INLAND CHAPTER OF THE SCTE

DISTORTION IN THE DIGITAL WORLD

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OVERVIEW

As the CATV industry moves deeper into the world of digital processing and transmission, the question of how to quantify, measure, and confront impairments to digital carriers becomes a subject of significant importance. The impact of noise and distortion on digitally modulated carriers produces a set of circumstances and results unique to this type of modulation.

We are all familiar with the singular visual impact of impairments to the digital signal: tiling and freezing, the presence of visual artifacts in the picture such as trailing, jerky motion and other aberrations unique to the digital signal.

The causes of some of these problems are related to transmission, reception, and processing of the digital signal, where other impairments are due to the usual problems on the cable plant familiar to us in the analog world: noise, intermodulation, coherent interference (CTB etc), and Hum effects.

As most CATV systems carry a legacy analog spectrum, as well as a digital line-up, we need to continue to manage the plant for the classic analog distortions and noise, as well as problems unique to digital transmission. It is important to realize that a well set-up and managed plant for quality analog transmission and reception will generally guarantee reliable digital transmission and reception as well. This is not always the case but for the most part is accurate. There are some distortions in the digital world, while not visible, or at least not objectionable, to analog signals, can cause serious digital problems. These will be discussed later in this paper.

There are numerous advantages of digital carriers vs analog carriers. Not the least of which is the ability of digitally modulated carriers to operate in a noise and distortion environment that would make analog signals unwatchable. Another very big advantage of digital modulation is the quality of the received digital signal regardless of transmission distance, amplifier cascade, and higher levels of analog noise and distortion. The digital picture is the same quality as introduced at the headend. No longer do we suffer from the gradual deterioration of the picture through the plant. These facts, plus the ability to pack multiple digital modulated programs on a single EIA 6Mhz carrier illustrates the obvious advantage of digital transmission.

DIGITAL vs ANALOG DISTORTIONS

All of the typical analog distortions we have dealt with over the years affect both the analog and digitally modulated carriers. These are:

> **CARRIER to NOISE – The RMS level of the carrier to the thermal noise floor generated by the electronics.**
>
> **CARRIER to COHERENT INTERFERENCE – Distortion components caused by non-linear mixing of carriers in the transmission system which includes CTB (Carrier to Triple Beat, (3d Order mixing), CSO (Carrier to Second Order, (2d Order Mixing)**
>
> **CARRIER to LOW FREQUENCY DISTORTION – Generally HUM at low frequency, 60Hz from the power system, 120Hz from linear power supplies, <1KHz from switching power supplies and other low frequency sources.**

In addition, for digitally modulated signals, there are some unique impairments that affect them that minimally affect analog carriers, or are not a concern. These include:

> **CARRIER to SUSTAINED IMPAIRMENTS (CI) – Continuous unwanted signal within the channel passband that can affect digital decoding but has minimal adverse effect on analog signals.**
>
> **SPECTRAL REGROWTH – Digital effect due to power loading on amplifier circuits, generally present in processing equipment.**
>
> **MULTIPATH and MICRO-REFLECTIONS – In the analog world this results in "ghosting" or "fringing" , also known as "ringing". These are reflections that, if high enough in level in relation to the carrier, cause digital decoding problems.**
>
> **PHASE NOISE – Generally has no effect in the analog world, but can cause severe reliability problems in digital carriers. This is usually due to oscillator instability in processing equipment.**
>
> **AMPLITUDE and PHASE DISTORTION – result of the presence of any of the distortion components listed above that cause the digital decoding to error.**

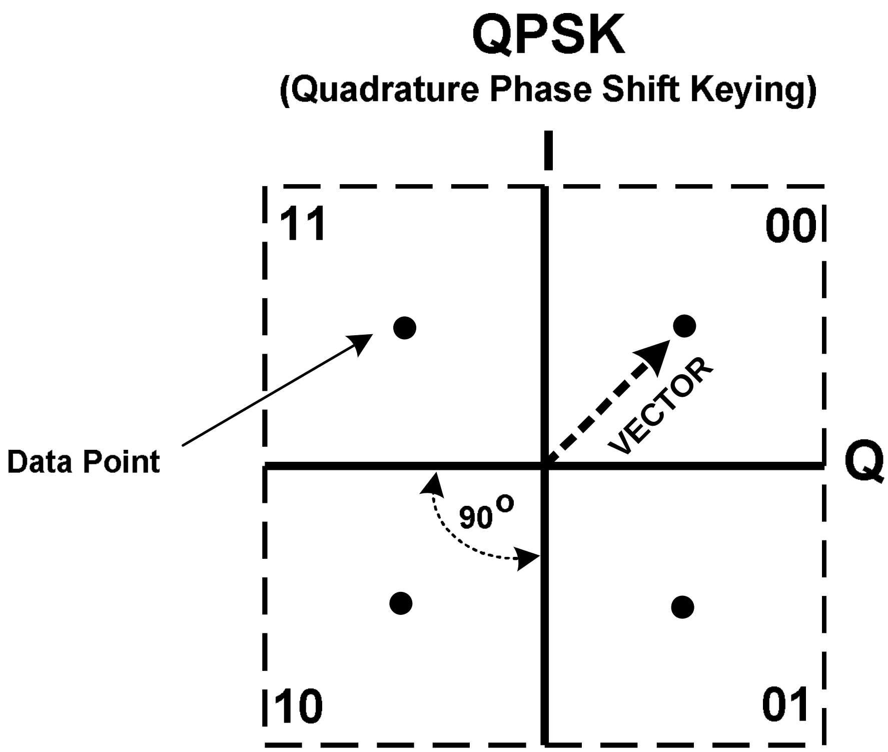
Of the impairments listed above, some are measured for digital signals the same as for their analog counterparts, other measurements unique to the digital signal, such as MER, BER, and the Constellation are measured with instruments designed to evaluate digital modulation.

The following sections discuss the various distortions and how to measure them for digital carriers.

DIGITAL CARRIER MODULATION BASICS

A digital EIA carrier is modulated with a digital data stream. The modulation process can be simply described as the rotation of an electrical vector representing a series of digital bits. How many digital bits the vector position represents is a function of the modulation rate, generally for CATV systems either 64QAM, or 256QAM. The term "QAM" stands for Quadrature Amplitude Modulation. The 64 or 256 mode differ in the number of bits each carrier position can represent, and how fast each sequential position (or distinct group of bits) is generated is known as the "SYMBOL RATE", 5.057 Mbs for 64QAM and 5.3614Mbs for 256QAM. Symbol Rate can be demonstrated with a simple example of QPSK modulation, a much simpler and basic QAM modulation, as shown in FIG 1.

FIG 1. QPSK MODULATION

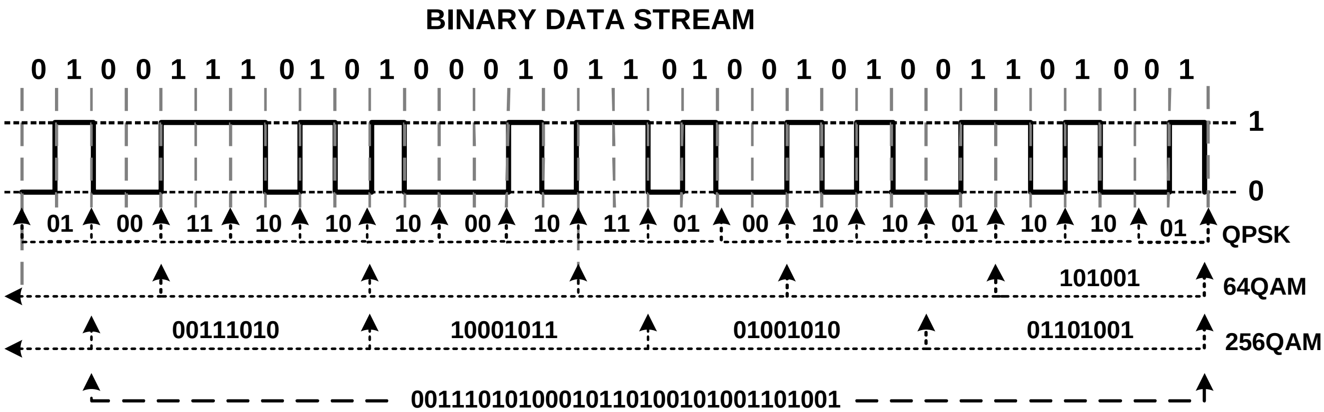


The plot consists of two carriers 90° apart in phase (I & Q carriers in Quadrature). These are fixed. The modulation vector carrier rotates around the 360° arc, actually, electrically through 360° of phase as shown in FIG 1. At the synchronized measurement interval (SYMBOL RATE), the position of the carrier is identified by the decoder and the corresponding bit sequence is added to the decoded data stream. This matches the original encoded data bits. In the case of the QPSK, there are four quadrants and one position in each quadrant. Each position can indicate the sequence of two data bits: 0,0; 0,1, 1,0; 1,1. As applied to the binary data stream, this is shown in FIG 2.

