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JERRY WHITAKER
SERIES ADVISOR

# Digital Television Fundamentals

## DESIGN AND INSTALLATION OF VIDEO AND AUDIO SYSTEMS

- Explains all relevant SMPTE and CCIR-ITU standards
- Details SDTV and HDTV equipment compatibility issues
- Suggests transition scenarios from SDTV to DTV

SECOND EDITION

(1)

MICHAEL ROBIN and MICHEL POULIN

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Design and Installation of Video and Audio Systems

Michael Robin
Michel Poulin

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# Contents

# Preface

Analog television, as it has been commercially available to the public for some 60 years, is undergoing major changes. These changes have to do with the manner in which the electrical equivalent of the image is generated, processed, recorded, and transmitted to the intended viewer.

Young professionals and recent graduates have a very sketchy and limited appreciation of the analog television technology on which all-digital television developments are based. However, mostly owing to job-related pressures, more mature professionals, deeply anchored in the analog television technology, have had only a limited opportunity to acquire an adequate understanding of the rapidly evolving digital technology.

The authors were fortunate in being able to make a smooth transition from the analog to the digital technology mostly during their tenure at the Canadian Broadcasting Corporation's Engineering Headquarters in Montreal, Canada. This book reflects the experience they have acquired in the areas of television production systems design and implementation, evaluation of equipment and technologies, active participation in the development of SMPTE standards, development of test procedures and equipment, training of engineering and technical personnel, presentations at various SMPTE conferences, and consulting to broadcasters and equipment manufacturers. This activity culminated in their active involvement in the development and implementation of the all-digital Toronto Broadcasting Center of the Canadian Broadcasting Corporation, the first major teleproduction complex using the bit-serial 270-Mbps signal distribution concept.

This book is intended for practicing engineers and technicians in the field of broadcasting and studio/video productions as well as for students of broadcast technology. It revisits the basics of analog television, video and audio, for the benefit of neophytes. It then proceeds to gradually introduce the reader to the basics of digital video and audio, reviewing, detailing, and explaining the international standards and their practical implementations.

Chapter 1 revisits the basic principles of television, irrespective of the scanning standards. It reacquaints the reader with some of the basic physical and physiological constraints, which have influenced the adoption of cost-effective analog television standards, given the technology of the times. Several aspects of the basic television standards such as scanning, resolution, video signal makeup, baseband spectrum, and transmission constraints are discussed in detail.

Chapter 2 deals with analog video fundamentals. It covers such topics as the general principles of color television (colorimetry, transducer transfer characteristics, the basic ingredients of the color television signal, and a detailed discussion of the reference color television signal: the color bars signal); the composite video concept (common characteristics of various color television systems such as compatibility with monochrome television and the principle of frequency-division multiplexing, summary of the contemporary standard definition composite analog color television systems NTSC, PAL, SECAM, performance-indicative parameters and measurement concepts, the distribution and recording of composite video signals); and the component video concept (detailed descriptions of component video signals, performance-indicative parameters and measurements concepts, the distribution and recording of component video signals).

Chapter 3 introduces the reader to the digital video world. It covers such topics as general considerations (historical background, the typical black box digital device, sampling of the signal, quantizing of the sampled values, dynamic range and headroom concept, quantizing error, and digital-to-analog conversion), the composite video digital standards (the $4f_{SC}$ NTSC and $4f_{SC}$ PAL standards detailing the general specifications, sampling structure, quantizing range and its implications, digital raster structure, performance-indicative parameters and test concepts, and a description of the bit-parallel signal distribution concept) and the component digital standards (the sampling rates, coded signals, sampling frequencies, quantizing range, sampling structure, time-domain multiplexing of data, timing reference signals, ancillary data concept, bit-parallel signal distribution concept, a review of component digital formats, and a discussion of the performance-indicative parameters and test concepts).

Chapter 4 revisits some basic principles of acoustics as they relate to the human hearing process and discusses such topics as the sound pressure level (SPL), loudness, as well as the dynamic range and spectral resolution of the ear.

Chapter 5 deals with analog audio topics such as electric signal levels, typical signal levels and level monitoring, performance-indicative parameters, dynamic range, and performance targets.

Chapter 6 introduces the reader to the digital audio world. It covers such topics as general concepts of digital audio, A/D conversion, D/A conversion, biphase mark encoding, general structure of the interface and its implementation, digital audio signal distribution, the MADI and SDIF interfacing protocol formats, audio synchronization, and digital audio recording.

Chapter 7 deals with the bit-serial signal distribution concept and the ancillary data multiplexing. It covers such topics as Shannon's theorem, channel coding, the eye diagram, the bit-serial distribution standard (interface characteristics, $4f_{SC}$, and 4:2:2 applications), performance-indicative parameters and measurement concepts (transmitter-related, medium-related, receiver-related), special test signals, digital audio multiplexing, digital videotape recording, and system considerations.



Chapter 8 covers with digital signal compression and distribution. It discusses such topics as general concepts, video data reduction techniques (with emphasis on the DCT coding process, video compression standards such as JPEG and MPEG, and video BRR performance and applications), audio data reduction techniques (with emphasis on audio compression standards and audio BRR performance and applications), and the distribution of compressed signals.

