

Digital Television Technology and Standards

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Digital Television



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This book is dedicated to our wives

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*whose support made possible both this book and our numerous
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Preface

In the last 50 years, television has arguably become the dominant source of entertainment and information in many countries. In the western world, most households own at least one television. Many have two or more. Over this half century, television technology has proved to be very adaptable, able to accommodate upgrades taking advantage of new technology without requiring existing receivers to be replaced. Indeed, a 50-year-old television receiver could still be used in most countries. The maintenance of compatibility with the existing receivers has been achieved through incremental improvements in service quality. The transitions from black-and-white to color television and from mono to stereo audio are both examples of this.

Digital television offers a number of potential advantages over the older, analog technology. High-definition services, providing much greater resolution than the conventional standard-definition television, are possible, as is the packing of several standard definition programs into the same bandwidth as a single analog television channel. The current international move to digital television is more revolutionary in nature than the previous changes, requiring the phasing-in of digital receivers and the subsequent phasing-out of the existing analog receivers. Consumers will therefore be required to purchase new equipment, in the form of a digital television or a decoder, to convert digital signals into a form that can be passed to their existing analog receiver.

This book describes the technology and standards behind digital television. It introduces the basic techniques used in video coding, audio coding, and systems, which provide for the multiplexing of these services and other ancillary data into a single bit stream. The description of standards covers the north-American Advanced Television System Committee (ATSC) and the European Digital Video Broadcasting (DVB). Aspects relating to these standards are described independently, allowing the reader to cover only those parts relevant to one system if desired.

The first chapter provides an introduction to analog and digital television, setting up the basic division of functionality into the representation of video, the representation of audio, and the underlying systems that provide services such as multiplexing of video and audio onto a single channel and modulation. The remaining chapters are grouped into three parts, covering the video, audio, and systems aspects of digital television, respectively. Each of these parts is written so that it can be read independent of the other parts. The first part deals with the coding of digital video signals using the MPEG-2 standard to produce a compressed digital video bit stream.

Chapter 2 describes the characteristics of video material. Chapters 3 and 4 describe the signal processing used to reduce the spatial and temporal redundancy

of digital video signals, with Chapter 3 describing predictive coding and Chapter 4 transform coding. Chapter 5 describes the principles behind the syntax used to represent the various data elements carried in a compressed video bit stream, whereas Chapter 6 introduces the specific features of the MPEG-2 video standard.

The second part covers the coding and compression of digital audio, using a similar structure to the first part. Chapter 7 introduces the aspects of the human ear that are critical in determining subjective audio quality, followed in Chapter 8 by a description of the signal processing used for digital audio compression, including the use of subband filter banks in audio coding. Chapters 9 describes the specific methods used by the MPEG-1 and MPEG-2 standards, respectively, with Chapter 10 describing the Dolby AC-3 system used primarily by ATSC.

The third part describes the modulation of digital television services for transmission, the system protocols used for multiplexing, timing, and control, and the other components of a digital television service that provide a range of data services, including closed captioning (also known as subtitling) and teletext. In this part, separate descriptions are provided for the different techniques provided by DVB and ATSC. Chapter 11 describes MPEG-2 systems, which provide the multiplexing, timing, control data for digital television. MPEG-2 systems also carry a collection of data, known as program-specific information, which describes the contents of a systems' bit stream. ATSC and DVB each provide its own extensions to the program-specific information, which are described separately in Chapter 12. Chapter 13 describes the terrestrial broadcast modulation schemes of ATSC and DVB, including the use of channel coding to protect bit streams from errors introduced in transmission. Finally, the closed-captioning and teletext systems are described in Chapter 14.

This book might be used as a textbook supporting a variety of different types of courses. An undergraduate digital television course might be based on a selection of material from Chapters 1–3, 5, 6, and 11. A postgraduate course in digital television, for which background in digital signal processing and digital communications theory is assumed, could extend this to include all material from Chapters 1–3 on video, 5 and 6 on audio, and 10 and 11 on systems, incorporating selections from other chapters. A more specialized course on video coding could be based on Chapters 1–5.

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Canberra, Australia
June 2007

Chapter 1

Introduction to Analog and Digital Television

1.1. INTRODUCTION

From small beginnings less than 100 years ago, the television industry has grown to be a significant part of the lives of most people in the developed world, providing arguably the largest single source of information to its viewers.

