Characterization of Color CRT Display Systems for Monochrome Applications

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Soft-copy presentation of medical images is becoming more and more important as medical imaging is strongly moving toward digital technology, and health care facilities are converting to filmless hospital and radiological information management. Although most medical images are monochrome, frequently they are displayed on color CRTs, particularly if general-purpose workstations or PCs are used for medical viewing. In the present report, general measurement and modeling procedures for the characterization of color CRT monitors for monochrome presentation are introduced. The contributions from the three color channels (red, green, and blue) are weighted according to the spectral sensitivity of the human eye for photopic viewing. The luminance behavior and the resolution capabilities of color CRT monitors are analyzed with the help of photometer and charge-coupled device (CCD) camera measurements. For the evaluation of spatial resolution, a two-dimensional Fourier analysis of special test images containing white noise (broadband response) is employed. A stage model for a color CRT monitor is developed to discuss the effects of scanning and dot sampling. Furthermore, display intrinsic veiling glare and reflectivity of typical color CRT monitors are measured and compared with those of monochrome CRT monitors. The developed methods and models allow one to describe the image quality aspects of color monitors if they are applied for medical monochrome image presentation. Particularly, because of the reduced luminance and dynamic range of color monitors, the calibration and control of their luminance curves is a very important task. For present color CRT monitors, $1,280 \times 1,024$ turns out to be an intrinsic limit for the displayable matrix of medical images.

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TODAY, more and more health care facilities are converting to digital filmless hospital and radiological information management. Within that scope, the soft-copy presentation of medical images gains more and more relevance for an efficient and cost-effective hospital organization. Although most medical images are monochrome, they are

presented frequently on color CRT display systems. Particularly, if general-purpose workstations or PCs are used for medical viewing, color monitors are more or less standard. These common computer graphic displays are applied without any further modification. This is in contrast to the medical monochrome monitors, which normally are developed especially to fulfill the high image quality requirements of medical imaging. Because the total number of medical displays is small in comparison to consumer applications, there is little incentive for the consumer display industry to develop special color CRTs for medical imaging. Hence, the limitations of the consumer monitor CRT also apply to medical usage and might limit the image quality for some applications.

The purpose of this report is to characterize the special image quality aspects of medical image presentation on color monitors and to develop measures for display selection, display calibration, and display maintenance.

COLOR CRT MONITOR TECHNOLOGY

Color viewing on monitors is realized by merging the three base colors—red (R), green (G), and blue (B)—emitted from a structured phosphor screen that is excited by three individual electron beams. This article provides a brief illustration of the current color CRT technology and discusses some descriptors that are important for image quality (eg, dot pitch). The major components of a standard color CRT are shown in Fig 1. Generally, it consists of an RGB triple-electron gun, a shadow mask, and a structured phosphor screen with red, green, and blue patches. Each of the three electron beams must pass the shadow mask before it hits the phosphor dots of its color. The screen shadow mask distance, of approximately 1 cm, provides the spatial separation of the three beams on the screen. A sketch of the screen shadow mask region is provided in Fig 2. The light emitted by the individual phosphor dots is merged by the human eye, forming a smooth colored image impression if the viewing distance is sufficiently high.

In Fig 3, the three major types of shadow masks and the respective screen structures are indicated. Typically, we find the dot mask in computer mon-

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Fig 1. The basic components of a color cathode-ray-tube (CRT).

itor tubes, whereas the slot mask is applied in television tubes. The Trinitron mask is applied with different line pitches in TV as well as monitor CRTs. The dot and slot masks provide a separation in horizontal and vertical direction, whereas the Trinitron mask separates in the horizontal direction only. A shadow mask is characterized by its dot or line pitch, giving the distance from hole to hole or slot to slot. For the dot mask, we have a hexagonal structure, and the dot pitches (eg, given in technical data sheets) refer to the diagonal pitch of two dots of the same color, as indicated in Fig 3. In the delta-gun arrangement, the three (RGB) guns form an equal triangle, and thus the phosphor dots do. The three guns are horizontally in line for the most

commonly used in-line gun. The horizontal and vertical dot pitches can be different. Usually they are chosen such that scan and video Moiré are minimized for the typical image matrix, which will be displayed on the screen.