Chapter 9 deals with computers and television. It covers such topics as the computer architecture, internal communication data buses (main, local, over the top, switched, router), computer display monitors, and expansion cards (controller, V/A, and PCMCIA).

Chapter 10 treats the subject of multimedia and television. It covers such topics as the concept, technologies, hardware, and systems (PC workstations, A/V signal processing, disk storage, servers, cameras, VCRs, CD-ROM, the DVI); the interconnections (interfaces, networks); multimedia software, systems, and applications (VOD, NVOD, Photo CD, CD-I, CTI); and multimedia standardization activities.

Chapter 11 covers advanced television (ATV) concepts. It treats such topics as the need for ATV, the ATV emergence, standardization efforts, the digital television (DTV) solution (interoperability, flexibility, compression, progressive versus interlaced scanning, image and pixel aspect ratio, production and clean aperture, audio considerations, and compatibility with film). A detailed analysis of the most important DTV formats follows, including the serial distribution concept and data embedding. The Grand Alliance system and the European approach are explained.

Chapter 12 introduces the reader to new infrastructure concepts and transport technologies that are needed in intra- and interfacility applications to transfer audio-video data streams and media files. Concepts of TV program conversion between all current video formats are developed. The remainder of the chapter is devoted to technical and practical considerations concerning the implementation of DTV systems, and cost-effective transition scenarios to implement a DTV architecture.

The book can be used as a tutorial, allowing the reader to proceed from basics to more advanced topics. Alternatively, an informed reader can select the chapter of particular interest.

This book could not have been written without the experience gained by the authors in the laboratories of CBC Engineering. The authors wish to thank SONY Corporation and Tektronix for their support and encouragement and the SMPTE for permission to use its standards as a reference source.

Last, but not least, the authors wish to thank their spouses for allowing them to scatter large amounts of paper in their respective homes in preparation for the publication of this book.

*Michael Robin*

*Michel Poulin*

Chapter

# 1

# Basics of Television

Conventional television, as is currently broadcast to home viewers, was developed in the 1930s, which was a time of rapid advance in the various techniques of telecommunication, among them, the transmission of sound and pictures. Conventional television standards are the result of these early developments. They reflect the technological limitations of the times, as well as human vision characteristics, and were a compromise between cost and performance. Given the large number of television receivers throughout the world, any technological advance has to be compatible in some manner with the existing standards.

## 1.1 Historical Background

After experimentation with unsatisfactory mechanical image-scanning methods, the electronic scanning method was adopted in the middle 1930s. Regular "high-resolution" television transmissions began almost simultaneously in England, Germany, and France. The picture definition of the day was about 400 lines per picture, for example, 441 lines in Germany and France and 405 lines in England. The horizontal-to-vertical aspect ratio of the picture was 4:3 and is still being used today in conventional television systems.

In 1941, after years of experimenting with various 300-line and 400-line picture formats, the United States adopted the 525-line National Television System Committee (NTSC) standard. This standard is still in use today with minor backward-compatible modifications.

After World War II, England continued with its 405-line broadcasts and France with its 441-line broadcasts. In 1948, France adopted the 819-line national television standard. The rest of Europe adopted the 625-line standard. For a while, there were no fewer than three scanning standards, two color standards [phase-alternating line (PAL) and séquential couleurs à mémoire (sequential colors with memory, or SECAM)], and seven incompatible transmission standards in simultaneous operation in Europe. The situation was corrected in the early 1980s when the French 819-line transmissions and the English 405-line transmissions were phased out. Currently, Europe shares a single scanning standard (625/50), two color standards (PAL and SECAM), and only four incompatible transmission standards.

## 1.2 The Eye-Brain Mechanism

### 1.2.1 The characteristics of visible light

Light is usually identified by wavelength rather than by frequency. Visible light is confined to a relatively narrow range of wavelengths, from about 380 to 760 nm (1 nm = $10^{-7}$ cm). The eye perceives various wavelengths as color hues. The wavelengths corresponding to the three primary colors are

- Red: 700.0 nm
- Green: 546.1 nm
- Blue: 435.8 nm

### 1.2.2 The light perception

The retina, upon which the image looked at is focused, consists of two types of receptors known as rods and cones. There are between 110 million and 130 million rods and between 6 and 7 million cones.

- The rods predominate in the periphery of the retina, are more sensitive to light than the cones, and are responsible for night (scotopic ) colorless vision. The rods have limited visual acuity.
- The cones predominate in the central area (fovea) of the retina, respond to higher levels of light intensity than the rods, and are responsible for day-light (photopic) color vision. At high light intensity levels the cones have a high colorless visual acuity and a diminished color visual acuity. As the light intensity decreases, the perception is shifted to the periphery of the retina where rods are more numerous.

The information received by the retina is transmitted to the brain through the optic nerve, which consists of about 800,000 individual fibers. Each fiber is fed by a dedicated ganglion cell. Almost every ganglion cell has connections to hundreds of rod cells and tens of cone cells. In the fovea region each cone has a direct connection to a dedicated ganglion cell in addition to sharing other ganglion cells with groups of cones and rods. This accounts for the high acuity of vision in the center of the visual field. This acuity diminishes as the light intensity decreases.

