1

Digital Signal Measurement Guidelines

This chapter introduces guidelines to help you understand digital signals in an analog world.

What you will learn

- Define analog and digital in cable communications
- How are digital signals different from analog signals?
- How does the nature of a digital signal affect your ability to make measurements?

Defining analog and digital for communications

If you asked your friends to define the terms analog and digital you would have as many answers as people interviewed. Everyone’s experience with these concepts is different. Digital is not just reserved for computers and digital audio and video. Digital is integrated into most of the products and services we use every day, especially in communications equipment.

What is Analog?

For the purposes of this book, an analog signal is one which contains information that is added to a carrier signal using a modulation technique. All signals, whether they contain analog or digital information, are transmitted within an analog medium, such as a coaxial cable, a fiber optic cable or through the open space.

In this book we use the terms digital and analog to describe the nature of the signal. All communications, whether analog or digital are ultimately transmitted from one physical location to another, using analog transmission medium such as a fiberoptics, a radio frequency (RF) cable, a telephone line, a terrestrial RF and microwave wireless link, or a satellite relay. Even computer network digital messages move between distant locations through an analog physical layer.

The emphasis in this book is on measuring digital signals in analog media.

We perceive the world as analog

Analog means information that changes as continuously varying values. When we look, feel, taste, or hear, we do it with analog senses and analog interpretation. Our senses receive information as continuous values. Only the finest differentiation breaks down an image as discrete values, for example, the rods and cones of our eye's retina. But our brains don't "see" it that way. The brain's interpretation of visual information is analog, blending this "dot" information into a contiguous picture.

Digital signals are all around us. Communications equipment as familiar as a FAX machine, or as remote as a microwave link relay station, uses a combination of analog and digital technologies. Table 1.1 shows some examples of common technologies and their signal characteristics.

Communication system or appliance	Signal characteristics
FAX	The scanned page of printed information is converted to a digital data stream by the FAX machine. The signal is sent on the telephone line.
CD - audio	Digital, as a series of dots on the disk surface read by a laser into a microprocessor. The coding AAD, ADD, and DDD chart the analog (A) and digital (D) history of the signal from recording, mixing and distribution, respectively. The CD player converts digital data stream to an analog audio signal which is output to the stereo system
Video Tape Recorder, VHS format	Analog video signal laid down as diagonal magnetic stripes on the tape. The player provides either a baseband or RF signal to the television.
Cellular telephone	Analog and/or digital signal processing, transmitted over the air as modulated RF.
Internet browser	Digital bit stream from a telephone modem, cable modem, or dedicated network line.

Table 1.1. Digital applications in everyday communications.

Similar uses of analog and digital formats are in your cable television system, shown in Table 1.2.

Cable television system components	Signal characteristics
Satellite feed to head end	Digital or analog microwave signals over the air on a microwave carrier
Return path pay-per-view message from set-top box	Digital information modulated onto a return carrier dedicated to the purpose
Fiber feed for importing remote TV channels	Analog and digital signals lightwave modulated onto an optical fiber
NTSC, PAL or SECAM television	Analog video modulated onto a carrier and transmitted over the air or on a cable or fiber
Cable modem (also on phone line)	Digital baseband modulated onto a burst carrier
Hybrid fiber coax (HFC) signal distribution	Analog and digital signals transmitted as analog signals

Table 1.2. Digital and analog use throughout cable television systems.

Analog is the non-quantized storage and transmission of data. **Digital** is the quantized storage and transmission of data. It is easier to distinguish between information sent as discrete values (digital) or continuous values (analog). Remember LP (for long play) records? The groove cut in the vinyl surface of an LP are analog. Close inspection with a microscope would show smooth curves in the groove's walls, as illustrated on the left side of Figure 1.1. The physical ripples are created from the sound waves themselves.

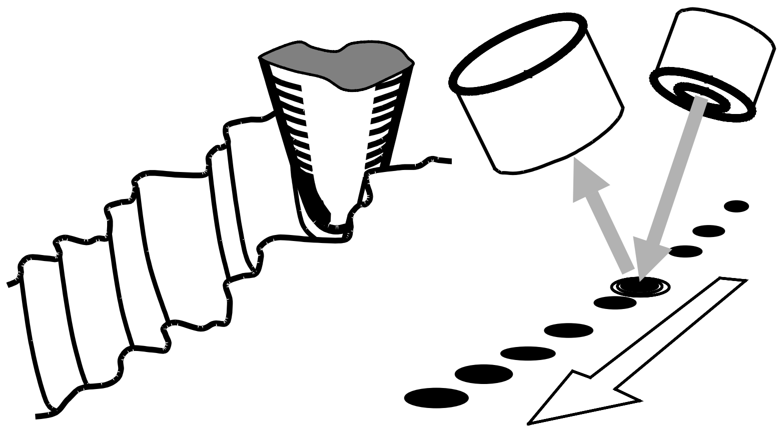


Figure 1.1. The groove of the vinyl record and pits of the CD.

