A DIGITAL COMPRESSED VIDEO TRANSMISSION SYSTEM - WITH SIMULATION RESULTS OF ECHOES IN 64-QAM TRANSMISSION

Jeff Hamilton, Zheng Huang, and Dan Sutorius
Jerrold Communications

Abstract

Digital compressed transmission is developing as an attractive method of video delivery to both headends and subscribers. This paper will review compression and transmission, and then focus on some key performance parameters for digital transmission. Finally we present the results of computer simulations of the effect of echoes on 64-QAM digital transmission.

Introduction

The US space program, through a multitude of outstanding examples, made the creation of spin-off technologies famous. Digital compression for Cable was born as just such a spin off, not from NASA, but from the desire to deliver high definition TV to consumers. The need to squeeze a high bandwidth HDTV signal into existing 6 MHz TV channel bands created the means to deliver several standard NTSC programs in the spectrum currently occupied by just one.

Various methods of transmitting HDTV signals have been proposed to the FCC. Of the six advanced TV systems under review four propose digital transmission. Each of these digital HDTV proponents has also proposed a multichannel NTSC delivery system in response to the CableLabs compression request for proposal.

Compression

Since the landmark announcement of the DigiCipher system in 1990, several other digital video compression systems have been proposed. Most of these, including all of the digital HDTV proponent systems and the work of the International Standards Organization's MPEG[1] committee, have been similar in function, based on the discrete cosine transform (DCT) and motion compensated inter-frame processing. This has proved to be an efficient technique for removing the many redundancies and, as needed, lower value components, from the video signal, with a minimum perceived effect on the reconstructed picture.

The use of digital compression offers operators and subscribers much more than just an increased number of programs. Digital transmission means every subscriber will get the same very high quality picture. It will be free of the noise and distortion common in analog systems. Most digital compression systems use component, not composite, color. With these systems there will be, for the first time a means of delivering a true component signal to the S-Video jack on high end consumer TV's and VCR's. Sound quality will also be uniformly excellent, indistinguishable from compact disc. True digital encryption will provide a level of security never before possible for video on Cable. Programming these new digital channels will become easier and more reliable with the introduction of digital switchers and digital compressed storage at the headend.

With satellite delivered digital compressed programs passing through to digital transmission on the Cable plant, the operator will no longer need to worry about picture quality anywhere in his operation. Headend processing to realize this, ranges from changing only the modulation, which offers very limited local features, to full video decompression and recompression, which allows all the control and programming options the operator now has with analog video.

The advantages of digital media have been realized by the telephone industry. They are arriving in TV network studios now, and they will soon offer major benefits to Cable operators system-wide.

Transmission

For analog video transmission, different forms of modulation are required on satellite and Cable. The satellite channel has a bandwidth of at least 24 MHz, but a reliable carrier to noise ratio (C/N) of only about 8dB. The Cable channel has only a 6 MHz bandwidth but typically 40 dB or more C/N. To make effective use of these very different transmission paths, we use a unique form of modulation in each. Frequency modulation (FM), a wide band noise insensitive technique, is carried on satellite. Amplitude modulation (AM), a noise sensitive but bandwidth efficient approach is appropriate for Cable.

For digital transmission of video the same logic applies. Satellite systems use quadrature phase shift keying (QPSK) which is an FM-like modulation for digital carriers. QPSK requires a wide bandwidth channel but offers high immunity to noise. For Cable, two AM techniques are proposed for digital carriers: double side band quadrature amplitude modulation (QAM), and the vestigial sideband multi-amplitude technique often called 4-VSB. These two approaches to amplitude modulation are very similar in performance. Both trade off noise immunity for spectral efficiency relative to QPSK. The following work addresses QAM with 6 bits per symbol.

To compare the data capacity of the disparate satellite and Cable channels we turn to Claude Shannon's pioneering work in information theory[2]. He developed a formula for calculating the maximum theoretical capacity of a channel based on bandwidth and S/N alone. For a signal of power S transmitted over a channel with noise power N and bandwidth W, the channel capacity C in bits per second is:

$$C = W \log_2(1 + S/N).$$

A satellite channel with 24 MHz bandwidth and 8 dB optimum signalling S/N would have a Shannon limit of 69 million bits per second (Mbps). Of course, this is for an ideal modem, operating in a channel free of secondary impairments. Commercial satellite modems commonly approach about one half this theoretical maximum rate.