The information generated by the rods and cones is fed simultaneously to the brain, where the process of perception takes place. Figure 1.1 shows a simplified "block diagram" of the eye-brain mechanism outside of the fovea region.

The eye-brain mechanism results in two consequences:



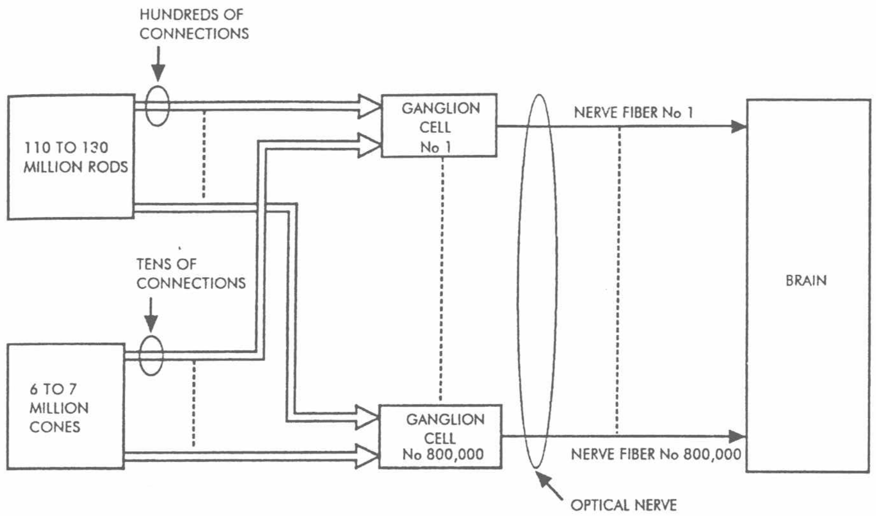


**Figure 1.1** Simplified block diagram of eye-brain mechanism outside the fovea region.

- The highest visual acuity occurs in the center of the image.
- Night vision is colorless.

### 1.2.3 Visual acuity

Visual acuity is measured as the angle subtended by the smallest visible detail in an object. Figure 1.2 illustrates the concept of visual acuity.

Television system design takes as a reference a visual acuity of the eye of the order of 1 minute of arc. The extent to which a picture medium such as television can reproduce fine detail is expressed in terms of resolution. Television resolution is equal to the number of alternately white and black horizontal lines that can be resolved vertically over the full height of the screen. It is expressed in lines per picture height (LPH). It is determined by the rod-and-cone structure of the eye and depends upon the brightness level and contrast ratio. The 525-line and 625-line standards were developed taking into consideration the visual acuity of the eye (1 min), assumed viewing conditions in the average home (viewing distance six times the picture height), and transmission-spectrum-saving concerns. The relationship between the number of picture elements that can be resolved given a specified picture height and viewing distance is given by

$$Nv = \frac{1}{\alpha n}$$

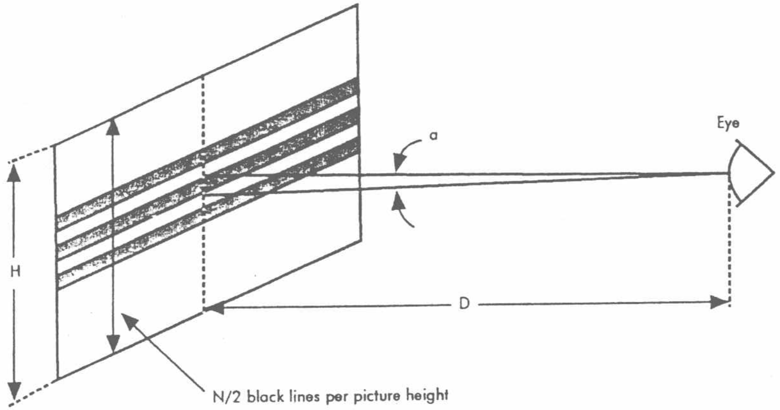


**Figure 1.2** Visual acuity concept.

where $N_v$ = Total number of elements to be resolved in the vertical direction
$\alpha$ = Minimum resolvable angle of the eye (in radians)
$n = D/H$ (viewing distance divided by picture height)

Given $\alpha$ = 1 min of arc, or $2.91\times10^{-4}$ radians, and $n$ = 6, we have

$$N_v = \frac{1}{(6 \times 2.91\times10^{-4})} \approx 572 \text{ lines}$$

This ballpark figure is at the origin of the number of lines specified for the two conventional television systems, namely, the 525-line system used mainly in North America and Japan, and the 625-line system used elsewhere in the world. The actual resolution is smaller than 525 or 625 lines for reasons explained in Sec. 1.4. High-definition-television standards, with 1125 or 1250 lines per picture, require shorter viewing distances (e.g., $n$ = 3) or larger screen sizes to enable the eye to resolve all picture details.

When color images are viewed, the visual acuity depends on the color. The acuity for blue and red is about 75% of that of a white image of the same brightness. The acuity for green is about 90% of that of a white image of the same brightness.

### 1.2.4 Persistence of vision

Persistence of vision is the ability of the viewer to retain or in some way to remember the impression of an image after it has been withdrawn from view. When light entering the eye is shut off, the impression of light persists for about 0.1 s. Ten still pictures per second is an adequate rate to convey the illusion of motion.