In QPSK, the modulation and de-modulation (decoding) is relatively straightforward as the vector carrier can be anywhere within the quadrant and be identified as being in Q1, 2, 3 or 4. A bit of phase shift or amplitude difference is inconsequential.

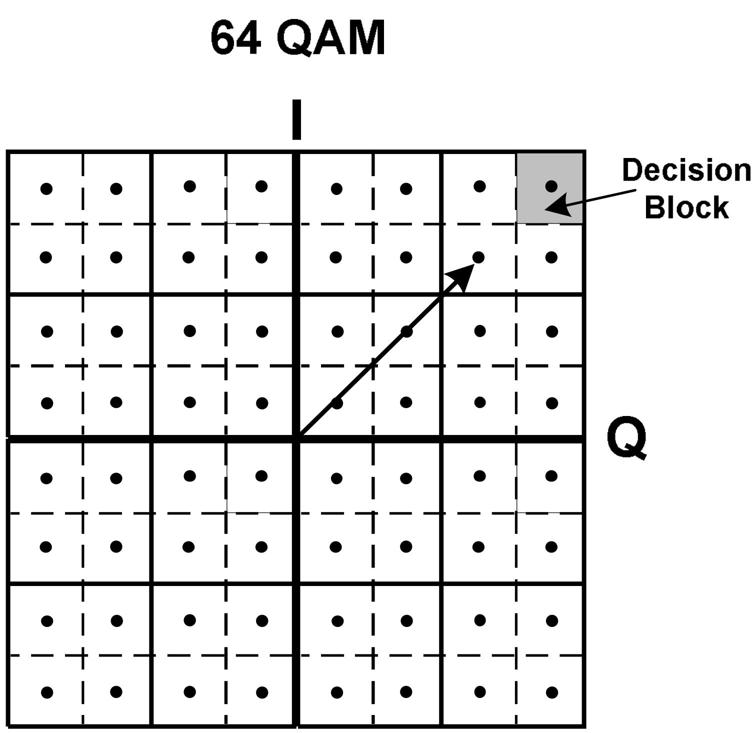
This is why QPSK is the dominant method of transmission over the satellite, as it is relatively immune to the long distance phase and amplitude shifts in the transmission path. It (QPSK) is also known as the bullet proof method of transmission and is used for reliability. However, the data conveyed per bit is limited.

FIG 2. BINARY DATA STREAM WITH QAM MODULATION



The problem with QPSK is that it can’t carry large amounts of data in limited bandwidths as necessary for video and high density data transmission. To do this we have to use a higher order of modulation, i.e. the rotating vector position has to represent more data bits for every read. To do this, we need to establish more points within the 90° quadrant. The initial modulation rate used by CATV was 64QAM (There are also lesser modes such as 16QAM and 32QAM, but these are not used for video, only data, primarily 16QAM on the return path). 64QAM, FIG 3, utilizes 16 points per quadrant, each point a unique amplitude and phase, and representing 6 possible data bit combinations per point.

FIG 3. 64 QAM MODULATION CONSTELLATION

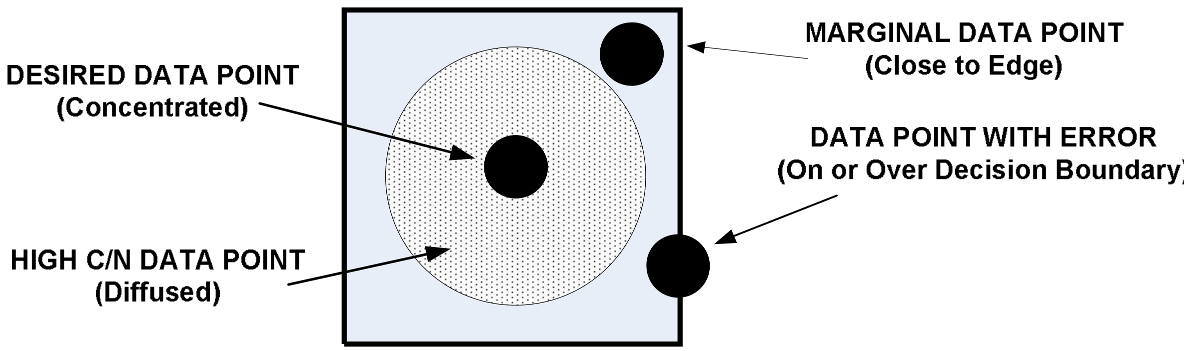


4 X 16 Data Blocks per quadrant = 64

QAM

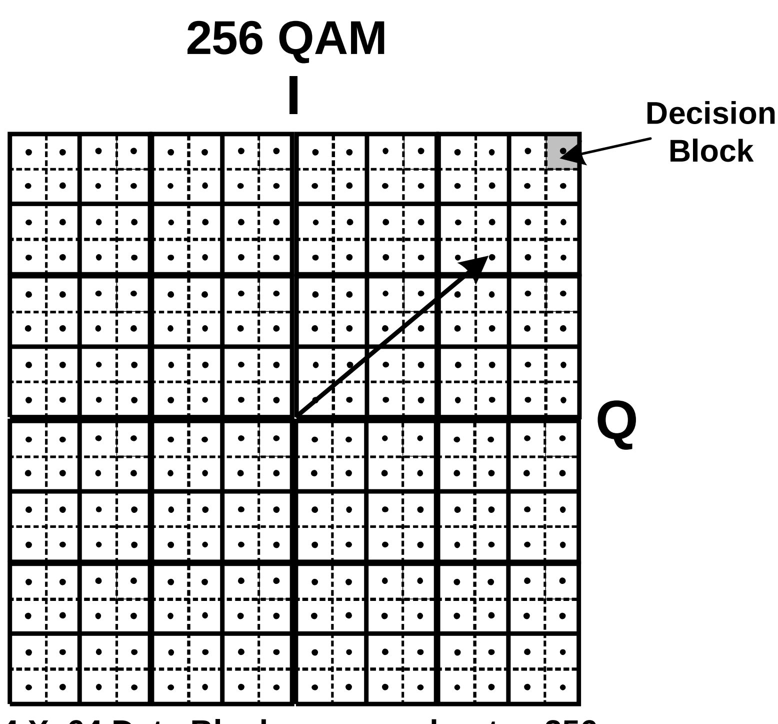
Using higher orders of modulation introduces complexity into the encoding and decoding process. The decoder must now resolve the exact position of the vector in both amplitude and phase. The quadrant is now divided into what are known as decision blocks. For 64QAM, there are 16 of these decision blocks within the quadrant (FIGs 3 & 4). The decoder has to place the vector within the block to reliably decode the bits. If the vector is on the decision block line or outside the block, the decoder becomes confused and an error results. Enough of these and the signal tiles, or even freezes. Anything that causes the decoder to become confused causes errors.

