

# Digital Video: Whatever Happened to Differential Phase and Gain

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*Abstract* - Digital video has moved from the background into operational systems and proposed systems which will be very important to cable television. The term digital video is applied to technologies including transmission of NTSC composite video via digital modulation, digital special effects and digital compression of images which may then be transmitted using digital or analog modulation. Most of us are comfortable with NTSC video transmitted via FDM/VSB-AM or FDM/FM. We understand the parameters of the baseband signal and the effect imperfections of the transmission path have on that signal. The parameters of digital video can relate to some of the parameters we understand but also introduce new ones. The same imperfections of the transmission path (noise, interference, linear distortion and nonlinear distortion) will affect digitally transmitted images differently than our familiar NTSC. It is often simplistically said that digitally transmitted images are "perfect" above some threshold and "crash" below that threshold. The process of digitizing affects the basic "perfection" of the image. When digital compression is used, the choice of compression algorithm affects image quality. This choice along with error correction and masking also determines the way transmission imperfections appear in the image.

## INTRODUCTION

In this paper, we will first present a brief review of those transmission channel impairments that we have come to know very well in the NTSC environment. The review will include such linear impairments as frequency response, ghosting, and C/L delay inequality and how they affect the received NTSC image. We will then review some non-linear distortions such as differential gain and differential phase, and also take a look at the effect that interference and random noise have on the NTSC signal. The emphasis on this portion of the paper will be to relate the particular transmission impairment to the subjective effect on the NTSC picture. Once we have reviewed the familiar impairments of the NTSC environment, we will take a similar look at the effects that certain transmission channel impairments might have on digitally transmitted video signals.

The use of digitally encoded video signals, especially compressed video, has made great strides in the last couple of years. All the current HDTV proponents except NHK, have now proposed all digital systems at bit rates (including audio and data) of less than 20 Mb/s. This compares to 100 Mb/s for currently operating non-compressed NTSC digital systems. Compression and

digital modulation schemes have also been proposed to place multiple NTSC signals within a 6 Mhz bandwidth using similar data rates.

How will the transmission channel's linear and non-linear distortions that we know about today affect these new digital signals? This question will lead us into a general discussion and definition of the measures that are commonly used to analyze transmission channel impairments, and their effects on a digital signal. In particular, we will focus on measurable quantities called "eye height" and Bit Error Rate (BER). Once we have an understanding of the BER and its interrelationship with the various channel impairments, we will discuss improvement of the BER by the use of Forward Error Correction (FEC) and improvement of the channel by adaptive channel equalization. Finally, since there are several different algorithms that have been proposed for the encoding of the digital video signal such as DCT, VQ, MVQ, etc., we will briefly examine the relationship between the type of algorithm and visible picture impairments resulting from certain transmission impairments.

## THE EFFECT OF CHANNEL IMPAIRMENTS ON ANALOG NTSC

Any transmission channel can offer a multitude of potential impairments to an analog NTSC video signal. When you consider that in the satellite/cable environment, a video signal may pass through as many as 40 or more active devices including the uplink electronics, downlink electronics, headend processing, through the distribution plant, and into the home, each providing its own form of impairment to the video, it is amazing that the signal is viewable at all! (Some of our detractors may, in fact, argue that the signals aren't viewable.) This cascade of electronics, as well as the transmission channel itself, can cause linear distortions such as poor frequency response, C/L gain and delay inequality and ghosting, non-linear distortions such as differential gain and differential phase, as well as interference and noise. Since the transmitted waveform directly controls the picture display, any distortion will be related directly to a visible effect. Because we are so familiar with the NTSC environment,

we are readily able to equate these various distortions to the visible picture impairments that we have come to know and love.

