31

Cathode Ray Tube Displays

Christopher J. Sherman

31.1 Introduction

The cathode ray tube (CRT) is unequaled in its ability to produce dynamic, quality, high-information-content imagery at high resolution. Even more impressive is that it achieves this for a lower cost per pixel than any other comparable electronic display technology. For the instrument designer requiring a high-information-content display, it offers numerous advantages. As a raw image tube, it is commonly available as an off-the-shelf item with a broad infrastructure of vendors, integrators, support, and part suppliers. Interface standards are well established and as a complete system, ready to take a standard signal input, it is available worldwide in a variety of performance ranges. To meet different application requirements, it is available in diagonal sizes from 12 mm to over 1 m with resolution from thousands of pixels to over 5 million pixels per frame. Tube characteristics improve on a yearly basis, and prices continue to decrease. Stanford Resources has been tracking the CRT market for almost 20 years, and is an excellent source of information. In its latest report, it indicates that despite competition from other display technology, the CRT will remain the single largest market in the display industry. The worldwide market for CRT tubes in 1997 was 261 million units worth $26 billion U.S. This is expected to grow to 341 million units worth more than $34 billion by 2003 [1, 2]. Although there are many competing information display technologies, the CRT will be with us well into the 21st century.

31.2 History

The CRT has a rich and distinguished history. The roots of today's CRT technology extend back more than 100 years to the latter half of the 19th century. Eugene Goldstein first introduced the term *cathode rays;* John W. Hittorf, Heinrich Geissler, Julius Plücker, and others made important contributions specific to CRT technology [3]. Throughout the 19th century, researchers were interested in the nature of a luminous gas discharge and shadowy rays that occurred when a high voltage potential was applied between two electrodes in a vacuum. Sir William Crookes was an active experimentalist in this field, and early cathode ray devices came to be known as Crookes tubes. Crookes noted that a glow was generated by the surface that the rays struck; the rays themselves were not the source of light. By producing tubes with a vacuum of 1.3×10^{-4} Pa (10^{-6} torr), he eliminated the luminous gas discharge and worked directly with the cathode rays [4]. Crookes demonstrated the following: luminance depended directly upon the material properties of the surface the rays struck; a magnetic field would deflect the path of the rays; the deflection was proportional to the strength of the magnetic field; and a magnetic field could be used to focus the rays into a beam. He also suggested the rays emitted by the cathode were a stream of charged tiny particles, which were soon to be identified by Joseph John Thomson as electrons. Continuing CRT experimentation lead to the discovery of x rays by Wilhelm Konrad Röntgen in 1895.

Ferdinand Braun was the first person to envision the CRT as a tool for the display of information and is generally credited with the invention of the first device to be a direct forerunner to the modern CRT [5]. Braun in 1896 designed a CRT "indicator tube" for monitoring high frequencies in power-generating equipment. His design contained all of the same elements as today's CRTs. It utilized a cathode as an electron source, two control coils for vertical and horizontal deflection, an anode for electron acceleration and beam control, and a focusing slit. He also incorporated a phosphor screen normal to the beam for tracing its path. Although crude by later standards, this was the direct prototype for CRT oscilloscopes. In 1903 to 1905 Arthur Wehnelt added several very significant advances to Braun's design. Wehnelt developed and implemented a hot oxide–coated cathode and a beam control grid [5]. This lowered the voltage necessary to generate the electron stream and provided for much finer control of the beam current. These developments were the forerunner of the modern electron gun.

The CRT remained mostly a laboratory device until three important applications ushered it onto the center stage of information display: oscilloscopes, television, and military radar. By the early 1900s oscilloscopes were being widely used for the study of time-varying electric circuits in communication. Television was developed in the 1920s and in July of 1930 the National Broadcasting Company began the experimental broadcast of television in New York City. During World War II the CRT underwent a second wave of maturation with the advent of radar technology. By the end of the 1940s the TV-CRT was available as a consumer product. In the 1950s RCA perfected shadow mask technology and before long color became a new standard, gaining wide consumer acceptance in the 1960s. While the principal components of a CRT system have not fundamentally changed in many decades, the CRT has continued to improve.

31.3 Image Formation with a CRT

Although there are many different CRT designs, some of which are quite intricate, the process of forming an image using a CRT is straightforward. The procedure can be divided into four basic stages: beam formation, beam focusing, beam deflection, and energy conversion. These stages occur in four different regions of the CRT and follow in order from the rear of the tube (the neck) to the faceplate. As shown in Figure 31.1, the elements at the rear of the tube are collectively called the electron gun.