A Cable channel with 6 MHz bandwidth and 35 dB optimum signalling S/N has almost the same Shannon limit as the above satellite channel: 70 Mbps. The Cable channel may have more secondary impairments and certainly the tolerable modem cost is much lower, but it is clear the Cable channel has a data transmission capacity similar to that of satellite.

Transmission Analysis

In designing a new digital communications system many factors must be considered. Among these are a wide variety of channel impairments, many of which will occur simultaneously in a working system. It is the combined effects of these impairments that define the transmission system operating parameters.

For the traditional Cable environment there are three principle impairments to the transmission of digital QAM carriers: channel noise, echoes, and modem implementation loss. Although there are many other impairments they are expected to be either avoidable, like not running high-level sweeps through active digital spectrum, or of lesser significance to digital transmission, like CTB and CSO.

Many prior papers have defined the effect of the primarily white channel noise on QAM. The following analysis will briefly discuss the specification of digital C/N in the Cable plant. We will then detail the results of our simulations of echoes on QAM transmission in the presence of white noise. Modem implementation loss, the third major factor, will be significant due to the severe cost constraints on the subscriber terminal for Cable applications. It includes such factors as filter imprecision, phase noise, receiver noise figure, clock jitter, and computation error. These factors are hardware specific and beyond the scope of this paper.

The block diagram for the following simulations is shown in Figure 1. It consists of a random data source, 64-QAM modulator, 5 MHz Nyquist bandwidth (BW) transmit filter, white noise and recursive echo sources, a matched receive filter, 64-QAM demod, and an error counter. All blocks are ideal floating point simulation models. Figures 2 and 3 show the eye-diagram and constellation with the noise and echo sources set to zero amplitude.

