Cathode-Ray Tube Displays for Medical Imaging

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This paper will discuss the principles of cathode-ray tube displays in medical imaging and the parameters essential to the selection of displays for specific requirements. A discussion of cathode-ray tube fundamentals and medical requirements is included.
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KEY WORDS: displays, cathode ray tube, medical imaging, high resolution.

The cathode-ray tube (CRT) is the heart of almost every medical display and its single most costly component. Brightness, resolution, color, contrast, life, cost, and viewer comfort are all strongly influenced by the selection of a particular CRT by the display designer. These factors are especially important for displays used for medical diagnosis in which patient safety and comfort hinge on the ability of the display to present easily readable, high-resolution images accurately and rapidly.

The CRT dates back to 1897 in its present form. In that year, Karl Ferdinand Braun, a German physicist and Nobel-prize recipient, demonstrated a tube intended for the measurement of electrical waveforms. It was not until 1929 that the CRT was applied to the display of actual images for television by Vladimir K. Zworykin of Westinghouse Electric. Subsequently, television provided much of the impetus for further refinements of the CRT, with imaging applications finally emerging rapidly during the 1980s with increased performance demands placed on the CRT and associated electronics. Today, CRT displays are used in almost every business, and much of society is dependent on them for low-cost entertainment.

The principles and operation of the CRT may be divided into six functional groups (Fig 1). These are

1. a mechanical structure known as the envelope to maintain a vacuum, provide electrical connections to the internal electrodes, and insulate them from each other;
2. the electron source and beam-intensity control section;
3. one or more acceleration electrodes to increase the velocity of the electron beam for increased light output from the screen;
4. a focusing section to bring the electron beam to a sharp focus at the screen;
5. a deflection system to position the electron beam to a desired location on the screen or scan the beam in a repetitive pattern; and
6. a phosphor screen to convert the invisible electron beam to visible light.

The assembly of electrodes or elements mounted within the neck of the CRT is commonly known as the "electron gun" (Fig 2). This is a good analogy, because it is the function of the electron gun to "shoot" a beam of electrons toward the screen or target. The velocity of the electron beam is a function of the overall accelerating voltage applied to the tube. For a CRT operating at an accelerating voltage of 20,000 V, the electron velocity at the screen is about 250,000,000 mph, or about 37% of the velocity of light. Although the velocity of the electrons is extremely high, their mass is very small, and normally, as a result, the phosphor screen luminesces where it is struck by the beam. However, if the beam power (accelerating voltage times beam current) is sufficiently high, intense localized heating may occur, with a resultant phosphor burn or glass damage.

Each function will now be discussed briefly.

PHYSICAL STRUCTURE

The glass envelope or bulb serves several purposes. These include maintaining the very high vacuum required to allow free movement of the electron beam without colliding with residual gas atoms, providing electrical connection to the electron beam–forming and –accelerating electrodes, and insulating these voltages, which may be as high as 30,000 V, from each other. The shape of the envelope required to meet the CRT

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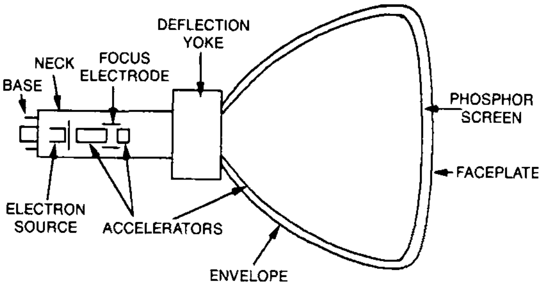

Fig 1. Basic CRT construction.

performance objectives largely dictates the physical configuration of the entire display. The envelope is divided into three distinct parts: the neck, which contains the electron gun and the base for making connections to the gun; the funnel, which literally contains nothing except an electrically conductive coating to accelerate the electron beam; and the faceplate, which contains the luminescent phosphor screen.

Glass has been the customary material for CRT bulbs, the only exceptions being metal or ceramic funnels for specific applications. Glass has the advantages of transparency, good insulating properties, strength under the compression of the high vacuum, an easy-to-clean, smooth, continuous surface to maintain the high vacuum integrity, and its separate pieces being easy to seal together.

ELECTRON SOURCE

The source of the electrons to form a beam is the cathode (Fig 3). The cathode consists of a metal cup containing a small filament or heater to increase the temperature of an oxide-cathode coating on the end of the cup to a sufficient temperature for the emission of electrons, usually around 800°C. Electrons, which are negatively charged, are drawn away from the cathode and towards the screen by positive voltages on the other electrodes. The oxide-coating purity, temperatures, and processing are critical to maintain high emission and long cathode life.