Present high-resolution monitor CRT technology comes with dot pitches of 0.26 to 0.28 mm for screen diameters of about 20". The transmission of the shadow mask is only about 10% to 15%, and the major portion of the current in the electron beam does not contribute to the luminance. Typically, color CRT monitors have a maximum luminance of 80 to 100 cd/m² only, whereas monochrome CRT monitors can achieve more than 800 cd/m².¹⁻³ Table 1 provides some typical numbers and compares them with actual monochrome CRT monitors.

Modern digital monitors provide a number of automatic corrections to improve image quality. Examples are controlling the uniformity of color and luminance, or adjusting dynamically the convergence of the three beams. A digital control interface allows for the establishment of interactive as well as automatic procedures to optimize or recalibrate the monitor in combination with the applied graphics card. These control opportunities are particularly important for medical image applications because they allow for the implementation of image quality maintenance procedures such as control of the display function.²

MONITOR CHARACTERIZATION

In this section, measurement procedures are described for analyzing the (gray) display function, uniformity of luminance and color, veiling glare, reflectivity, resolution, and screen fixed pattern. Before the detailed description is provided, it is important to consider some basic luminance aspects on the formation of monochrome images on a color monitor.

Basically, color vision can be described by a set of three parameters.⁴⁻⁶ Most common is the x, y, z system of the CIE 1931 standard colorimetric observer. For this system, all three color matching functions [x(λ), y(λ), z(λ)] have a positive sign, and the y(λ) curve represents the standard spectral luminous sensitivity curve [V(λ)] of the human eye for photopic viewing. For the characterization of luminance performance as well as spatial resolution, the contributions of the three color channels of a CRT monitor are weighted according to the V(λ)

Fig 2. The shadow-mask screen region of a color CRT.

Fig 3. The different screen structures of color CRTs (shadow masks) and their relevant dot pitches (P_h , horizontal pitch; P_v , vertical pitch).

curve. Although the dark part ($<10 \text{ cd/m}^2$) of the luminance range of color monitors falls into the mesotopic viewing range of the human eye, it appears to be sufficient to apply the photopic sensitivity curve for the characterization of the displayed image quality.

Figure 4 shows a CIE x, y chromaticity diagram overlaid by the black-body line (BBL) or Planckian locus and a color triangle formed by typical television, here EBU (European Broadcast Union) phosphors. Color temperatures or correlated color temperatures⁷ refer to coordinates falling on or close to the Planckian locus. Many natural light sources have coordinates very close to the BBL and, roughly, a white color impression is perceived between 2,500 K (warm white) and 10,000 K (bluish white). Modern color computer monitors

allow selection of the color temperature; a typical preset value is 9,300 K with $x = 0.294$ and $y = 0.294$. Television studio monitors often are standardized to 6,500 K (D65) with $x = 0.313$ and $y = 0.329$. For an RGB monitor, all colors falling into the phosphor triangle can be realized. A gray impression on a color CRT monitor is achieved if the applied video signal for the RGB channel is almost equal. Important for the analysis of gray-

Table 1. Typical Properties of Color and Monochrome CRT Monitors

	Monochrome CRT Monitor	Color CRT Monitor
L_{max}	$>800 \text{ cd/m}^2$	$\leq 100 \text{ to } 150 \text{ cd/m}^2$
Maximum useful matrix @ 20" diagonal	$2,560 \times 2,048$	$1,280 \times 1,024$
Veiling glare ³	0.6% to 1.0%	1.0% to 1.4%
Color temperature	Fixed, determined by phosphor and glass	Adjustable, but possibly nonuniform
Noise, artifacts	Basically screen fixed-pattern noise	Fixed dot raster, aliasing and Moiré

Fig 4. The x, y chromaticity diagram of the CIE 1931 standard.

scale performance is the relative luminance contribution from each RGB channel, a value that is dependent on the chosen color temperature. For example, for D65 and EBU phosphors, 71% of the perceived luminance stems from the green channel, 22% from the red, and only 7% from the blue.

Measurement Principles and Setups

Apart from reflectivity and spectral analysis, all measurements were performed with the setup as sketched in Fig 5. The patterns used for the analysis are generated by a standard workstation graphic driver board (Sun Microsystems creator) or a high-bandwidth video generator (Astro VG 829). The video generator is capable of running with a 440-MHz pixel clock. Yet, because the monitors typically are operated at a 76-Hz refresh rate with an active matrix of $1,280 \times 1,024$ pixels, the actual pixel clock is only approximately 135 MHz. Under these conditions, the video generator exhibits 100% contrast transfer, even for a square-wave function, with a period of only two pixels and a magnitude of 700 mV. The graphic driver board has somewhat worse transfer than the video generator. These losses are considered in the interpretation of measurement results, ie, resolution measurements with the broad-response method as described later.