Beam Generation with the Electron Gun

The cathode generates the stream of electrons used to form the image-writing beam. The traditional cathode is a metal conductor such as nickel coated with a thin layer of oxide, typically a barium strontium

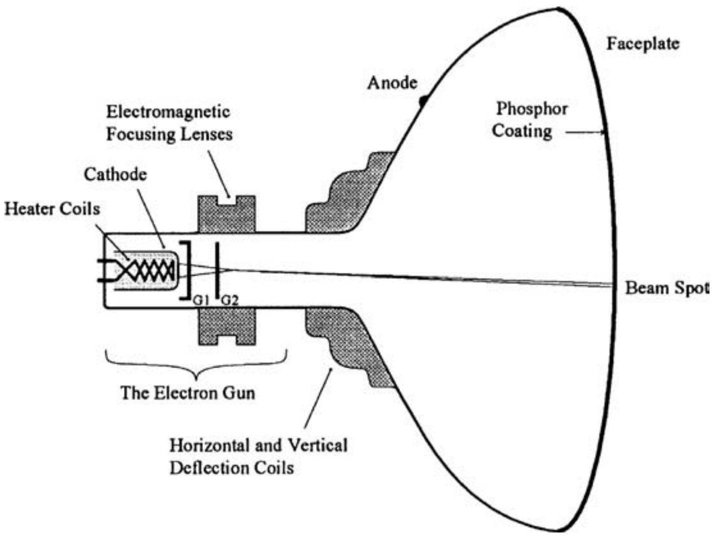

FIGURE 31.1 Example of a typical CRT with electromagnetic focus, and electromagnetic deflection. This type of tube design is usually used for demanding applications such as bright, high-resolution image projection. Tubes like this are available from a number of manufacturers such as Sony, Matsushita, and Thomson.

compound. To reduce the voltage required to generate electron emission, the cathode is heated to 700 to 1200°C. Applications that require high brightness often use more advanced and expensive dispenser cathode designs to increase the beam current while maintaining reasonable cathode life. These designs incorporate complex cathode structures and materials such as barium ceramics, molybdenum, rhenium, and tungsten. Readers interested in advanced cathode designs and additional information on CRT materials technology should consult References 6 through 10. The flow of electrons from the cathode is controlled by varying the potential between the cathode and a series of control grids commonly known as G1 (the control grid) and G2 (the acceleration grid). A voltage potential of 100 to 1000 V between G2 and the cathode creates the potential necessary to pull a stream of electrons off the cathode, forming the beam. The beam amplitude can be controlled and even completely shut off by varying the potential on G1. Thus, the voltage at G1 controls brightness because the brightness is proportional to beam current. The design of the cathode with respect to impedance and loading influences the maximum rate at which the beam can be modulated. The cathode and its associated control grids can be designed to produce a crossover flow of electrons or a laminar flow. In crossover gun designs, the emitted electrons converge to a point in front of the cathode. By using electron optics, this beam spot is imaged onto the phosphor screen. Due to inherent advantages, the crossover design is widely used. A crossover beam is narrow, making it easier to deflect than a thicker beam, and the spot can be very small, improving resolution at the screen. In theory, a laminar flow design provides for the possibility of higher beam current from a similar-sized cathode. In practice, the improvement is not usually advantageous enough to offset the added difficulty of controlling a wider beam.

Electron Beam Focusing

Beam focusing and beam current are critical in determining the final spot size and thus the resolution of the CRT. Focusing a beam of electrons is directly analogous to focusing a beam of light; the discipline is called electron optics. Concerns familiar to optical imaging such as magnification, spherical aberration, and astigmatism also confront electron optics. As CRTs become larger, and operate at higher deflection angles, spot control becomes critical. Beam focusing is achieved using either electrostatic focusing grids or electromagnetic focusing coils. Electrostatic focus is the most extensively used technique. It can be found in use in applications from television to desktop computer monitors. Electrostatic focus is achieved by applying a succession of potentials across a complex sequence of focusing grids built into the electron gun. As designers seek to improve performance further, grid designs have become intricate [11, 12]. Magnetic focus is the system of choice for all high-performance systems where resolution and brightness are design objectives. Magnetic lenses are better at producing a small spot with few aberrations. External coils in a yoke around the neck of the tube control the beam. Since it provides superior performance, electromagnetic focus is common on high-resolution commercial systems. Magnetic focus can also be achieved using permanent magnets and specialized hybrid electrostatic/magnetic focus components. Due to the tremendous impact focus has on resolution, tube suppliers continue to improve focus control [13, 14]. For an excellent and comprehensive treatment of electron physics in CRTs, beam control, detailed design discussions, and other aspects of CRT devices, consult Sol Sherr's textbook [15].