FIG 4. QAM DECISION BLOCKS



64QAM was used as an example, however, most CATV systems have moved to more complex 256QAM carriers that can carry more data bandwidth. In the 64QAM case the nominal 6MHz carrier program bandwidth is about 27mbs, and for 256QAM, 38mbs (plus overhead. This all happens at the Symbol Rate (1MBsSymbol Rate is roughly = 1 MHz).

FIG 5 256QAM CONSTELLATION



4 X 64 Data Blocks per quadrant = 256

FIG 5 is a plot of the 256QAM Constellation. Each vector point represents an 8 bit sequence of the encoded data stream. 256QAM carriers can pack much more programming into the 6Mhz bandwidth. As can be seen, the decision blocks for the vector points are very small for each amplitude/phase combination. It doesn't take much distortion to shift the vector point outside the correct decision block.

DIGITAL CARRIER DISTORTION MEASUREMENTS

MEASURING DIGITAL CARRIER to NOISE

Digital Carrier to Noise is measured in the same fashion as analog Carrier to Noise, with a Signal Level Meter (SLM), or spectrum analyzer. For field operations, usually a SLM is used, but most modern meters have a spectrum function built in which makes the measurement very quick and easy.

The ratio between the Digital carrier RMS level and the noise floor RMS level determines the C/N. For the normal CATV modulation modes the nominal acceptable C/N for reliable operation is:

QPSK	**12dB**
16QAM	**20dB**
64QAM	**31dB**
256 QAM	**38dB**

In actual service these numbers can vary widely depending on a number of program parameters. There are numerous factors that contribute to digital carrier stability: type of programming, compression ratios, SD vs HD. Some programs might run at significantly poorer C/N than these listed, and some might have problems at these levels.

These required numbers can be significant given the minimum FCC required analog C/N on the system of 43dB. At this level, the C/N for a 256QAM signal which runs typically 4 to 6dB below the analog is 37 to 39dB and for a 64QAM signal at -10dB below analog: 33dB. These minimum C/N levels are O.K. but if you consider the fact that the highest analog carrier is typically in the CH 70-80 range, and digital carriers extend to CH135 (for an 860MHz system) , if there is negative slope at the higher end, this can cause a C/N problem at the higher digital carriers.

Examples of instrumentation measurements for digital carriers are given in FIGs 6a (Spectrum Analyzer) and 6b (Constellation Diagram).The SLM measurement for digital carriers is typically not automatic as it is for analog carriers on most instruments. Generally the analog C/N is measured and the digital level differential is subtracted, i.e. Analog C/N on CH78 = 44dB, 256QAM C/N with the QAM level at analog -4dB = 44-4 = 40dB Digital C/N.

FIG 6. MEASUREMENT OF DIGITAL SIGNAL CARRIER to NOISE

FIG 6a SPECTRUM ANALYZER

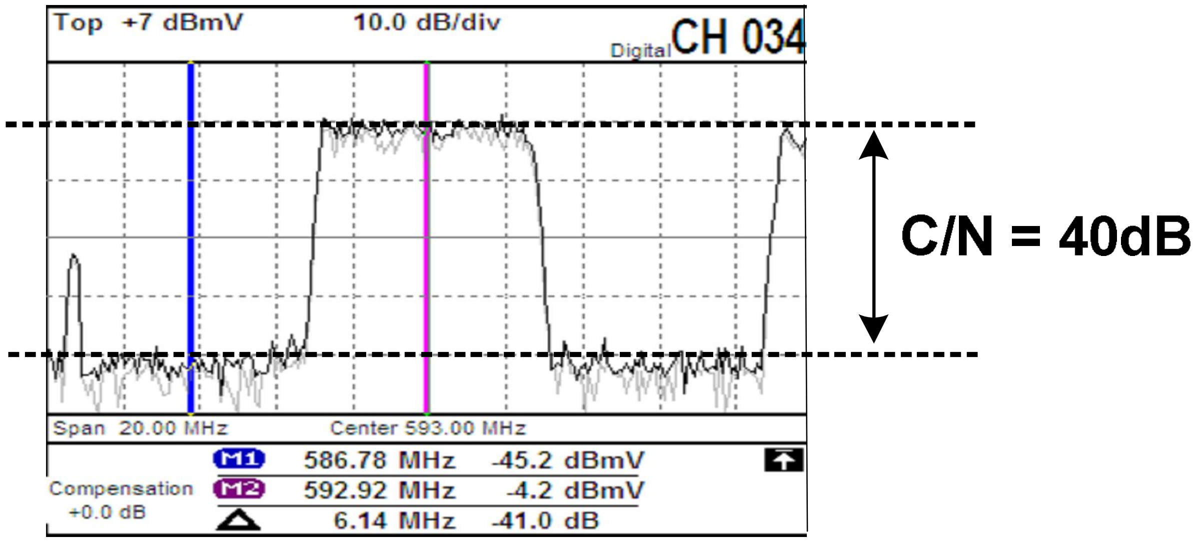
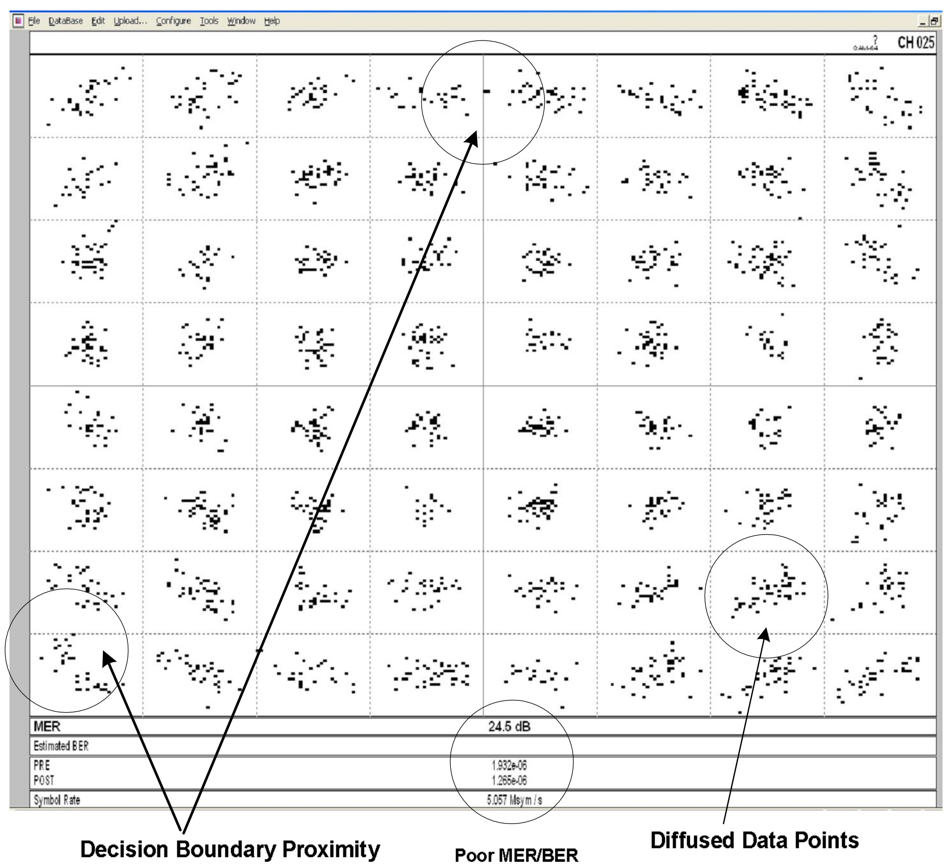


FIG 6b CONSTELLATION

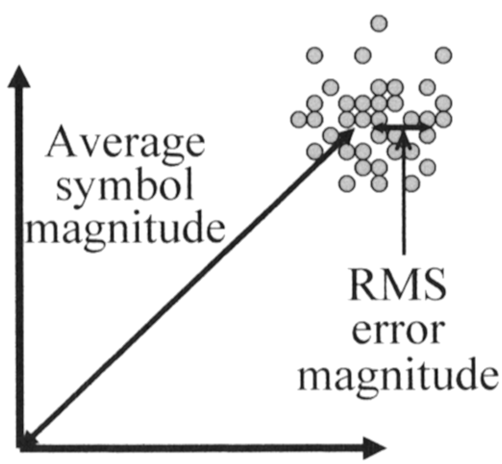


MER & BER

The two basic parameters used to evaluate the quality and performance of digital signals are BER (Bit Error Rate) and MER (Modulation Error Ratio).