Motion pictures and television use higher rates than 10 still pictures per second in order to reduce the visibility of flicker. The critical flicker frequency is the minimum rate of interruption of the projected light that will not cause the motion picture to appear to flicker. The perceptibility of flicker varies widely with viewing conditions. Among the factors affecting the flicker threshold are luminance of the flickering area, the color of the area, the solid angle subtended by the area at the eye, the absolute size of the flickering area, the luminance of the surrounding area, the luminance variation with time and position within the flickering area, and the adaptation and training of the observer. In a constant viewing situation, that is, no change in the image or surrounding area, the luminance at which flicker just becomes perceptible varies logarithmically with luminance (the Ferry-Porter law). Empirical data indicate that increasing the flicker frequency by 12.6 cycles per second raises the flicker threshold level 10 times.

Motion pictures consist essentially of a sequence of 24 photographs (frames) of a single subject that are taken every second and projected in the same sequence to create an illusion of motion. Each successive image of a moving object is slightly different from the preceding one. When projected, each frame is presented twice, through the use of a mechanical shutter, resulting in a flicker rate of 48 cycles per second.

In television the picture elements are laid down on the screen one after the other through a process of scanning, but are perceived at the same time because of the persistence of vision. Scanning consists of breaking down the picture into a series of horizontal lines, for example, 525 or 625 in conventional television. In a process called interlaced scanning, each image is analyzed and synthesized in two sets of spaced lines. Each of the two sets comprises one half of the total number of lines (262.5 or 312.5) and fits successively within the spaces of the other. Each successive set of lines is called a *field*. Two consecutive (interlaced) fields constitute a frame. The field repetition frequency is nominally 60 Hz in the 525-line standard and 50 Hz in the 625-line standard. The frame repetition frequency is 30 and 25 Hz, respectively. In television the applicable flicker frequency is the field frequency. Two adjacent lines of two consecutive fields may not be identical, resulting in interline flicker. Interline flicker is tolerable because the eye is relatively insensitive to flicker when the variation of light is confined to a small part of the field of view.

Table 1.1 gives the flicker threshold for commonly encountered flicker frequencies. The low flicker threshold typical of motion pictures explains why

**TABLE 1.1 Flicker Threshold for Commonly Encountered Flicker Frequencies**

| Picture source | Flicker frequency, Hz | Frames per second | Flicker threshold, cd/m² |
|---|---|---|---|
| Movies | 48 | 24 | 68.5 |
| 50-Hz television | 50 | 25 | 99.4 |
| 60-Hz television | 60 (nominal) | 30 (nominal) | 616.7 |

they are projected in darkened rooms. The flicker threshold of the 525/60 scanning standard is considerably higher than that of the 625/50 scanning standard, resulting in more comfortable viewing in brightly lit rooms.

### 1.2.5 Spectral visibility

The physical quantity that primarily determines the sensation of light is its wavelength. What is physically defined as wavelength is subjectively perceived as color. Ordinary white light contains a continuum of wavelengths throughout and beyond the range of visibility. Any visible radiation of uniform wavelength is perceived by the eye as a single (monochromatic) color. Under photopic viewing conditions, the brightest part of a spectrum, consisting of equal amounts of energy at all wavelengths, corresponds to a wavelength of about 560 nm. From this maximum, visibility falls off toward both ends of the spectrum. Under scotopic viewing conditions, the maximum perceived brightness shifts down to about 500 nm, resulting in a drastically reduced visibility in the red region. Figure 1.3 shows the relationship between scotopic and photopic vision.

## 1.3 The Scanning Standards

The scanning standards define the manner in which a television scene is explored for its luminance and chrominance values. They specify the number of lines per frame and the number of frames per second. Technical and economic considerations have led to certain compromises in the transmission of the essential information required by the eye. The first important consideration is the fact that any electronic system is capable of transmitting only one bit of information at a time. Consequently, the picture has to be broken down into

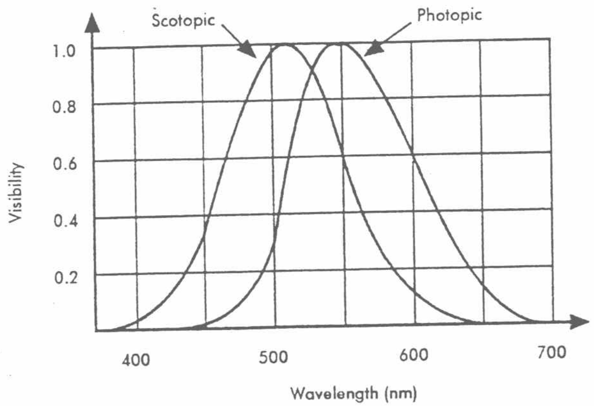


**Figure 1.3** Visibility curves of the human retina.



small elements transmitted sequentially and then reconstructed at the receiver. In the end, all the elements of the reconstructed picture have to appear simultaneously to the eye.