Electron Beam Deflection

The beam deflection system is responsible for controlling the position of the spot on the front face of the CRT. As with focusing, beam deflection techniques can be electromagnetic or electrostatic. A magnetic deflection system consists of two electromagnetic yolks on opposite sides of the CRT neck; a horizontal deflection coil and a vertical deflection coil. The position of the beam is easily controlled; the amount of beam deflection is directly proportional to the current in the coil. Deflection coil design also influences spot size and shape. Coil designs can incorporate correction for coma, convergence errors, and pincushion distortion [16]. Because of its low cost and efficiency, CRTs for both moderate- and high-resolution applications normally use magnetic deflection. Electrostatic deflection provides faster beam displacement but less spot size control. It is typically used in oscilloscope systems, where resolution requirements are moderate and deflection speed is paramount.

31.4 CRT Addressing: Raster Scanning vs. Stroke

Raster scanning is the most common CRT addressing technique. In raster scanning the electron beam writes each frame one line at a time. This means the horizontal deflection system requires a higher bandwidth than the vertical deflection system. High-performance raster CRTs have a horizontal bandwidth of 15 to 150 kHz, and a vertical deflection bandwidth of 30 to 180 Hz. The information is written onto the front face of the CRT from left to right and top to bottom, one line at a time. Raster scanning can be interlaced or progressive (noninterlaced). In interlace scanning, each frame of information is decomposed into two fields. The first field consists of all of the odd-numbered lines in the original frame, and the second field contains all of the even-numbered lines. Each field is scanned onto the CRT at twice the frame rate. Commercial television is interlaced. In the U.S., the frame rate is 30 Hz and the field rate is 60 Hz; this scheme is known as the NTSC standard. PAL and SECAM are two other well-known commercial formats in use today. There are numerous other standards, both analog and digital, in use worldwide, each with slightly different scan rates, resolution/addressing formats, luminance and color encoding, and timing protocols [17, 18]. Interlace scanning is an engineering compromise that conserves transmission bandwidth, electronics bandwidth, and CRT bandwidth, while maintaining acceptable performance with respect to moving imagery, resolution, and flicker. Computer monitors employ a progressive raster scan. Each frame has one field. The display is generated line by line, in order from the first pixel to the last pixel. Frame rates for the typical desktop monitor vary from 60 to 85 Hz to over 180 Hz for specialized systems.

Stroke is an alternative addressing technique that was once quite common. The name for the technique comes from the phrase "the stroke of a pen." Stroke is a point-to-point addressing system. The beam is directed to the starting point of a line, turned on, and then moved directly to the end of the line. Because there are no raster lines, stroke CRT resolution is independent of direction and is limited primarily by spot size. Stroke addressing is excellent for low-information-content screens with detailed graphic characters or simple vector graphics. It provides extremely high quality drawing, clean lines, precise detail,

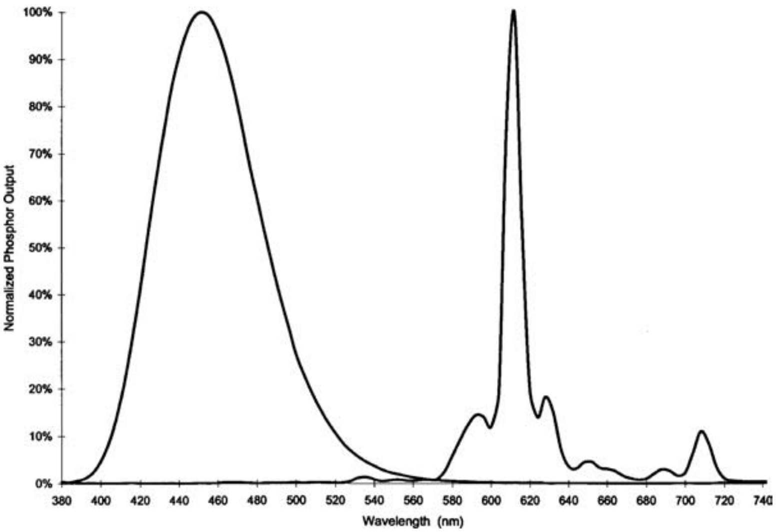

FIGURE 31.2 Phosphors can have a wide range of spectral characteristics. This graph illustrates the spectral profiles of two representative cases. The blue source is an example of a phosphor with a wide and smooth profile. The maximum output for this phosphor is in the blue at a wavelength of 452 nm. The red phosphor shows a sharper profile with several narrow peaks. The largest peak for this phosphor is at 612 nm.

and high speed while conserving power and bandwidth. Stroke systems address the CRT only where there is information, not the entire screen as in raster scanning. This technique is uncommon today because it is too slow and computationally intensive for systems that have high information content, gray scale, or imagery.