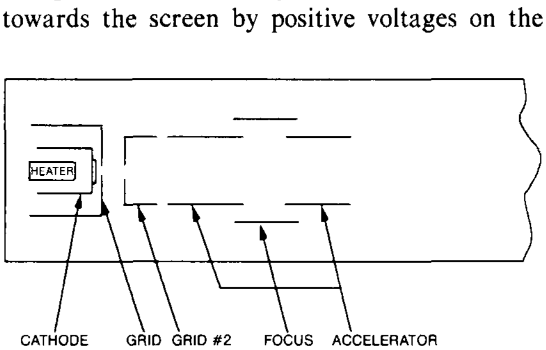

Fig 2. Electron gun profile.

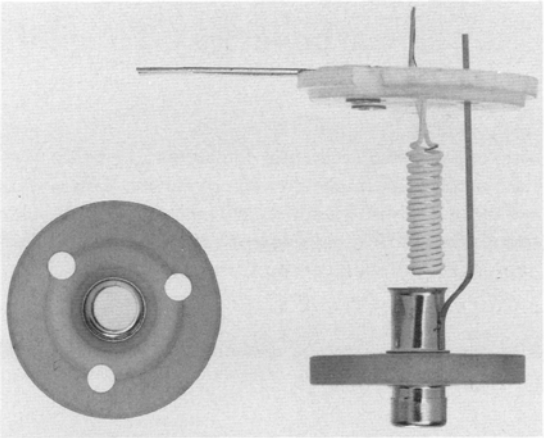

Fig 3. Heater cathode assembly.

A second cup that surrounds the cathode cup is the control grid. The grid has a small aperture in front of the cathode coating that normally permits the electrons to flow through on their way to the screen, if it is at the same voltage as the cathode. By applying a negative voltage to the grid, the number of electrons is decreased until at a sufficiently high voltage, usually around 60 V, a point is reached known as "cutoff," at which all electrons are repelled back to the cathode. By making the relationship of the grid-to-cathode voltages synchronous to the scanning of the electron beam across the screen, the brightness of any point on the screen may be controlled to create a picture with many shades of gray or "gray scale." The number of gray levels that may be produced is primarily determined by the associated electronic circuits used to drive the CRT.

ACCELERATION

To produce a bright display, the electron beam must be accelerated to a high velocity before impinging on the phosphor screen. This is accomplished by a two-step process.

Another cup-shaped electrode with a central aperture, variously known as anode no. 1, grid no. 2 or G2, immediately follows the control grid. This electrode has a positive voltage of several hundred volts and forms a controlled field to pull electrons from the cathode and to provide initial acceleration prior to focusing the beam.

The final accelerating voltage of typically 15,000 to 25,000 V positive is applied to the entire funnel and screen as well as to a cylindrical electrode at the end of the electron gun. The entire region is called the anode. Contact is made through a metal connector sealed into the glass funnel and called the "anode button." The interior of the funnel is coated with a conductive carbon paint called "dag" to form the major portion of the second anode. It connects with the screen, usually backed with conductive aluminum, and extends into the neck to make contact with the end of the gun through "snubber springs." These provide mechanical centering of the gun within the neck as well as electrical contact.

The high voltage applied to the anode is related roughly to screen size. For a given beam current (number of electrons), a tube having a larger screen will spread the available electrons "thinner" by scanning the larger area. Consequently, the brightness of the image will be lower for a large screen than for a small one. This brightness may be gained back by the use of a higher accelerating voltage which increases the beam power to the screen. A good rule of thumb is 1,000 V/in of screen diagonal. Thus, 10,000 V is suitable for a 10-in screen, and 25,000 V for a 25-in screen is fairly typical.

FOCUSING

Focusing of the electron beam to a sharp spot at the screen may be done through use of either an electrostatic field or a magnetic field. Both methods form an electron-optic "lens" capable of converging the beam that is diverging as it leaves the cathode toward the grid no. 2 region. The degree of convergence is adjusted to bring the electron beam to a sharp focus at the screen. Electrostatic lenses are most common today and usually consist of a cylindrical-focus electrode inserted in the space created by cutting the second anode cylinder into two sections. An adjustable voltage intermediate between those of grid no. 2 and the second anode allows the focus to be adjusted. A number of other focusing methods are in use today. These differ in the configuration of the electrodes in the focusing region and the magnitude of the focus-voltage required.