These parameters are closely linked. The Modulation Error Ratio is a measurement of the average deviation of the desired signal vector point (center of decision box) to the RMS (Root Mean Square) of the actual landing point. i.e. how tightly concentrated the symbols are in the box. This is roughly analogous to analog C/N or S/N.

FIG 1. ILLUSTRATION OF MER CALCULATION PARAMETERS



$$\text{MER} = \frac{\text{RMS ERROR MAGNITUDE}}{\text{AVG Symbol Magnitude}}$$

MER Requirements at the set top box are : 64QAM = 23dB; 256QAM = 28dB; preferably with a 3-4dB margin, i.e. 28dB for 64QAM and 32dB for 256QAM.

The Bit Error Rate (BER) is a measure of how many bad, or un-recognizable bits occur for every sequence of good bits. Two measurements exist, PRE and POST FEC (Forward Error Correction). In the first, the BER is the raw error rate as received in the instrument, the second, with FEC, is the corrected rate as determined by the decoder. The acceptable BER for 64QAM signals is in the 10-5 range and for 256QAM, 10-6. MER impacts the BER as the poorer the MER is, the more bit errors you have.

It is important to note that, although all other indications of a good digital signal such as level and flat response are present, and even with a relatively good MER, there might still be signal degradation due to BER from bad connections causing mis-matched impedance, and other plant issues

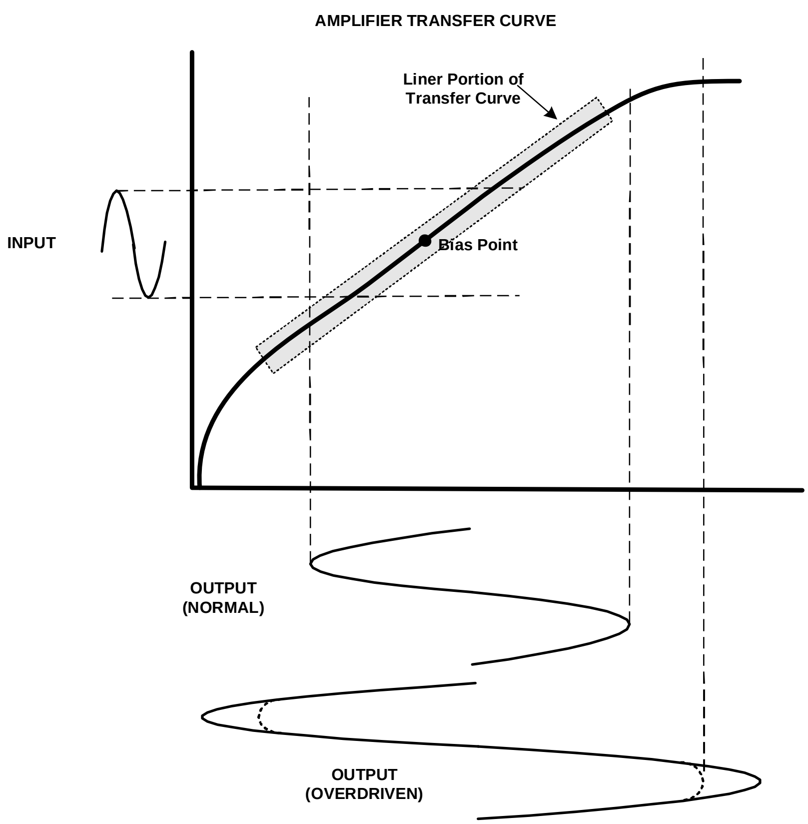
MEASURING DIGITAL DISTORTION

Coherent distortion, Intermodulation, CTB, CSO, are impairments produced in digital transmissions by the same mechanism as in analog signals. The basic factor is the power loading and overdrive of active amplifiers in the electronics, as well as other level related issues such as input overload.

The usual cause of overload in the field plant is running amplifier output much too high. This causes non-linear mixing of the carriers, as well as signal clamping and clipping. This can have a much more severe effect on digital carriers than on analog ones.

The basic mechanism for overload is shown in FIG 7. This is a typical transfer curve for an amplifier. The gain characteristic is set such that, at nominal gain, the output signal resides on the liner portion of the curve and the signal throughput is linear with no mixing. If the amplifier is overdriven, either with a very high input level (compressing the front end) or very high output level, the signal will have a non-linear component and the carriers will mix together creating beats. For the digital carriers, this can also cause compression which will degrade the signal.

FIG 7. AMPLIFIER NON-LINEARITY

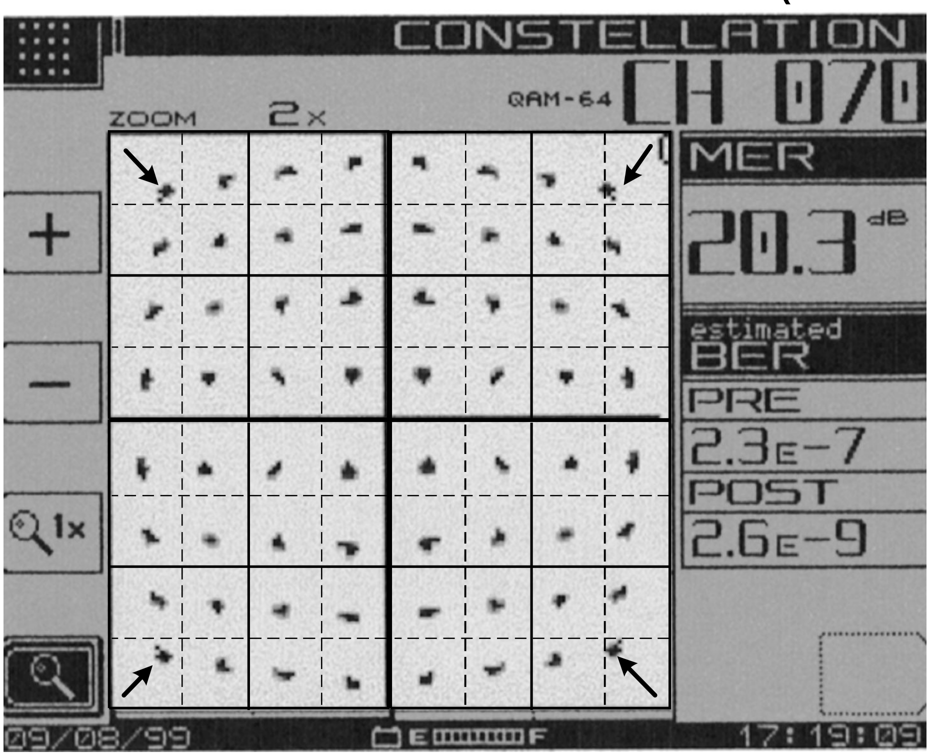


As noted above, digital distortion takes the form of intermodulation, or mixing of the carriers, caused by the same mechanism that produces analog CTB and CSO, due to overdrive or power loading of the amplifier circuits. The effect of this distortion is to replicate the digital mixed carriers throughout the spectrum. If the beats land on digitally modulated carriers, that causes an increase in BER (Bit Error Rate) and a corresponding decrease in MER (Modulation Error Ratio). Landing on analog carriers, this can cause the affected analog carrier C/N to severely degrade in C/N and visible beats. It is valid to note that, if the digital intermodulation is severe enough to affect the digital programming, the analog will have excessive CTB and beats.