The luminance output of the monitors is analyzed with a photometer, having a spectral sensitivity that closely follows the $V(\lambda)$ curve. For laboratory luminance measurements, we use an LMT L1003. The photometer is shielded against stray light very carefully by a conical tube. Color coordinates are analyzed with a spectrometer (Photo Research PR704) and compared with measure-

ments of a hand held-type chroma meter (Minolta CS100). The analysis of veiling glare (low frequency drop [LFD]) is similar to previously described measurements for monochrome CRTs.³ To compare reflectivity of the displays, we use a simple box of diffuse reflecting material. The setup is sketched in Fig 6. A common view box for presentation of x-ray images is used as an adjustable light source. A photometer is placed behind a small hole drilled in the box on the central axis of the CRT. The measurement provides an estimation of reflection of ambient light for a more-or-less diffuse illumination of the screen. If the monitors under investigation are placed on the same position, a good relative comparison of their diffuse reflectivity is possible. We did not analyze the specular reflection. The specular reflection can significantly deteriorate the image quality in presence of any light sources that are reflected into the viewing angle. Here antireflective or antiglare coatings applied on the surface of the front-glass can improve performance. For the measurements of screen fixed pattern and resolution, we use a monochrome charge-coupled device (CCD) camera system with a 12-bit slow scan readout (Photometrics CE 200A). The camera has been analyzed with respect to read-out noise and gain uniformity. For all relevant integration times (ie, up to a few seconds), the read-out noise has a standard deviation of less than 40 electron rms. The applied $1k \times 1k$ CCD sensor (Thomson TH7896A) provides a high saturation capacity of 400,000 electrons. Thus, the signal-to-noise ratio is sufficiently high so that measurements are not affected by electronic camera noise or signal shot noise. The CCD sensor has excellent uniformity of the gain, with a pixel-to-pixel standard deviation of less than 0.5%, ie, no gain correction for the CCD sensor is required.

In the monitor analysis, we employ only the center 512×512 pixels region of the $1k \times 1k$ CCD pixel matrix to minimize the effect of vignetting in the camera optics. Therefore, no correction of the vignetting is applied, and the camera images are corrected only for the dark offset. The restriction to the CCD center region also reduces potential losses of the optical transfer function outside the center of the images. We typically realize four- to eight-fold oversampling of a monitor pixel by a CCD camera pixel. Hence, MTF losses of lens and CCD are negligible. Measurements of the MTF of the camera provided values of more than 95% at one fourth

Fig 5. Experimental setup for photometer and CCD camera measurements.

Fig 6. Sketch of the measurement box for analysis of reflected ambient light.

of the Nyquist frequency of the CCD sensor. The camera is mounted on an x-y-z table in order to position the camera at different locations of the screen.

Generally, for the analysis of monochrome images on a color CRT, we prefer a monochrome high-resolution CCD camera over a color CCD. The monochrome CCDs provide better signal-to-noise and resolution performance than color CCDs and can be calibrated fairly easily with the help of a photometer. We apply the following procedure. First, the relative contributions of the RGB channels to the total luminance are measured with the photometer by displaying a red, green, and blue flat image in a central window of 10% area at the desired video signal level. Second, the three images also are captured with the CCD camera, and the averaged pixel data for red, green, and blue are determined. Subsequently, a weighting factor is derived to normalize the CCD camera images according to the photometer measurements. For all

further analyses, the three RGB images acquired by the CCD are multiplied by the weighting factor and summed up to give the gray luminance representation. Because the final image is composed from three individual exposures, spatial shifts of the camera are very critical and must be avoided by providing a very stable mechanical setup of the camera and the monitor.

Measurement Examples and Discussion

Luminance. In Fig 7, a typical display function of a color CRT monitor is shown for typical contrast and brightness settings. As for monochrome CRT monitors,^{2,8,9} the slope of the display function is very much dependent on the contrast and brightness settings. However, the maximum luminance of a color monitor is typically 5 to 10 times lower than that of a monochrome CRT, and thus careful control of the display function, and proper application of the gamma-correction look-up

Fig 7. Typical display function for gray images displayed on a color CRT monitor. The individual contributions of the red, green, and blue channel to the total gray luminance also are indicated. The DICOM display function standard for the covered gray-luminance range is given.