DEFLECTION

We have seen how the CRT produces a pencil-like beam of electrons. Without some means of positioning the beam to desired locations on the screen, or scanning it past all areas of the screen, there would be merely a bright spot of light in the center of the screen. Either electrostatic or magnetic fields may be used to bend the electron beam toward other locations on the screen. Today television, computer, and imaging displays use magnetic deflection because it produces bright, sharply-focused displays over large screen areas with a minimum tube length. Magnetic deflection apparatus consists of two sets of deflection coils, called a deflection yoke, over the CRT neck at its juncture with the funnel. Each set of coils is mounted at right angles to the other to produce vertical and horizontal deflection when energized. By applying a fast sawtooth current (Fig 4) to the horizontal coil, the spot is rapidly scanned across the screen to form a thin horizontal line repetitively. The horizontal sweep rate may be anywhere between 15,750 times per second for television to 150,000 times per second for ultra-high resolution imaging displays. By applying a considerably slower sawtooth current to the vertical deflection coils, a series of horizontal lines will be formed, beginning at the top of the screen and continuing to the bottom, before returning rapidly to the top to begin again (Fig 5). This process known as "raster scan" occurs typically 60 to 80 times per second. The persistence of vision makes the raster appear continuous, although the only visible evidence of it may be a slight flicker. Under close examination of the screen, the individual scan lines may be seen on a well-focused display. At the same time the beam is being swept around the screen, video signals are fed to the cathode or grid to produce one million or more individually controlled points called pixels that make up the total picture. More on this later. Alternatively, "stroke" or "vector" writing is used for some specialized applications. This involves directed movement of the beam to

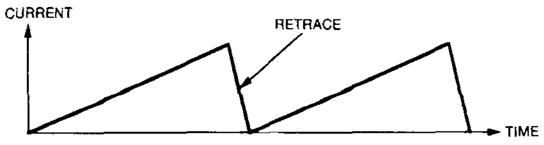

Fig 4. Sawtooth current waveform.

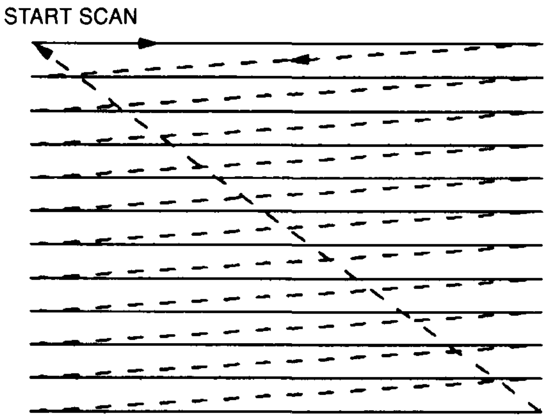

Fig 5. Raster scanning.

locations where information is to be displayed, in much the same manner as a person writes on paper.

SCREENS

The screen is the portion of the tube upon which pictures or images are displayed. A phosphor, a crystalline material having the property of emitting light (luminescence) upon excitation by an otherwise invisible electron beam, is applied uniformly to the glass faceplate. CRT phosphors are characterized by several properties including color, persistence, brightness, and resistance to burning and aging. The most useful phosphors for monochrome image displays are the types WW and WB (previously designated P4 and P45) that are white-emitting materials.

Color displays use a complex screen structure. A thin metal shadow mask having a similar pattern of holes is mounted a short distance behind the screen consisting of a pattern of red, green, and blue phosphor dots or stripes. Three individual electron guns are mounted within the CRT neck and aligned such that one gun lines up with small holes in the shadow mask to strike only the red phosphor dots or stripes (Fig 6). The other two guns can excite only the green and blue phosphors respectively. All three beams are scanned in unison, and the grids or cathodes of each are driven to produce the proper proportions of each color to reproduce the correct blend of color for each location of the image. Because of limitations on the size of the shadow mask holes and phosphor patterns that may be manufactured, resolution of color CRTs is significantly lower than that of monochrome tubes. Also, the electron beams must be aligned precisely to pass through the shadow-mask holes and strike only the desired-color phosphor. Any misalignment of the three beams due to magnetic fields or improper adjustment will result in loss of color "purity" in some areas of the screen, or "misconvergence" where displayed images have color fringes around any sharply-defined object or character.

To maximize viewability of a display, some form of contrast enhancement is usually applied to the CRT screen. This may take several forms. The simplest is a slight etching of the glass faceplate to prevent specular or mirrorlike reflections of ambient light from the screen. This prevents the images of objects behind the viewer from being visible, but does allow diffuse light to reflect from the glass surface. Another simple means of contrast enhancement is the use of neutral gray glass faceplates to make the entire screen background appear dark. This is effective because light from the phosphor is attenuated once as it passes through to the viewer, whereas ambient light must pass through twice in the process of being reflected from the phosphor (Fig 7). A more costly approach to contrast enhancement is the use of an anti-reflective (AR) coating on the glass surface to better match the index of refraction of the glass to that of air. AR coatings reduce specular reflections from the glass surface