The first true television system was demonstrated by John Logie Baird in the 1920s. Further experiments were conducted in the following decade, leading to trial broadcasts in Europe and the United States, and eventually to the regular television service we know today. Originally, only monochrome pictures were supported. Color television was introduced in the United States in 1954 and in Europe in 1967.

Television systems have evolved as *simplex* transmission systems, as shown in Figure 1.1. The term simplex means that information flows only in one direction across the channel. A transmitter, whose antenna is usually mounted on a tall tower, broadcasts a signal to a large number of receivers. Each receiver decodes the transmission and passes it on to a display device. Sometimes, the receiver and display are integrated into a single device, such as in a standard television that incorporates a means for the user to select the channel to be viewed. Sometimes, the receiver and display are separate devices, such as when a signal is received through a video cassette recorder (VCR) and passed to an external display. This system is known as *terrestrial broadcast* television.

Satellite and cable television systems operate on similar models. Figure 1.2 shows the outline structure of a cable television system.

1.2. ANALOG TELEVISION

Traditional television services make use of analog technology to provide an audio-visual, broadcast service. The basic structure of an analog television transmitter is shown in Figure 1.3. Video and audio signals, which may be derived from live sources such as cameras and microphones or from storage devices such as video

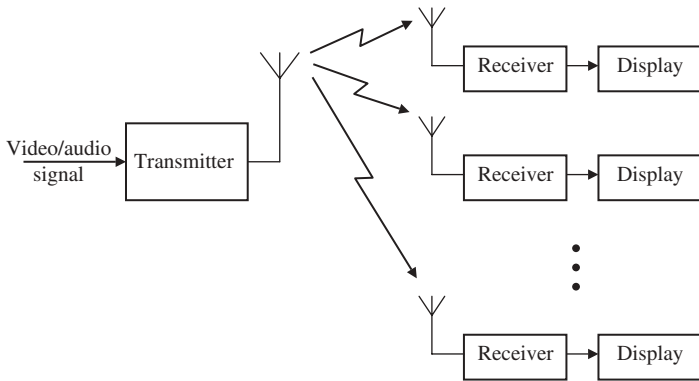


Figure 1.1 Simplex structure of terrestrial broadcast television.

recorders, are fed into separate modulators, whose output is multiplexed and upconverted to form the broadcast signal.

Various methods of modulating, multiplexing, and upconverting the signals to specific broadcast frequencies (as shown in Figure 1.3) are defined in the various analog television standards. Three of the major standards used for analog television are National Television System Committee (NTSC) [1], used primarily in North, Central, and South America, Systeme Electronique (pour) Couleur avec Memoire (SECAM), used in France and countries in eastern Europe such as Poland and Russia, and Phase Alternating Line (PAL) [2], used in many other countries including western Europe and Australia.

In this chapter, we discuss the operation of analog television with reference to three areas: the representation of video, the representation of audio, and the systems that provide the multiplexing of video and audio services into a single channel.

1.2.1. Video

An analog video signal is created by a time sequence of pictures, with 25 or 30 of these pictures displayed every second. Each picture consists of a number of lines,

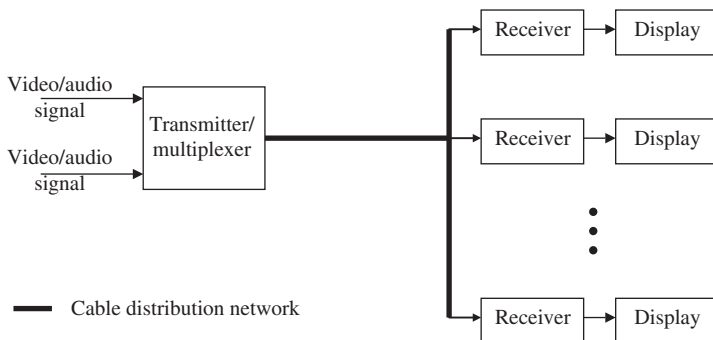


Figure 1.2 Structure of a cable television system.