### 1.3.1 The scanning process

The conventional television standards reflect the image pickup and display technology of the 1930s. This assumes that the camera uses a pickup tube where the image is focused onto a photoconductive layer. Electrical charges, proportional to the illuminated scene at each point, are developed and stored capacitively on this layer. An electron beam is used to convert the charge image into an electrical current. This beam is focused to a circular spot and deflected continuously over the image in two consecutive fields of horizontal lines. Each consecutive field contains half of the total number of scanning lines into which the picture is scanned. Two consecutive fields (field 1 and field 2) are displaced vertically such that their scanning lines are interlaced, and together they form a frame. The image is scanned from left to right, starting at the top and tracing successive lines until the bottom of the picture is reached. The beam then returns to the top and the process is repeated. The continuous deflection of the electron beam is achieved by subjecting it to two perpendicular (vertical and horizontal) magnetic fields that result from repetitive sawtooth-shaped currents flowing through a pair of (horizontal and vertical) deflection coils. The process is called *linear interlaced scanning*. The repetition rate of the horizontal component is related to the vertical component by the factor *n*, resulting in the formation of *n* lines during a complete vertical period. The retrace times involved (both horizontal and vertical) are a result of the physical limitations of early scanning systems. The retrace times are not utilized for the transmission of a video signal but for the transmission of auxiliary information such as horizontal and vertical scanning synchronization.

In the display device, a cathode-ray tube (CRT) re-creates the original picture. A focused electron beam, deflected horizontally and vertically in synchrony with the pickup tube electron beam, is projected onto a phosphor-coated viewing screen. The CRT beam current is, ideally, proportional to the beam current in the pickup tube, and the deflection currents through the deflection coils are in synchrony with those of the pickup tube. In reality, the CRT electron beam current versus control voltage transfer characteristic is not linear. To correct for this condition, the camera video amplifier introduces an opposite nonlinearity, called *gamma correction*, resulting in a linear relationship between original picture brightness and CRT-reproduced brightness. This subject will be discussed further in Chap. 2. Figure 1.4 shows a simplified block diagram of the monochrome television system from signal source to CRT display.

### 1.3.2 Lines per frame

This parameter was chosen to provide a value of vertical resolution appropriate to the acuity of normal vision at a distance of about six times the screen height.

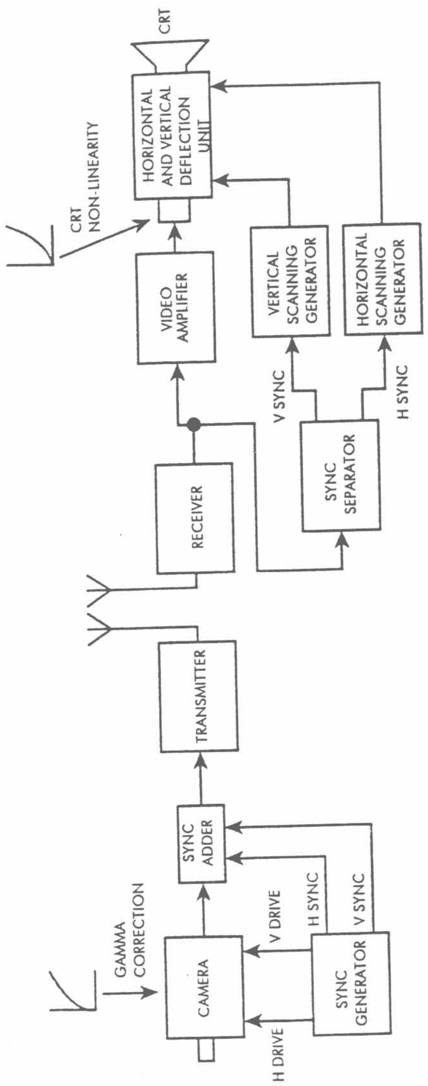


**Figure 1.4** Simplified block diagram of monochrome television system from signal source to CRT display.





There is an odd number of lines per frame. The standardized values for conventional broadcast television presently are 525 and 625 lines per frame.

### 1.3.3 Pictures per second

The pictures per second standard is chosen to provide a sufficiently rapid succession of complete pictures (frames) to avoid flicker at levels of image brightness appropriate to viewing images in domestic surroundings. The frames are made up of two consecutive fields, each containing half of the total number of lines (262.5 or 312.5). The lines in two consecutive fields are interlaced, resulting in a frame made up of the total amount of lines (525 or 625). Historically, the values for the field repetition frequency were chosen to be equal to the power-line frequency, 60 Hz in the United States, Canada, and Mexico, and 50 Hz in other parts of the world. Under extreme conditions, a display in synchrony with the power-line frequency reduces the visibility of scanning distortions caused by stray magnetic fields and hum components, should they exist. This reduced visibility is obtained when the receiver and the transmitter operate from the same power source, which is not always the case. Consequently, the practice of synchronizing the field rate to the power line frequency has long been discontinued and, today, the vertical scanning frequency is only nominally equal to the power-line frequency, since it is obtained by counting down from a highly stable crystal-controlled high-frequency oscillator.

### 1.3.4 The conventional scanning standards

Two conventional television scanning standards coexist in the world today. These are the 525/50 standard and the 625/50 standard. These standards represent a cost versus performance choice based on the technology of the 1930s. Table 1.2 summarizes their characteristics.