Vinyl records became part of history when the audio compact disk, or CD, came to the market. The CD stores the music as digital information, placed as pits and spaces on the smooth surface of the CD. The signal, unlike the vinyl record, is not a physical representation of the sound waves, but a digitally coded signal, created by signal processing from the musical sounds. The pattern is read by the CD player as laser reflections, as shown on the right side of Figure 1.1, and reconstructed as digital information, called a digital **data stream**. The data stream is decoded into an analog audio signal.

The signal presents itself to your ear as a reproduction of the original analog audio information using analog audio components, such as preamplifiers, power amplifiers, equalizers, copper cables, and loud speakers.

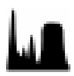
Digital signal	**A digital signal, defined for this book, is data stored and transmitted as a well-defined set of quantized values. Quantized means that the numbers have been saved as a collection of discrete digital values. Using the binary numbering scheme is just one way to digitize numbers.**

Digital and analog, similarities and differences

Here are some general rules, or guidelines that distinguish digital and analog signals. Each is represented by an icon and phrase in the left-hand column of this text. Throughout the book, you will see these icons when a point is made that re-enforces the guideline. Some of these are common sense, but others need more explanation.

Transmission of analog & digital

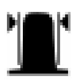
All signals, whether digital or analog are transmitted using analog techniques. Even the cable that connects your printer to your computer sends bit after bit of data as a varying voltage signal over an analog medium, copper wire.



Distributed in analog

Digital and analog signals are transported in analog media.

A digital signal is sent down the same cable as an analog signal, separated only by frequency. The cable or hybrid fiber/cable system is an analog transmission path. It does not matter to the cable distribution system whether the signals are analog or digital; their treatment by the retransmission hardware is the same. The analog and digital signals survive corruption by keeping within their allotted channel frequency bandwidth and by maintaining power levels consistent with the analog cable system performance requirements.



All signals are in channels

Digital and analog signals ride on a signal carrier and are confined to a specific bandwidth.

To be transmitted, all signals, whether digital or analog, need a **carrier** signal. The carrier signal has no information of its own, but provides steady energy at a stable frequency for reliable transmission. Information is **modulated** onto a carrier allowing bandwidth for the modulated information. This is **channelization**. Figure 1.2 shows analog and digital signals residing side-by-side in channels in a system's frequency spectrum. The information of the analog or digital signal is added to this carrier using modulation. The frequency band occupied by the modulation, also known as **transmission bandwidth**, surrounds the carrier. The carrier and its modulation must stay within the confines of the allocated channel bandwidth.

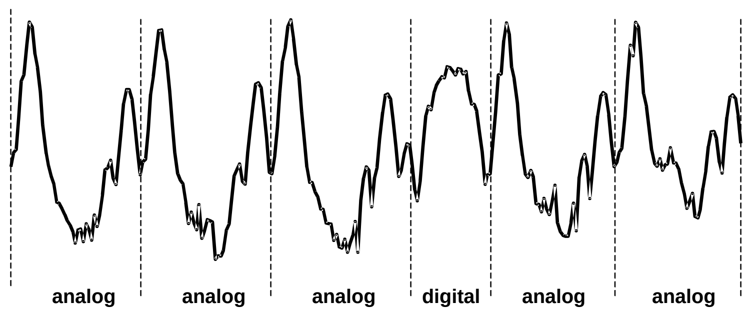


Figure 1.2. Analog and digital television channels in the frequency domain of a cable television distribution system.

Measurable parameters

Digital signals have unique measurement parameters. The performance of a signal, that is, its specified quality, is quantified by measuring one or more parameters. The analog performance parameters, such as C/N and CSO/CTB are familiar. But parameters for digital modulation quality, such as MER, EVM, and margin, may not be. The measurement parameters are divided into general application requirements:

- Analog performance (called proof-of-performance in North America)
- Digital modulation quality
- Data quality

In general, most of the cable television analog performance measurements apply to analog and digital signals alike. Meeting analog performance is a good starting point for digital signal quality, but many analog tests are not useful for digital signals at all. Digital signal technologies bring a whole array of new measurement requirements to cable television. **Bit error rate** (BER), **modulation error ratio** (MER), and **error vector magnitude** (EVM) are a few measurements only applicable to digital signals. Discussion of these parameters starts in How an Analog Wave Becomes Digital Data, Chapter 3 beginning on page 33.