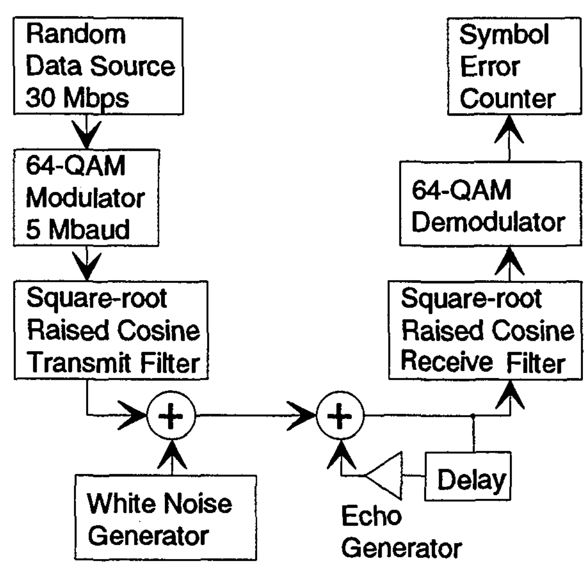

Figure 1: Simulation Block Diagram

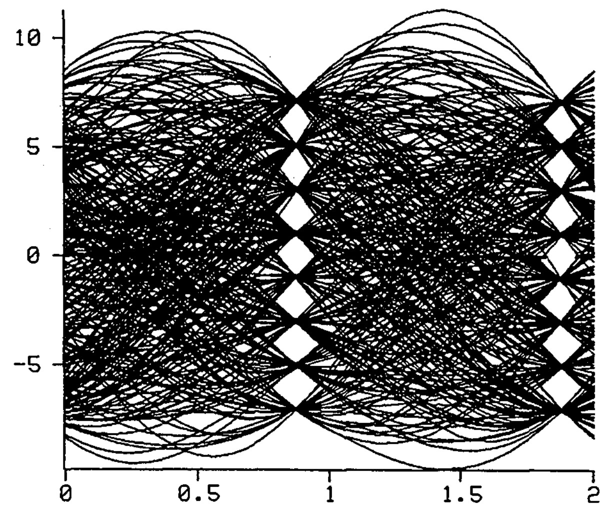

Figure 2: Eye Diagram - Noiseless

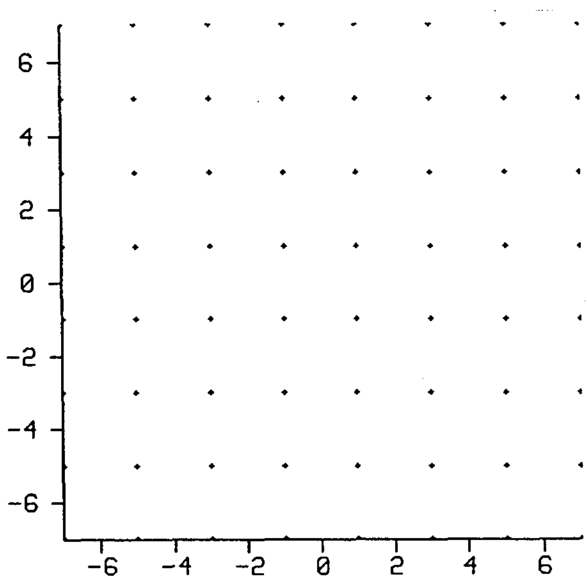

Figure 3: 64-QAM Constellation

Noise

Channel noise is the familiar broadband white noise floor we now measure as C/N on the Cable distribution plant. Easily seen with a spectrum analyzer, it comes primarily from the active devices in the distribution plant: trunk amps, line extenders, AML, and fiber links. Digital carrier to noise as referred to in the literature and this paper, is average modulated digital carrier power divided by rms noise power in the modulation bandwidth. Digital carrier modulation bandwidth will be about 5 MHz. This contrasts with our standard analog C/N spec. We measure analog carrier power during sync tip peak level and divide by noise power in the 4 MHz video bandwidth.

To relate these different C/N measures, consider that average modulated analog carrier power depends on picture content. Indeed, this is why it's impractical to measure average power on a modulated analog carrier. The peak to average ratio ranges from 7 dB to 2 dB for 0 to 100 IRE pictures respectively. A long time average of all possible picture contents will eventually yield a peak to average ratio near that for a 50 IRE flat field: 5dB. From this we can say that a digital carrier with the same average power as an analog carrier will have a 6 dB lower measured C/N. Five dB for the peak vs. average power measurement method and 1 dB for the 4 vs 5 MHz noise bandwidth.

Figure 4 shows symbol error rate as a function of (average modulated) digital carrier to noise. Simulation results are shown to be close to calculated theoretical values. Symbol error rate (SER) is very close to bit error rate (BER) when error rates are low ($<10^{-2}$). Figures 5 and 6 show the effects of -24 dB white noise on the eye-diagram and constellation.

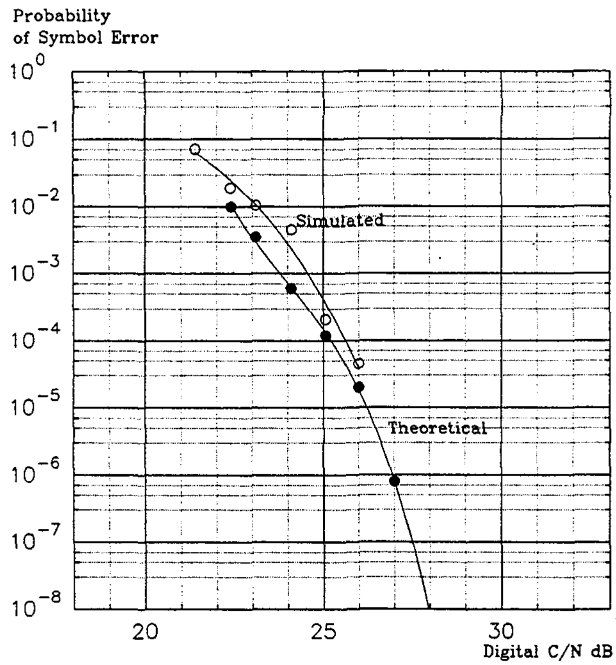

Fig.4: Error Performance
of 64 QAM with White Noise

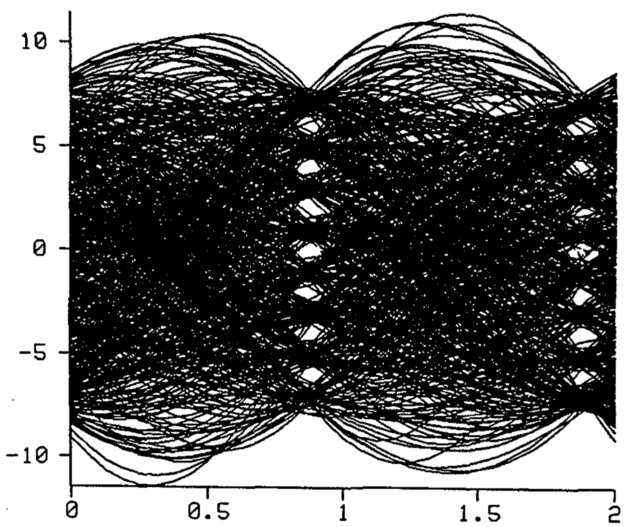

Figure 5: 24 dB Digital C/N

Echoes

There are many sources of echoes in the traditional Cable plant. Most of these are the result of imperfect impedance matching at the myriad connection points along the RF distribution path. At each of these points a

