CHAPTER 9.3
DISPLAY TECHNOLOGY

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CATHODE-RAY TUBES

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Introduction

Generation of Radiation. The cathode-ray tube (CRT) produces visible or ultraviolet radiation by bombardment of a thin layer of phosphor material by an energetic beam of electrons. The great preponderance of applications involves the use of a sharply focused electron beam directed time-sequentially toward relevant locations on the phosphor layer by means of externally controlled electrostatic or electromagnetic fields. In addition, the current in the electron beam can be controlled or modulated in response to an externally applied varying electrical signal.

General Design Principles. The generalized modern CRT consists of an electron-beam-forming system, electron-beam deflecting system, phosphor screen, and evacuated envelope (see Figs. 9.3.1 and 9.3.2).

The electron beam is formed in the electron gun, where it is modulated and focused, and then travels through the deflection region, where it is directed toward a specific spot or sequence of spots on the phosphor screen. At the phosphor screen the electron beam gives up some of the energy of the electrons in producing light or other radiation, some in generating secondary electrons, and the remainder in producing heat.

The magnetic field imparts no kinetic energy to the electron, since it always acts in a direction perpendicular to the velocity.

Electrostatic Deflection. In electrostatic deflection, metallic deflection plates are used in pairs within the neck of the CRT (see Fig. 9.3.2).

The simplest deflection plates are merely flat rectangular parallel plates facing each other, with the electron beam directed along the central plane between them. The deflection plates are located in the field-free space within the second-anode region, and the plates are essentially at second-anode voltage when no deflection signal is applied. Deflection of the electron beam is accomplished by establishing an electrostatic field between the plates.

The well-made modern electrostatic-deflection CRT does not exhibit excessive deflection defocusing until the beam deflection angle off axis exceeds the neighborhood of about 20°. Most electrostatic-deflection CRTs are used to display electric waveforms as a function of time.

To display the electric waveform it is necessary to generate a sweep representing passage of time and to superimpose on this an orthogonal deflection representing signal amplitude. This is most readily accomplished by the use of two pairs of deflection plates. The second pair of deflection plates must have an entrance window large enough to accept the maximum deflection of the beam produced by the first pair. This requires that although the plates may be close enough together at the entrance to afford high deflection sensitivity, they must

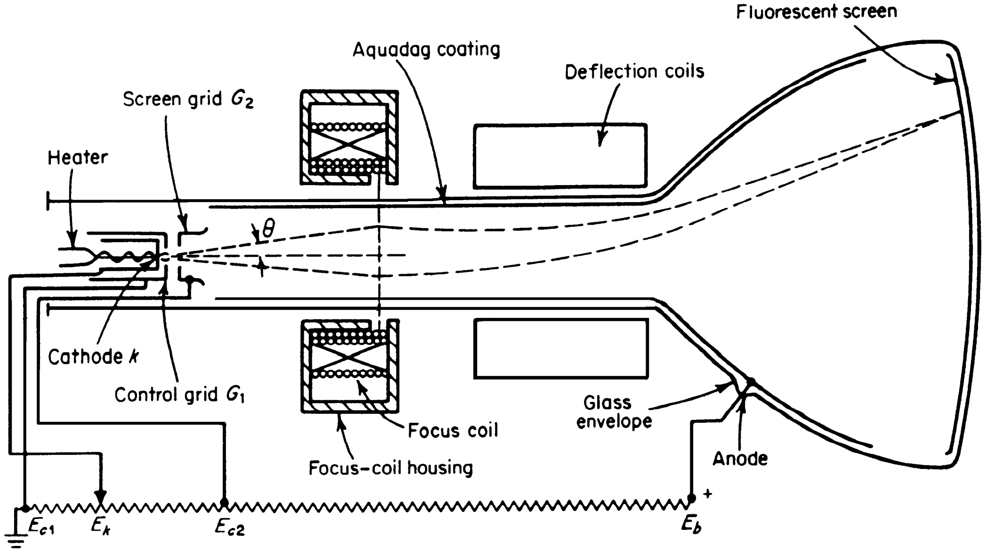

FIGURE 9.3.1 Generalized schematic of a cathode-ray tube with electromagnetic focus and deflection.

also have an appreciable width, which results in high capacitance. The plates must also diverge, to accommodate their own deflection of the beam.

To obtain an acceptable deflection sensitivity, the plates must be made long, and consequently the capacitance is increased.

