DigiPoints Volume 1

Leader Guide

Module 6 – Error Detection and Correction

Summary

This module describes typical errors that can exist in digital communications systems and describes methods for detection and correction of these errors.

Outcomes

Students who complete this lesson will be better prepared to identify and correct errors occurring in digital networks. A fundamental understanding of error detection and correction methodology is provided as a building block prior to an explanation of error measurement techniques.

Objectives

Upon successful completion of the module, the student should be able to:

- Describe eight (8) common line errors that can exist on coax, twisted pair, or fiber.
- Explain typical causes and corrective measures used to eliminate line errors.
- Describe two (2) common data errors and their causes.
- Explain two (2) basic methods of error detection.
- Explain two (2) basic methods of error correction.

Prerequisites

Students should have read Chapter 6 of *DigiPoints, Volume 1*.

Length

60 - 75 minutes

Materials/Preparation for Instructor

- One workbook per student
- Visual Aids
- Instructor should read Chapter 6 of *DigiPoints, Volume 1*.

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Supplies/Equipment

- Dry Erase Board/Markers, chalkboard or flipchart
- Masking Tape
- Pointing tool
- Tent cards for students' names

Audience

The intended audience will be mid- to senior-level technicians or other associates who are seeking an understanding of digital basics.

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Module Outline

This is an introductory level module that will provide a review of the following topics:

Objectives 1
Introduction 2
Sources of Errors 3
Error Detection and Correction Techniques 15
Error Detection 16
Error Correction 20
Digital Error Measurements and Terms 23
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Objectives

EXPLAIN

REFER TO WB 6.1

Tell students that when they have completed this module, they will be able to accomplish these objectives.

- Describe eight (8) common line errors that can exist on coax, twisted pair, or fiber.
- Explain typical causes and corrective measures used to eliminate line errors.
- Describe two (2) common data errors and their causes.
- Explain two (2) basic methods of error detection.
- Explain two (2) basic methods of error correction.

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Introduction

DISCUSS

Ask the students the following:

- What types of errors can exist in analog transmission of TV channels?

  Answer:

  - ◊ *Noise, distortions, etc.*
- What are typical causes of these errors?

  Answer:

  - ◊ *Loose connectors, poor grounding, poor shielding, amplifiers, etc.*
- Tell students that the same types of problems exist in digital systems and that is the focus of this module.

Use this intro as a way to evaluate the background and skill base of students.

Sources of Errors

Make clear that this module's focus is on twisted pair.

Line Errors

Line conditions depend, in part, on the medium used for transmission.

Digital TV typically uses fiber and/or coaxial cable.

DISPLAY VA 6.1
DISCUSS WB 6.2

Fiber is the least susceptible to electromagnetic interference and other conditions that cause digital errors.

Coaxial cable is more susceptible than fiber to line conditions that can cause errors.

Common problems found on coaxial systems that cause digital line errors are connector problems, poor grounding, or damage to the outer conductor of the coax.

Telephony systems are also deployed on fiber, coax, as well as twisted pair.

Twisted pair is very susceptible to a wide range of line conditions that cause both analog and digital faults.

The eight common types of line problems found on twisted pair medium are:

- Attenuation Distortion
- Envelope Delay Distortion
- Signal-to-Noise Ratio
- Harmonic Distortion
- Jitter
- Impulse Noise
- Frequency Shift
- Echo

DISPLAY VA 6.2
REFER TO WB 6.3

USE WB 6.3 QUESTIONS TO STIMULATE DISCUSSION THROUGHOUT THIS MODULE

Attenuation Distortion

A digital pulse, a square wave, can be represented as the sum of an infinite number of sine waves of varying frequencies.

To maintain the square shape of the original signal, each frequency component must maintain its amplitude in relation to all other frequency components.

If some of the amplitudes of the different sinusoidal frequencies are reduced the shape of the original square wave will be changed.

Amplitude of Frequency F2 falls off more rapidly than F1. Digital Pulse would distort.

The effect is known as Attenuation Distortion.

The physical characteristics of the medium being used to carry the signal will cause different frequencies to lose power, i.e., attenuate, at different rates.

Some amount of attenuation distortion is unavoidable.