### Linear Distortions

Linear distortions can be roughly defined as those distortions which may occur to a signal passing through a transmission channel that are independent of the amplitude of the signal. In other words, all signal amplitudes would be affected equally by the device causing the impairment. Inadequate filter bandwidths in the transmission path, for example, can cause poor frequency response which may result in soft pictures. Such filters may also exhibit an unequal envelope delay throughout the passband. If this is the case, we know that the chrominance information or luminance information may be delayed with respect to the other (C/L delay) resulting in the well known funny-paper effect. This may also cause video waveform transitions to be slow or ring resulting in a lack of definition or smearing of the video at transitions. Ghosting is another linear phenomena with which we have become very familiar as it is probably the most disturbing distortion imaginable and shows itself as a complete leading or trailing image superimposed on the original. Short delay ghosts, on the other hand, can cause picture softening or sharpening.

### Non-linear Distortions

Non-linear distortions can be classified as those distortions whose magnitudes depend upon the signal level through the channel. Typically, such distortions will occur as a result of amplitude compression of the video waveform in active devices such as modulators, amplifiers, and demodulators. Differential Gain and Differential Phase are examples. Differential Gain can be defined as an unwanted change in the amplitude of chrominance signal with changes in the amplitude of the luminance signal--in other words changes in color saturation with changes in the brightness of the scene. Similarly, Differential Phase is an unwanted change in the hue (phase) of the chrominance signal with changes in the brightness of the scene. These distortions are not as easily recognizable on a monitor as some of the linear phenomena because they are more dynamic--varying with the content of the scene. Differential Phase is probably the most recognizable because hue (color) changes are more easily seen than saturation (depth of color) changes. A classic example of an extreme case of Differential Phase distortion might show up on a baseball players face as he stands out in the sun with his cap on such that the bill casts a slight shadow over half of his

face. With differential phase, instead of a bright flesh--tone on one side of his face, and a shadowy flesh tone on the other, we might see either side of the individual's face to appear slightly green or magenta depending upon whether the shift in phase were positive or negative.

### Interference

Interference, for purposes of this discussion, can be classified as any unwanted spurious signal, other than noise, which may affect the signal within the channel. Typically, the interference of which we speak in the cable environment consists of 2nd and 3rd order beat products caused by active devices in the distribution plant which may fall within the CATV band. In addition, such spurious beat products may be found at the output of CATV modulators and signal processors at levels close to 60 dB below the video carrier. These types of spurious signals, when they fall within a typical TV channel, manifest themselves in the form of clearly visible vertical, horizontal, or diagonal lines or beats in the picture. The magnitude of this effect is dependent upon both the magnitude of the interfering signal as well as its placement within the video channel. Beats that fall close to the video and color carriers are more readily visible than those farther away. Another factor that affects the visibility of the beat, is whether or not the interfering signal is itself modulated (or dispersed in energy). Spurious interfering signals which are unmodulated tend to show up as well defined beats in the picture, while those that are modulated tend to look more noise-like with lesser defined beats.

### Noise

Random noise, of course, is a fact of life in any transmission system, and is one of the primary reasons that the CATV industry is working feverishly to limit the number of active devices in cascade in the distribution plant through the judicious use of fiber optics. Noise, of course, can have a devastating effect on an analog NTSC picture, with weighted signal to noise ratio (S/N) being its classical measure. S/N is defined as the ratio of peak-to-peak video (100 IRE) to rms noise present in the video waveform, after bandlimiting and weighting. Bandlimiting is used in the measurement to exclude irrelevant noise energy, while weighting is a form of low-pass filtering to weight the measurement with what is visible to the naked eye. This is done to account for the eye's inability to perceive high frequency noise. The subjective effect of random noise on the video signal of course, is a pronounced graininess or "snow" in the picture.

## THE EFFECT OF CHANNEL IMPAIRMENTS ON DIGITAL TELEVISION SIGNALS

The review of NTSC analog transmission above shows that various channel impairments can be related directly to visible effects in the picture. While most of these channel impairments affect digital signals, this sort of direct relationship between impairment and visible effect does not occur with digital transmission. We will consider the various steps in the process of digital video transmission in order to understand how impairments in various parts of the system affect the picture.