Electrostatic deflection CRTs are particularly suited for the display of arbitrary waveforms, as opposed to electromagnetic-deflection CRTs, because the deflection plates generally have capacitances with reference to each other and to all other electrodes of the order of 10 pF or less.

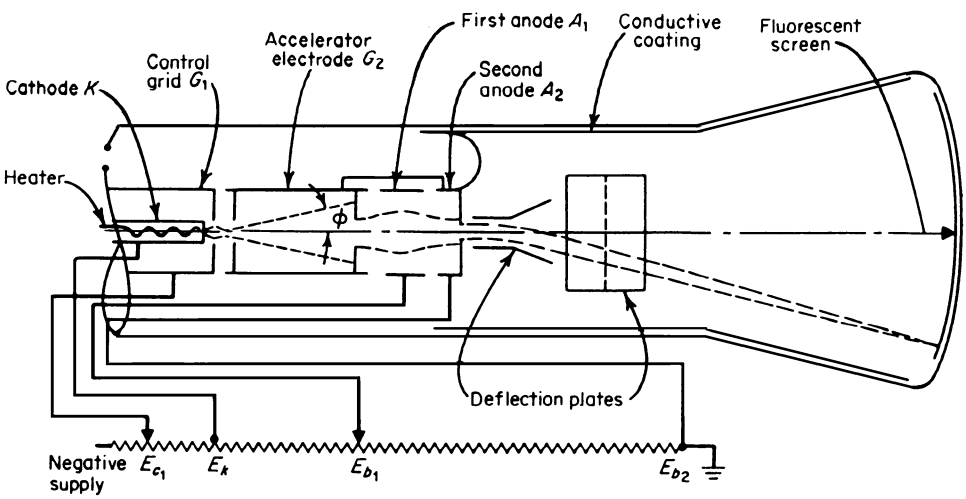

FIGURE 9.3.2 Generalized schematic of a cathode-ray tube with electrostatic focus and deflection.

Electromagnetic-Deflection Systems. In contrast to electrostatic-deflection systems, the deflection components in electromagnetic-deflection systems are almost universally disposed outside the tube envelope, rather than inside the vacuum. Since the neck of the CRT beyond the electron gun is free of obstructions, a larger-diameter electron beam can be used in the magnetic-deflection CRTs than in the electrostatic-deflection CRTs, which permits a much greater beam current to the phosphor screen and consequently a much brighter picture than if electrostatic deflection were used. In fact, included deflection angles of 110° (55° off axis) are commonly used in television picture tubes without excessive spot defocusing. As is apparent, large deflection angles permit CRTs to be made with shorter bulb sections for any given screen size.

Cathode-Ray-Tube Faceplates. The CRT envelope consists of the faceplate, bulb, funnel, neck, base press, base, faceplate safety panels, shielding, and potting. Not all CRTs will incorporate each of these components, of course.

The *faceplate* is the most critical component of the envelope, since the display on the phosphor must be viewed through it. Most faceplates are now pressed in molds from molten glass and are trimmed and annealed before further processing. Some specialized CRTs for photographic recording of flying-spot scanning use optical-quality glass faceplates sealed to the bulb section in such a way as to produce minimum distortion.

To minimize the return scattering of ambient light from the white phosphor, many CRT types, especially for television applications, use a neutral-gray-tinted faceplate. While the display information will be attenuated as it makes a single pass through this glass, ambient light will be attenuated both going in and coming out, thus squaring the attenuation ratio and increasing contrast.

Certain specialized CRTs have faceplates made wholly or partially of fiber optics, which may have extraordinary characteristics, such as high ultraviolet transmission. A fiber-optic region in the faceplate permits direct-contact exposure of photographic or other sensitive film without the necessity for external lenses or space for optical projection.

Categories of Cathode-Ray Tubes

Oscilloscope Tubes. For oscilloscopic applications the general requirements on a CRT include a sharp, bright, rapidly deflectable, single-line trace with a minimum of deflection defocusing or astigmatism. The rapidity of deflection and the fact that arbitrary waveforms must be displayed dictate the use of ES deflection, at least for the vertical direction. For general use, both horizontal and vertical axes employ ES deflection. Since the included deflection angle must be small, usually less than 45°, to preserve good spot size and shape, these CRTs are relatively long compared with the face diameter.