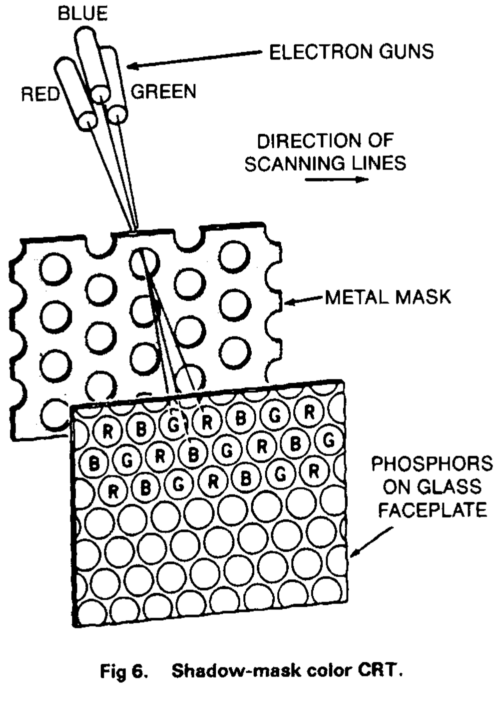

Fig 6. Shadow-mask color CRT.

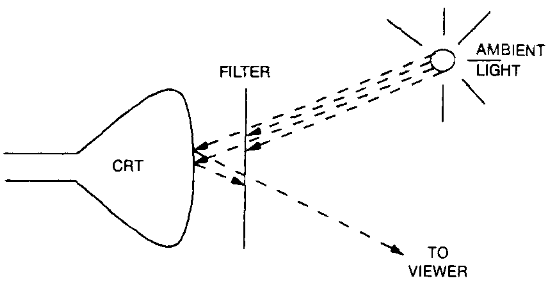

Fig 7. Contrast enhancement filter. Note that light from CRT passes through filter once while ambient light passes through twice.

without increasing diffuse reflections as does etching. These coatings are identifiable by a blue cast as on a camera lens. AR coatings are durable, but oils left by fingerprints cause noticeable reflective spots requiring more-frequent cleaning.

DISPLAY FUNDAMENTALS

Imaging displays and monitors are available in a bewildering range of signal input and scan-rate configurations. We will now look at the important considerations when choosing one for a specific application.

DISPLAY FORMAT

Three display formats are available to match the format of images or data to be displayed. These are page or portrait mode, landscape mode, and square format.

The first consists of a CRT mounted with the long axis of the screen in a vertical direction. This is known as page mode to the electronic publishing market because of its capability of displaying a complete page. It is usually referred to as portrait mode for medical-imaging applications, and is especially useful in presenting chest radiographs. The raster-scan lines may be in either the vertical or horizontal direction, depending on performance requirements. Aligning them vertically can give about a 10% increase in performance, but needs to be understood mutually between the manufacturer and user because the digital images must be formatted for the appropriate orientation. Also, the origin of the scan must be specified; top right origin is the most common.

Landscape mode is the conventional television scan mode. Two complete pages of text may be presented side-by-side, or multiple medical images may be displayed. This is a relatively straight-forward display from the specification standpoint. The origin of the raster scan is always in the upper-left corner of the screen.

Square format displays usually employ special square-screen CRTs. They are specialized displays, not yet very common. They find application in the display of square-format imaging sensors such as 2,048 × 2,048-pixel CCD (charge-coupled device) arrays. Either portrait or landscape displays may be adjusted, when ordered, to display a square raster, allowing their use for square format. However, some screen area will be wasted. The raster-scan origin for square displays is also in the upper-left corner.

ASPECT RATIO

Aspect ratio refers to the ratio of width to height of the raster. The most common is 4:3 because of its long history in television use; most CRT glassware is in that configuration. Also used is 5:4 which is close to the aspect ratio of x-ray film, and is fairly good fit on standard 4:3 ratio CRTs. As described previously under "Display Format," 1:1 may also be used. The future promises CRTs with 16:9 aspect ratios for high-definition television. It remains to be seen what impact these CRTs will have on computer and imaging displays.

SCREEN SIZE

CRTs are available in a wide range of sizes from less than 1 in to 45 in. This dimension refers to the overall CRT glass faceplate diagonal dimension from corner to corner. The usable screen area is somewhat less. For computer and imaging displays, 19 in and 20 in tubes are becoming widely used. They have useful screen-quality areas of about 10.5 × 14 in. This is known as "underscanning" and is desirable for two reasons. The first is to avoid possible loss of information at the edge of the image, and the other is to minimize image distortion and defocusing near the edges, and especially the corners, of the screens.

Twenty-four-inch displays are becoming available and are suitable for reproducing 14 × 17-in chest x-rays full size, although the displays are a bit overwhelming in magnitude.