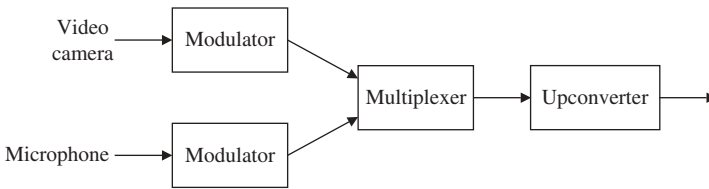


Figure 1.3 Basic structure of an analog television system.

each of which is scanned left to right, as illustrated in Figure 1.4. The vertical resolution is usually 576 lines for 25 Hz systems and 480 lines for 30 Hz systems.

In addition to the displayed lines, a number of other lines of data are transmitted. These are intended to provide time for the scan in a cathode ray tube to return from the bottom right of the display at the end of one picture to the top left of the display at the beginning of the next picture. The inclusion of these nondisplayed lines brings the total number of lines per picture to 625 for 25 Hz systems and 525 for 30 Hz systems. The time in which these nondisplayed lines are transmitted is known as the *vertical blanking interval (VBI)*.

1.2.1.1. Horizontal Synchronization

In an analog television signal, a synchronization pulse is provided at the start of every line in the picture as shown in Figure 1.5, which shows the waveform for a single line where the brightness decreases in steps from left to right. This means that the display begins its horizontal scan at the same place in the signal as the camera that captured the video signal. In addition, a longer synchronization pulse is used to indicate that the scan should restart at the top left of the display. These synchronization pulses allow the receiver to achieve synchronism with the incoming signal.

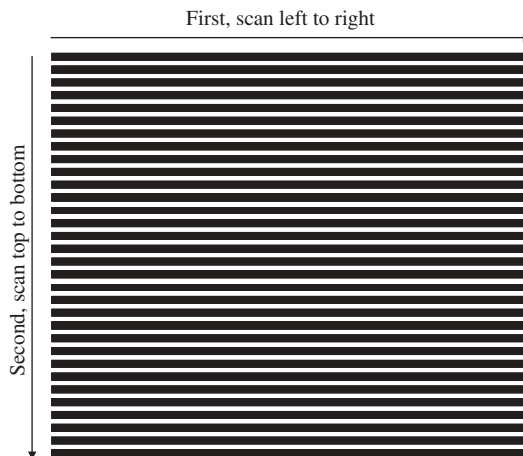


Figure 1.4 Simple left-to-right, top-to-bottom scan.

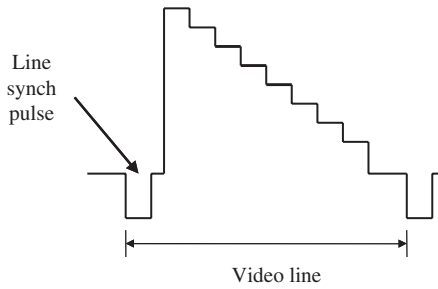


Figure 1.5 Waveform of a single picture line of analog video.

The interval allocated for transmission of the line synchronization pulse and the immediately surrounding regions (known as the front and back porches) is known as the *line blanking interval* or the *horizontal blanking interval*. Its length is 11 μs in NTSC and 12 μs in PAL and SECAM systems.

1.2.1.2. Horizontal Resolution

The horizontal resolution of an analog television system depends on the bandwidth of the video signal. Roughly speaking, the resolution of the system is 2 pixels per Hertz of video bandwidth. These pixels are shared equally between the transmitted lines. The number of useful pixels in each line is reduced by the length of the line blanking interval. The horizontal resolution r_h of an analog video system with bandwidth B is therefore

$$r_h = 2Bt_{\text{ULI}}$$

where t_{ULI} is the useful line interval. The horizontal resolutions for a number of in-service analog television systems are shown in Table 1.1. In the case of PAL and SECAM, there are a number of different implementations, each denoted by a

Table 1.1 Approximate horizontal resolution for selected analog television systems.

System	Lines per second (KHz)	Line period (μs)	Useful line interval (line period – line blanking interval) (μs)	Video bandwidth (B) (MHz)	Approximate horizontal resolution (pixels)
NTSC	15.750	63.5	52.5	4.2	441
PAL (B, G, H)/ SECAM (B, G)	15.625	64.0	52	5.0	520
PAL (I)	15.625	64.0	52	5.5	572
PAL (D)/SECAM (D, K, K1, L)	15.625	64.0	52	6.0	624

single letter. The video bandwidth varies between implementations, and a number of options are shown.