Fig 8. Display intrinsic veiling glare values.

table (LUT) of the video driver are much more important, particularly if ambient light is present. For instance, if the DICOM display function¹⁰ shall be realized, Fig 7 illustrates the differences between the intrinsic display function and the DICOM standard. Because the maximum luminance is significantly lower than that of high-brightness monochrome monitors, the number of discernible gray steps is limited.

Intrinsic contrast (veiling glare). The measurement procedure of veiling glare for color monitors is very similar to the evaluation of monochrome monitors. A black square is displayed on a uniform white background, and the luminance in the center of the black square is measured as a function of the size of the square. From the measured luminance, the intrinsic dark luminance (black level) is subtracted to reflect only the light and electron scatter processes. The white background fills the entire screen. Figure 8 provides the results for some color and monochrome CRT monitors.

Fig 10. Typical values of reflected ambient light as a function of the ambient light level.

For small objects ($<100 \times 100$ pixels), color CRT monitors show significantly higher veiling glare than monochrome CRTs. This is mainly caused by electron back-scatter in the region between the phosphor screen and the shadow mask. Figure 9 illustrates the effects. The veiling glare reduces the intrascene contrast in a real image scenery, particularly the small detail contrast in dark image parts. As is clear from Fig 8, the contrast detail perceptibility is much worse for color than for monochrome CRT monitors.

Reflectivity. Perceived image contrast also is reduced by reflected ambient light.^{8,9} Figure 10 presents typical measurements for several display systems at ambient light levels up to 400 lux, which is not unusual for office situations. We find values of 0.035 to $0.06 \text{ cdm}^{-2}/\text{lux}$ for monochrome monitors. Color monitors show lower values (of approximately $0.027 \text{ cdm}^{-2}/\text{lux}$) because of their darker front glass and the applied black matrix. The

Fig 9. Illustration of electron back-scatter effects in color CRTs.

observed variations between the monochrome monitors are caused by differently tinted glass of the CRTs. The reflected light amounts to more than 10 cd/m², and obviously this high value reduces significantly the dynamic range and the number of noticeable gray steps, particularly for low-luminance color monitors. Consequently, ambient light always should be reduced as much as possible.

Resolution. The resolution for monochrome CRT monitors is determined basically by the electron spot profile. For color CRT monitors, the screen structure of the color patches and the convergence between the electron beams play an additional role.

Figure 11 shows a simplified stage model of the formation of a monochrome image on a color CRT. Starting from the digital gray image in the memory of the graphics card, the RGB values are assigned by a gray-to-color LUT. Typically, for monochrome images, $R = G = B$ is assigned. The RGB values are then fed to three digital-to-analogue converters (DACs), commonly having a maximum resolution of 8 bit. At these two stages, the gray-scale resolution is determined. The three analogue video signals are connected to the video amplifiers of the monitor. Bandwidth limitations of the video amplifier generally reduce the modulation transfer of the monitor in horizontal direction. The subsequent formation of an electron beam is the major low-pass of the system and has a significant impact on the total MTF of the display system. Each electron beam is scanned horizontally over the screen. Here, convergence between R, G, and B

becomes important, and scan Moiré effects can occur. The electron beam information is sampled in the next step by the individual phosphor dots. Note that this is a sampling by a fixed matrix of phosphor dots. As long as the aperture of the dots/strips is small compared with the video pixel distance, the sampling has no impact on the MTF but determines the relevant frequencies for which aliasing and video Moiré are observed. It is important to understand that there is no fixed coupling between the scan raster of video lines and the phosphor dot matrix. The displayed video matrix (eg, 1,024 × 768 or 1,280 × 1,024) is always sampled by the same dot structure. The consequences will be illustrated later in this chapter by a Fourier analysis. Finally, light is generated by the phosphor, and light scattering in the front glass can further reduce the MTF.

In the following sections, two different procedures to assess the resolution capabilities of a color monitor for monochrome images are discussed. For both procedures, we split the monochrome image into its three color parts: red, green and blue. The information for each color channel is then weighted according to its luminance contribution to white, ie, green, 71%; red, 22%; and blue, 7%).

