DIGITAL DROP TESTING: What Constitutes Breakage?

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ABSTRACT

The introduction of digital signals to the cable industry is inevitable—with digital technology you have higher quality transmission, increased channel capacity (more revenue), and ultimately lower costs (via VLSI integration) than analog. These benefits, however, come at a cost: the cost to properly install, maintain, and troubleshoot a complex digital communication system running over a largely non-engineered subscriber premises wiring system and a drop system that can be unintentionally "invaded" by subscriber activities. This paper introduces the key test and maintenance procedural differences between analog and digital signal transmission and the "link breakage" performance differences, as well.

INTRODUCTION

Digital signals perform better than analog signals in noise since the digital "threshold of visibility" (TOV) is obtained at a C/N substantially below that of the NTSC VSB signal. Furthermore, the NTSC signals will have noticeable distortions (albeit, small) in comparison to the digital "near perfect" results whenever the signal is above TOV. Digital signals also provide more capacity with high-quality, efficient compression schemes such as MPEG II. For these two key reasons digital compression/modulation schemes have been widely adopted.

There does exist, however, a "dark side" to the cable network—drop/subscriber premises wiring, governed by a "Mr. Fix-it" mentality, beset by the low-grade, low-performance components. It is in this area, that cable technicians and installers face the significant challenge of properly engineering and maintaining the system for digital signals. Proper training and test equipment will be key to proper qualification and troubleshooting of households for digital.

Headend modulation, fiber transport, and coax/trunk amp links will also impair the signals; however, these segments can be engineered and routinely maintained to yield good performance. In this discussion, we examine potential impairments from headend, trunk, and distribution subsystems to calculate the level of signal impairment accumulated that enters the drop/premises environment. Network operations staff concerned with setting the proper signal power levels and maintaining the network at this level should gain more understanding of the requirements for proper transmission of the digital signals.

Thus, the purpose of this discussion is two-fold: first to present the key differences in the diagnosis of analog versus digital transmission problems and, second, to relate to the cable technician how performance thresholds will differ between analog and digital signals.

DIAGNOSIS

Presently, for analog NTSC transmissions technicians can derive much information from the TV picture such as approximate C/N, hum, ghosting, interference type and level (e.g., Terrestrial TV interference, CTB, etc.). This "pictoral" or visual information is then used to locate/isolate the problem. Digital signals will not afford the technician this effective diagnosis tool. Problem diagnosis for digital signals will need to come—not from the examination of the video—but from the *digital signal itself.* Distortions viewed on a digital video signal are not highly correlated to the impairment type. For example, high enough error rates that are not correctable via the error correction circuits may cause a high number of undetected errors. These undetected errors will cause different distortions depending on their location in the frame structure and picture scene content (dynamic or static), and the burstiness of the errors (impacting the error randomization circuits). NTSC transmissions, with their simple AM (amplitude modulation) transmission scheme and simple framing, retain much of any amplitude distortion in a linear fashion allowing diagnosis via observations of the picture. Table 1 summarizes the issues involved.

Analog	Digital
Impairments and their levels can be inferred from the TV picture.	Impairments and their levels cannot be inferred from the TV picture but must be derived from the digital signal itself.

Table 1. KEY Analog/Digital Transmission Differences

In addition to the diagnosis problem, additional performance threshold differences can occur between analog and digital signals as discussed in the following sections.