31.5 The Phosphor Screen

The phosphor functions as the CRT transducer. It converts the energy of the electron beam into light. This conversion process is called cathodoluminescence. CRT phosphors are inorganic crystalline materials doped with one or more impurities called activators and coactivators. Phosphors emit light in two ways, fluorescence and phosphorescence. Fluorescence is the emission of light by the phosphor material while it is under bombardment by the electron beam. The continued emission of light after the bombardment has ceased is called phosphorescence. The length of time phosphorescence lasts is known as persistence. Persistence can vary from tens of nanoseconds to many minutes, or even hours. CRTs take advantage of both forms of cathodoluminescence. Briefly, cathodoluminescence occurs when the electron beam excites the electrons of the phosphor into higher, unstable energy states available due to the presence of the activators. When the electrons transition back to their stable states, light is emitted. The choice of phosphor depends on the requirements of the application with respect to wavelength characteristics (narrow emission spectra or broadband emission), color, brightness, resolution, and persistence. Commercial television CRTs typically make use of the following phosphor powders: ZnS:Ag:Cl (blue), Zn(Cd)S:Cu:Al or ZnS:Cu:Au:Al (green), and Y_2O_2 S:Eu [19]. Television CRTs use moderately shortpersistence phosphors. This ensures a new frame does not exhibit blurring due to the previous frame. Traditionally, phosphors for radar displays, where the screen is refreshed infrequently, had a mix of short and long persistence. However, with the advent of today's digital systems, the use of long-persistence phosphors has declined. The Electronics Industries Association maintains an information database of commercial phosphors for CRTs. The interested reader should consult its publication TEP116-C [20]. Figure 31.2 illustrates the spectral characteristics of several typical phosphors.

31.6 Color CRTs Using Shadow Masks

Color has been a part of the CRT world since the early 1950s. A sound understanding of human color perception is important for a detailed understanding of color in CRTs. Readers interested in an excellent comprehensive treatment of color science should consult Wyszecki and Stiles [21] or Robertson and Fisher [22] for a brief overview. The most common method of introducing color to the CRT is the three-gun shadow mask technique. The shadow mask is a metal grid of many tiny apertures held in place immediately before the phosphor screen. The phosphor screen is an array of three different phosphor subpixels. Three electron guns are placed closely together in the neck of the tube, one gun for each one of the primary colors (red, green, and blue). The guns make a small angle with respect to each other. The shadow mask and beams are aligned so that each beam falls on the appropriate phosphor dot. The dots are placed closely together so the eye spatially integrates the subpixels into a continuous blend of color. There are two common configurations, delta and in-line. Delta, the traditional method, arranges the electron guns and the phosphor dots in a triad. This requires a shadow mask consisting of a grid of circular apertures. More recently, Sony introduced the Trinitron™ design. In the Trinitron tube the guns are placed in line, the shadow mask consists of vertical slots, and the phosphors are in vertical stripes. The design offers improved vertical resolution and is easier to converge, but the mask is slightly more difficult to support and is subject to thermal stress problems.

Trinitron continues to be an important and popular design [23]. The shadow mask technique of producing a color image has three main drawbacks. First, the shadow mask typically absorbs more than 75% of the electron beam energy, limiting brightness and causing undesirable thermal effects. Second, both require precise beam control to converge the three different images from the electron guns. Third, the resolution of the display is limited by the requirements of spatial color; three subpixels are needed to make each full-color pixel.

31.7 Alternative Techniques for Realizing Color Using CRTs

There are alternative approaches to producing color with CRTs. In its own way, each seeks to improve upon one or more of the enormously successful shadow mask designs. The three most noteworthy challengers are beam index tubes, penetration phosphor tubes, and field sequential color systems. All three have been around for decades, but only field sequential color systems are commercially available.