## 1.4 The Resolution Concept

Historically, *resolution* was understood to mean "limiting resolution," or the point at which adjacent elements of an image cease to be distinguished. Various disciplines measure and specify resolution differently. Resolution can be specified as

- The number of units (i.e., lines or line pairs) per unit distance along the vertical and horizontal axis, such as lines per millimeter.
- The number of units (i.e., lines) for a full display, such as lines per picture height (LPH).

In television, the resolution is specified in terms of LPH. The various conventional television systems in use today were designed to achieve equal horizontal and vertical resolution, better known as *square pixels*.

**TABLE 1.2 Significant Parameters of Conventional Scanning Standards**

| Parameter | 525/60 Standard | 625/50 Standard |
|---|---|---|
| Number of lines per frame | 525 | 625 |
| Number of lines per field | 262.5 | 312.5 |
| Number of frames per second | 29.97 | 25 |
| Number of fields per second ($f_V$), Hz | $2f_H/525 = 59.94$ | $2f_H/625 = 50$ |
| Horizontal scanning frequency ($f_H$), Hz | $3 \times 5 \times 5 \times 7(f_V/2) = 15{,}734.25$ | $5 \times 5 \times 5 \times 5(f_V/2) = 15{,}625$ |
| Field blanking duration (lines) | 20 | 25 |
| Frame blanking duration (lines) | 40 | 50 |
| Number of active lines per frame | 485 | 575 |
| Vertical resolution ($N_V$), LPH | $485 \times 0.7 \approx 339$ | $575 \times 0.7 \approx 402$ |
| Total line duration, µs | 63.556 | 64 |
| Horizontal blanking duration, µs | $10.7 \pm 0.1$ | $12 \pm 0.3$ |
| Active line duration, µs | 52.856 | 52 |
| Horizontal pixels for equal *H*/*V* resolution | $339 \times (4/3) \approx 452$ | $402 \times (4/3) = 536$ |
| Line-pair cycle duration (*T*), µs | $52.85/226 \approx 0.2338$ | $52/268 = 0.194$ |
| Bandwidth for equal *H*/*V* resolution, MHz | $1/T \approx 4.28$ | $1/T = 5.15$ |
| Horizontal resolution factor, lines/MHz | $339/4.28 \approx 79.2$ | $402/5.15 = 78$ |
| Horizontal resolution ($N_H$), LPH | 333 (@4.2-MHz bandwidth) | 390 (@5-MHz bandwidth) |
| *H*/*V* resolution ratio | 0.98 | 0.97 |

### 1.4.1 Vertical resolution

The vertical resolution is independent of the system bandwidth and defines the capability of the system to resolve horizontal lines. It is expressed as the number of distinct horizontal lines, alternately black and white, that can be satisfactorily resolved on a television screen. Vertical resolution depends primarily on the number of scanning lines per picture and the combined effects of the camera pickup tube and the CRT scanning spot size and shape.

Ideally, the vertical resolution would be equal to the number of active lines per frame. This would happen if the scanning lines were centered on the picture details as shown in Fig. 1.5. The scanning lines cannot be assumed to occupy a fixed position relative to vertical detail at all times. Complete loss of vertical resolution will occur when the scanning spot straddles picture details as shown in Fig. 1.6. From subjective data, it has been found that raster lines in excess of the number of elements to be resolved are necessary, as shown in Fig. 1.7. This can be expressed by

$$N_V = kN_{AL}$$



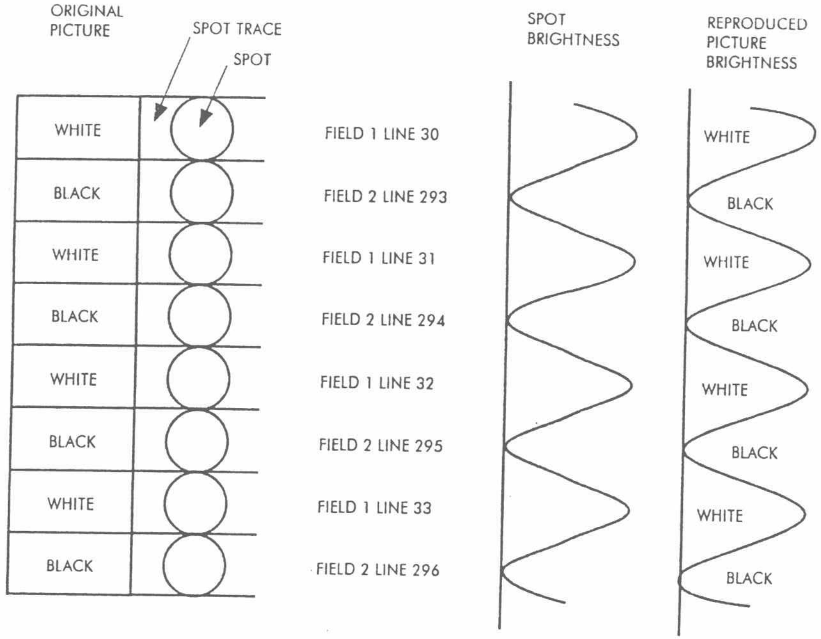


**Figure 1.5** Vertical resolution equals number of active lines when the raster lines are centered on the picture details.

where $N_V$ = Number of active vertical picture elements (pixels) to be resolved.
$N_{AL}$ = The number of active lines (excluding lines formed while the beam is returning to the top of the picture).
$k$ = Constant obtained from subjective measurements. This is called the *Kell factor* and is usually taken as 0.7.