To prevent attenuation distortion from becoming a problem serious enough to disrupt service, attention must be paid to:

- The type medium being used,
- The distances signals travel before being repeated, and
- Line conditioning, which will be discussed later.

DISPLAY VA 6.3
REFER TO WB 6.4

DISCUSS QUESTIONS ON WB 6.4

Envelope Delay Distortion

The digital pulse is the sum of an infinite number of sine waves of varying frequencies.

It is necessary for all frequency components of the signal to travel together and arrive at the receiving end at the same time.

Failure to arrive together causes a condition called Envelope Delay Distortion.

The physical characteristics of the medium being used to carry the signal will cause different frequencies to travel through the medium at different speeds.

Sine waves 1, 2, & 3 are different frequencies and arrive at slightly different times at the far end.

- The different frequencies arrive at the far end at slightly different times.
- Some amount of envelope delay distortion is unavoidable.

To prevent envelope delay distortion from becoming a problem serious enough to disrupt service, attention must be paid to:

- The type medium being used,
- The distances signals travel before being repeated, and
- Line conditioning, which will be discussed later.

These are the same factors that must be managed to control attenuation distortion.

REFER TO WB 6.5

Write the conditioning methods on the board

Line Conditioning

To assure twisted cable pairs support digital pulses, it is necessary to condition the lines. There are two types of line conditioning methods:

- C conditioning which places limits on attenuation and delay distortions.
- D conditioning which places limits on signal-to-noise ratio and harmonic distortions.

Both of these methods can ONLY be applied to private lines.

C conditioning is available in five varieties. These apply to voice grade private lines.

- C1, C2, and C4 apply to voice grade private lines between user sites. C4 can only handle a maximum of three remote sites.
- C3 applies to lines that are part of some large dedicated network such as the military AUTOVON; the restrictions are similar to C2 conditioning.
- C5 applies to international point-to-point circuits.

DISPLAY VA 6.4
REFER TO WB 6.6

The higher the "conditioning number", the more restrained are the specifications for both attenuation distortion and envelop delay distortion.

Consider a non-conditioned basic 3002 private line.

The left scale of the chart shows the Differential Delay in milliseconds. Zero, that is no delay, is the best condition. Zero is at the top of the scale.

The right scale of the chart shows attenuation in dB. Zero, that is no attenuation, is best. Zero is at the bottom of the scale.

The bottom scale shows the frequency being measured. For a 3002 line it is from 100 Hz to 3300 Hz.

The Frequency Delay specified is a heavy line that the Frequency Observed line is not to go BELOW where indicated.

The Attenuation specified is a heavy broken line that the Attenuation Observed line is not to go ABOVE where indicated.

DISPLAY VA 6.5
REFER TO WB 6.7

The C1 conditioned circuit has more restricted requirements for attenuation and delay.

DISPLAY VA 6.6
REFER TO WB 6.8

The C4 conditioned circuit is even more restricted. For example, between 500 Hz and 2.8 kHz the Frequency Delay is specified to be less than 1 millisecond.

Between 900 Hz and 2.5 kHz the attenuation must be less than 2 dB. Compare this to the basic 3002 line.

DISCUSS WB 6.9

Signal-to-noise ratio

- Signal-to-Noise ratio
  - ◊ Ratio between the magnitude of lower frequency baseband, or *unmodulated* information signal, and the noise present within the same spectrum.
  - ◊ S/N measurements are only done with unmodulated video information, usually in CATV headends.
- Carrier-to-Noise ratio
  - ◊ Ratio between the magnitudes of higher frequency carrier signal and the noise present within the same spectrum.
  - ◊ C/N measurements are done by technicians in the field.

Make a point of the differences between S/N and C/N on the easel or white board.

DISPLAY VA 6.7
DISCUSS WB 6.10

Harmonic Distortion

- A harmonic signal is an integer multiple of the original frequency, e.g., 2, 3, 4 or more times the original frequency.
- Harmonic distortion can be caused by clipping of the sine wave or having a signal injected to interfere with the original signal.
- Examples of harmonic distortion affecting typical analog CATV signals include inter-modulation, cross-modulation and ingress.