Victims of distortion, noise, and interference

Digital and analog signals produce and are the victims of distortion, noise, and interference. Distortion is an unwanted change to a signal as it passes through a distribution system. The unwanted effects of distortion, noise and interference degrade the signal's quality. **Noise** is the random signal energy added to the signal by active devices in its distribution which degrades the signal quality, usually by randomizing the signal's information so much it cannot be recovered. **Interference**, also called **ingress**, is noise and/or distortion which comes from sources outside the system such as over-the-air broadcast and ham radio transmissions.

Every signal is subject to the distortion produced by other signals or system hardware. In systems with many digital signals, distortion looks like noise because the digital signals causing the distortion are noise-like themselves. Every signal can produce distortion that interferes with other signals. Signals interfere with others by leaking power outside their allocated bandwidth. This type of distortion is called **out-of-channel**. When a signal creates an unwanted signal within its own bandwidth, the distortion is called **in-channel**.

Distortion, noise, and interference are discussed in Chapter 11 beginning on page 211.

Digital signal can send more information

For a given bandwidth, a digital signal can send more information than an analog signal. Six or more digital television channels can be transmitted in the same channel bandwidth now occupied by a single PAL or NTSC analog channel. This bandwidth economy requires digital data **compression**. Data compression, not to be confused with power compression, is reduction of signal data by eliminating repetitive and non-essential information.

Many services, besides television, use digital signal processing. Here are a few examples:

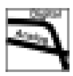
- Teletext
- Pay per view and video on demand
- Game subscription
- Internet access
- E-mail
- Telephony

Digital technology makes many of these services cost-effective. In fact, video motion picture transmission, as high definition, or compressed groups in a single channel, would not be possible without signal compression. This topic is discussed in , Chapter 7 beginning on page 99. **The emphasis in this book and these guidelines is on the delivery and maintenance of quality digital video transmission**. But many of the topics and measurement procedures also include aspects of digital information transmission that will help you understand the integration of computer networking into your systems.

Repair data at the receiver

Some digital signals carry information that allows damaged data to be repaired at the receiver.

When a signal is converted into digital bits, a certain percentage of the code is reserved for specially coded data that is used at the receiver for repair of the signal's information. The term commonly used for this process is error correction. See Error Correction, Equalization, and Compression, Chapter 7 beginning on page 99.



Digital signals crash without warning

Digital signals keep consistently high quality, but can crash with little warning.

Analog signals manage to convey information even if they are badly distorted. You can watch a television show through the snow of poor carrier-to-noise or the zig-zag lines of intermodulation distortion and still be entertained by the show. A digital signal maintains a higher level of quality than an analog signal when subjected to the same amount of transportation **impairment**, such as linear distortion, nonlinear distortion, noise, and interference. But at some level of impairment, long after customers begin to rebel against the poor analog picture quality, the digital signal crashes. This is shown graphically in Figure 1.3. The middle region represents the superior robustness of digital video over analog signals especially in the presence of noise and distortion. In video this crash is a black, scrambled, or frozen picture, sometimes with a buzzing sound. In data transmission, a crash means an application cannot run, or a file cannot be opened.

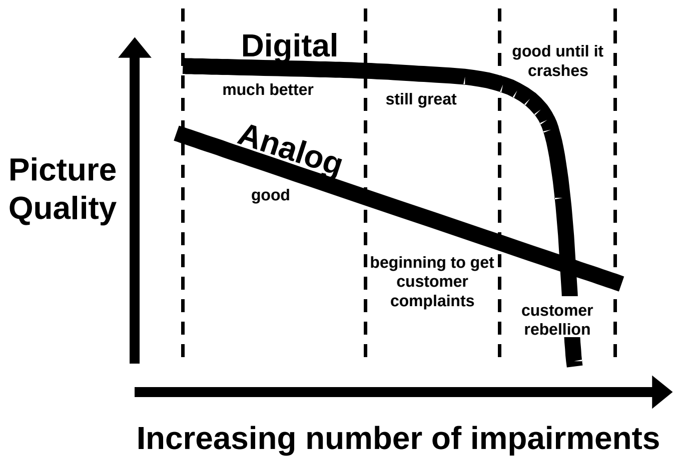


Figure 1.3. Analog and digital signal response to increasing impairments.