Beam Index and Penetration Phosphor Tube Designs

A beam index tube uses a slotted mask and vertical phosphor stripes. One electron beam is focused to less than the width of a phosphor stripe. A reflected ultraviolet signal from the mask provides a feedback signal. This signal is used to index the position of the beam very accurately. Color selection is achieved by precise beam positioning and rapid beam modulation. Although beam indexing offers perfect convergence, few guns, energy savings, and high resolution, practical problems in control and manufacturing have left this approach unrealized. Penetration tubes are potentially even more advantageous since color is produced with one electron gun and no mask is required. The phosphor screen consists of a layering of several different phosphors. There are many approaches to the layering structure, but the basic principle is that each layer produces a different color. To select among the different colors, the beam energy is varied, altering its layer penetration. In theory, multiple layers of phosphors could be used to produce a full-color display. Unfortunately, this design requires high switching voltages, and the color purity is poor because of the dilution caused by leakage from the unselected phosphor layers. In the past, a few two-color systems have been produced on a limited basis with stroke writer systems (p. 147 of Reference 4).

Field Sequential Color

Field sequential color (FSC) is a different approach to realizing color using a monochrome CRT and color filters [24]. The shadow mask relies on the ability of the eye to perform a *spatial integration on a* *group of color elements.* Field sequential color exploits the ability of the eye to perform a *temporal integration of color fields.* Field sequential color is not a new concept; it was an early design suggestion for commercial color television. To implement field sequential color, each full-color frame is decomposed into primary color fields (red, green, and blue). Each of these color fields is displayed sequentially on a monochrome CRT while simultaneously a color filter is placed over the front of the CRT. The filters must be rapidly changed to stay in sequence with the individual fields which are displayed at three times the desired frame rate. This sequence is so quick that the eye fuses the individual color fields into a steady blend of continuous color. Field sequential color systems have all of the advantages of a monochrome CRT, namely, superior resolution and simplicity. The major historical drawbacks to field sequential color have been the difficulty in controlling a bulky, spinning, mechanical filter wheel, and two thirds of the light energy of the phosphor is thrown away in each field. In the past, some viewers have reported the ability to perceive the individual color fields intermittently; this artifact is known as “color break up.” Field sequential color systems have seen a commercial rebirth due to several factors. The luminous efficiency of several phosphors has improved to the point where the light loss penalty is no longer a severe price to pay. Awkward, mechanical filter wheels have been replaced by several different types of compact, low-power, liquid crystal shutters. The use of faster frame rates and digital sampling techniques has reduced color artifacts. And finally, monochrome CRTs using field sequential color meet the growing market need for small high-resolution displays.

31.8 Image Quality and Performance

For any display technology, the ultimate test of performance and quality is how the image looks to the viewer in a real-world environment. This is highly subjective, but critical none the less. Table 31.1

TABLE 31.1 Parameters That Influence CRT Performance and Image Quality

Resolution	Spot size and shape
	Focus accuracy
	Line width
	Addressing/scan format
	Shadow mask design
Luminance	Dynamic range
	Maximum brightness
	Gray scale in high and low ambient light
	Gray scale vs. display brightness
	Phosphor luminous efficiency
Contrast	Contrast under high ambient illumination
	Contrast under low ambient illumination
	Large area contrast
	Pixel-to-pixel contrast (small area)
Image fidelity	Frame rate
	Flicker/refresh
	Uniformity and linearity
	Aberrations (linearity, pincushion, barrel distortion, keystone, and focus)
Color	Phosphor selection
	Convergence accuracy
	Color gamut and saturation
	Color uniformity
	Color accuracy
Bandwidth	Video bandwidth (cathode design)
	Horizontal deflection design
	Vertical deflection design
	Bandwidth of the CRT supporting electronics
	Bandwidth of the signal delivery electronics