1.2.1.3. Interlaced Video

When analog television was designed, an important design trade-off was between the service picture rate and the service bandwidth. The picture rate chosen needs to be sufficiently fast to ensure that a human viewer perceives an apparently continuous service (as opposed to a rapid series of individual pictures—called flicker—which would be subjectively most unpleasant). Once the appropriate horizontal and vertical resolution of a television picture had been decided, the desired bandwidth meant that a relatively low picture rate (25 or 30 Hz) was all that could be achieved. These picture rates are insufficient to avoid flicker in all circumstances. However, simply increasing the picture rate would lead to an increase in the required service bandwidth. This was an unacceptable outcome. The developers of analog television overcame this problem using a technique called interlacing.

Interlacing divides each picture into two fields, as shown in Figure 1.6. One field contains the odd lines from the picture (i.e., lines 1, 3, 5, ...) and is called the odd field, whereas the other field contains the even lines from the picture (i.e., lines 2, 4, 6, ...) and is called the even field (Figure 6(a)). The odd lines are scanned from the camera system and then half a picture time later (i.e., $1/50$ th or $1/60$ th of a second) the even lines are scanned (Figure 6(b)). This approach improves the rendition of moving objects and also completely removes the flicker problem discussed earlier. The trade-off is some loss in vertical resolution of the picture.

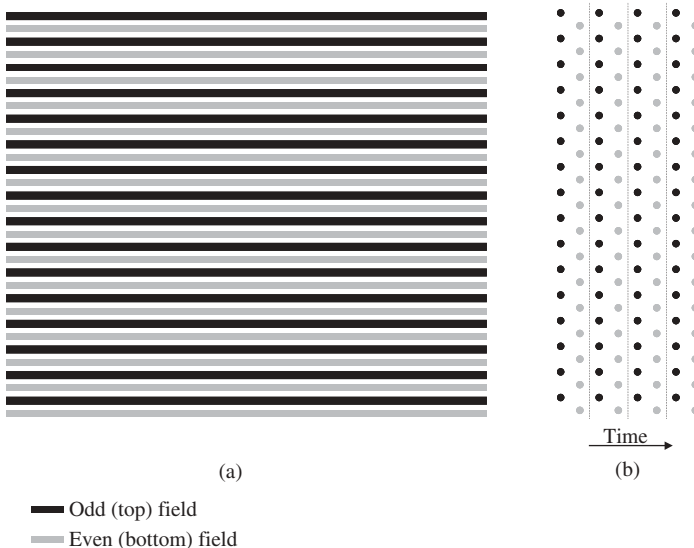


Figure 1.6 Interlace structure showing location of odd and even fields, (a) as seen on the display, and (b) the formation of pictures from two consecutive fields.

Table 1.2 Numbers of video lines per field and picture.

System	Notional picture frequency Hz	Field frequency Hz	Displayed lines per picture	Displayed lines per field	Total lines per picture	Total lines per field
PAL, SECAM	25	50	576	288	625	313 (odd)/ 312 (even)
NTSC	30	60	480	240	525	263 (odd)/ 262 (even)

Table 1.2 shows the number of lines per picture and field for 25 and 30 Hz analog television systems.

EXAMPLE 1.1—MATLAB

The aim of this example is to demonstrate the impact of combining two fields containing a moving object into a single picture.

SOLUTION Figure 1.7 shows two fields of 128×128 pixels consisting of a black background and a white square of size 32×32 pixels that has moved four pixels to the right between fields.

```
A = zeros(128);           % black background for odd field
B = zeros(128);           % black background for even field
A(49:80, 49:80) = 255 * ones(32); % white square in odd field
B(49:80, 57:88) = 255 * ones(32); % white square in even field
                                   (moved 8 pixels right)
```

The individual fields can be displayed using the MATLAB function `image.m`:

```
image(A)           % display odd field
image(B)           % display even field
```

The images obtained by displaying *A* and *B* are shown in Figure 1.7.

The two fields can be merged into a single picture, which is then displayed, using the commands below.

```
C = zeros(256,128);
C(1:2:255,:) = A;
C(2:2:256,:) = B;
image(C);
```

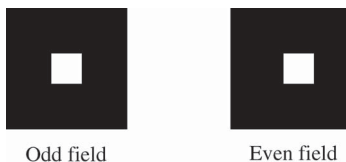


Figure 1.7 Odd and even fields produced in Example 1.