RESOLUTION VERSUS ADDRESSABILITY

The difference between resolution and addressability is one of the most frequently misunderstood parameters for proper choice of a display. Resolution is primarily a function of CRT spot size, and defines the smallest area of the CRT that may be individually illuminated. Commonly this is expressed as spot size in thousandths of an inch (mils) or in millimeters at the half-intensity points, although the human eye can usually detect light to about the 5% level. The light output from the spot is usually a near-Gaussian distribution as in Fig 8. Dividing the raster dimensions by the spot size gives the number of resolvable points ("pixels" or picture elements).

Addressability is determined by the electronics used to drive the CRT and defines how many points in each axis may be individually controlled as distinct pixels. Ideally, the addressability and resolution should be fairly closely matched to avoid wasting the capabilities of either the CRT or the electronics. Both resolution and addressability may be expressed in pixels such as a 1,280 × 1,024-pixel display, although addressability is the more commonly used specification, at least for digital displays. (Note that the horizontal value is usually expressed as the first number.) It is important to verify that a display described thusly is indeed 1,280 × 1,024 *resolvable* pixels since it is of little use to be able to address pixels that cannot be seen.

There are two cases where less resolution than addressability can be of some benefit. The first is to reduce "Moire" patterns in shadow-mask color displays where the mask pattern and a displayed pattern "beat" together to produce a closely-spaced series of dark and light lines not present in the original image. The other case is for diagonal lines which produce a staircase effect, as the lines cross the horizontal scanning lines. This effect is called "jaggies" (Fig 9). A CRT with poorer resolution tends to blur the steps between scan lines.

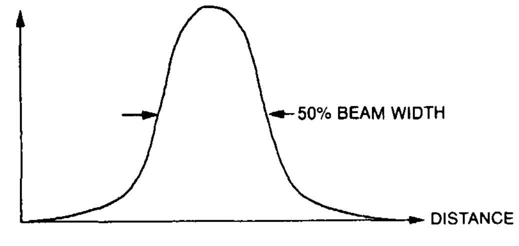

Fig 8. **Gaussian beam profile.**

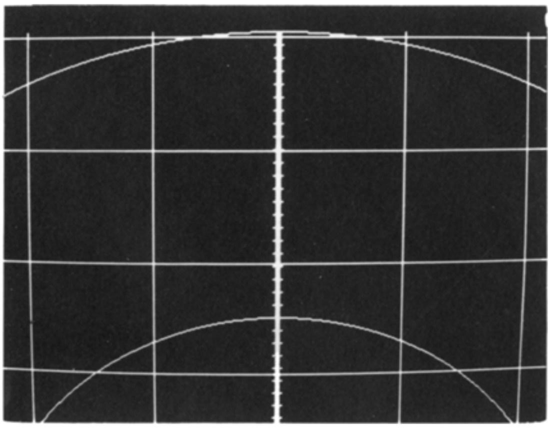

Fig 9. **"Jaggies" on curved lines.**

DYNAMIC FOCUS AND ASTIGMATISM

As the electron beam is deflected further from the screen center, the spot loses focus and becomes elliptical or, "astigmatic," due to the electron beam's having to travel a greater distance to the edges of the screen than to the center. This effect is becoming more of a factor with the continuing trend from spherically-shaped faceplates to flatter, more squarely-shaped screens.

Deflection defocusing may be corrected by use of dynamic focus circuits that automatically adjust the CRT focus voltage as the beam is deflected across the screen. The simplest technique is to apply parabolic waveforms, derived from each axis of the deflection circuits, to the focus electrode of the CRT. The parabola approximates the variation in focus voltage required with distance from the screen center. A more elaborate scheme has been patented by Tektronix Inc. (Beaverton, OR) where the correction voltages for each location on the screen are digitally derived and stored in PROMs (Programmable Read-Only Memory) for the individual CRT. This solves the problems of slight electron-gun misalignments and nonuniform deflection yoke magnetic fields which result often in three corners' being in-focus and the fourth fuzzy.

The PROM approach is also applied to correct for the astigmatic spot in the corners; however, this requires a special CRT electron gun that contains additional "stigmator" electrodes to dynamically control the spot ellipticity. Such extreme spot-control pays large dividends in precision ultra-high resolution displays for critical applications such as medical-imaging and photo-reconnaissance. Corner spot size can be controlled to virtually the same as that in the center of the screen, rather than the 1.5 times larger spot typical of dynamic focus alone.

GRAY SCALE

Medical imaging requires accurate reproduction of a wide range of light intensities, or "gray scale," with as many discernable levels as possible. Gray scale (or "halftones"), is frequently expressed exponentially in terms of binary "bits." An 8-bit gray scale is 2^8 or 256 steps. Some displays used for computer displays are 1 bit displays and are either black or white with no intermediate steps. As with newspaper printing, it is possible to reproduce halftones with 1-bit displays by using many small dots of different sizes or spacings.