SYSTEM TRANSMISSION PERFORMANCE AND DISTORTIONS

Headend

The major transmitted signal distortions appear when the "bits" are "modulated," e.g., placed into 64 QAM modulation format, transmit filtered (for optimal transmission), and further filtered to maintain the signal within the 6 MHz channel allocation so as to not substantially interfere with adjacent channel signals. For digital signals, the modulation process is generally done with digital signal processing circuits. Thus the distortions involve quantization errors and finite digital filter lengths for the transmit filter. In our experience, for 64 QAM good modulator design requires that total distortion products be approximately –40 dbc. At the headend, the digital signal is combined with other signals and upconverted. Figure 1 shows a 64 QAM signal being transmitted at an actual cable headend with an empty adjacent channel slot. As can be seen by the noise in the adjacent channel slot, the average C/N is approximately 36 to 37 dB. Note also that the digital signal was transmitted at an average power approximately 15 dB below the NTSC carrier peak power. Assuming that the transmitted QAM signal can be transmitted at a level of –10 dB (level recommended from [Hamilton and Stonebeck]) below the NTSC carrier yielding 41–42 dB C/N, the combination of modulation distortion (–40 dbc) and transmit C/N (–41 dB) results in total signal-to-distortion-plus-noise-ratio of approximately 37 to 38 dB. In comparison with the NTSC analog system, the equivalent NTSC C/N would be 36 to 37 dB (QAM average C/N) + 15 dB + 7 dB (correction factor[1]) = 58 to 59 dB C/N.

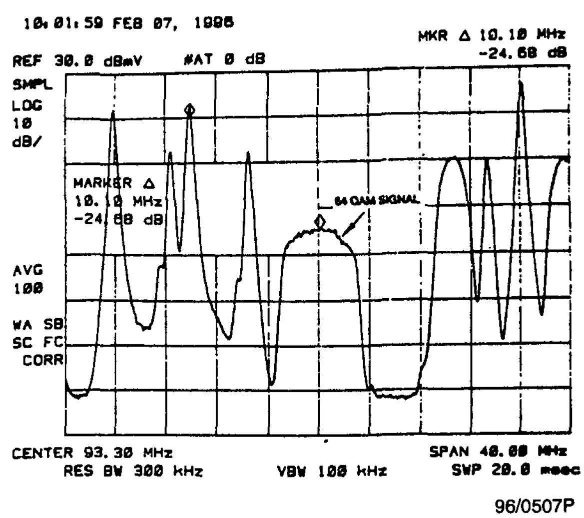


Figure 1. Headend 64 QAM Signal

Fiber "Trunk" Link

After transmission over the fiber optic link (Figure 2), the signal C/N has been seen to degrade by less than 1 dB or so during an actual field test over a 10-mile fiber link.

Distribution System

At the fiber node distribution point, the C/N will degrade proportionally to the number of trunk, bridge, extender, etc., amplifiers that lead to the subscriber drop. Prudent system design should allow the digital 64 QAM C/N to drop to no less than approximately 30 dB or so at the tap for the subscribers going through the maximum number amplifiers in the system.

There is no difference here between the noise affecting the NTSC vs. the digital carriers. However, the CTB, CSO, cross- and intermodulation products will differ from that of the NTSC carriers which are relatively narrowband. The products produced by the digital carriers on the NTSC and Digital Signals will tend to be wide-band or "noiselike." The impact of this characteristic will be two-fold. First, the CTB of the digital signals on the NTSC carriers would appear to be more "snow-like" or noise-like than "liney" or narrowband, with relation to the present NTSC CTB effects which may confuse a technician that was observing the TV picture. Secondly, the "noise-like" CTB would require modified measurement techniques for the NTSC signals and, of course, new procedures for the digital signals to both diagnose and estimate level of impairment would be required.

Drop/Premises

Presently at the subscriber premises, the cable technician observes and diagnoses the impairment(s) on the TV picture and then "repairs" the system so as to achieve the required performance. In most cases, the tolerated impairment levels of the new digital signals will be much higher than the NTSC signals (see Table 2 which presents the approximate differences in performance for typical cable system impairments measured at the drop or at subscriber premises). In some cases, the digital signals will be more sensitive than the NTSC to certain impairments (see Table 3 which shows the impairments that affect digital signals only and not NTSC-transmitted signals).