D conditioning comes in three varieties:

- D1 Point to Point
- D2 Multipoint with up to 3 remotes
- D5 Multipoint with up to 20 remotes

D conditioning was developed for 9600 bps and higher operations of 3002 lines.

The 3002 line has signal-to-noise ratio of 24 dB, a signal to 2nd harmonic distortion of not more than 25 dB, and a 3rd harmonic of not more than 30 dB.

D-type conditioning specifies a S/N ratio of 28 dB, a signal to 2nd harmonic at 35 dB, and a signal to 3rd harmonic of 40 dB.

The restrictions for D-type conditioning do not change as the number increases; the increasing number does indicate more locations being conditioned.

DISPLAY VA 6.8
REFER TO WB 6.11

Jitter

- There are several types of jitter that are referred to in communications.
- In this module only two types are discussed because they typically cause problems in digital systems.
- These two types are:
- Line Phase jitter
- Peak Cell-Rate (PCR) jitter

Line Phase Jitter involves variations in the timing of individual data bits from a standard clock pulse as the data moves through the transmission system.

In other words, there are short-term variations of digital signals from an ideal position in time.

The signal gets a little "jittery" and is not in perfect time with the ideal clock. Thus, each bit is arriving at slightly different expected intervals.

DISPLAY VA 6. 9

This slide gives another view timing jitter

In the VA the difference between the ideal clock and the jittered clocked is shown as J_1, J_2, J_3, J_4, & J_5. Each of these represents a certain amount of variance from the ideal.

When these variations are plotted over time for a large number of bits, the result is a sine wave.

The amplitude of the sine wave at each instant is proportional to the variation (J_N) of the pulse at that point in time.

If the maximum amplitude of the sine wave becomes large enough, there will be an error when the signal is decoded. The decoder will not know when a bit begins.

The ideal amount of time from the beginning of a bit to the beginning of the following bit is called a Unit Interval (UI) peak to peak.

It is the time required for the transmission of one bit of information.

Jitter can be induced from various sources. A common source is the ubiquitous 60 Hz alternating frequency found on power lines. Unintended coupling of that signal onto a digital line carrying clocking will result in the digital clock pulses being modified.

There are different jitter tolerances for different digital systems at different bit rates.

Jitter standards are specified in terms of UI vs. jitter frequencies for different bit rates. This allows a standard to be stated without respect to specific digital systems.

DISPLAY VA 6.10
REFER TO WB 6.12

This is the CCITT recommendation G.824 for a telecom network node. Note the relationship between frequency and UI.

For lower bit rate systems, deriving the clock timing from the data signal can control jitter. Then the jitter is the same for the clock and the data.

At higher speeds this does not work as well because the clock recovery circuits are not as accurate.

DISPLAY VA 6.11
REFER TO WB 6.13

Peak Cell Rate

Peak Cell Rate (PCR) jitter is the second type of jitter to be considered.

"Cells" exist in some type of packet digital network, such as an ATM network. ATM can be used to handle digital television signals encoded according to MPEG specifications.

The digitized signal is placed in a number of packets that are sent out over the network. These packets can travel over different paths on the network to the final destination.

During periods of light usage on the network, these packets will arrive, be held in a buffer, will be sorted into the correct order, and decoded.

If the network is busy, the buffers may become overloaded or the time it takes subsequent packets to arrive may be too long. Packets could be lost.

The effects may only be a blurring of the signal, high frequency noise, blocking, inadequate motion, etc.

If PCR jitter was very severe, the failure would be catastrophic…a complete loss of signal.

DISPLAY VA 6.12
REFER TO WB 6.14

Impulse Noise

Impulse noise is a short duration pulse of unwanted noise.

Examples would be lightening, a buzzer, or some other irregularly occurring electrical disturbance.

This sort of disturbance can be limited by the use of shielding around the conductor or by the use of higher grade twisted pair.

Frequency Shift

The move to digital transmission facilities has greatly reduced this type of signal impairment on long distance facilities.

Frequency shift occurs when signals modulated onto microwave carriers are found to be different frequencies when demodulated at the receiving end.

Echo

Echo is the reflection of a portion of the transmitted signal.

It is typically caused by a mismatch in impedance where two objects interface in a transmission path. Splices or equipment in the circuit can cause this.