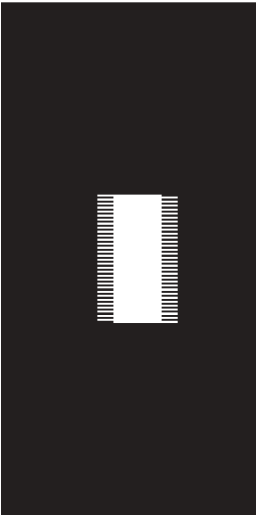


Figure 1.8 Merged fields to form a picture.

The resulting image is shown in Figure 1.8. The jagged edges are caused by the movement of the white block between the odd and even fields. In some circumstances, these jagged edges can lead to localized flickering. ■

When fields containing moving objects are merged to form a single picture, straight edges that are moving horizontally are turned into jagged edges. An example from the “Mobile and Calendar” sequence is shown in Figure 1.9, in which the jagged edges of moving objects such as the spots on the ball and the numbers on the calendar are clearly apparent.

1.2.1.4. Color Television

Television was initially a monochrome (black-and-white) service. When color television was to be introduced, the color information needed to be introduced in a way that did not affect substantially the quality of service received by consumers who still had a black-and-white television receiver. As is well known, color receivers display only three colors (red (*R*), green (*G*), and blue (*B*)). The mixing of these colors at the human eye provides the range of colors that we are used to with color television.

Transmitting separate signals for red, green, and blue would triple the bandwidth requirement for color television compared to monochrome television. Because a monochrome signal is not present in this set, the only way to provide a good quality monochrome picture for existing receivers would be to send yet another signal just for this purpose; this would be a very wasteful use of valuable spectrum. The quality of reception at monochrome receivers would have been significantly compromised.



Figure 1.9 Picture from the “Mobile and Calendar” sequence.

The approach taken was to transmit not the color signals R , G , and B but the monochrome signal (known as the luminance Y) accompanied by two color difference, or chrominance, signals (U and V) from which the three colors R , G , and B can be reconstructed. The values of the luminance signal and two chrominance signals can be calculated from R , G , and B according to

$$Y = 0.299R + 0.587G + 0.114B$$

$$U = \frac{B - Y}{2.03}$$

$$V = \frac{R - Y}{1.14}$$

Slightly different versions of these equations are used in different television systems.

The three color signals R , G , and B are reconstructed at the receiver and displayed. Because the luminance signal is still transmitted, it is still available to monochrome receivers and so there is a minimal impact on existing viewers. The color difference signals can also be transmitted with a significantly smaller bandwidth than the luminance signal. This is acceptable because the resolution of the human eye is lower for chrominance than it is for luminance. The use of color difference signals was therefore an early attempt at bandwidth compression.

1.2.2. Audio

The audio accompanying video in an analog television system usually has a bandwidth of approximately 15 kHz. The audio system in analog television originally supported only a single (monophonic) channel. It has been extended with the same philosophy of backward compatibility used for adding color information in the video to provide a range of services, including options for stereo audio, and two independent audio channels. In all cases, the original monophonic audio is still transmitted to support older receivers, with other signals added to provide higher levels of functionality.

1.2.3. Systems

Specification of the representation of audio and video is not sufficient to define a television service. A means is required to multiplex the video signals (luminance and chrominance) and the audio (mono or stereo) onto a single channel. We refer to this capability as the “systems” part of the television service.

Each country specifies a channel bandwidth for broadcast television systems. In North and Central America, 6 MHz is used, whereas 7 or 8 MHz is commonly used in the rest of the world. Approximately 70% of the bandwidth of the channel is allocated to video, with the remaining capacity available for audio and guard bands between channels.

Figure 1.10 shows the spectrum of a typical, monochrome, analog television channel with a single audio channel. Most of the capacity of the channel is allocated to the video, with a small amount available for audio. The video signal is usually modulated using vestigial sideband amplitude modulation with the upper sideband dominant, whereas the audio signal is frequency modulated with a maximum deviation of approximately 50 kHz (giving an audio bandwidth of 100 kHz). The audio carrier is located within the channel, but outside that part of the channel specified for the transmission of video. Each of the analog television standards specifies the locations of the video and audio carriers.

