurement relies, however, on correctly recovering the bits that were transmitted. If the correct data bits are known, the perfect phase and amplitude variations of the carrier due to digital modulation can be reconstructed for any digital modulation format. This perfect baseband modulation reconstruction can be subtracted from the actual baseband modulation recovered by the digital demodulator to yield the error in phase and magnitude of the received digital video transmission. Figure 11.15 shows the modulation error vector on a 16QAM constellation plot. The modulation error can be averaged over many symbols.

Modulation error ratio (MER) is analogous to a signal-to-noise ratio of the baseband digitally modulated signal. MER is a comparison of modulation error power to the average transmission power in decibels. MER measures the modulation impairments that affect the ability of the digital receiver to recover the data bits. In addition, the MER can be analyzed to phase and amplitude error components. High MER due to linear phase errors is usually due to carrier frequency error, or spurious interference. MER due to amplitude errors indicates amplifier compression problems. MER is most useful when considering digital video system margin or SNR issues.

Figure 11.16 shows a modulation error measurement on an 16-VSB signal. In this example, the modulation error is expressed as a linear amplitude ratio called error vector magnitude (EVM).

EVM is a measure of the modulation error magnitude normalized to the peak symbol magnitude, expressed as a percent number. For 16-VSB, the maximum symbol magnitude is at the points on the I axis furthest from the I/Q origin. In the lower right quadrant of the picture, EVM and its phase and magnitude components are shown with the recovered bit sequence. EVM gives a measure of the size of the clusters of symbols about the target symbol points on the constellation.

In the modulation error measurement setup shown in Figure 11.14, the digital test receiver downconverts and demodulates the RF digital video transmissions at test points A and B. Adaptive equalization may or may not be applied, depending on whether or not the desired modulation error reflects linear distortions of the transmission channel. The baseband digital modulation is routed past the FEC to a digital modulation analyzer. The digital modulation analyzer reconstructs the perfect baseband modulation trajectory and calculates MER and EVM. Unlike BER, MER or EVM can be measured over several hundred symbols, making measurement time very short. These metrics are fast, and sensitive measurements of digital modulation impairments. Note that modulation error measurements reach a sensitivity limit when bit errors in the recovered bit stream cause the perfect baseband modulation reconstruction to use the wrong bit sequence.

Note that the adaptive equalizer also contains information about linear channel distortions, analogous to the magnitude and phase components of the MER. Since the adaptive equalizer compensates for channel amplitude ripple and group delay distortion, the shape of the adaptive equalizer filter reflects linear impairments of the digital modulation. Modulation error information can be drawn from the adaptive equalizer chip, if the access pathways are present.

The digital modulation analyzer probes test point C, or the adaptive equalizer in the test receiver. Different adaptive equalizers have different compensation abilities. Correct interpretation of adaptive equalizer results requires understanding the limits of the exact equalizer used in the cable system or in the test receiver.