Higher-resolution displays require wider bandwidth video amplifiers to display fine image detail. This works counter to gray scale because amplifier noise tends to increase with wider bandwidths. For a 2,048 × 2,048-pixel display, the required bandwidth is about 200 MHz with a resultant noise level nearly equal to one bit out of 256, thus limiting gray scale to 8 bits.

GAMMA

It is a characteristic of all CRTs for the intensity of light from the screen to respond nonlinearly to a linear increase in video input signal. The effect is analogous to "gamma," for photographic film. CRT gamma is the exponent of the voltage input required to produce a given light output. A gamma of one results in a 1:1 relationship between the input and output. A gamma of two gives a 10:1 relationship. A typical value is about 2.3. Gamma may be corrected in the software for driving a digital display by referring to a table that converts the exponential output to a linear output.

COLOR DISPLAYS

Color displays have become widely accepted for many display applications; however, color comes at the price of a significant penalty in resolution. The current limit of about 1,280 × 1,024 pixels is imposed by two factors, both of which are a result of the shadow-mask screen structure necessary to produce colors. These are the spot size attainable at the high electron-beam current required to overcome efficiency losses in the shadow-mask, and the number of phosphor dot or line triads that can be deposited on the screen. Beam diameters of 0.015 to 0.030 in or more are the norm for color CRTs, whereas 0.005-in beam diameters are now available in high-resolution monochrome CRTs.

SCAN RATES

Many different raster-scan rates are in common use today, beginning with the standard television frequencies of 15,750 Hz horizontal and 60 Hz vertical. Higher scanning frequencies are used in medical and other displays for two reasons.

Higher horizontal frequencies produce more horizontal scanning lines, hence more vertical addressability by breaking the vertical scan into more individual elements. Horizontal frequencies of up to 160 KHz or more are becoming available as the demand for ever-increasing resolution continues. Higher vertical refresh frequencies reduce perceptible flicker of the image that is most visible with brighter displays at the periphery of the field of vision. This is particularly a problem where two or more displays are located in close proximity as in medical PACS (Patient Archival and Communication System). Generally, vertical refresh or "frame" (one complete picture) rates above 72 Hz will not have flicker apparent to most of the population, although some individuals are more sensitive to it than others. As the vertical refresh rate is increased to reduce flicker, the horizontal scan frequency, video amplifier bandwidth, and pixel rates must be increased proportionately in order to maintain the same resolution. Refer to the formulas in the appendix to see the close relationships between scan rates, video bandwidth, and resolution.

INTERLACE

Interlacing is a method that was first used for television raster displays to reduce apparent flicker without requiring higher horizontal scan rates and video bandwidth. Usually, it consists of two "fields" that make one frame which is referred to as 2:1 interlace. Every other scan line is displayed in field one; the remaining lines are filled in for field two (Fig 10). Persistence of vision makes it appear to be a continuous picture; because a partial picture is displayed more often, flicker is reduced. However, the trade-off is that small movements of the eye or head cause the image to appear (momentarily) to break up into horizontal bands. Another drawback is that minor electrical and magnetic disturbances cause some scanning lines to be closer together than others. This is called "line pairing" and can be very objectionable at close viewing distances. For these reasons, *interlacing is recommended only for lower cost products that will be viewed from a distance. Almost all digital-image displays should be noninterlaced.*

VIDEO BANDWIDTH

Video bandwidth is a measure of the speed at which the intensity information of an image may be applied to the CRT grid or cathode to produce gray levels on the screen. It is expressed in megahertz (millions of cycles per second) that indicate how many times it can change from light to dark in one second.

Video bandwidth is related directly to the horizontal addressability of a display, as it determines how many individual points may be controlled along each horizontal scan line. The video amplifier must be "flat" (have equal output at all frequencies throughout the bandwidth range) in order to produce the correct shading for all-sized objects on the screen. It must not "ring" or have excessive "overshoot" which can cause problems in displaying sharply defined objects. Greater video bandwidths do not come easily, and 200 MHz is about the current practical limit. The difficulty of driving the CRT gun, which is both capacitive and inductive, to the 40 to 60 V-levels to produce bright displays with good contrast makes greater bandwidths very difficult without a major breakthrough. Wider bandwidth can be obtained using "one-bit" video in which only two brightness levels exist—either on or off. The obvious trade-off is a lack of gray scale.