The normal indication of this type of problem with digital carriers is visually with the signal tiling, or even freezing, and through measurement of MER, BER, and observing the constellation of the affected carrier. Often, observation of analog channels will indicate a typical overload problem. The method of troubleshooting is to make signal level measurements and observe the digital specific parameters on a digital capable meter such as a D-SAM or Trilithic 860dsi.

Gain compression (overdrive) can be indicated by poor MER, but by observing the constellation for compression (FIG 8) a better idea of what might be happening can be obtained. The fix of course is to set the levels properly.

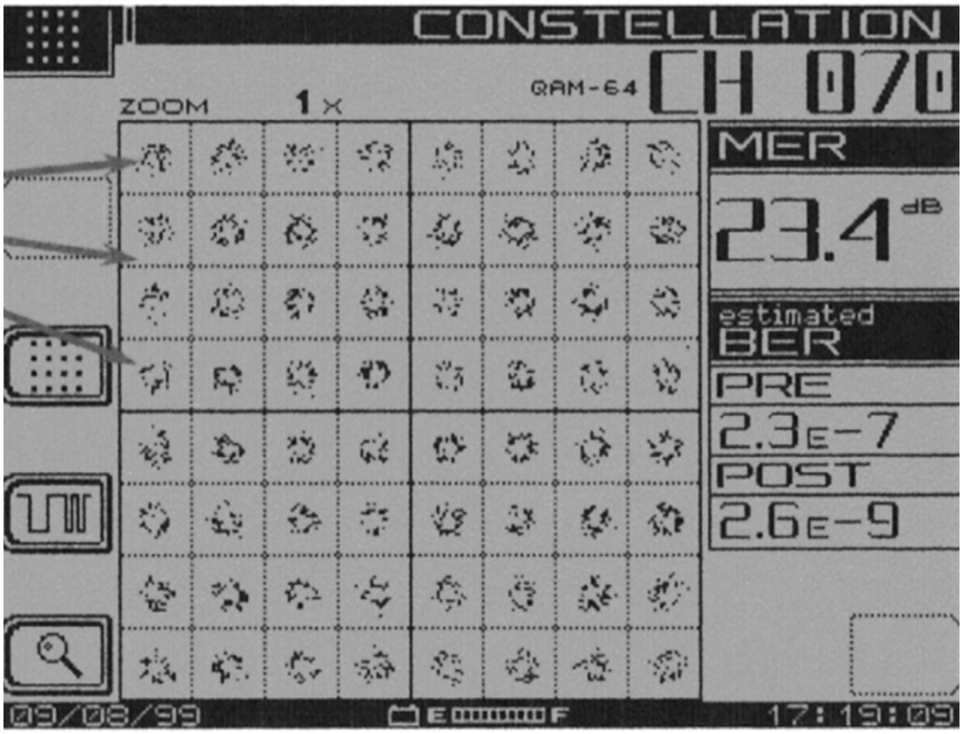
FIG 8 CONSTELLATION SHOWING GAIN COMPRESSION (OVERDRIVE)



Data Blocks pulled in at edges

The same can be said for CTB and CSO effects. Although the result is different for digital carriers, the presence of this type of non-liner distortion can be seen in the constellation pattern, as shown in FIG 9.

FIG 9. CTB, CSO, COHERENT DISTORTION



PROBLEMS UNIQUE TO DIGITAL CHANNELS

There are some problems that are unique to digital processing and transmission that, while present in analog transmission systems, generally result in lower intensity problems with analog pictures.

Three digital distortions we should be concerned with are:

1) **Spectral Re-growth**

2) **Multipath and Reflections**

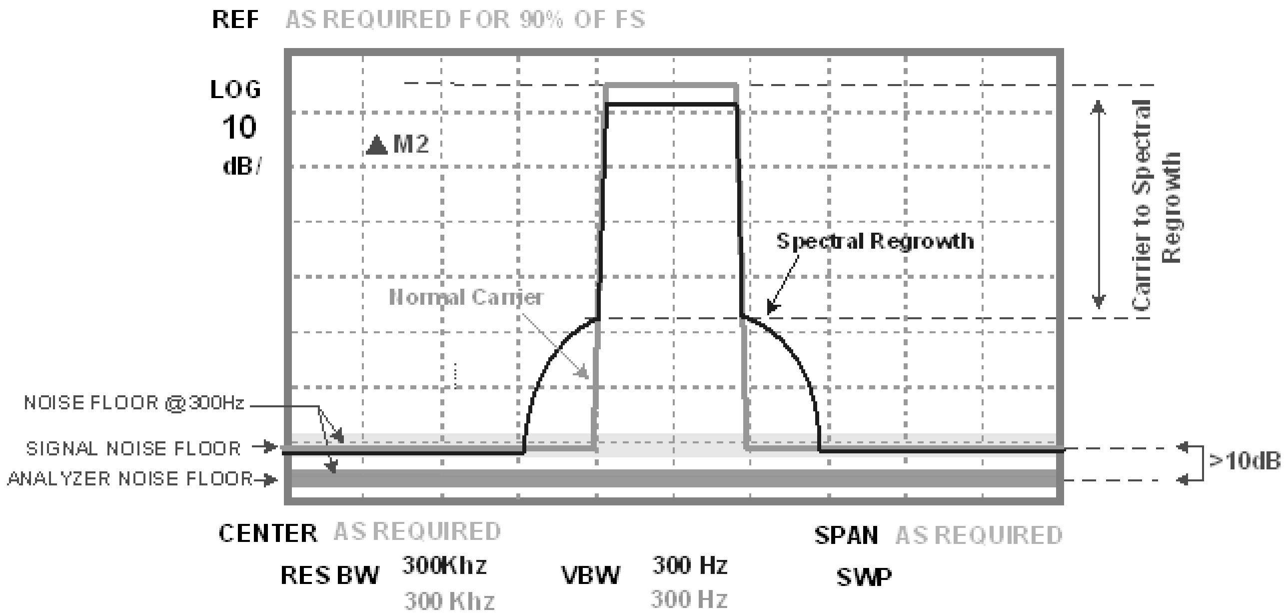
3) **Phase Noise**

Spectral Re-growth

Spectral Re-growth is typically an overload effect noted through digital signal processing equipment. This is an overdrive, or overmodulation of a single carrier. Sometimes an isolated carrier such as a return data carrier will show the problem as a result of return laser overdrive.

The problem is observed on a spectrum analyzer (or you can measure it with a SLM if a careful measurement is done). FIG 10 is a plot of a carrier with spectral re-growth.

FIG 10 SPECTRAL REGROWTH PLOT



As can be seen the problem is the generation of sidebands or "ears" adjacent to the desired carrier. How tolerable this is, is dependant on the ratio of the sidebands to the carrier level. As the sidebands are similar to noise, the acceptable ratio for noise generally is the controlling factor. It is very important to keep in mind that the sidebands extend through the carrier and significantly into the carrier spectrum on either side. If the adjacent carriers are analog, the sidebands can degrade the C/N of the channel. i.e. If the analog carrier adjacent to a 256QAM digital carrier with spectral re-growth has a C/N of 44dB, and the spectral re-growth ratio to the digital carrier is 36dB, and the digital carrier is 4dB below the analog, the ratio of the SG to the analog carrier is 36+4 = 40dB, With the analog carrier at 44dB C/N the composite C/N is 40 + 44 dB = 39dB, a significant degradation.

Spectral Re-growth, as noted, is basically an overdrive of amplifier, or laser, circuits. Restoring the correct levels usually solves the problem, but not always if a defective circuit is at fault.