### FUNDAMENTAL CONCEPTS OF DIGITAL VIDEO

#### Quantizing

The first step in digital transmission is quantizing. Quantizing is the process of selecting a finite number of discrete values which the signal will be permitted to assume. Signal values other than those permitted are assigned one of the permitted values according to a specific algorithm or rule. Simply stated, the signal is assigned the nearest permitted value. The luminance portion of the NTSC composite baseband video, for example, can have any value within a 100 IRE range. The quantized signal would be constrained to a particular set of values, say integer IRE values. A luminance level of 72.68 IRE might be assigned the nearest permitted value, 73 IRE. A similar process is applied in time. Only the values of the signal at specific sample times are retained. An example of a luminance waveform before and after quantizing is shown in Figure 1. The quantizing steps have been made large for clarity in the illustration. We have retained the NTSC sync and line format because it is familiar. The quantization process described above is called Pulse Amplitude Modulation (PAM). The reverse process is applied to the received waveform. That is, the level at each sample time is compared to the permitted values and assigned the nearest permitted value. Unless noise or other impairments caused by the transmission channel are large enough to cause the received waveform to be quantized to an incorrect level, the impairment will not appear in the recovered waveform. In our example of quantizing in 1 IRE steps, the distortion or interference would have to be 0.5 IRE or greater to cause an error in the quantized level of the received signal. If the distortion level becomes larger, however, it will appear in the signal in much the same manner as it would if the signal were transmitted without quantizing. The digital video signal is not usually transmitted in this relatively direct manner.

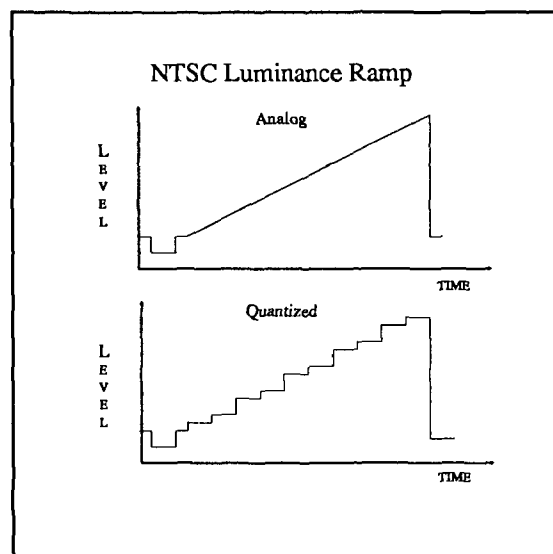


Figure 1 Analog and Quantized Luminance Ramp

Instead, the level of each sample is represented by a series of bits. The series of bits are then transmitted rather than the analog sample. The coding of the analog samples into a series of bits is called Pulse Code Modulation (PCM). Since each permitted signal level is exactly defined, the quantized waveform at the receiver can be a replica of the quantized waveform at the transmitter. For replication, the digital to quantized analog converter at the receiver must exactly match the quantizer at the transmitter and there must be no errors in transmission of the digital bit stream.

#### Modulation and Demodulation

Some form of modulation must be used if we are to transmit the digital bit stream on an RF carrier. Several different modulation techniques exist [1]. These include Bi-Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), Offset Quadrature Phase Shift Keying (OQPSK), Quadrature Amplitude Modulation (QAM) and Quadrature Partial Response (QPR) as examples. Each is different in detail and has particular advantages but most share certain basic characteristics. They can generally be broken down into double sideband suppressed carrier amplitude modulated (DSBSC-AM) channels with two or more discrete levels. These fundamentals are not so difficult to understand and we can begin by looking at the basic case of amplitude modulation.

Amplitude modulation can be expressed by the following general equation [2]:

$$M(t) = a(t) \cos(\omega_c t)$$

where

$M(t)$  = the modulated carrier EQ (1)

$a(t)$  = the modulating waveform

$\cos(\omega_c t)$  = the carrier

This equation can be used to describe NTSC luminance modulation. In that case,  $a(t)$  is directly related to the luminance. The value of  $a(t)$  at sync tip (-40 IRE) is 1 and at peak white (+100 IRE) is .125. As you can see,  $a(t)$  has only positive values in NTSC VSB-AM. The carrier level varies from the peak value at sync to 87.5% depth of modulation at peak white and is never fully turned off. The equation can also be used to describe DSBSC-AM. In that case, the value of  $a(t)$  ranges from +1 to -1. We can see that as  $a(t)$  varies between the value of 0 and +1 the carrier amplitude varies from off to full on, but what of the negative values? Negative values simply mean a phase reversal of the carrier. In other words, between the values of 0 and -1 the carrier amplitude varies from off to full on but with a relative phase of 180 degrees.