In the 525/60 scanning standard there is a total of 525 lines per frame, of which 40 are blanked, leaving 485 active lines per frame. Given a Kell factor of 0.7, the effective vertical resolution of the 525/60 scanning standard is:

$$N_V = 0.7 \times 485 \approx 339 \text{ LPH or pixels}$$

In the 625/50 scanning standard there is a total of 625 lines per frame, of which 50 are blanked, leaving 575 active lines per frame. Given a Kell factor of 0.7, the effective vertical resolution is:

$$N_V = 0.7 \times 575 \approx 402 \text{ LPH}$$

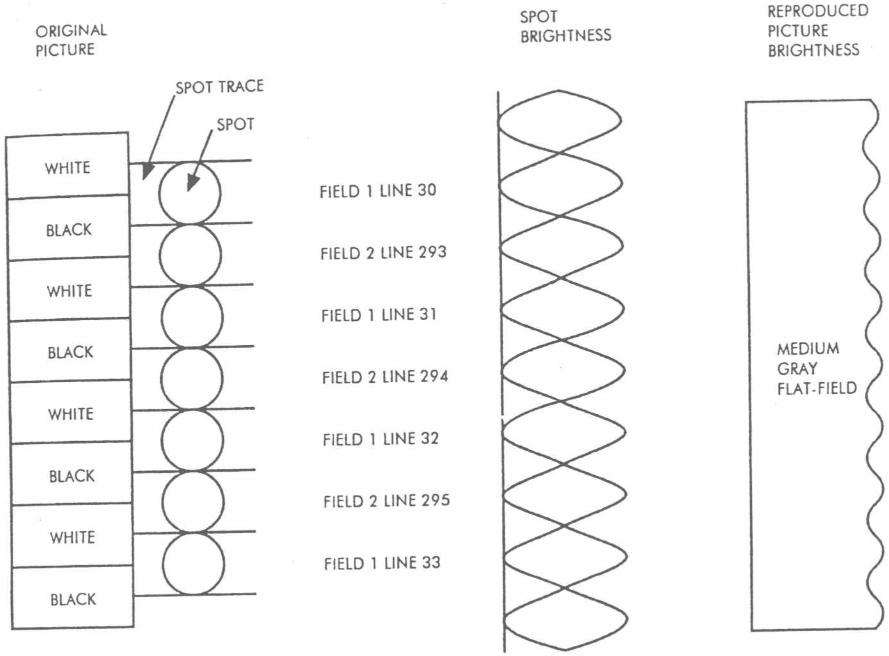


**Figure 1.6** Loss of vertical resolution resulting from scanning spot straddling picture details.

### 1.4.2 Horizontal resolution

The horizontal resolution is directly related to the system bandwidth and defines the ability of the system to resolve vertical lines. It is expressed as the number of distinct vertical lines, alternately black and white, that can be satisfactorily resolved in three quarters of the width of a television screen. The horizontal resolution depends on the combined effects of the camera pickup tube and CRT scanning spot dimensions as well as the high-frequency amplitude and phase response of the transmission medium. A system with a horizontal to vertical aspect ratio of 4/3, as in conventional television, needs to allow for $(4/3)N_V$ horizontal pixels to be resolved. In the 525/60 scanning standard, this results in $339 \times 4/3 \approx 452$ horizontal pixels.

Because of the finite size of the scanning spot, a beam exploring a pair of contiguous white-and-black pixels (line pair) results in a sine wave with a positive half-wave corresponding to the white pixel and a negative half-wave corresponding to the black pixel (see Fig. 1.8). A scanning beam exploring a