highlights some important parameters associated with performance and image quality. Resolution is the most critical characteristic of any CRT. A note of caution: resolution should not be confused with addressing. A system can have a precise addressing format, but if the spot is too large the CRT resolution capability will be poor despite the addressing format. Alternatively, if the spot is precise and the addressing format is coarse, the *image* will be low resolution, but the CRT resolution will be high. Resolution is affected by almost every system parameter: spot size, focus, deflection, raster format, the mask, and beam current. For a perfectly designed system, line width and spot size will ultimately determine the resolution. Spot diameter is limited by the quality of the electron optics, the particle size and thickness of the phosphor layer, and beam current. The cross-section energy distribution of the electron beam is approximately Gaussian. The higher the current, the larger the beam cross section. Scattering by individual phosphor particles also increases the spot size. Thus, high resolution is much more difficult to achieve for high-brightness applications. The champions of small spot sizes are the small 12 to 25 mm monochrome CRTs. Several commercial systems achieve ≤25 μm spot sizes, and sizes ≤15 μm have been reported [25]. Monochrome CRTs in the 53 cm class (21-in.) have spot diameters ≤150 μm. Color CRTs with shadow mask pitches ≤250 μm are available in sizes up to 21 in. at commodity prices, and this will continue to improve. Spot size does not tell the whole resolution story. In most systems something other than spot size limits performance. The scan format may be well below the performance of the CRT, the bandwidth of the support electronics is frequently less than the tube bandwidth, and, for color, the shadow mask will limit resolution more than spot size. Engineers can still design a CRT that maintains its performance even with state-of-the-art electronics. MTF (modulation transfer function) is the standard metric for resolution. MTF compares the modulation of the displayed output with the modulation of a known input signal. As the spatial frequency of the input increases, the performance of the output will show a steady roll-off in modulation depth and quality. Readers interested in an introduction to this complex topic should consult Infante's review [26]. Contrast and its related companion, gray scale, are also important to CRT image quality. Since contrast can be measured and stated in so many different terms, gray scale is probably a more practical indicator of performance from a user's standpoint. As it attempts to replace traditional film, the medical imaging community demands the most of the monochrome CRT. Medical CRTs can produce up to 256 shades of gray with 8-bit controllers. Systems are available that will do 10-bit monochrome and color. Although frequently quoted, *shades of gray* is not a true indication of CRT performance and should not be confused with true *gray scale* capability. Shades of gray is a characteristic of the image source and the capability of the electronics; gray scale reflects the capability of the CRT. Gray scale is typically defined as a series of steps in brightness in increments of $2^{1/2}$ from black to maximum CRT output. Thus, gray scale is a realistic indicator that combines CRT dynamic range, contrast ratio, halation, and ambient reflections. More than 12 steps of gray scale is considered good performance.

The subject of display image quality and evaluation is an important topic. In addition to resolution and gray scale, users and designers need to consider many other metrics, such as luminance, dimmability, contrast, readability, color, persistence, and convergence. Users may also be aware of visual distortions such as pincushion, barrel, and keystone. A discussion of these topics and the other issues raised by Table 31.1 is beyond the scope of a single chapter; indeed, it has been the subject of books. There are good sources of information in this area [15, 27]; in particular, Keller's [28] text is superb. It is essential to remember that no matter which metrics are used, the most single most important metric is the subjective determination of the end users. Although many factors will affect final display performance, the bottom line remains *how good does the display look* in the real-world application environment it was designed to meet.

31.9 CRT and Phosphor Lifetime

The lifetime of a CRT depends on how it is driven. The higher the beam current, the more rapidly its performance will degrade. In general, degradation is due to a failure of three parts of the CRT — the

TABLE 31.2 The Strengths and Weaknesses of CRT Technology

Advantage	Weakness
Highest resolution technology	High power consumption
Versatile addressing formats	Weight of glass
Excellent image fidelity	Size of footprint
High speed	Emits EM radiation
Bandwidth (_350 MHz)	Must be refreshed
Excellent contrast/gray scale	
Good selection of phosphors	
High luminous efficiency	
Bright display (up to 20,000 fL)	
Excellent color gamut	
Simplicity of interface	
Universal interface standards	
Good design flexibility	
Broad application base	
Long life and reliability	
Mature and broad knowledge base	
Worldwide sources of tubes and parts	
Inexpensive — low cost per resolution element	

cathode, the phosphor, and the glass. Brighter displays require higher beam current, and this, in turn, requires a higher level of cathode loading. Oxide cathodes can comfortably operate with a loading range of 0.1 to 10 A/cm^2. This will provide a typical lifetime in the range of 10,000 h. Dispenser cathode designs can improve cathode life 2 to 3 times, but again, individual cathode life depends on how much brightness the user regularly demands from the tube. Phosphor degradation is the second mechanism affecting CRT lifetime and performance. All phosphors degrade under constant electron bombardment, an effect called phosphor burning. The rate of degradation is related to beam current, anode voltage, and material parameters specific to each phosphor. Today, there is a broad range of good phosphor materials with greatly improved aging characteristics. The third mechanism is glass browning. This effect is a complicated interaction between the high energy of the electron beam and the molecular structure of the glass [10]. In recent years, glass suppliers have made great strides in providing CRT manufacturers with improved glass materials. However, phosphor aging and glass browning are still important concerns, especially in extremely bright (high beam current) applications, such as CRT projection.