When DSBSC-AM is used for transmission of digital information, discrete values of  $a(t)$  are used to represent digital values. For example, two states +1 and -1 could be assigned. One state would represent a logical 1 and the other a logical 0. The carrier would be at full amplitude in both states but would have 180 degrees difference in phase. A modulation scheme of this type is often called Bi-Phase Shift Keying or BPSK. Here, the two modulation states represents "one" and "zero" states of a single bit. Actual data will consist of a stream of "ones" and "zeroes". Figure 2 shows a typical modulation waveform and modulated carrier. The

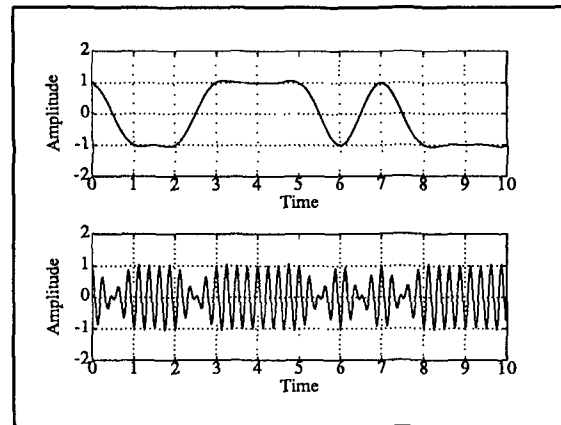


Figure 2 BPSK Data Waveform and Modulated Carrier

bits occur at regular intervals (clock periods) and the change between states follows a sinusoidal shape. In ?, the sample time for each bit is at the grid line (10 bits are displayed). Note the relative carrier phase between sample points where the data is at -1 and +1. We have now described the essentials of a basic digital modulation format. More complex schemes which carry more bits within the same bandwidth can be employed but each can be built up from this fundamental model. All of the basic ideas remain the same.

At the receiver, the signal is demodulated to produce an output level proportional to the phase and amplitude of the received carrier. Note that envelope detection cannot be employed since both the amplitude and phase of the modulated carrier must be detected. Synchronous detection is required. We can now form a simple diagram the entire digital transmission process Figure 3.

### Eye Diagrams

In the ideal case with no noise, interference or distortion, it is easy to determine each state. For

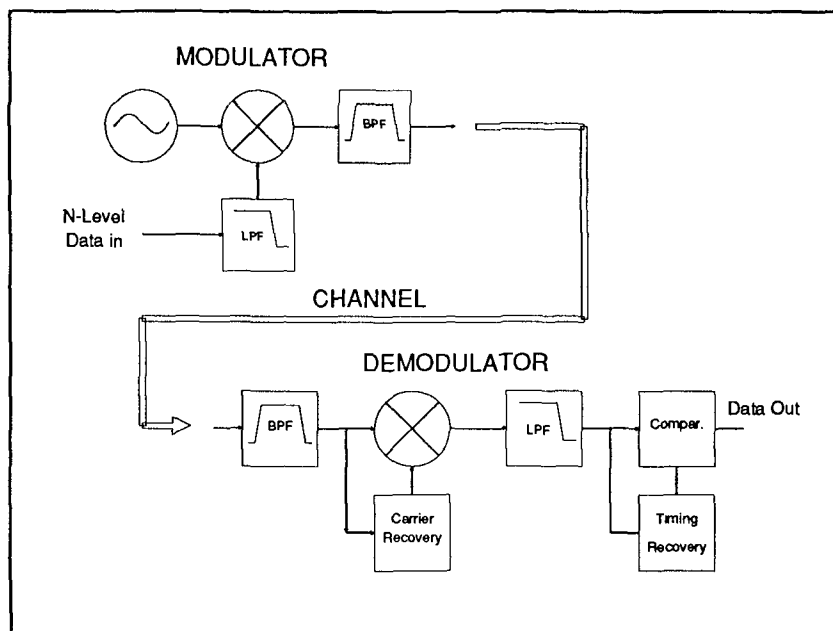
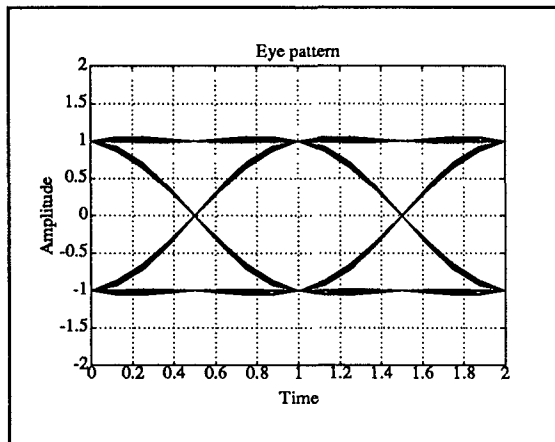