The phosphors generally used for oscilloscope CRTs are P1 (green, medium persistence) or P2 (yellow-green, medium persistence, but with a much longer, low-level "tail" than P1).

Radar Display Tubes. Except for the *A-scope* radar display, which is essentially the same as an oscilloscope display, most radar displays consist of a two-dimensional coordinate display with beam-intensity modulation. Since the coordinate scans are mathematically regular and at preselected rates, EM deflection is generally used, in as much as this permits greater deflection angles and consequently shorter tubes to be used for a given face diameter.

Especially in filtered radar displays, it is often necessary to include alphanumeric characters, symbols, and vectors in the display along with the radar information. Shaped-beam tubes, such as the Charactron, or a multiple-beam tube, in which one beam is devoted to the tracing of the characters of symbols and the other to the plan-position-indicator (PPI) display, are used for this purpose.

Long-persistence phosphors are generally used in CRTs for radar displays, since it is desirable to be able to see the radar situation in the entire area covered at any given time.

Television Picture Tubes

Monochrome tubes. Since the standards for television transmission in the United States call for 30 frames of two interlaced fields each per second, producing the effect of 60 pictures per second, which is above the flicker fusion frequency for all light levels, there is no stringent limitation on phosphor persistence for monochrome

TV picture tubes so long as the persistence does not cause picture smearing. The white luminescence used for most applications is achieved by a mixture of phosphors rather than any single component. Several white-luminescencing combinations, all designated P4, have been in common use, namely, the all-silicates, the silicate-sulfide mixture, and the all-sulfides.

Color tubes. Many types of full-color CRTs have been developed for television use, but the shadow-mask tube is in most widespread use. This type of CRT uses a cluster of three electron guns in a wide neck, one gun for each of the colors red, green, and blue. All the guns are aimed at the same point at the center of the shadow mask, which is an iron-alloy grid with an array of perforations in triangular arrangement, generally spaced 0.025 in between centers for entertainment television. For high-resolution studio-monitor or computer-graphic readout monitor applications, color CRTs with shadow-mask aperture spacing as small as 0.012 in center-to-center are now readily available. This triangular arrangement of electron guns and shadow-mask apertures is known as the *delta-gun configuration*. Phosphor dots on the faceplate just beyond the shadow mask are arranged so that after passing through the perforations, the electron beam from each gun can strike only the dots emitting one color.

Because of the close proximity of the phosphor dots to each other and the strict dependence on angle of penetration of the electrons through the apertures to strike phosphor dots of the desired color, close *attention* must be paid to shielding the CRT from extraneous ambient magnetic fields and to degaussing of the shield and shadow mask, which is usually carried out automatically when the equipment is switched on or off. All three beams are deflected simultaneously by a single large-diameter deflection yoke, which is usually permanently bonded to the CRT envelope by the tube manufacturer. The three phosphors together are designated P22, individual phosphors of each color being denoted by the numbers P22R, P22G, and P22B. Most of the present color CRTs are made with rare-earth-element-activated phosphors, because of the superior colors and brightness compared with previously used phosphors.

Two other classes of multicolor CRTs are those with parallel-stripe phosphors and those with voltage-penetration phosphors. In the *parallel-stripe class* of CRTs, such as the *Trinitron*, sets of very fine stripes of red-, green-, and blue-emitting phosphors are deposited in continuous lines repetitively across the faceplate, generally in a vertical orientation. The Trinitron, unlike conventional color CRTs, has a single electron gun that emits three electron beams across a diameter perpendicular to the orientation of the phosphor stripes. This type of gun, also used by some United States CRT manufacturers, is called the *in-line gun*. Each beam is directed to the proper color stripe by means of the internal beam-aiming structure and a slitted *aperture grille*.

The *Lawrence tube*, or *Chromatron*, is another example of the parallel-stripe-phosphor class of color CRT. It employs a single electron beam, and color selection is accomplished solely by control voltages applied between the integrated combs of wires constituting the grille itself.

In the voltage-penetration type of phosphor screen, two or three unstructured layers of phosphors emitting different colors are deposited on each other, sometimes with a nonluminescing, transparent barrier layer between them for better color differentiation. A second important structure consists of individual phosphor grains built up in layers, called *onionskin phosphors*. The core phosphor is generally green-emitting. This is surrounded by a nonemitting layer which in turn is surrounded by an outer red-emitting layer. With both types of phosphor screen, a single electron beam is employed, and the resultant color of the screen is determined by preselected beam-accelerating voltages, which are changed to control the depth of beam penetration into the phosphor layers.