31.10 CRT Strengths and Weaknesses

With a century of development behind it, the CRT has abundant advantages that make it an attractive display option for the system designer dealing with high information content or dynamic imagery. Table 31.2 lists some attributes, positive and negative, which the system designer should consider in evaluating whether or not to use CRT technology. The most notable traits of the CRT are flexibility and cost. CRTs can operate over a wide range of resolution formats from commercial television to the strict requirements of medical imaging and digital-to-film recording. One unit can easily be designed to accept a myriad of scan formats and resolutions from static text to dynamic imagery with megapixels at frame rates of hundreds of frames per second. This flexibility means the system can be upgraded later without having to redesign the display subsystem. Interfacing with the CRT is also straightforward; there are well-established standards and hardware for many scan formats from the television NTSC to the RGB standards of the personal computer industry. Finally, cost is important to emphasize; CRTs are inexpensive. The desktop CRT delivers its performance for ≤\$0.00005 per color resolution element. Currently, no other high-information-content display technology can match this cost.

31.11 CRT Selection

The design requirements for (1) resolution, (2) brightness, and (3) screen size will quickly steer the system designer to a particular class of CRTs. If the design requirements are close to either television or desktop computer monitors, the choice is easy. There are literally hundreds of vendors offering integrated CRTs and electronic drivers as off-the-shelf items. Color shadow mask systems with more than 40 elements/cm are commonly available. If higher resolution is required, then medical imaging and film recorder CRTs may meet the requirements. Physically large display requirements can be supplied by projection CRTs or by tiled CRTs using video wall processors. Small to miniature CRTs provide resolutions up to 500 to 600 elements/cm and portability. If the application falls out of the mainstream, the designer will need to speak directly with CRT vendors. Table 31.3 is a partial list of CRT suppliers. Since CRTs have been designed to satisfy a broad range of specialty applications, the chances are excellent that an acceptable design will already exist. If not, the CRT is so mature that vendors working from a proven experience base can design a tube directly to customer specifications with little in the way of design problems or surprises.

31.12 Future Trends in CRT Technology

CRT technology is mature, and the industry does not foresee major surprises on the horizon. The CRT will continue to evolve, resolution will improve, screens will be flatter, deflection angles will be larger, and footprints will be reduced. The computer world continues to demand more resolution. In 1987, the 36-cm (14-in.) VGA class monitor (640 × 480) with its 300,000 pixels and 16 colors was the new standard. In 1998, the 43-cm (17-in.) desktop monitor is now capable of 1600 × 1200 performance (1.9 megapixels) with 24-bit color. The 53-cm (21-in.) monitor class, once an expensive custom device, is also widely available. The trend of increasing resolution and performance for decreasing cost shows every sign of continuing. The medical community is quickly moving to monochrome systems with 12-bit gray scale at a resolution of 2560 × 2048 (5 megapixels). All of this means the instrument designer has better resolution and fidelity for less money.

There is a quiet revolution taking place in the information display industry, which may have a significant effect on CRTs and all information display technology. There is a design trend to decouple the resolution and fidelity of the display device from its physical size. There are a number of applications motivating this change: communications, military, portable computing, simulation, and virtual reality. This is why miniature CRT technology has been more active in recent years. This is also the engine driving some of the major competitors to the miniature CRT, such as on-chip field emission displays (FED), deformable mirror devices (DMD), ferroelectric liquid crystal integrated circuit displays, and on-chip active matrix liquid crystal display (LCD) technology. If realized, these promise to be low-cost solutions because they are built on the technology foundation of the silicon chip industry. These challengers have the very real potential of eliminating the miniature CRT, and in some application areas, the LCD panel as well. However, the CRT backed by its formidable 100 years of design evolution and maturity is not standing still; its assets and market remain impressive. Although it is one of the few vacuum tubes still in use today, the traditional CRT is not doomed for obsolescence any time in the immediate future.

TABLE 31.3 Companies That Manufacture Cathode Ray Tubes

Clinton Electronics Corporation
6701 Clinton Road
Rockford, Illinois 61111
Tel. 815-633-1444 Fax. 815-633-8712
Tel. 040-783749 Fax. 040-788399

Hitachi, Ltd.
New Marunouchi Bldg.
Marunouchi 1-chrome
Chiyoda-ku, Tyoko 100, Japan
Tel. 81-3-3212-1111 Fax. 81-3-3212-3857
U.S. address
Hitachi America, Ltd., Electron Tube Division
3850 Holcomb Bridge Road, Suite 300
Norcross, Georgia 30092-2202
Tel. 770-409-3000 Fax. 770-409-3028