This is called the **cliff**, or **waterfall** effect. A digital signal has the capacity for self repair in real-time. The technologies that make it possible for a digital signal to hold out against adversity are

- Digital signal processing
- Signal compression
- Error correction
- Adaptive equalization

Digital signal processing is covered in How an Analog Wave Becomes Digital Data, Chapter 3 beginning on page 33, and Viewing Digital Modulation, Chapter 6 beginning on page 77. Compression, error correction, and adaptive equalization are covered in Chapter 7 beginning on page 99.

Digital information is hidden

Digital signal content is hidden deep in the signal. You are used to tapping into your cable system almost anywhere and looking at the familiar television channel spectrum or picture on your TV test monitor. Not so with the digital channel. To be robust and compact, the digital signal is "homogenized" until it is more like noise than an analog-modulated signal. Compression, and error correction help conceal the signal. This signal processing is called digital **encoding**. The modulation that puts the digital baseband information onto the carrier does so by spreading the signal almost uniformly over the entire bandwidth of the channel, further disguising the nature of the signal.

See Chapter 7 beginning on page 99, Chapter 2 beginning on page 15, and Chapter 6 beginning on page 77.

Multiplexing combines several signals into one

Multiplexing combines several signals into one. Multiplexing means combining more than one signal in the same transportation medium, usually for more efficient use of the available frequency spectrum. A cable television combiner, which adds channels to the trunk cable, multiplexes signals using **frequency division multiplex,** or **FDM**. FDM is just a fancy way to describe the function of a broadband RF cable distribution scheme as shown in Figure 1.4.

Digital information is also multiplexed by combining baseband data streams together into a single data stream. The zipper symbol in the left margin icon is a reminder of how data streams can be combined. These streams may, in turn, be combined in a broadband transmission medium such as wireless or cable, using any one of many multiplexing techniques. These techniques can usually be recognized by the word “division” in their name. Examples are **time division multiple access,** or **TDMA,** and **code division multiple access,** or **CDMA**.

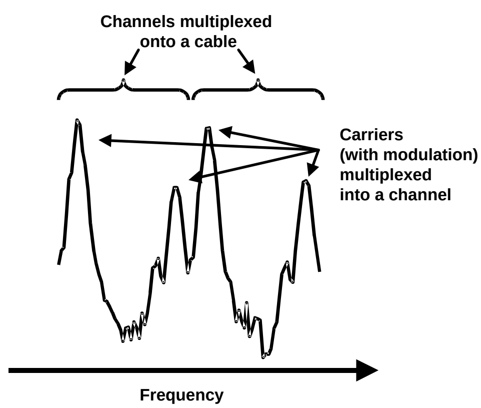


Figure 1.4. Analog channels in a cable system.

Multiplexing is covered in Distributing, Layering, and Multiplexing, Chapter 4 beginning on page 53.

Performance and measurements preview

Measurements are necessary to judge system performance. In an analog signal cable television system, analog performance is the primary set of measurements and performance levels required. When digital signals are added, a new set of interactive performance gauges and measurement tools are introduced. Two ways are used to look at performance and measurements: Where to measure, and what to measure. The where to measure is shown in Figure 1.5. The signal path through the forward direction is shown for a typical hybrid fiber/cable system. The only digital addition is the digital-to-analog blocks near each end of the system. Power and spectrum measurements, many of which are made in the analog performance suite of tests, are made in this RF portion of the system.

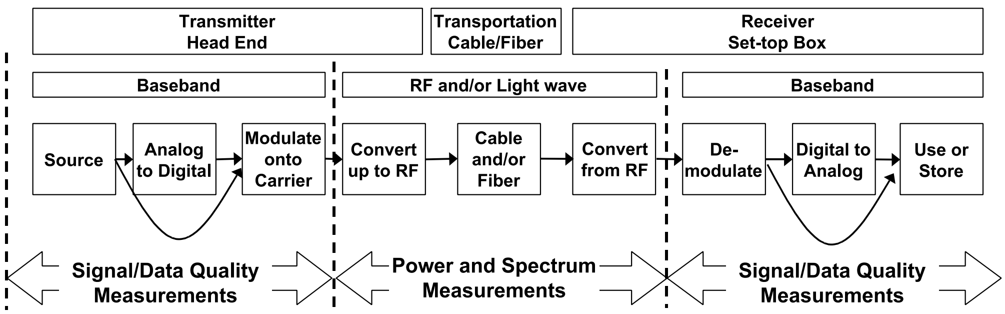


Figure 1.5. Typical signal transportation through a system.