Echo can be controlled with echo suppressors or echo cancellers. These devices are designed to attenuate any reflected signals.

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DISCUSS
WB 6.15

Data Errors

Use the easel. Write "Data Errors"

Hardware and/or software that organizes and formats the data for transmission can cause data errors.

One category of data errors is the result of problems incurred when grouping data into packets or cells.

One type of data error was discussed earlier under jitter:

- Peak Cell Rate Jitter (PCR)

PCR

Another type of data error related to cells or packets is called protocol errors. Two examples are:

- Committed Information Rate (CIR), and
- Data Collisions.

CIR

CIR errors result when the data rate agreed upon between the customer and the carrier is exceeded.

This can occur when the customer attempts to send more information than was guaranteed during a peak period.

Since it is not guaranteed, it may become corrupted or dropped.

Data Collisions

Data Collisions occur when two terminals attempt to transmit at the same time. This is an illegal operation. A certain amount of data collision is normal.

On an Ethernet system, the system will stop transmitting ALL data if a threshold is exceeded and restart the system one terminal at a time.

Error Detection and Correction Techniques

DISPLAY VA 6.13
REFER TO WB 6.16

Error Detection provides an indication that an error has occurred.

To correct the error, the data must be retransmitted.

Error Correction provides a way of detecting and correcting the error without retransmission of the data.

Two types of error detection are:

- Checksum techniques, used in
  - ◊ Block Parity Check
  - ◊ XMODEM Check Sum
- Cyclic Redundancy Check (CRC)

Two methods of error correction are:

- Automatic Repeat Request (ARQ)
- Forward Error Correction (FEC)

Error Detection

DISPLAY VA 6.14
REFER TO WB 6.17

Block Parity Check

This is one of the simpler forms of error checking. It is also known as the Longitudinal Redundancy Check (LRC).

It operates on blocks of data words being transmitted. An agreed number of data words are grouped together into a “block”.

This block then has parity bits at the end of each row (word) and at the bottom of each column.

The parity bit is appended to each row and column in the block. The result is that the sum of 1s in each row and column is either always an even or odd number.

The far end checks to see that the parity bits are correct for both the rows and the columns.

If the parity bits do not check, it is known that an error has occurred in this block of data.

This method is limited in that it can only detect one error per block and it cannot be used to correct errors.

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DISPLAY VA 6.15
REFER TO WB 6.18

XMODEM Check Sum

This is a common protocol found on PC modems.

It operates by sending data in 128 character blocks. The 128 character block is preceded by a Start of Header (SOH) character and the block number.

At the end of this 128 character block is a XMODEM checksum.

The checksum is calculated by adding the bits of all 128 character blocks.

This total is divided by 255.

The remainder is the checksum.

This checksum is what is transmitted and computed at the receive end.

If there is no match, the receive end requests retransmission of the block that was in error.

DISCUSS
WB 6.19

Cyclic Redundancy Check (CRC)

Just as XMODEM Checksum and Block Parity Check are two specific checksum error detection methods, CRC is an implementation of a general class of error detection techniques called:

- polynomial error checking

It is a much more sophisticated error detection method than the checksum techniques. There are several standard CRC calculations in use:

- CRC-6
- CRC-12
- CRC-16
- CRC-CCITT

These different designations refer to the polynomial being used. For example, CRC-CCITT has the following appearance:

$$X^{16} + X^{12} + X^{5} + 1$$

Write this on the board

This particular error detection technique can:

- Detect both single and double bit errors,
- Detect two pairs of adjacent errors,
- Detect bursty errors of 16 bits or less, and
- Detect 99.99% of all bursty errors greater than 16 bits.

The transmitting DTE takes all the bits in a block of data and applies the polynomial algorithm to the data. It generates a bit sequence from the remainder of the arithmetic calculation known as the frame check sequence (FCS), so that the resulting frame containing the data and the FCS is evenly divisible by the polynomial variable.

The receiving DTE performs the calculation with the incoming block of data concatenated together with the FCS, and, if the remainder is 0, the probability of there being any error in the data is 1 in a billion.

Cyclic redundancy checking has become one of the most widely used error detection methods for block data transmission because of its accuracy.