Figure 3 Simplified Digital Transmission System Diagram

BPSK we simply sample at the correct time and determine whether the level is positive or negative. It is somewhat more difficult when the impairments are added. A look at Figure 4 will reveal why. Here we see a display of the demodulated BPSK (two level case) waveform such that two bit periods are displayed with successive bits overlaid in the same window. A sequence of bits containing many combinations of ones and zeroes are overlaid. This type of diagram is called an "eye" dia-



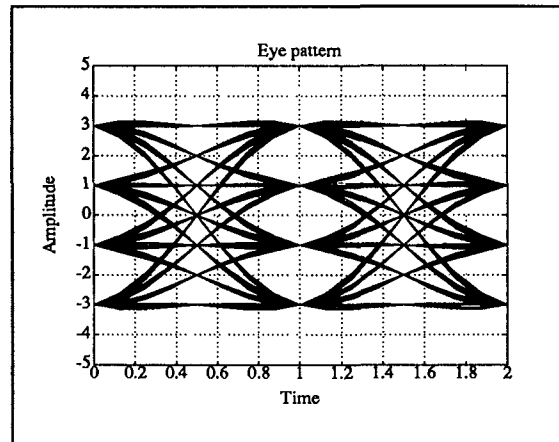
**Figure 4** Two Level Eye Diagram (Without Impairment)

gram because of its similarity in shape to the human eye. We can determine each bit value by determining whether the signal is positive or negative at a sample time. Note, however, that the time of sampling may vary somewhat according to our ability to recover timing information and the actual decision level may vary due to circuit variations. Because of this, the signal must be outside the box defined by timing variation horizontally and decision level uncertainty vertically. This will present little problem in this unimpaired case. The "eye" is said to be open when there is a clear open area between signal states as in this diagram. We will see later how the eye closes due to interference and noise. Other impairments due to distortions within the channel as well as imperfection of the filters which shape the data modulation waveform can also close the eye.

These same arguments will apply even when we consider a more complex modulation scheme. We can be more general by referring to the states as Symbols and each period as a Symbol period. A symbol can represent more than one bit value in some modulation schemes. For example, a second carrier may be added in quadrature with the first and similarly modulated. We now can transmit twice as many symbols. This type of modulation would be classified as QPSK or 4 QAM. Each

carrier is independent and the analysis is identical to that above. There are simply two channels of data.

Alternately, the number of discrete levels can be increased. For example, we can let  $a(t)$  have four discrete levels. An eye diagram for the four level case is shown in Figure 5. We have multiplied  $a(t)$  by three to obtain scale lines at particular locations. One can see that the