Extension to support color television can be achieved by the multiplexing of the chrominance signals onto the channel, as shown in Figure 1.11. This is done by using

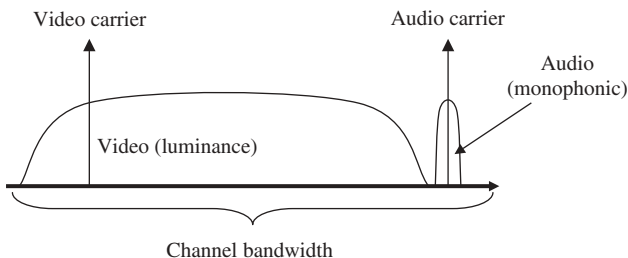


Figure 1.10 Spectrum of a typical monochrome analog television channel.

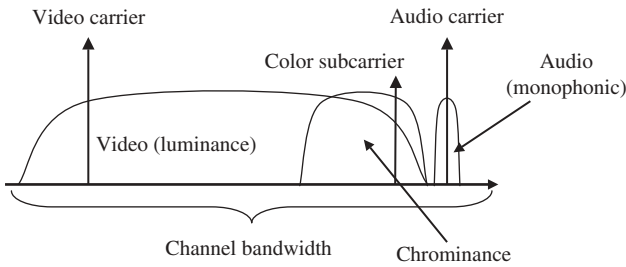


Figure 1.11 Spectrum of a color analog television channel.

vestigial sideband modulation for the chrominance signal, with the lower sideband dominant. Each of the three standards specifies the location for the color subcarrier, which is the carrier frequency associated with the modulation of the chrominance signal. The carriers for the two chrominance signals have the same frequency, but differ in phase by 90° . This “phase multiplexing” allows separation of the signals at the receiver. Noting that most of the energy in video signals occurs at low frequencies, the chrominance information is transmitted toward the upper end of the video spectrum. This does have the effect that high-frequency luminance information can sometimes be mistakenly decoded as color information. It is for this reason that herringbone tweed jackets sometime flair purple on color television receivers. The high-frequency monochrome information from the tweed is incorrectly decoded as color information. The problem has been addressed by television producers becoming aware of the problem and making sure that presenters do not wear inappropriate clothing.

A second audio channel can be incorporated simply by specifying the location of its carrier. Frequency modulation is usually also used for the second audio channel. Backward compatibility is maintained by ensuring that a valid monophonic audio signal for the program is transmitted on the original audio carrier. This is illustrated in Figure 1.12.

Each of the various standards for analog television (NTSC, PAL, and SECAM) specifies frequencies for the video carrier, color subcarrier, and audio carriers. Each standard also specifies maximum bandwidths for the video and each of the audio channels.

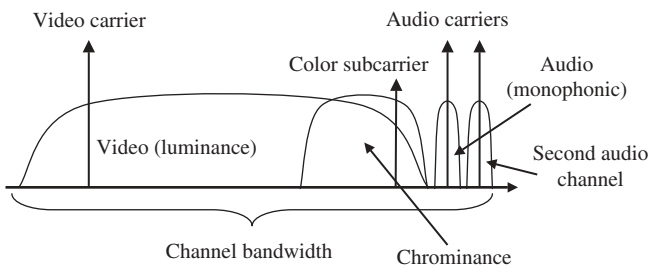


Figure 1.12 Spectrum of a typical color analog television channel with stereo audio.

1.2.3.1. Ancillary Services

Analog television systems have evolved to carry not only audio and video signals, but also a range of ancillary data services. These ancillary services make use of the nondisplayed lines of the video vertical blanking interval to provide low-rate data services such as closed captioning (also known as subtitling) and teletext. Because these services are carried in the vertical blanking interval, they have no impact on receivers that are not equipped to decode them.

1.3. THE MOTIVATION FOR DIGITAL TELEVISION

The initial impetus for moving to a digital signal was standards conversion (e.g., from 525 line NTSC at 30 pictures/s to 625 line PAL at 25 pictures/s). This is an extremely difficult process in the analog domain. Significant signal processing is still required in the digital domain. However, appropriate high-speed hardware can be built to allow the task to be successfully carried out. Other motivations for the change from analog to digital television include carrying multiple digital television channels within the existing bandwidth allocated to a single analog television service, the ability to carry higher resolution services (such as high-definition television) in a single channel, and the integration of a range of interactive services into the television broadcast.