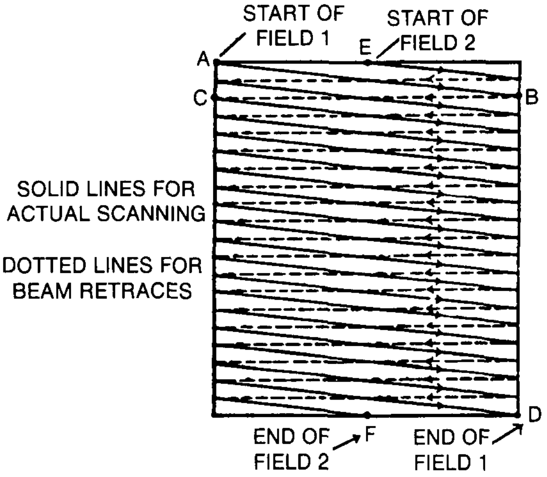

Fig 10. The path of the electron beam for interlaced scanning.

SIGNAL INPUTS

Many types of signal inputs are available to interface displays to various systems. The most common are noted below.

Composite Video

The video information is combined with the vertical and horizontal synchronizing signals to provide a single input connector to the display.

Block Sync

The vertical and horizontal synchronizing signals are combined on one input connector. (This is also called "composite *sync*.")

Separate Sync

Three separate input connectors are used for the video, vertical sync, and horizontal sync.

RGB

Color displays often use three separate video signal inputs for each of the three primary colors (red, green, and blue). The vertical and horizontal sync signals are usually combined with the green video input, similar to the method described in composite video.

Digital Input

Some displays, such as the Tektronix GMA-251, (Fig 11), contain digital circuitry to interface to a host computer via data lines such as those conforming to the industry RS-422 standard. Internal memory is used to store one complete frame without the need to continually

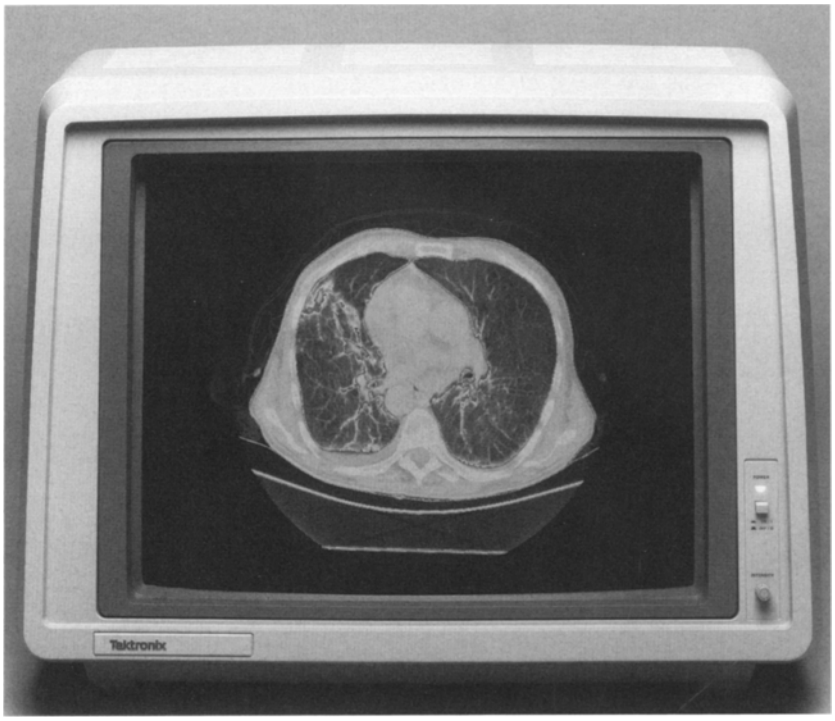

Fig 11. Tektronix GMA 251 digital image display.

feed information to the display from the computer. Many image-enhancement and presentation operations may be done by the computer, including contrast enhancement, image subtraction, windowing, negative images, scrolling to view selected areas of a large image, and simultaneous display of several smaller images.

Update speed for new images is an important consideration for digital displays and is determined by both the host computer and the display. Greater resolution and faster update rates require faster data transfer rates to produce a complete image on the screen in the same amount of time. Doubling the resolution requires four times the interface speed to produce a complete image. Increasing the refresh rate to reduce flicker requires a proportional increase in interface speed. The GMA-251 described previously uses a 16-bit parallel interface, high speed gallium arsenide D to A (digital to analog) converter, and carefully tuned delay lines to achieve transfer times of 0.2 second for storing and displaying a complete 2,048 × 1,536-pixel image. Actually, 2,048 × 2,048 pixels may be stored in the display memory with any selected 2,048 × 1,536 area displayed. The internal data bus is a 64-bit parallel that presents the opportunity to further increase the update speed by a factor of four.

PHOSPHOR CHOICE

Four phosphor screens are commonly used for image displays. These are X (previously designated P22), used in all color displays; WW (P4) which was widely used in black-and-white television receivers; WB (P45), used often for medical displays, and "paper-white." The first, X, is the standard color display screen, and the others are used for monochrome displays.