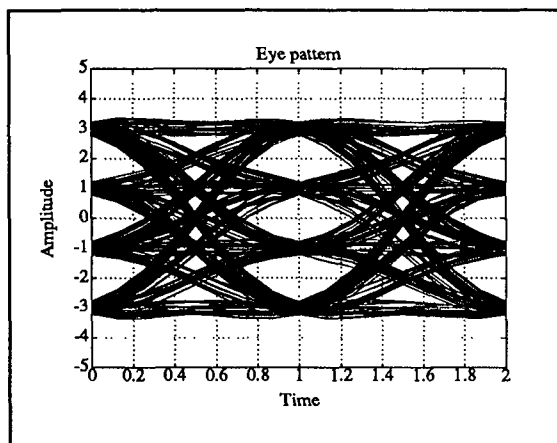
**Figure 5** Four Level Eye Diagram (Without Impairment)

separation between levels has been reduced in both amplitude and time. The area free for the decision "box" is now smaller and the eye opening will be more easily closed by interference or other impairment than the simpler two state case. Each symbol (level) now represents a particular two bit sequence. There are four states representing 10, 01, 11, and 00.

If we need more data throughput, we can add a quadrature carrier with the same four level modulation to double the number of symbols which can be transmitted. This would correspond to 8 QAM.

### Interference and Noise

To understand how certain types of interference may affect eye closure, consider the effect of a CW interfering signal near the carrier frequency. This interference will alternately add to or subtract from the transmitted carrier, changing the level and/or phase of the received signal. The demodulated waveform under these conditions might look like that of Figure 6. The same "beats" seen as diagonal (or other) lines in NTSC video are visible in the demodulated data waveform. The "beats" cause the states to be less clearly separated. The open area between states has been reduced in both time and

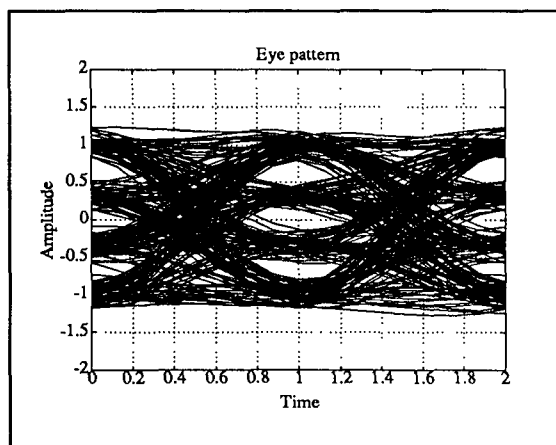


**Figure 6** Four Level Eye Diagram With CW Interference

amplitude by the interference. Other impairments such as noise result in similar filling in of the open area as seen in Figure 7. If the distorted waveform passes through the decision "box", errors in the decoding may occur. When the eye closes, symbol errors will be generated and the quantized waveform at the receiver will differ from that at the transmitter.

#### Linear Distortion

Ghosting will also appear in digital transmission. The effect of longer delay ghosts will be to create lower level delayed replicas of the symbols. Short delay ghosts will be equivalent to frequency response errors. Quadrature ghosts, which sometimes appear in NTSC as image sharpening, can produce cross talk in some digital transmission systems. In all cases, the eye opening will be reduced. Ghosting can be a severe problem requiring ghost canceling, a form of adaptive channel equalization.



**Figure 7** Four Level Eye Diagram With Noise

Adaptive equalization can also correct for amplitude and phase errors from various sources within the channel.

#### Summary of Channel Impairments

The important points to understand about the discussion to this point are:

1. The analog source is quantized to discrete levels.
2. These levels are represented by a sequence of bits.
3. The bits are represented by discrete modulation states i.e. carrier amplitude and phase state.
4. The demodulated received signal will exactly reproduce the transmitted bit pattern unless a combination noise, interference and distortion causes errors in decisions on modulation state.
5. Noise, interference and distortions close the decision "eye".
6. Less noise, interference and distortion can be tolerated as the number of modulation levels is increased.
7. In the absence of errors in the received bits, the reconstructed quantized waveform at the receiver will exactly match that at the transmitter to the extent that the digital to quantized analog converter at the receiver exactly matches the quantizer at the transmitter.