If an error is detected, the block has to be retransmitted.

Error Correction

DISPLAY VA 6.16
REFER TO WB 6.20

Automatic Repeat Request (ARQ)

This is a common error correction technique.

The "correction" is a request to resend the data. ARQ works in conjunction with an error detection technique such as CRC.

The receiving DTE determines if the incoming block has any errors.

This DTE signals the sending DTE that it has either accepted or rejected the block of data.

Draw on easel two DTEs.

If it rejects the data, it requests a retransmission. This requires a reverse communications path. It also requires that the sending DTE has sufficient memory, called buffer, to hold the data sent until the receiving DTE accepts it.

Discuss the send, ACK, send, NAK, and resend process.

ARQ can work in one of two ways:

- Stop and Wait
- Continuous

Point out advantage of return path.

In the **Stop and Wait ARQ** technique, the sending DTE sends a block of data and waits for the receiving DTE to

- acknowledge (ACK) receipt of good data, or
- send negative acknowledgement (NAK) indicating the data was Erred and requesting that it be resent.

Draw two more DTEs.

Point out the required reverse channel.

If there is not a separate return communications path, the line must be "turned around" to send the ACK or NAK to the sending terminal.

While the receiving terminal is checking the data block and sending information to the sending terminal, no data is being sent. This slows the throughput of data.

Stop and wait ARQ is most effectively used in systems where the data blocks are long, the error rate is low, and a reverse channel exists.

The **Continuous ARQ** technique has the sending DTE constantly sending blocks of data UNTIL the receiving DTE sends a NAK upstream via the reverse channel.

Ask for input concerning efficiency of these two methods.

This NAK will indicate which block was Erred. There must be a reverse channel.

Upon receipt of the NAK, the sending DTE will respond in one of two pre-determined ways.

- The simplest method is to retransmit ALL the blocks beginning with the Erred block. The receiving DTE throws away everything it received after the error was discovered, and then receives, again, all the data beginning with the erred block.
- The second method has the receiving DTE requesting a resend of the specific erred block of data. In this case, only that block is resent. The receiving terminal has sufficient storage to hold all the data coming in UNTIL the resent erred block is received, put into the data stream in the correct place, and then the data is sent to the DCE in proper sequence. This requires a more complex receiving DTE and sending DTE.

The more widely used Continuous ARQ method is the first one, which requests a resend of all blocks after the erred block. It is less complex.

Continuous ARQ is commonly used on systems with long propagation paths, such as satellite systems.

DISPLAY VA 6.17
REFER TO WB 6.21

Forward Error Correction (FEC)

Detecting errors and correcting them via ARQ methods is a way of insuring quality data. It does require retransmission of the data.

A more complex method is Forward Error Correction.

FEC techniques require that the data block be processed through a complex mathematical operation that puts in check bits, parity bits, and other information that allows the receiving DTE to reconstruct a damaged block of data.

Typically, an adjunct computer at the receiving DTE will perform the complex task of reconstructing the erred block.

This is a complex and expensive process. Initial applications were military in nature.

For systems in which the information is critical and the transmission path is simplex, FEC is the required method to ensure a block of data gets to the receiving DTE correctly.

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Digital Error Measurements and Terms

DISPLAY VA 6.18
REFER TO WB 6.22

How are errors defined?

What is being looked for in digital systems that indicates errors?

How are errors measured? In terms of what?

There are several types of errors to look for and measure. Common indicators of errors on a digital system are:

- Bit Error Rate (BER)
- Block Error Rate (BLER)
- Erred Seconds and Severely Erred Seconds
- Phase Jitter
- Constellation and Eye Diagrams
- Digital Power Level Measurements

Bit Error Rate (BER)

This measurement is performed in an out-of-service condition. A test set sends a known bit pattern.

The signal is looped back to the test set to determine if any errors are observed. This test needs to be run for a predetermined time.

The BER will be based on the statistical average of errors measured. This compensates for any temporary conditions that might cause short-term problems.

Typical acceptable BER rates are between 10^{-6} and 10^{-9}; the exact level is a function of the system.

The Bit Error Rate Test (BERT) is the first step in the troubleshooting process.