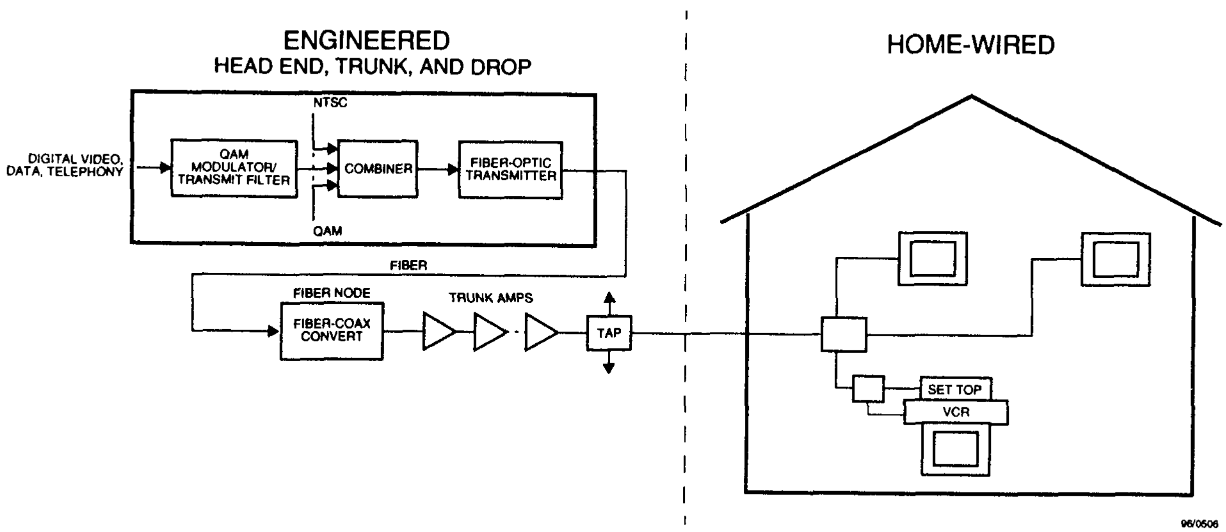


Figure 2. Headend-to-Subscriber Communications Link

Impairment	Analog	Digital
Co-Channel (TV in TV)	30 dB marginal, 25 dB bad ("strong horizontal lines" in picture)	22 to 24 dB at TOV
Composite Second Order Distortion (CSO)	53 dB	28 dB at TOV
Ghosting or Micro-reflections C/G = Carrier to "ghost" power	20 to 40 C/G dB observable; 10 to 15 dB objectionable [Jones]	5 to 15 dB C/G level at TOV
CTB	53 dB, (46 dB is bad: "noise/lines" in picture)	41 dB
C/N	Target values are 48 to 50 dB, 42 to 44 dB just visible, 40 to 41 (objectionable) [Ciciora]	21 to 25 dB
AM hum	3% ("moving bars" in picture)	14% at TOV

Table 2. Key Analog/Digital Performance Threshold Differences

Impairment	Analog	Digital
Residual FM	AM detection makes the NTSC circuits very tolerant of this distortion	Few kHz to 100 kHz dependent on demodulator design
Phase Noise (1/f**2)	Essentially no effect due to AM detection for NTSC	–75 to –80 dbc at 20 kHz away from the carrier at TOV
Minimum Isolation in Splitter (Surfing Problem)	Negligible transient ghost	21 dB required, above which, the adaptive equalizer may lose lock and cause a momentary video outage

Table 3. Impairments Affecting Digital Only

For the digital signals a parameter is used (developed by CableLabs) called TOV or "Threshold of Visibility." This is the level at which an average 3 x 10^{-6} bit error rate is attained. This was experimentally verified by CableLabs to be a threshold at which digitally compressed pictures become unacceptable. This is the parameter we will use to compare the digital performance results to the NTSC performance parameters mandated by good cable operator practices and/or the FCC.