#### THE PICTURE IMPAIRMENTS OF DIGITAL VIDEO

We have already commented that a direct relationship between channel impairment and visible effect does not occur in digital video. Indeed, some types of impairments simply do not exist because of the way picture information is encoded. An example is differential phase and gain. These are distortions of color information in NTSC caused by nonlinear interaction between luminance and the color subcarrier. There is no subcarrier in digital video to suffer phase or gain distortion. Further, color and luminance are transmitted as separate components in the digital video systems of interest here. The video is typically divided into three analog signal channels, one carrying luminance and two others carrying color difference signals. The color difference signal may be the I and Q signals as used in NTSC or some other matrix. Each of these signals is digitally sampled separately and the three digital channels are time division multiplexed

before modulation. Because they are handled separately, there can be no interaction. The same is true for other impairments related to NTSC encoding such as cross color and cross luminance.

Some new impairments such as quantizing noise are added. Quantizing noise is essentially the difference between the original analog signal and the analog signal recovered by filtering the quantized signal. This noise might appear as false contours in picture areas with low detail, for example. As a practical matter, quantizing noise can generally be made negligible in digital video system design.

Other impairments, such as luminance non-linearity still can occur in digital video but are limited to analog circuitry ahead of the digitizing process or following the digital to analog conversion. The picture information cannot suffer nonlinear distortion while in a digital format. Transmission channel, modulator and de-modulator nonlinearities can cause data waveform distortion and contribute to bit errors but cannot cause nonlinear distortion of the picture information. Similarly, noise in the circuitry preceding digitization will cause a different effect from that in the transmission channel. Noise ahead of the digitizing process can cause some disturbing effects, particularly when digital video compression is used. Noise in the transmission channel will simply contribute to bit errors. Cable system equipment can contribute to bit errors but will not cause or correct nonlinear distortions in digital video.

Bit errors certainly will cause picture impairment but how will the impairment appear visually in the picture? Even in the simple case of Pulse Code Modulation (PCM) with no compression, the effects can be varied. An error in the least significant bit representing the amplitude of a single sample may be nearly invisible. The same error in several adjacent samples might be more noticeable. The appearance could be a shift in hue, color saturation or luminance level of the affected pixels. An error in the most significant bit would likely be apparent. The effects of errors becomes more complex when digital video compression is considered.

There may be impairments caused by the compression algorithm itself. These impairments will depend on the source material rather than the transmission channel. For example, noise in the source material can cause false motion to be detected and can cause "blocking" artifacts. The video information is often processed as rectangular groups of adjacent pixels. Noise or other distortion within the block may affect the way the entire block is

compressed. The individual processing blocks may not fit together, causing their boundaries to be visible. The degree of background detail and complex motion may also cause artifacts. An example of complex motion would be small foreground objects moving left with a detailed background moving right. All of these are akin to NTSC encoding artifacts. They are inherent in the algorithm used and cannot be caused or corrected by cable system equipment. The degree to which they are objectionable is dependent on psychophysical effects in perception.

There are a number of compression techniques which are in use [3]. These include predictive coding, transform coding, sub-band coding and vector quantization. Other processes which are used in one or more of these techniques are Huffman coding and run length coding. It is interesting to note that the bit errors which we have been discussing can affect more than a single sample in all the compression techniques mentioned above. In predictive coding, for example, certain sample values are determined from algorithms involving several other sample values and a correction value. One sample may therefore affect several others. In many compression schemes, spatial blocks of samples are processed together so that an error may affect an entire block of samples. The visual effect of errors can be quite different between compression schemes. The statistics of the errors are also important. Errors which occur in bursts will cause different effects than those occurring with a rather even distribution. In all cases, a fairly error free transmission is required for satisfactory performance. This leads us to a discussion of error correction techniques.

Error correction is a necessity in any practical transmission channel for digital video. Forward Error Correction (FEC) can be accomplished by adding some number of bits to the data. The values of these added bits are determined by algorithms involving various combinations of the data bits. By cross correlating various data and correction bits, errors can be discovered in the recovered data and the faulty bits corrected. Of course there are limits to the number of errors and the local frequency of errors which can be corrected successfully. These added bits also use some of the data channel capacity requiring a tradeoff between correction capability and the amount of image data which can be transmitted. Error masking can also be employed where errors can be detected in a block of data but the exact bit or bits cannot be determined. A simple type of error masking would be interpolation between known values. Digital systems are often viewed as working perfectly as error rate increases until the point that catastrophic failure occurs, causing a

complete loss of signal. Error masking can afford a more graceful failure, allowing a less nearly perfect picture to be received under high error conditions such as found near the boundaries of coverage area in broadcast television. Hierarchical coding can provide a similar effect. A core picture of lower resolution can be carried by a lower data rate robust data stream with enhancement data carried in a higher rate less robust format. When the enhancement data is lost, the core picture can be displayed. Whether such techniques are needed will have to be evaluated.