BER Testing

To perform a BERT requires a test set with a standard signal source AND detector.

DISPLAY VA 6.18

The VA is an overview of such a system.

A bit sequence is generated by a feedback shift register that is driven by a clock source.

The bits are passed through an interface circuit to generate the correct code format and output level for the system being tested.

At the receive end, the same type of interface circuit strips off the code, recovers the clock, and reports bit errors.

A properly operating testing device will detect all the errors received.

The Error Detection device then can compute the BER and analyze the results.

Block Error Rate (BLER)

A test similar to the BER is the BLER. It also looks at predetermined bit patterns.

The BLER is different in that it looks at blocks of data versus individual bits.

If the “test” block is the same size as the block being used on the system, then the BLER can provide the technician with a measurement called the *Effective Information Throughput (EFT).*

A block received in error must be transmitted.

If the BER is such that the BLER is 2%, then in every 100 blocks of data, two will require retransmission. In a stop and wait ARQ system, this would indicate an EFT of 98%.

Erred Seconds and Severely Erred Seconds

A second in which an error occurred is an Erred Second.

A second in which the BER exceeds 10^{-3}, that is, more than 1 error per 1000 bits, is a Severely Erred Second.

Phase Jitter

This was discussed earlier.

As a review, Phase Jitter involves variations in the timing of individual data bits from a standard clock pulse as the data moves through the transmission system.

In other words, there are short-term variations of the digital signal from an ideal position in time.

The signal gets a little “jittery” and is not in perfect time with the ideal clock. Thus, each bit is arriving at a slightly different expected time.

DISPLAY VA 6.19
REFER TO WB 6.23

Constellation and Eye Diagrams

This is not an actual picture.

These are measurements that a technician views directly on a scope.

These two techniques are used on systems on which digital signals are modulated on an analog carrier. This was briefly discussed in Module 2.

An example of such a system would be a 16 QAM system.

A constellation measurement is the plotting of the amplitude and phase of a digital signal along the “X” and “Y” axes (The horizontal and vertical axis).

The constellation is using the axes to plot the amplitude and the angle. The measured digital pulses should fall directly on top of the predicted point on the graph.

Thus the term “constellation” because the result resembles stars. If the “stars” are not crisp, e.g., fuzzy, then there is a problem in the system.

Eye diagrams track the transitions in a modulated signal that represent the space between successive digits.

The lines that are formed should be well defined straight lines which leave areas of open space (eyes) between the lines.

When the lines blur or the eyes close, this is an indication of a problem.

Digital Power Level Measurements

This measurement is also used on systems that modulate a digital signal over an analog carrier.

The complexity of the coding and modulation process has the digital signal spread over a large frequency spectrum.

If signal level is insufficient, the pulses cannot be detected. This will result in loss of signal.

Noise becomes a greater problem with digital signals.

Summary

REFER TO WB 6.24 AND WB 6.25

Have students answer the study questions at the end of Module 6. Review the answers.

Answers in Appendix

Appendix

Answers to the questions at the end of the Student Workbook.

1. Name the two places where errors may be generated in a digital system.

   Errors can be due to the transmission medium (line errors) or to faults within the data source (data errors).

2. Name the four types of line impairment that may be corrected by line conditioning, and identify which type of conditioning corrects which type of impairment.

   Attenuation distortion is the distortion caused by the differences in signal level attenuation at different frequencies. It is corrected by C conditioning.

   Envelope delay distortion is the distortion caused by the difference in propagation speeds at different frequencies. It is also corrected by C conditioning.

   Signal-to-Noise Ratio is the ratio in decibels of the signal power to noise power. It is maintained within limits by D conditioning.

   Clipping a sine wave at its peaks causes harmonic distortion. It is corrected by D conditioning.

   All of these impairments are analog line impairments of signals sent over twisted pair wiring. They affect digital signals because digital signals are often transported over analog facilities using a sine wave carrier.

3. Name two types of jitter, and describe what effect each one has on a digital signal.

   Two types of jitter are line phase jitter and peak cell rate (PCR) jitter.