From a communication point of view, digital transmission has many advantages. In particular, it offers considerable noise immunity. Consider the analog signal shown in Figure 1.13. The original analog signal is perturbed by noise. If the noise is

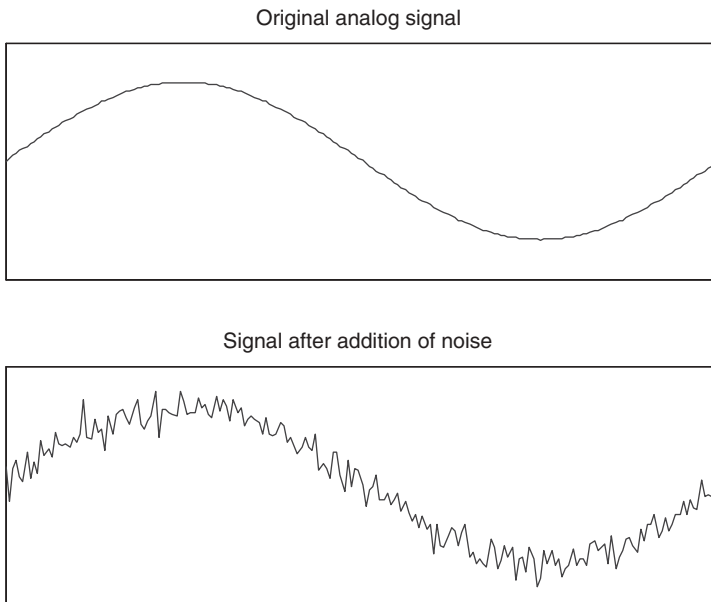


Figure 1.13 Impact of noise on an analog signal.

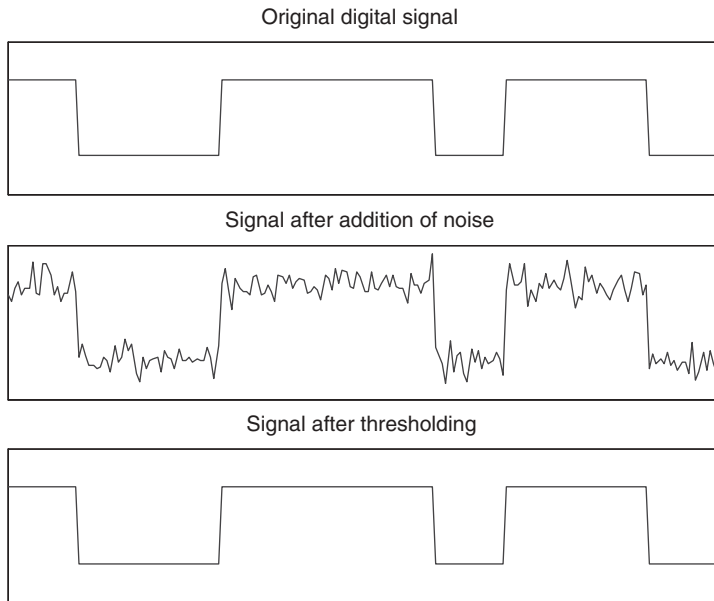


Figure 1.14 Impact of noise on a digital signal.

in the same area of the spectrum as the signal (so-called in-band noise), then there is little that can be done to remove it.

The impact of noise on a digital signal is quite different, as illustrated in Figure 1.14. In this case, a simple thresholding operation allows the original signal to be perfectly reconstructed. Even when the noise is large enough to cross the threshold, enhanced signal processing techniques such as matched filtering [3] can be employed to achieve good performance (which can be improved still further using error correction techniques such as those described in a later chapter). The ability of digital signals to reject noise makes digital systems ideal for long-distance transmission because quality can be maintained through many repeaters.

Other advantages of digital systems include the fact that digital components are of low cost and are very stable. In addition, many digital networks are now emerging for the transmission of audiovisual material at a range of transmission rates.

1.4. THE NEED FOR COMPRESSION

If digital systems offer so many advantages, why have we not moved to digital television long ago? The answer lies in the very high data rates required for transmitting raw, uncompressed digital video and the complexity of the digital systems required to provide real-time processing for compression and decompression.