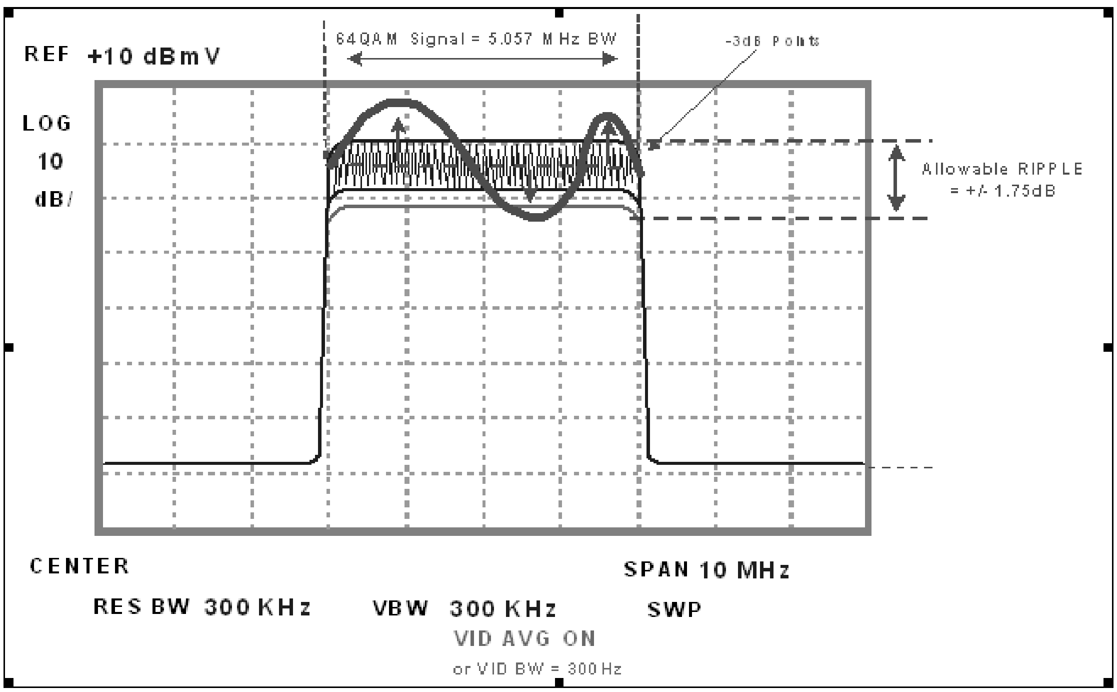
Multipath and Reflections

Digital signals are subject to multipath effects and reflections. This is a common problem for digital carriers transmitted wirelessly, where multipath reflections are common and where recognized as "ghosting" in the analog world, in the digital world, this relates to phase differential in the received signal which tends to increase MER and BER to the point of affecting digital decoding.

As wireless transmission is not common to CATV (with the exception of off air 8VSB digital carriers which are subject to the same issues), the problem can exist with impedance mismatch within the closed plant, which can cause some of the same problems due to reflection.

Open ports or shorts reflect 100% of the signal, and If the transit time is long enough to create significant phase differences, and the losses back into the incident signal path are low enough to result in significant reflected signal arriving at the input of the active device, digital distortion can result. The issue is normally discovered by observing the digital carrier for a sine wave effect riding on the top of the "haystack" this is normally fluid, the pattern moves rapidly across the carrier. This effect can cause intermittent tiling and some freezing, related to the phase relationships. FIG 12 illustrates this effect.

FIG 12 CARRIER MULTIPATH OR REFLECTIONS



The obvious solution to the reflection issue within the plant is to identify the reflection point and repair it. This can include corroded, and loose, fittings, corroded splitters etc

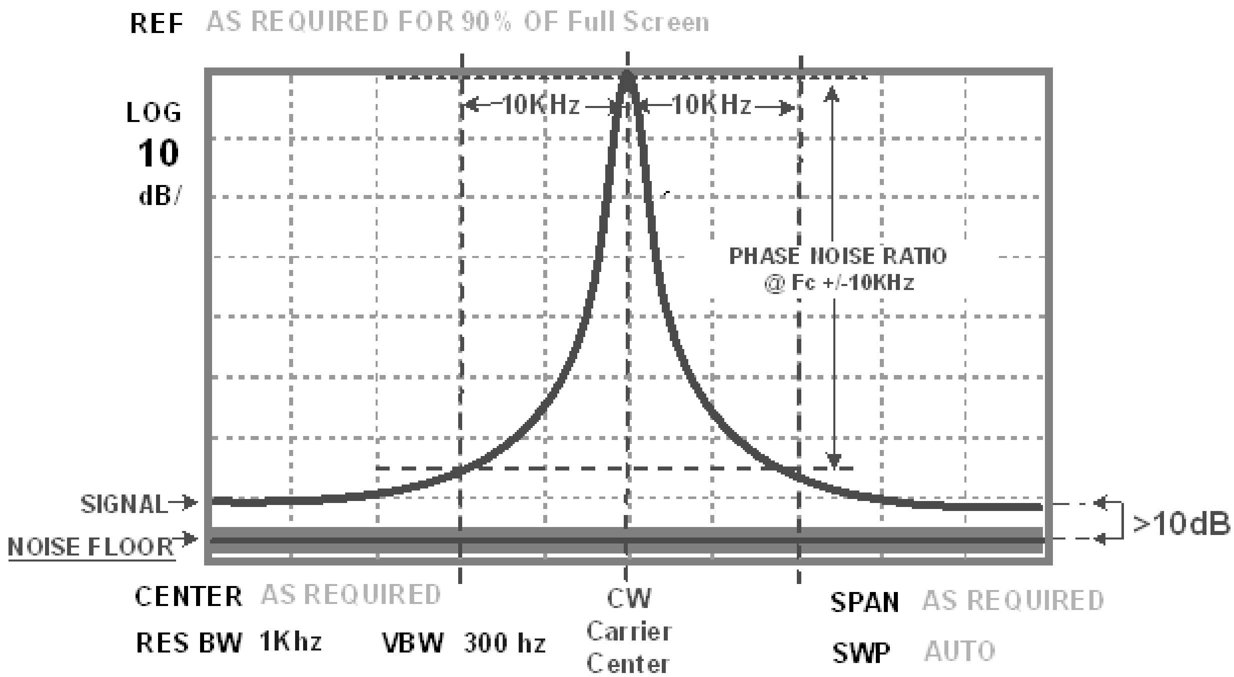
Phase Noise

A problem unique to digital modulation, present in analog transmission but generally not an issue with the analog, is Phase Noise. This is an impairment usually present in conversion oscillators used throughout the electronics used to process the signal. Local Oscillators must be very stable, typically for a 64QAM signal, 84dBc @ 10khz is required, and for 256QAM, 90dBc @ 10khz. This is essentially jitter or instability in the oscillator, which is translated to the signal in the conversion process.

As modern oscillators tend to be well below 100dB in phase noise, this is usually not an issue in CATV, with the lower frequency oscillators used. The problem is normally seen in very high frequency (1GHz +) microwave conversion oscillators. However, an unstable oscillator in a modulator or processor is not unheard of.

Phase noise appears as a spreading of the noise floor on the carrier when examined with a spectrum analyzer at very narrow bandwidths. The noise measurement is generally taken at a point 10Khz out from the carrier center, and corrected for video bandwidth. i.e. 1KHz video BW corrected to 1Hz bandwidth = 10log(1/1000) = -30dB. FIG 13 is a plot of the measurement. A lab quality analyzer is normally needed to measure this parameter as lower cost analyzers don't have the narrow bandwidth capability required for the measurement.

FIG 13. PHASE NOISE MEASUREMENT



The only solution to this issue is to replace the oscillator, or in the case of an unstable power supply, replace the power supply.