The "NTSC Picture" performance criteria for analog signals was derived from an SCTE video tape [SCTE], and 64 QAM results from a paper presenting Applied Signal Technology, Inc. results on a QAM demodulator test at CableLabs [Laudel].

All the digital performance results are presented in terms of the average QAM signal power to distortion level in dB, and analog results in peak NTSC power to distortion power, again in dB.

The TV interference seems to be comparable between analog and digital since both are marginal at about 30 dB after the digital is corrected from average (shown in Table 2) to peak power (+6 dB) to afford a fair comparison with the analog NTSC performance.

However, the digital signals are significantly more tolerant of CSO (tested with NTSC signals generating the CSO only) since the adaptive equalizer in the demodulator circuit will actually cancel this narrowband interference problem. For "noise-like," digital signal-generated CSO, the results may be more comparable between analog and digital signals since in this case the adaptive equalizer will not be nearly as effective in the cancellation of this wideband interference.

For CTB, the digital adaptive cancellation appears to be less effective in providing comparable rejection to the analog signal (after adding the 6 dB correction for peak vs. average power). This may be due to the fact that the CTB interference is a wider bandwidth signal than CSO and therefore is more difficult to cancel.

AM hum is caused by poorly regulated power supplies, and NTSC signals can be significantly degraded with as little as 3%. The digital signal demodulators have circuits that mitigate this effect and allow a significant 14% of hum before reaching TOV.

Micro-reflections are caused by impedance mismatches, deformations in the cable, etc., and can be a significant problem in the subscriber premises. However, the adaptive equalizers in the digital demodulator, again, are called upon to cancel this type of interference and can attain performance superior to that tolerated in the NTSC signals.

Finally, C/N is a very key performance parameter, and digital signals significantly outperform (by 10 dB) analog signals for this impairment This improvement is primarily due to the powerful error correction techniques employed and the efficient coherent demodulation (need precise phase knowledge of the received signal) technique over the AM detection for the analog signals.

The first two effects listed in Table 3 are caused mainly by set-top box tuner electronics and are included here for completeness. The only exception to this is if an AML link is used for trunking of the digital signals the up- and downconversion process can generate significant phase noise that needs to be addressed. The third effect, isolation, is purely a subscriber problem and may occur when a TV set is connected by a low isolation splitter along with a set-top. This problem is transient since it would only occur as the TV tuner moves through the same channel as the set-top.

As can be observed from the performance data, digital signal transmission techniques have many advantages over analog transmission and may, in fact, be more robust in practice. However, system designers, trying to avoid amplifier overload, dictate that the digital signals be transmitted 10 dB below the analog signals reduce significantly the "robustness margin" of the digital transmissions over analog. Furthermore, when impairments do exceed the ability of the digital demodulator and equalizer to correct them properly, the cable technician will be challenged to infer the degradation without the TV picture.

Ingress Field Tests/Example

A comprehensive study of what to expect of the drop and subscriber environment was presented by [Prodan, et. al]. The most significant finding relevant to performance testing was that spurious power is actually higher than noise power. It was found that 5% of the subscriber premises have less than 36 dB of shielding in their wiring systems. The shielding problem is due, in many cases, to the

F-connectors which will cause degraded shield performance when they are loose, corroded, improperly installed, or damaged. It was shown that loose connectors can cause an additional 20 to 30 dB loss over tight connectors [Bauer]. Since digital signals will be transmitted at a higher frequency than analog, connector shielding will decrease additionally by 30 to 60 dB at 750 MHz vs. 100 to 400 MHz [Bauer].