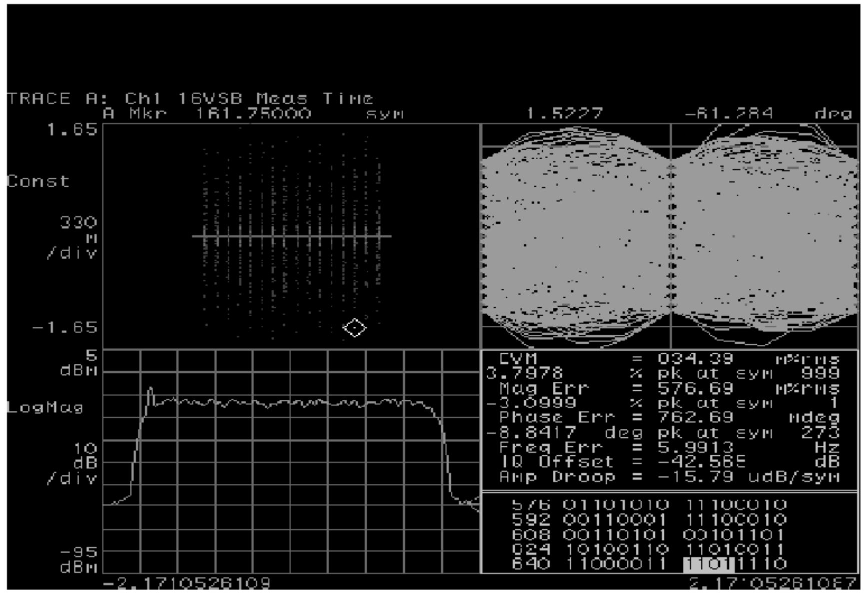


Figure 11.16: 16-VSB Modulation Error Measurement

Conclusions

We have explored four types of digital video measurements used to assess modulation and data quality. Setup and maintenance of digital cable services requires choosing a balanced set of metrics to provide both overall system checks, and useful troubleshooting tools. Both intrusive and non-intrusive tests may be desired. Designing a test strategy for digital cable systems includes identifying key test points in the plant to apply the right tests to the right digital video signals.

Cable operators can look for new capabilities to be added to test equipment to probe the layers of a digital transmission. The exploding possibilities in the emerging digital cable services may place many different digitally modulated signals on the cable. Measuring the modulation and data quality of each one will require more capabilities in the equipment. Obtaining low cost, flexible tools for digital video testing is a key challenge in implementing digital video services.

Digital transmissions on cable systems require new measures of signal quality. Understanding the advantages and limitations of the possible measurements is critical to tailoring a test strategy to a real digital cable system. As digital services are implemented, the key digital video tests and tools will be determined in practice.

References

ATSC Doc T3/269. Annex E. Draft VSB RF/Transmission Characteristics, Dec 30, 1994.

Chen, Helen., *Time Division Multiple Access (TDMA) Transmitters: Characterizing Power, Timing, and Modulation Accuracy*, 1993 Wireless Communications Symposium. Hewlett-Packard. pp 93-118.

European Telecommunication Standard Institute Draft pr ETS 300 429. Digital framing structure, channel coding and modulation for cable systems. ETSI 1994.

Grand Alliance HDTV System Specification, Version 1.0, April 14, 1994.

HP 8591C Cable TV Analyzer Cable TV Measurements User's Guide. HP part number 08591-90105.

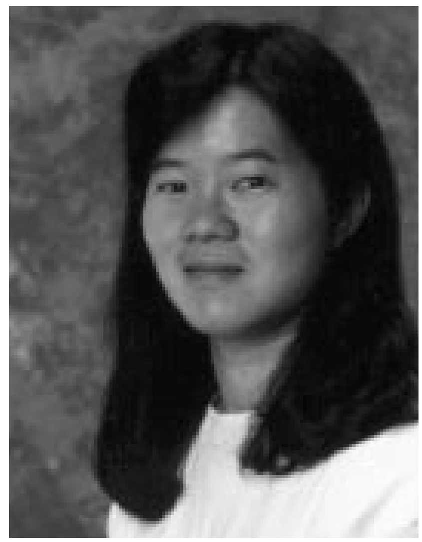
IEEE G2.2.3 Working Draft Standard. Draft for Standard Test Methods for Measuring the Performance of Digitally Modulated Signals in Television Transmission Systems, Document G2.2-203. Rev 5. Sept 22, 1994.

Pasupathy, Subarayan. *Minimum Shift Keying: A Spectrally Efficient Modulation*, IEEE Communications Magazine. Vol. 17, no.4. July 1979. pp.14-22

Thomas, Jeffrey L., Cable Television Proof-of-Performance, PTR Prentice Hall, 1995.

Watkinson, John. The Art of Digital Video. Second Edition. Focal Press 1994.

Working Draft Standard IEEE BTS Committee G2.2. Draft for Standard Test Methods for Measuring Digitally Modulated Signals in Television Transmission Systems. P1380 and P1381.



About the Author

Helen Chen is a Development Engineer at HP's Microwave Instrument Division in Santa Rosa, California. She received a BSEE from Cornell University and an MSEE from Stanford University. Helen joined Hewlett-Packard in 1985, and has been involved in analog, RF and DSP system design for HP spectrum analyzers. She is currently developing new test instruments for digital video.