Another way to look at measurements that helps you see the relationships between analog and digital signals in the RF domain, is shown in Figure 1.6. This is a sample performance and measurement map of the measurement parameters. (The full performance and measurement map is provided in Appendix B, beginning on page 247.) Every block is either a measured parameter, such as CSO/CTB distortion, noted by the dotted boxes, or a system performance characteristic, which may or may not be a measured parameter. Examples of performance characteristics are gain, noise, and interference.

The lines and positions of the blocks show their relationship. Blocks connected from the left have a direct influence on the right-hand block. As an example, look at carrier-to-noise to the left of center in the figure. The analog carrier level and the system noise determine C/N, so they are shown connected on the left.

Boxes connected directly to a performance, such as the way Proof-of-Performance is attached to Analog Channel Quality, indicate that the quality of the parameter is measured by that parameter. Another example, is the Digital Channel and Data Quality, where bit error rate (BER) is a direct measure of the signal quality, and the cliff effect is shown to be an indicator of quality.

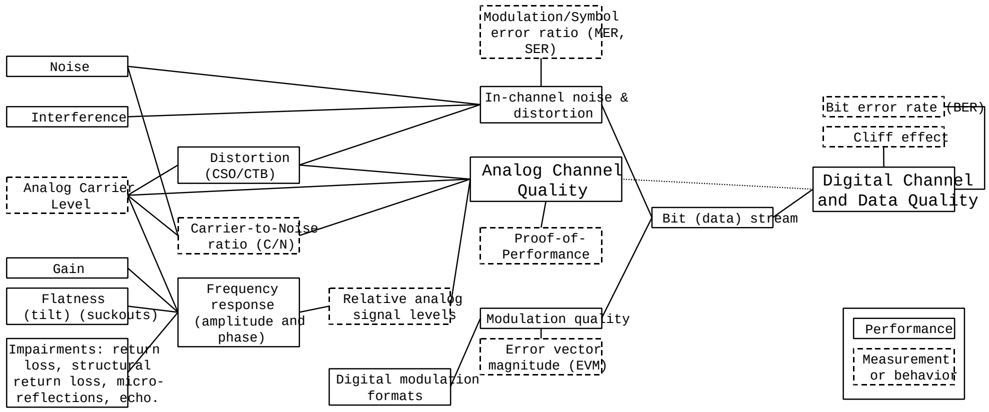


Figure 1.6. Performance and measurement flow in a cable television system.

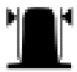
The rest of this book uses subsets of the full map in the appendix to illustrate performance and measurement basics. Measurement instrumentation is added to these maps in the measurement chapters.

Every map reemphasizes a key point: the system performance that provides high analog signal quality is a mandatory starting point for your system to provide superior digital signal quality.

Summary

This chapter introduced some guidelines for helping to understand the behavior of digital signals, especially in relation to the familiar cable television analog signals. These guidelines are better defined and their messages reinforced throughout the remainder of the book. The left margin logos help you spot guideline material.

It is almost as important to know where to make the measurement as it is to know what measurement to make. A list of the measurements covered in this book show the suggested test equipment and the location of the tests.



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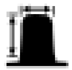

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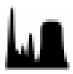
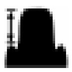


Digital and analog signals are transported in analog media.



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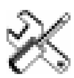

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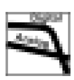

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Questions for Review

1. What are the characteristics of an analog signal (for the purposes of this book)? (check all that apply)
   a) continuously varying amplitude over frequency
   b) continuously varying amplitude over time
   c) signal may be discrete amplitude values over time
   d) the energy of the signal is spread over frequency

2. What characterizes a digital signal? (check all that apply)
   a) the amplitude of the signal is limited to a set of specific voltages
   b) the amplitude levels of the signal can easily be measured by a spectrum analyzer
   c) the energy of the signal is spread over frequency

3. The guidelines outlined in this chapter are always true. True or False?

4. Generally, digital signals hold their quality better under adverse transmission conditions than analog signals. True or False?

5. Analog and digital signals are distributed through an analog media such as the coax cable and amplifiers of a cable television distribution system. Which of the following systems are sending digital signals? Check all that apply.
   d) Computer sending print information to a local printer
   e) Computer sending print information to a network printer in a remote site.
   f) Hybrid fiber-coax head end to node transport in a cable television distribution system.
   g) The audio cable output of a compact disk player.
   h) The FAX output to a telephone line.

6. It is easy to tell what program material is being sent on a digital signal. True or False?

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