Variable length coding can be damaged severely by errors. For example, Discrete Cosine Transform (DCT) coding often takes advantage of a large number of zero coefficients by transmitting the number of zero coefficients rather than transmitting each zero coefficient using the standard bit pattern for zero. This reduces the number of bits required for transmission and causes the number of bits required for each picture block to vary depending on content. The same is true for Huffman coding [4]. An uncorrected error in such a bit stream can cause all following data to be in error until a hard reset is encountered. Systems which use variable length coding schemes are therefore required to send periodic system resets to assure that the system can recover if an uncorrected bit error occurs. This periodic reset requires additional data to be transmitted.

We can see that the performance of the transmission channel (including its modulator and demodulator) can be characterized without regard for a particular compression algorithm. We have already discussed how the characteristics will depend on the modulation format being used. The number of bits which can be transmitted per second increases as the number of discrete levels increases but the amount of noise etc. which can be tolerated decreases. Applying a knowledge of the channel frequency response, noise and interference along with the modulator and demodulator characteristics will permit an analysis of Bit Error Rate (BER). The effect BER and its statistics on various digital video compression formats can be evaluated separately. Included in this evaluation would be the Forward Error Correction and any Error Masking which is a part of that system.

## Summary of Picture Impairments

The important points to remember about this discussion of the impairments of digital video are:

1. Familiar impairments of NTSC video caused by the transmission channel such as Differential Phase and Differential Gain, etc., will not appear in digitally transmitted video.
2. Compression algorithms may introduce new inherent impairments which are independent of transmission channel characteristics. In other words, these impairments cannot be caused or corrected by the cable system equipment.
3. The source video supplied to most compression systems must be of very good quality and free of noise. Source video impairments can cause failure of the compression algorithm.
4. The effects of cable channel impairments can be characterized by Bit Error Rate (BER) and the statistics of these errors. These effects are dependent on modulation format but independent of the digital video system.
5. Digitally transmitted video can be designed to fail in a graceful manner if this is required.
6. The effect of BER and error statistics will depend on the digital video compression system employed.

## SUMMARY

Digital video transmission of both HDTV and NTSC has become a key interest throughout the entertainment and information delivery industries. It is a subject which is likely to be new to many in the cable industry. The objective of this presentation is to provide a basic understanding of digital transmission. Impairments which occur in digital video are compared and contrasted with the familiar NTSC. We have briefly reviewed the effect of channel impairments on NTSC, relating the signal impairment to visible effect. The fundamental concepts of digital modulation and transmission have been presented. These impairments were related to measurable effects such as eye diagrams. The concept of Bit Error Rate was introduced and the visible effect of BER was discussed. We have briefly discussed how the compression algorithm affects susceptibility to errors and the use of Forward Error Correction and Error Masking. This



discussion should prepare those unfamiliar with digital transmission for a better understanding of more detailed treatments of the various modulation formats and the effects of various impairments and compression schemes.

#### ACKNOWLEDGEMENT

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1. Dr. Kamilo Feher, *Advanced Digital Communications Systems and Signal Processing Techniques*, Prentice-Hall, Inc. Englewood Cliffs, New Jersey, 1987, Chapt. 7.
2. Members of the Technical Staff Bell Telephone Laboratories, *Transmission Systems for Communications*, Revised Fourth Edition, Western Electric Company, Inc., Winston Salem, North Carolina, 1971, p 97.
3. Joseph B Waltrich, "A Tutorial on Digital Video Compression Techniques", 1990 NCTA Technical Papers, PP 37-49.