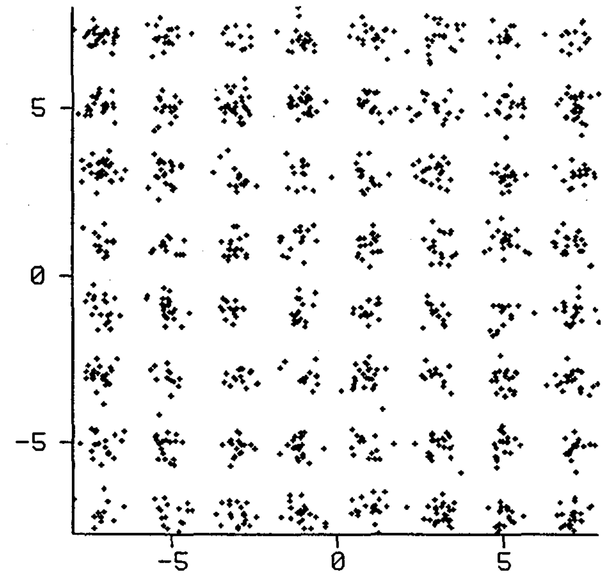

Figure 6: 24 dB digital C/N

small amount of the downstream RF power reflects back to its source. The example in figure 7 shows the reflection through the 8 dB return loss of a digital receiver input. Reflected power returns to the next upstream device, delayed and attenuated by its double pass through the connecting coax. A fraction of this returning power then reflects again through a second return loss. The twice reflected signal is now a downstream echo with a delay and power relative to the primary signal.

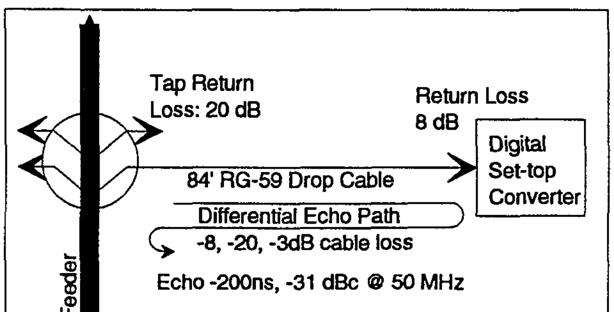

Figure 7. Echo Example

The simulation model for echo generation is a recursive structure as shown in

Figure 1. This is appropriate as the echo is by nature a repeating effect. A -20 dB 200ns delayed impulse will be followed by impulses at -40 dB 400ns, -60 dB 600ns, ..., as the twice reflected signal continues to be reflected four, six, ..., times with diminishing amplitude.

Echoes will have a specific phase relative to the primary signal carrier, determined by their exact delay in carrier cycles. A 200ns echo on a 50 MHz carrier will have a 0 degree phase because the delay is exactly 10 cycles of carrier. The constellation of a signal with this echo is shown in Figure 8. A 205ns echo on a 50 MHz carrier will have a 45 degree phase as shown in Figure 9. In this example, the difference would be an 86 versus 88 foot run of coax between the reflecting devices.