   Line phase jitter involves variations in the timing of individual data pulses (bits) from a standard clock pulse position, as data moves through a digital transmission system. This type of jitter may be encountered in a T1 transmission system, or in a digital video transmission. If line phase jitter is bad enough, a pulse representing a coded digit may actually appear at another pulse position, resulting in an error.

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Peak cell rate (PCR) jitter involves variations in the time it takes to transmit packets of data through a broadband digital system, such as the transmission of MPEG data over ATM networks. If peak cell rate jitter is bad enough, individual cells of data will be lost. The result in video transmission systems will vary depending on the number of cells that are lost. Possible effects are blurring that looks like soft focus, high frequency visual noise, blocking/mosaic patterns, sparkles, inadequate motion portrayal, fringing and shadowing on high contrast transition, or even complete loss of picture.

4. Describe how Bit Error Rate is measured. Include a discussion of the signal source for the Bit Error Rate test in your description.

   Bit Error Rate is measured by injecting a known bit pattern into a circuit at the transmitting end and comparing the pattern at the receiving end to what was sent. A very stable clock should drive the signal source, so that any error in the pattern will be due to the system under test, and not the test equipment.

5. Why is Block Error Rate a better measurement of digital error than Bit Error Rate, and what should determine the block size for the BLER measurement to be meaningful?

   Block Error Rate is similar to Bit Error Rate, in that a predetermined bit pattern is sent over the line. BLER provides more information in that it tracks data on a block basis, rather than just individual data bits. This type of tracking is helpful in detecting recurring patterns of errors. To be most effective, the test block size should be the same as the typical block of actual data.

6. Describe how Automatic Repeat Request corrects errors. What is the difference between selective ARQ and Go Back N ARQ, both in terms of how they operate and in terms of buffering of data?

   Automatic Repeat Request corrects errors by requesting a retransmission once an error has been detected. It therefore must work together with any of several error detection methods, such as block parity check.

   With selective ARQ, the transmitter will resend only the faulty block of data (the one which generated a negative-acknowledgment (NAK) on the receiving end). In continuous transmission, acknowledge (ACK) and NAK signals are sent on different channels than the actual data, and the system will allow a predetermined number of

blocks of data to be transmitted without receiving an acknowledgment or rejection. Transmission of several valid data blocks may therefore occur prior to the retransmission of the faulty block. For selective ARQ to work, the receiver must manage the data with buffers (storage) so that a retransmitted block is correctly reinserted into the data stream where the faulty block would have been.

Go back N ARQ simplifies the management of the retransmitted data by having the transmitting end resend all blocks of data from the faulty block to the present block. Because several blocks of data may need to be resent with Go back N ARQ, the transmitter must buffer (store) as many blocks as the receiver will allow to go unacknowledged.

7. What is the difference between the constellation diagram and the eye diagram? What do each measure?

The constellation diagram plots amplitude and phase of a digital signal stream in four quadrants. It is so named because the visual representation of the plot points looks like a group of stars in a constellation, especially as the n in nQAM increases. The axes of the graph are amplitude and phase. In the ideal system, any digital pulse should fall directly on top of one of the points (stars) on the constellation diagram. Amplitude and phase deviations from the specification cause the star to become fuzzy.

Eye diagrams track the transition area of the modulated signal that represents a space between digital pulses. The lines in an eye diagram should be well defined straight lines, leaving areas of space (the eyes) between the lines. When the signal deviates from specification, or when a signal that is not supposed to be there is on the line, the lines become blurred, ("closing the eye"). An eye diagram provides an indication of phase shifts, also known as jitter.

8. List some points in a cable TV system where the following digital error testing tools would be applied: Bit Error Rate Test set, Constellation and Eye Diagram, Jitter test.

The Bit Error Rate Test is the most general type of digital error test, and could be applied at any point in a digital system where system performance needs to be measured. Typically, the diagnostics in a set-top box would include some measurement using BERT. BERT tests could be performed at any time system performance was in question.

Constellation and Eye Diagrams and Jitter tests are more sophisticated testing methods, and would typically be used as digital programming is being added to a system during the installation to ensure the system is "digital ready." During system setup, these tests would be conducted at several points in the system, including at the

set top, possibly at the entrance to the residence, at amplifiers and at various taps in the distribution plant.