Intermediate colors are produced by the visual combination of the first color, resulting from the penetration of the first layer by the electron beam, with varying intensities of the second color, as more electrons penetrate into the second color-emitting layer. The range of colors producible is thus limited by the hues of the two phosphor layers, which must lie on the same side of the CIE chromaticity diagram and as close to the spectral locus as possible. A major problem associated with voltage-penetration color CRTs is the change in deflection sensitivity and focus of the electron beam as the screen voltage is changed to change the color displayed. This usually dictates operation at only a few preset screen voltages (and therefore colors) where the deflection amplifications and focus voltages are also preset to correspond. Another type of voltage-penetration CRT features a constant-potential mesh grid very close to the phosphor screen to separate the deflection and focusing space from the color-adjusting space. In this type of CRT a maximum residual deflection error of 1 to 2 percent can be automatically compensated for by means of a large weak electron lens formed between electrode bands deposited on the inside surface of the bulb.

Recording Tubes. Cathode-ray tubes for recording or transcribing information on photographic or otherwise sensitized film are usually of the very-high-resolution (vhr) or ultrahigh resolution (uhr) types. The great majority of these types have nominal faceplate diameters of 4 or 5 in. The spot diameters of the vhr and uhr tubes range from approximately 0.0015 in. down to 0.00033 in.

The displayed information is transferred to the recording medium either by an external focusing optical system or by direct contact with a fiber-optic faceplate, requiring no focusing.

Computer-Terminal Display Tubes. Cathode-ray tubes for computer display are very similar to tubes used in high-resolution video monitors, but since the display is principally alphanumeric and vector-graphical, the linearity of the beam-modulation characteristics is less important. Well-focused round spots with minimum spot growth or deflection aberrations from the center to the useful edges of the display area are required. High legibility is of primary importance, implying high contrast. White-emitting phosphors are not necessary, so that highly efficient, high-visual-response phosphors emitting in the yellow or green spectral regions are applicable. Most of these CRTs are made with rectangular faceplates.

ELECTROLUMINESCENT DISPLAYS

David A. Bosserman

Background

Destriau discovered intrinsic electroluminescence (EL) in ZnS among other materials. Sylvania's powdered SZnS EL panel dominated EL work in the 1950s and early to mid-1960s, when most of the projects were cancelled or deferred because of life and/or crosstalk-contrast problems. Attempts were made to correct crosstalk and contrast problems by placing addressable electronic components at each pixel site to serve as turn-on or threshold devices and to provide address-state memory, needed for bright displays where the addressing duty cycle is a factor. These attempts ran into manufacturing difficulties concerning the uniformity and reproducibility of the pixel circuit-elements.

Thin-Film Display

In 1972, Sigmatron, working on the thin-film EL (TFEL) [also called light-emitting film (LEF) and AC-TFEL], reported an *XY* matrix with inherent threshold and an optical light-absorbing layer in the otherwise transparent thin-film structure which enhanced the display contrast when viewed in bright ambient illumination. Shortly thereafter, Sharp Corporation in Japan achieved a breakthrough with a panel life of over 10,000 h coupled with a continuous ac excitation brightness of over 3500 cd/m^2 (over 1000 fL). Many laboratories now work on applying the TFEL structure to various types of matrix-addressed displays. Sharp has since reported on a memory phenomena intrinsic to the TFEL structure which can be used to freeze a frame or to increase the brightness of line-at-a-time addressed displays. Rockwell International has reported on a 500-pixel/in TFEL display.

The early successes of TFEL displays are attributable to the thin-film planar sandwich structure, consisting of electrode-dielectric-phosphor-dielectric-electrode, where at least one electrode is transparent. Since the thickness of this structure is less than 1 nm, high field strengths can be achieved with modest voltages across the structure. This high field strength produces hot electrons through tunneling from relatively deep traps. The hot electrons are fired across the ZnS film, exciting the color centers associated with the dopant, usually Mn. This process is relatively temperature-independent, which translates into a wide operational temperature range. The details of the tunneling and subsequent retrapping of activator electrons are being studied in various laboratories to determine the best structure for enhancing the various desirable operational parameters such as threshold, brightness, memory, and uniformity.

The low-cost production processes inherent in the planar TFEL structure make them eminently suitable for the commercial and consumer markets.

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