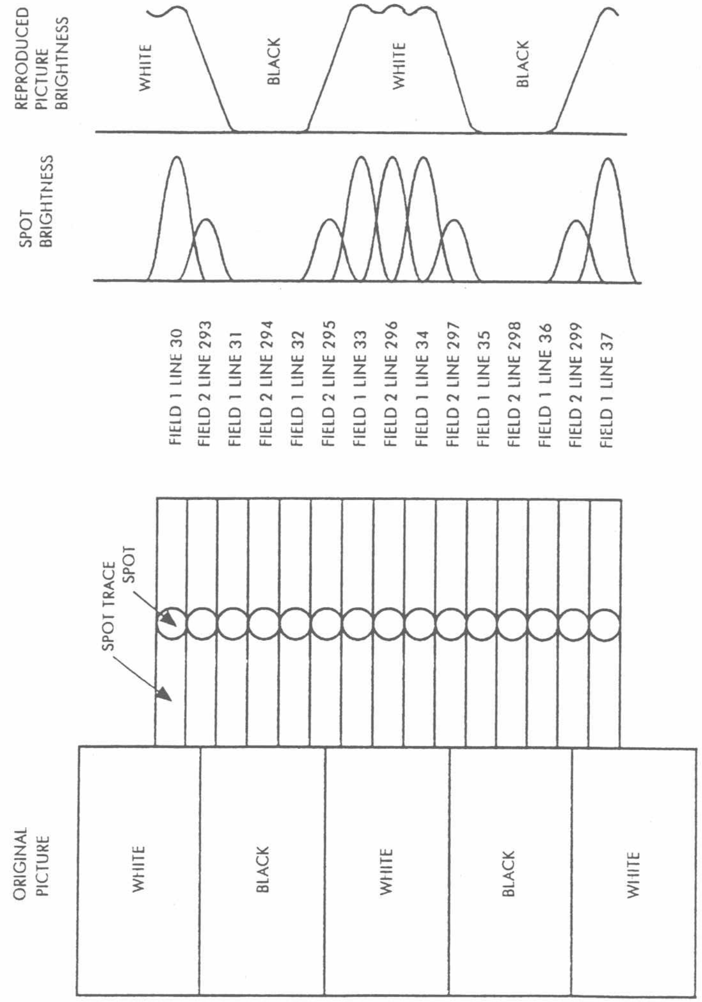


**Figure 1.7** Effect of scanning spot shape and size on vertical resolution.

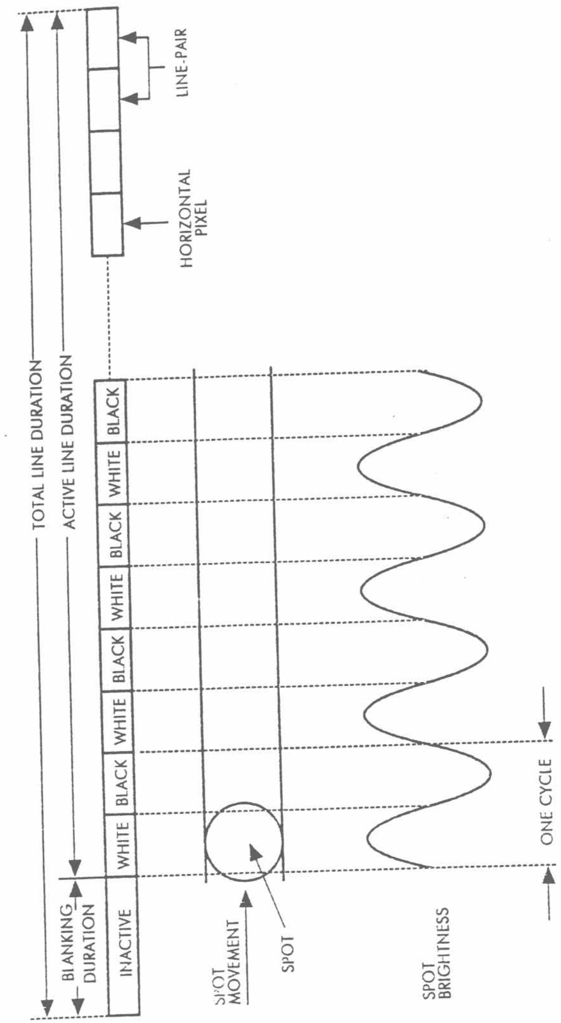


**Figure 1.8** The horizontal resolution concept.





picture made up of 452 horizontal pixels results in an electrical signal with 226 complete cycles during the active horizontal scanning line.

In the 525/60 scanning standard the total horizontal scanning line duration is 63.5 μs and the horizontal blanking duration is 10.7 μs, resulting in an active line duration of 52.85 μs. The duration of a single cycle is

$$T = \frac{52.85\ \mu s}{226} \approx 0.2338\ \mu s$$

The fundamental frequency resulting from scanning 452 horizontal pixels is

$$F = \frac{1}{T} = \frac{1}{0.2338\ \mu s} \approx 4.28\ \text{MHz}$$

This is the bandwidth required for equal horizontal and vertical resolution. The horizontal resolution factor for a 4.28-MHz bandwidth is

$$\frac{339}{4.28}\ \text{MHz} = 79.2\ \text{lines/MHz}$$

In countries using the 525/60 scanning standard (CCIR M) the maximum transmitted baseband video frequency is 4.2 MHz, resulting in a transmitted horizontal resolution of

$$N_H = 4.2\ \text{MHz} \times 79.2\ \text{lines/MHz} \approx 333\ \text{lines}$$

The resulting horizontal versus vertical resolution ratio is therefore 333/339 ≈ 0.982. From an analog point of view, this represents a quasi-square pixel.

The minimum video bandwidth for equal horizontal and vertical resolution in the 625/50 scanning standard is 5.15 MHz, and the resulting horizontal resolution factor is 78 lines/MHz. Various countries have adopted different maximum transmitted baseband video frequency values, resulting in different transmitted horizontal resolutions as shown in Table 1.3.

Table 1.2 lists relevant figures of significant parameters for the 525/60 and 625/50 scanning standards.

**TABLE 1.3 Horizontal Resolution Capability of Various 625/50 Transmission Standards**

| Standard | Bandwidth, MHz | $N_H$, LPH | $N_H/N_V$ |
|---|---|---|---|
| CCIR N | 4.2 | 327 | 0.81 |
| CCIR B,G | 5 | 390 | 0.97 |
| CCIR I | 5.5 | 429 | 1.067 |
| CCIR K,L | 6 | 468 | 1.16 |