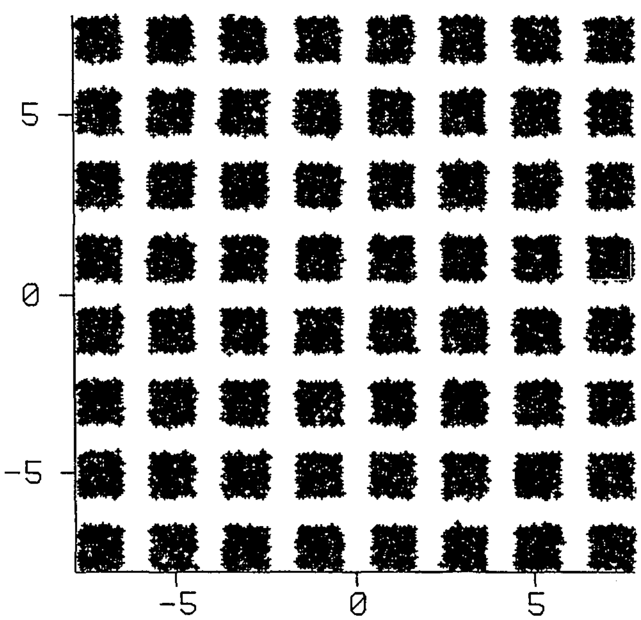

Figure 8: 0° Echo Phase

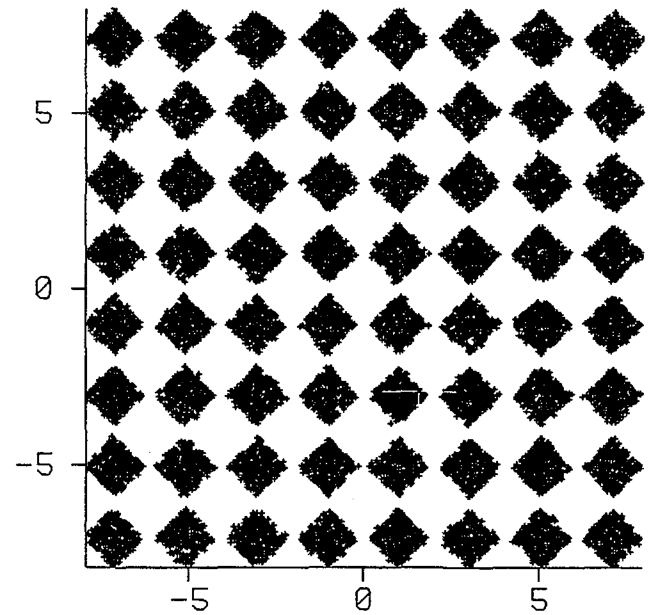

Figure 9: 45° Echo Phase

The effect of phase on QAM transmission in the presence of other impairments is shown in figure 10. We used white noise at -30dBc to model the combined effect of all non-echo impairments for this example. The phase of echo has a 1 to 2 dB effect on sensitivity, with the maximum effect at 45 degrees. All following simulations assume a 45 degree echo phase.

Figure 11 shows the effects of a range of echo powers on QAM with three different levels of white noise. From Figure 4, the SER for -25 dB noise alone is 10^{-4}. At this noise level even a -37 dB echo increases the SER substantially, to 10^{-3}. With white noise in the range of -27 dB echoes of -30 dB are still significant. As used here 'white noise' includes all of the non-echo transmission impairments including: channel noise, implementation loss, and secondary transmission impairments. For the sum of these in the range of -25 to -30 dB, even very low level echoes will be significant.