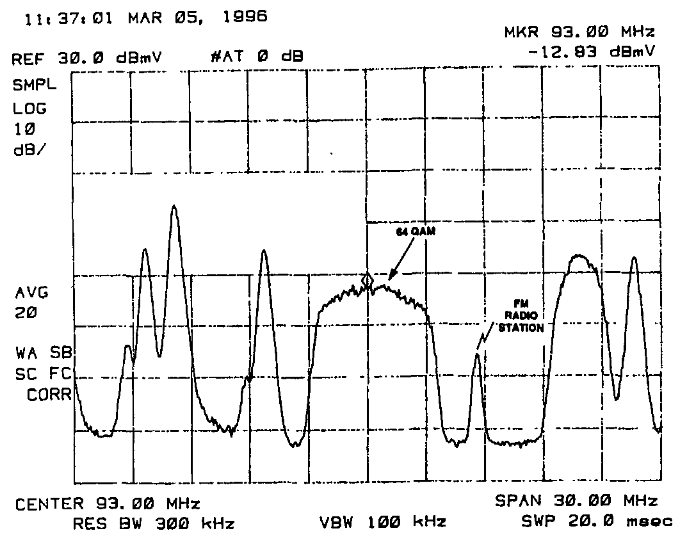
As an example of ingress that actually occurred on home wiring, Figure 3 shows the spectrum of a 64 QAM signal with an FM radio signal in an adjacent channel (empty) slot. Figures 3a and 3b show the ingress at the tap and set-top, respectively. Observe that at the tap, the FM ingress level is appreciably lower than the level at the set-top. The estimated signal-to-ingress ratio at the tap is approximately 27 dB versus the in-home of approximately 9 dB. This increased ingress was due to poor shielding by the connectors and/or the cable in the home.

SUMMARY

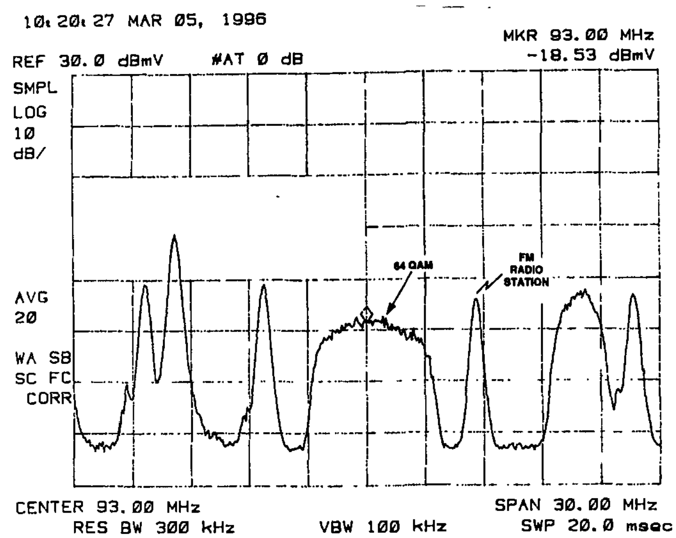
Digital signals afford outstanding benefits in the areas of additional capacity and picture clarity. In order to provide these benefits, operators will need to understand why digital links can break and at what impairment levels

These impairments and levels will need to be diagnosed and estimated from the modulated digital signals themselves before they are decoded into bits. This will be even more important for future cable modem and telephone signals where there is no "picture" to begin with.

Cable technicians/engineers must also understand that although digital signals are very robust, the subscriber premises wiring "hurdle" may require more comprehensive characterization to insure successful installation/maintenance and system power allocation trades.



a) 64 QAM and Adjacent FM Interferer at the tap (C/I ~ 27 dB)



b) 64 QAM and Adjacent FM Interferer at set-top (C/I ~ 9 dB) 96/0505P

Figure 3. Field Example of FM Ingress Enhancement Due to Subscriber Wiring

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FOOTNOTE

[1] To generate the average 64 QAM power from which an SNR can be computed: the average QAM power is approximately 6 dB reduced from the QAM peak power. Finally, for a typical 64 QAM signal, the bandwidth is measured in 5 MHz vs. 4.2 MHz bandwidth for the NTSC signal, which results in an additional 0.75 dB conversion for SNR. Thus, the average QAM SNR or C/N compared to the equivalent NTSC C/N will be lower by approximately 7 dB.