OTHER MEASUREMENTS

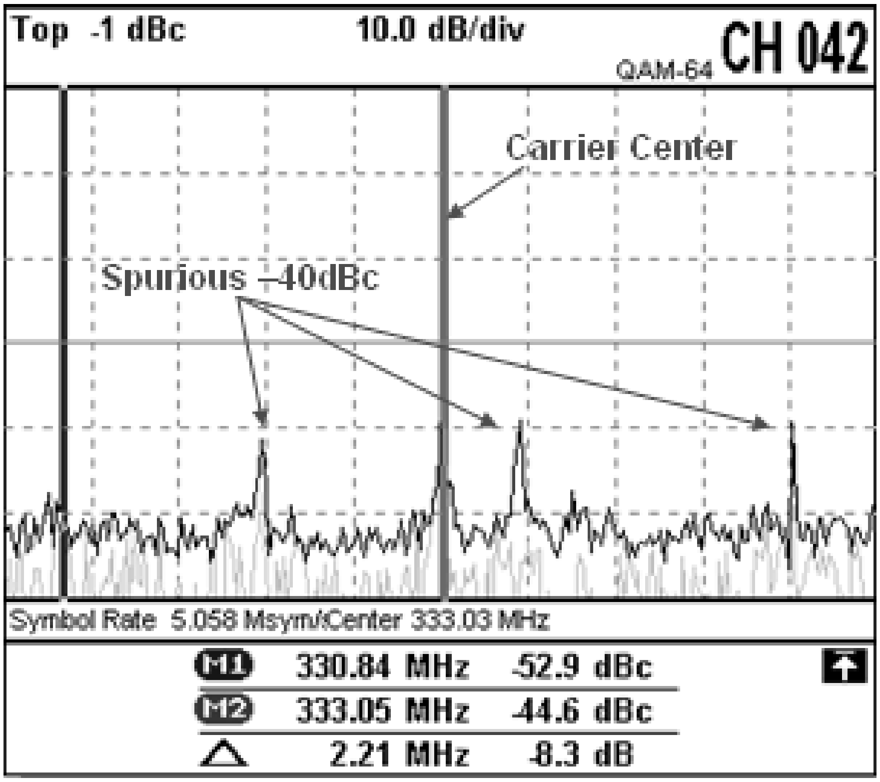
Some instruments have diagnostic tools to help troubleshoot problems in digital carriers. Channel Response, Group Delay, and Ingress are measurements that can help determine nagging problems.

Ingress

Particularly useful is the function in JDSU meters to look under the digital carrier for ingress. This can be especially useful to identify intermittent interfering carriers popping in and out of the digital spectrum causing tiling and possible freezing on an intermittent basis.

FIG 14 is a plot of the INGRESS function of the SAM-5000. This particular plot shows a number of ingress signals about 40dB down. If these were higher, say 25dB down, there would be intermittent tiling. Note that when examining the ingress, there will be a small carrier bump at the channel center, which is normal.

FIG 14. INGRESS UNDER CH 42 DIGITAL CARRIER SPECTRUM



The ingress function measures undesired carriers within the spectrum of the signal in question. This can be from the CATV headend mixing, with spurious carriers, LO leakage etc., or direct ingress to the CATV plant from external sources.

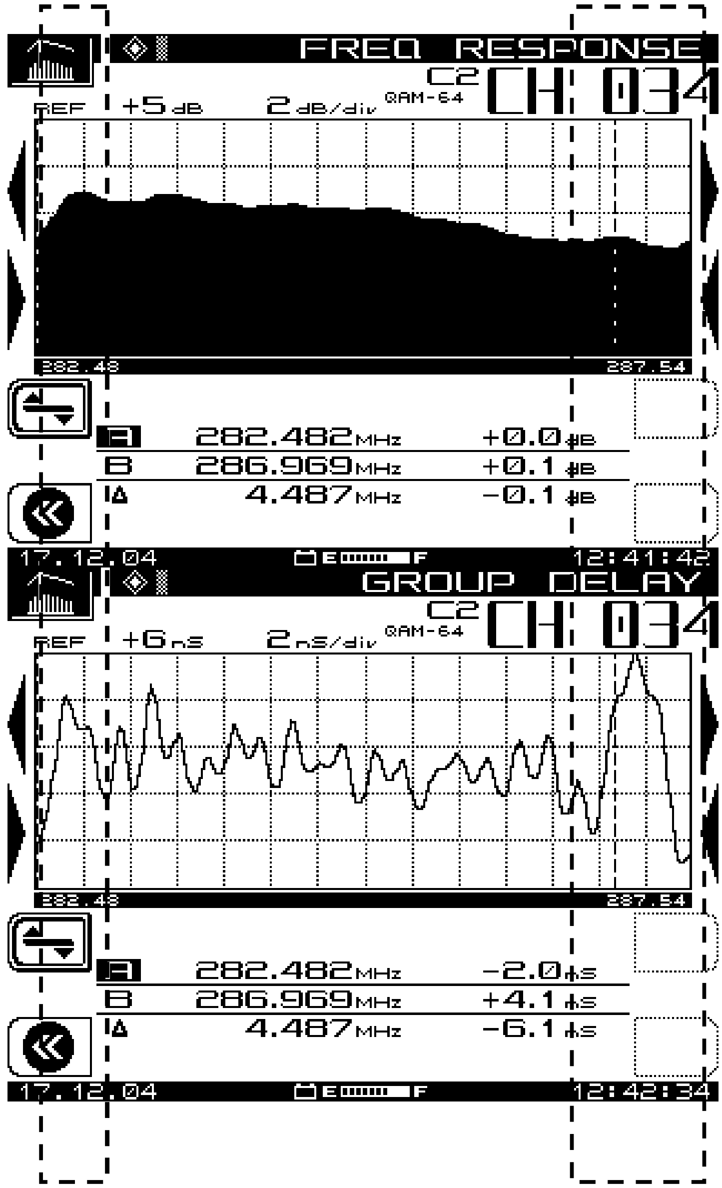
Response and Group Delay

The other useful measurement function on some meters is the measurement of channel spectral response and Group Delay. It is important to note that the digital carrier should meet response characteristics of a few dB at 64QAM, and 1dB or so with 256QAM signals or instability can result. The response slope affects group delay, the transit time across the circuit for all frequencies meeting acceptable frequency selective delays. If the delay from one side of the response is greatly different from the other side or any other area in the response curve, error will result at the decoder.

FIG 15 is a linked comparison of Group Delay vs Channel Response on a digital CH34. As can be seen, the Group Delay tends to change with response non-linearity's.

Dealing with these kinds of problems can be problematic. The response issue usually is internal to modulators or processing equipment. This can be at the CATV headend, or in more unusual cases in the plant spectral response. The SLM meter is used to track the problem to the source.

FIG 15 SIGNAL CHANNEL RESPONSE vs GROUP DELAY



The delays shown above are as high as 8ns. This may, or may not result in any problems. The DOCSIS 1.1 specifies that 75ns delays are acceptable