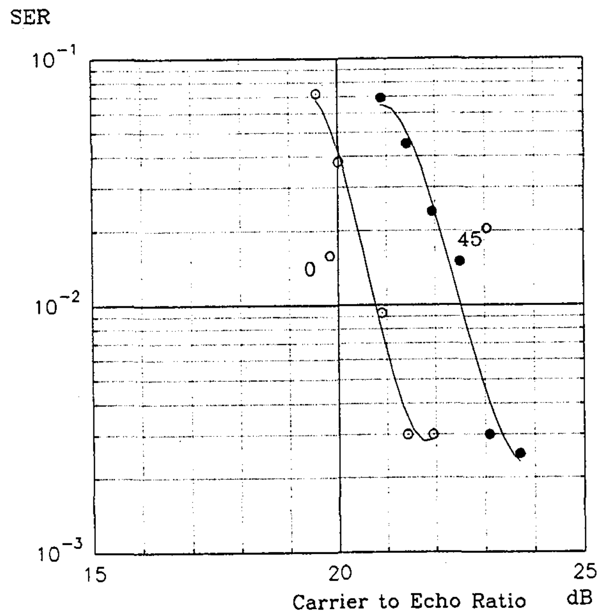

Fig. 10: Effect of Echo Phase

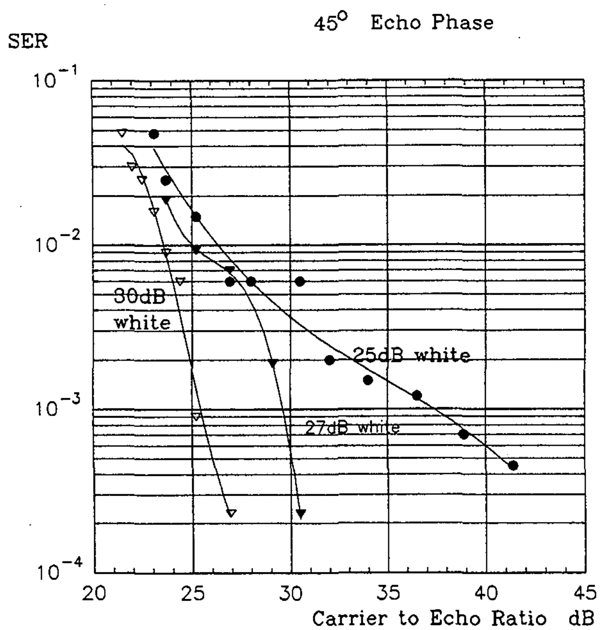

Fig.11: Echo Sensativity For Three Level of Added White Noise

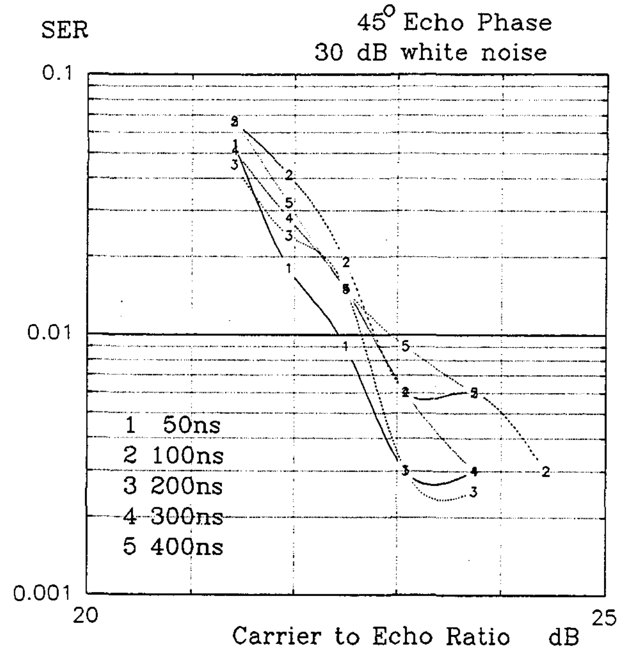

Fig. 12: Effect of Delay on Echo Sensitivety

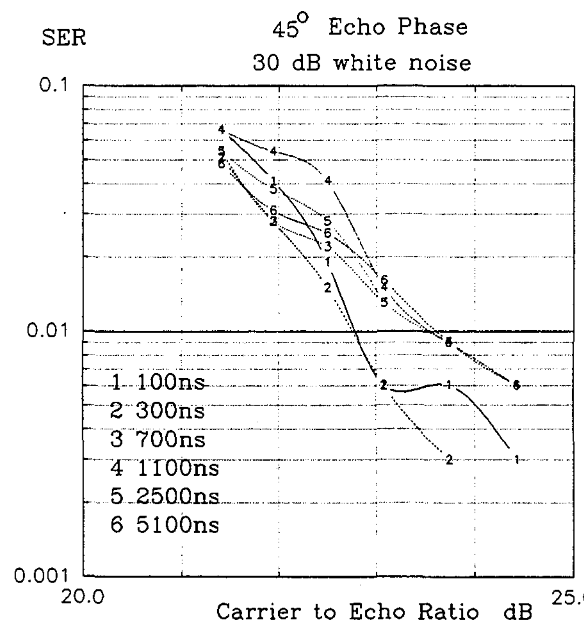

Fig.13: Effect of Delay on Echo Sensitivity

Figures 12 and 13 show the results of simulations over a range of echo powers for several different delays. All include white noise of -30 dB. The echo power is far more significant to SER than the delay. The effect on SER is almost unchanged over the range of delays. Even the short delays of 50ns and 100ns, one quarter and one half the 200ns symbol period, have the same general level of impairment as the longer echoes.

Conclusion

Digital compressed transmission will offer substantial benefits to the Cable operator and subscriber. Data rates similar to those of satellite systems are feasible using unique modulation, and demodulation, optimized for the Cable environment. These new digital carriers will require a new C/N measurement specification.

Digital transmission of 64-QAM will be sensitive to echoes at very low power. For a sum of other impairments equivalent to white noise of -30dBc or above, even echoes below -30dBc, will be significant.

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[1] Motion Picture Expert Group (MPEG)

[2] Shannon, Claude E., a series of papers including "A Mathmatical Theory of Communications," Bell System Technical Journal, volume 27, pages 379-423, July 1948.