Hughes Lexington, Inc.
A subsidiary of Hughes Electronics Company
1501 Newtown Pike
Lexington, Kentucky 40511
Tel. 606-243-5500 Fax. 606-243-5555

Image Systems Corporation
11595 K-tel Drive
Hopkins, Minnesota 55343
Tel. 612-935-1171 Fax 612-935-1386

Imaging & Sensing Technology Corporation
300 Westinghouse Circle
Horseheads, New York 14845-2299
Tel. 607-796-4400 Fax. 607-796-4482

ITPO Institute of Surface Engineering and Optoelectronics
Teslova 30
1000 Ljubljana, Slovenia
Tel. 386-61 1264 592/111 Fax. 386-61 1264 593

L. G. Electronics
20 Yoido-dong Youngdungpo-gu
Seoul, Korea
E-mail display2@www.goldstar.co.kr or
monitor@www.goldstar.co.kr
U.S. address
L G Electronics, Monitors Division
1000 Silvan Avenue
Englewood Cliffs, New Jersey 07632
Tel. 201-816-2000 Fax. 201-816-2188

Matsushita Electric Industrial Ltd.
Twin 21 National Tower
1-61, Shiromi, 2-Chome, Chuo-ku,
Osaka 540, Japan
Tel. (06)908-1121
U.S. address
Panasonic Industrial Company
Computers and Communications Division
2 Panasonic Way
Secaucus, New Jersey 07094
Tel. 201-392-4502 Fax. 201-392-4441

Phillips Netherlands, BV
Phillips Components and Semiconductors
Bldg. VB Postbus 90050
5600 PB Eindhoven The Netherlands
U.S. address
Discrete Products Division
2001 West Blue Heron Blvd.
Riviera Beach, Florida 33404
Tel. 407-881-3200 or 800-447-3762 Fax. 407-881-3300

Rank Brimar, Ltd.
Greenside Way
Middleton, Manchester M24 1SN, England
Tel. 0161-681 7072 Fax. 0161-682-3818
U.S. address
25358 Avenue Stanford
Valencia, California 91355-1214
Tel. 805-295-5770 Fax. 805-295-5087

Sony Corporation
Display Systems
16550 Via Esprillo
San Diego, California 92127
Tel. 619-487-8500

Thomas Electronics
100 Riverview Drive
Wayne, New Jersey 07470
Tel. 201-696-5200 Fax. 201-696-8298

Thomson Tubes Electronics
13, avenue Morane Saulnier
Bâtiment Chavez — Vélizy Espace
BP 121/F-78148 VELIZY CEDEX France
Tel. 33-1 30 70 35 00 Fax. 33-1 30 70 35 35
U.S. address
Thompson Components and Tubes Corporation
40 G Commerce Way
Totowa, New Jersey 07511
Tel. 201-812-9000 Fax. 201-812-9050

Toshiba Corporation
Electronic Components, Cathode Ray Tube Division
1-1 Shibaura 1-Chrome, Minato-KU
Tokyo 105, Japan
Tel. 03-457-3480 Fax. 03-456-1286
U.S. address
Toshiba America, Inc.
1220 Midas Way
Sunnyvale, California 94086-4020
Tel. 408-737-9844

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Electronic Industries Association (EIA), 2500 Wilson Blvd., Arlington, VA 22201 (Internet: www.eia.org). The Electronic Industries Association maintains a collection of over 1000 current engineering publications and standards. The EIA is an excellent source for information on CRT engineering, standards, phosphors, safety, market information, and electronics in general.

The Society for Information Display (SID), 1526 Brookhollow Dr., Suite 82, Santa Ana, CA 92705-5421 (Internet: www.display.org). The Society for Information Display is a good source of engineering research and development information on CRTs and information display technology in general.

Internet Resources

The following is a brief list of places to begin looking on the World Wide Web for information on CRTs and displays, standards, metrics, and current research. Also many of the manufacturers listed in Table 31.3 maintain Web sites with useful information.

The Society for Information Display	www.display.org
The Society of Motion Picture and Television Engineers	www.smpte.org
The Institute of Electrical and Electronics Engineers	www.ieee.org
The Electronic Industries Association	www.eia.org
National Information Display Laboratory	www.nta.org
The International Society for Optical Engineering	www.spie.org
The Optical Society of America	www.osa.org
Electronics & Electrical Engineering Laboratory	www.eeel.nist.gov
National Institute of Standards and Technology (NIST)	www.nist.gov
The Federal Communications Commission	www.fcc.gov