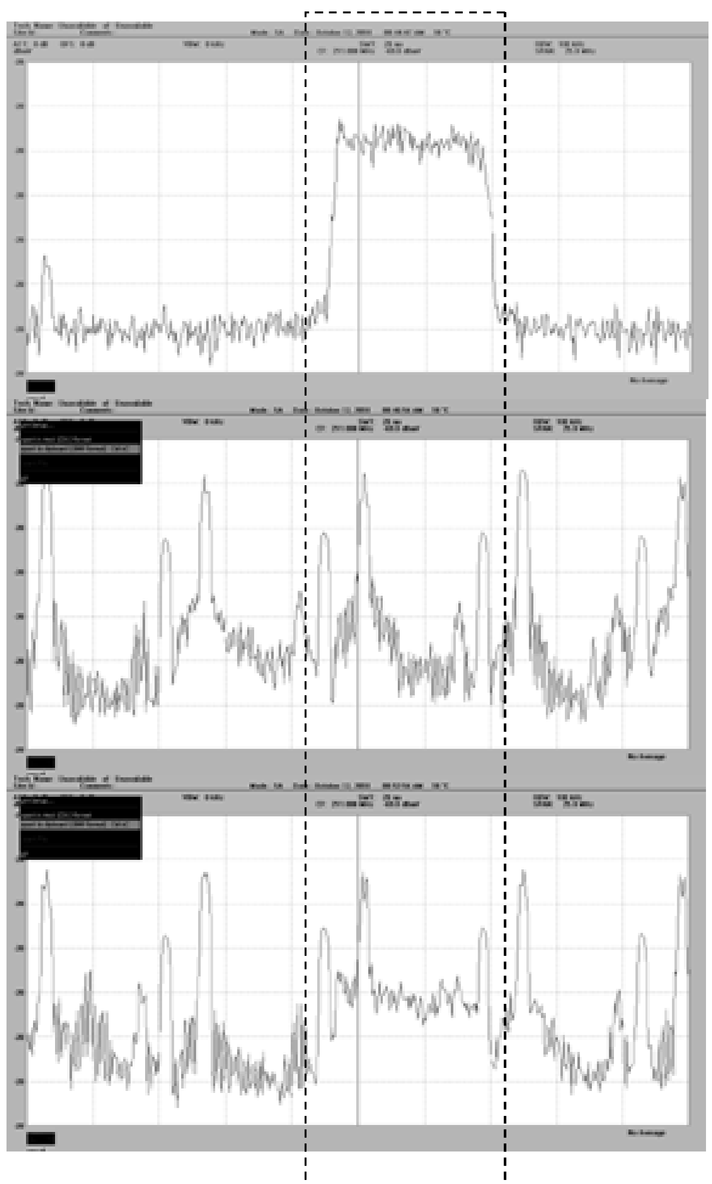
Group Delay is a function of transit time across a circuit. Iif the circuit is not linear, as in a filter with flatness problems, the frequency vs time component will not be linear, or constant, impacting digital stability. The only solution to this is to identify the source of the non-linearity and change filters or align the circuit. Common culprits for these types of distortion in the plant is a misaligned or poorly connected amplifier, dips in the response due to kinks or dents in the cable, particularly at high frequency, and the use of bad data carrier traps.

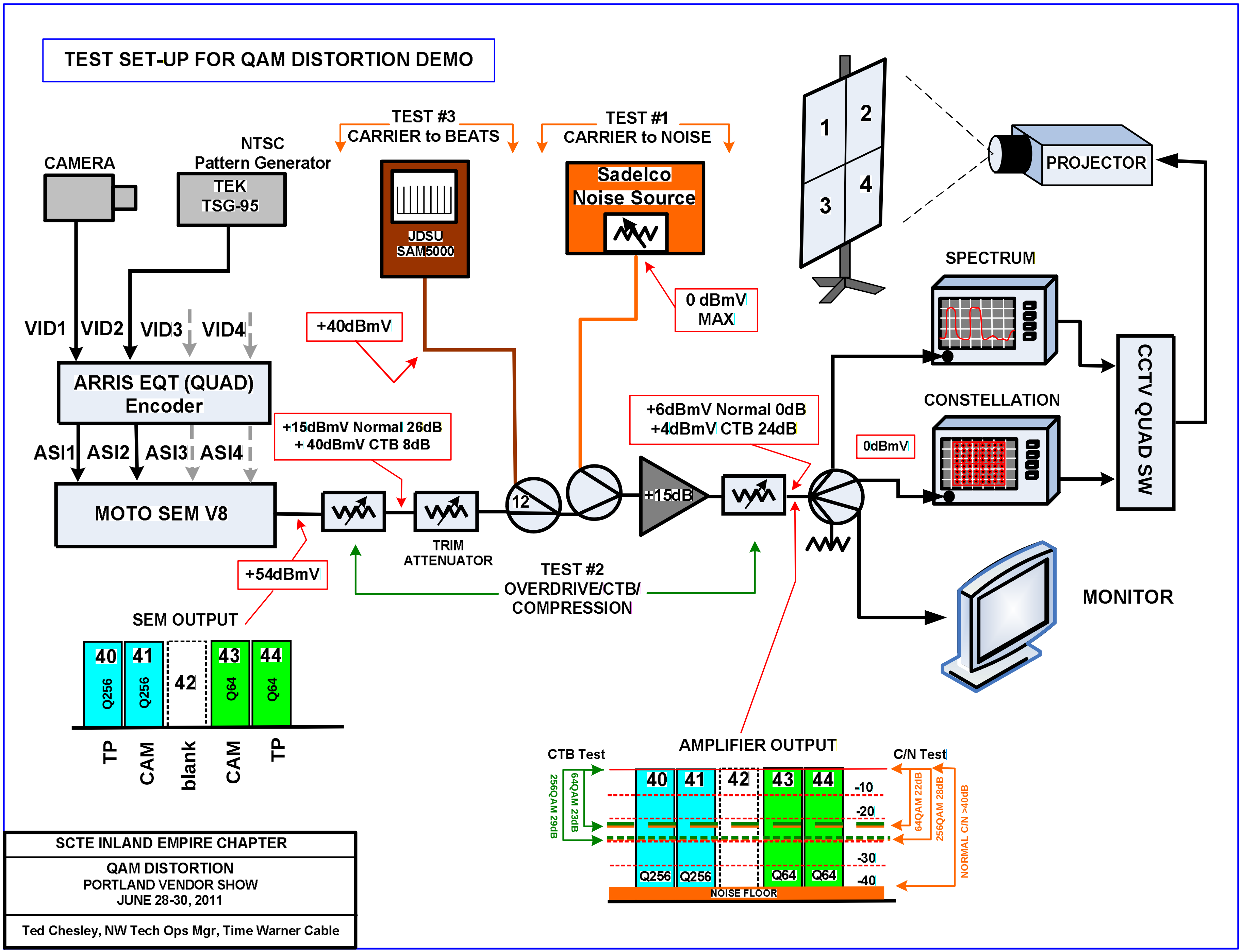
Troubleshooting for these types of problems should always begin by verifying the signal is exiting the headend OK.

EXTERNAL INGRESS PROBLEMS

The age old issue of internal ingress into the CATV plant and the interference it can generate in the channels is still with us in the digital world. Where previously we would see ghosting on the analog channels, beats in the picture due to coherent interference, and bursts of interfering transmitter signal in the pictures, with digital signals this translates to tiling and freezing in the digital pictures. The need to maintain a tight plant is not reduced by the use of digital modulation.

Another twist on the ingress issue is the affect of excessive ingress of an off air digital 8VSB transmission on a co-frequency analog carrier. Most CATV systems still carry an analog channel plan. In many locations there are off air digital broadcast channels that overlay the CATV analog spectrum. The effect of excessive ingress is to noise up the analog carrier. The channels on either side will be clean. This is obvious indicator of ingress. The usual fix applies: TIGHTEN UP THE PLANT!





TEST SET-UP FOR QAM DISTORTION DEMO
CAMERA
NTSC
Pattern Generator
TEK
TSG-95
TEST #3
CARRIER to BEATS
JDSU
SAM5000
TEST #1
CARRIER to NOISE
Sadelco
Noise Source
0 dBmV
MAX
1
2
3
4
PROJECTOR
SPECTRUM
CONSTELLATION
CCTV QUAD SW
MONITOR
VID1
VID2
VID3
VID4
+40dBmV
ARRIS EQT (QUAD)
Encoder
ASI1
ASI2
ASI3
ASI4
+15dBmV Normal 26dB
+ 40dBmV CTB 8dB
+6dBmV Normal 0dB
+4dBmV CTB 24dB
0dBmV
MOTO SEM V8
12
+15dB
TRIM
ATTENUATOR
+54dBmV
TEST #2
OVERDRIVE/CTB/
COMPRESSION
SEM OUTPUT
40
Q256
41
Q256
42
43
Q64
44
Q64
TP
CAM
blank
CAM
TP
AMPLIFIER OUTPUT
CTB Test
256QAM 29dB
64QAM 23dB
C/N Test
64QAM 22dB
256QAM 28dB
NORMAL C/N >40dB
-10
-20
-30
-40
NOISE FLOOR
SCTE INLAND EMPIRE CHAPTER
QAM DISTORTION
PORTLAND VENDOR SHOW
JUNE 28-30, 2011
Ted Chesley, NW Tech Ops Mgr, Time Warner Cable