The reasons which made P4 the best choice for black and white television, good brightness and a "crisp" bluish-white color, are the reasons for its suitability for image displays. The only drawback is the fact that it is actually a blend of two different phosphors having yellow and blue colors to produce white. This makes it a little more difficult to achieve identical color screens, and each manufacturer's P4 will be slightly different; close examination of the screen will show a slight yellow and blue mottling. On the positive side, it is possible to tailor the blend of phosphors to a customer's specification to produce a particular shade of white; this is exactly how paper-white screens are achieved. Because paper-white has more yellow, which is sensed more easily by the eye, it is correspondingly brighter.

P45 screens are made of a single-component phosphor and will have better color consistency. P45 is used for a number of medical applications to present a color similar to that of x-ray film. The trade-off, which is fairly severe, is a loss of 30 to 40% in brightness.

Approximately 200 other phosphor screens are available commercially. Most are not suitable for medical-image displays because of low efficiency, objectionable colors on prolonged viewing, and/or more rapid aging.

GEOMETRIC DISTORTION

Several forms of geometric distortion may be present in a display. The ability to tolerate distortion of an image is highly dependent on the application and, as would be expected, higher-precision displays have price tags to match. Displays used for medical diagnostics must be as accurate as possible, whereas displays used for text editing do not require such a degree of refinement.

The following are the more common distortions and some of these are illustrated in Fig 12.

Pincushion

This is common in larger screen displays, especially those with wide CRT deflection angles used to shorten tube length. Electronic pincushion correction circuits are included in more sophisticated displays. These allow adjustment for near-straight edges on the raster. At the expense of spot size and shape, low-cost displays use permanent magnets mounted on the deflection yoke to correct for pincushion distortion.

Barrel

This is less common and can be the result of overcorrecting for pincushion distortion.

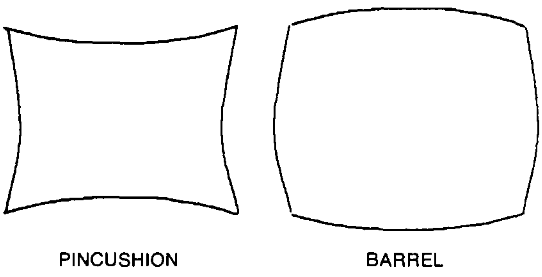

Fig 12. Raster distortion.

Nonlinearity

This is particularly noticeable when a large circle is displayed and will cause flattening or stretching of portions of the circle. Adjustment is usually provided for linearity, at least in the vertical direction.

Hook or Flagging

Hook is usually exhibited as a bending of the upper left corner of the screen on the edge of the raster. This is caused by parts of the circuitry's not being quite ready at the beginning of the vertical scan.

Line-Pairing

This is particularly common with interlaced displays and those with more than 1,500 scan lines. Line-pairing is a bunching of horizontal scan lines which show up as bright and dark areas at normal viewing distances. The cause may be either electrical or magnetic disturbances within or nearby the display.

Ringing

A deflection yoke improperly matched to the horizontal deflection circuits or of poor quality will cause a series of dark and light shaded bands at the left side of the screen that die out after an inch or so of horizontal scan.

Eliminating the above distortions requires great care in the design of a display.

DISPLAY STANDARDS

A number of standards organizations are actively pursuing display standards aimed at common definitions and ways of specifying display performance. These include the Society for Information Display (SID), Electronic Industries Association (EIA), and American National Standards Institution (ANSI). The Human Factors Society (HFS) and ANSI have jointly issued a particularly useful document on human factors for displays as ANSI/HFS 100-1987. A list of current and forthcoming display standards from many standards organizations has recently been published by the Society for Information Display.[4]

THE FUTURE

There is a continuing trend towards higher resolution CRT displays in both color and monochrome. Flat panel displays are still on the horizon, although cost is high and performance lags behind that of CRT displays at present. Many breakthroughs being made in flat panels will allow their wider usage in the future.

High definition television (HDTV) can be expected to produce fallout in display devices and associated electronic circuitry. The next few years promise to be exciting as the contest between competitive display technologies heats up and further technological advances are made.

APPENDIX

Formulas for calculating scan frequencies, video bandwidth, and digital clock frequencies are

$$f_h = f_v \cdot l_v / d_v$$

$$f_{clk} = f_h \cdot 10^{-6} \cdot p_h / d_h$$

$$bw = f_{clk} \cdot k$$

where

f is frequency in hertz;
h is horizontal;
v is vertical;
l is number of scan lines;
d is duty factor, typically 0.98 for vertical and 0.8 for horizontal (active scan/scan period);
f_{clk} is the pixel clock frequency in megahertz;
p_h is the number of horizontal pixels;
bw is the video bandwidth in megahertz; and
k is a constant of about 0.6.

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