Line and Spot Profiles

Most commonly, resolution is assessed by evaluation of electron spot profiles with CCD cameras that scan an image with a line sensor (eg, Microvision). Because of the scan and sampling effects, the monitor resolution generally is different in horizon-

Fig 11. A simplified stage model of the formation of monochrome images on color CRT monitors.

tal and vertical directions. Figure 12 shows examples of horizontal and vertical line profiles. Generally, the spot profile is dependent on the electron beam current, and the spot performance becomes worse for higher brightness. For color CRTs, this effect is somewhat masked by the aperture grill. We measured typically at 20% of the maximum luminance, which roughly corresponds to 50% video signal.

For the analysis of the MTF, we adapt our method from monochrome monitor assessment.³ First, a horizontal or vertical line is displayed on the red channel and acquired with a CCD camera. The same is done for the green and the blue channel, subsequently. Second, each image is multiplied with a weighting factor corresponding to its luminance contribution to white. Finally, the three images are summed together, and averaging in the line direction and a Fourier analysis³ are done.

The following points of the procedure are critical. First, the applied method can only be correct if the MTF of the CCD camera and the lens are equal for all color channels. Particularly for the red

channel, this is not true. However, because more than two thirds of the luminance is coming from green, the effect is negligible. Second, if the applied video pitch (the distance of a horizontal pixel for the chosen image matrix) is comparable or even smaller than the phosphor dot pitch, the analysis of vertical lines becomes critical. The measured profile will depend on the actual position of the line with respect to the dot raster, ie, the maximum of the electron spot does not match with the color dot. Therefore, a better method would be analysis of the broad-band response, which is discussed in the next section. Third, similar to monochrome monitors, the video amplifier does not reach its steady state within a single pixel. For a more accurate evaluation, vertical lines should be displayed as a black line on a background with the corresponding video level.³

Broad-Band Response

A method that better represents the resolution capabilities for the display of medical images is the

Fig 12. A white cross on a color CRT monitor acquired with a monochrome CCD camera. For the upper left picture, three individual exposures have been taken, one for each color.

analysis of the broad-band response of the monitor. This method has been described in detail.³ Briefly, three images (R,G,B) consisting of a flat video signal overlaid by broad-band noise are displayed on the screen and captured with the CCD camera. For each color, a flat gain image also is acquired. The individual images are then gain-corrected and weighted according to the luminance of the color channel. A broad-band noise image of gray is formed by summing up the three color channel images. Finally, a two-dimensional (2D) Fourier analysis is performed and the MTF is calculated from the noise power spectrum.³

Figure 13 illustrates this method. In the upper part, the flat gain mask image (left) and its 2D

Fourier spectrum (right) are shown. The white spots in the FFT image represent the hexagonal sampling structure of the dot mask of the CRT, and its repeated frequencies. In the lower part, the broad-band noise image (left) and its 2D Fourier spectrum are shown. The central ellipse indicates the frequency response of the monitor to the white noise input image. This spectrum is repeated several times at the position of the phosphor dot sampling frequency. The Nyquist frequency of the video image is roughly half the dot sampling frequency (Fig 14). If we would have displayed a higher image matrix (eg, $1,600 \times 1,200$ instead of $1,280 \times 1,024$), the spectra clearly would overlap and a lot of aliasing would occur. As a rule, to

Fig 13. Flat and noise images (left) displayed on a dot mask color CRT. On the right, corresponding 2D Fourier spectra are shown.

Fig 14. The 2D broad-band response spectra of a monochrome CRT monitor (upper part), a Trinitron CRT monitor (center part), and a dot mask color CRT monitor (lower part). The dashed square indicates the Nyquist frequency of the $1,280 \times 1,024$ image matrix.

realize an unambiguous representation of the video image, the repeated spectra in the 2D Fourier spectrum must not overlap.

Figure 14 shows the broad-band response for a monochrome monitor, a Trinitron color monitor,

and a dot mask color monitor. The central square indicates the Nyquist frequency of the displayed image matrix of $1,280 \times 1,024$ pixels.

For the monochrome monitor, we find only the central ellipse because the screen is not structured. The two smaller dots above and below the center indicate the raster frequency of the electron beam scan. For the Trinitron monitor, the central ellipse is repeated several times owing to vertical sampling by the phosphor stripes (Fig 3). The spectra already are slightly overlapping because the horizontal distance of a video pixel for $1,280 \times 1,024$ is $280 \mu\text{m}$, whereas the horizontal pitch of the stripes is $310 \mu\text{m}$. Consequently, for the horizontal MTF curve, which is provided in Fig 15, terms from the

Fig 15. Comparison of BBR analysis with Fourier analysis of an inverse line for a color CRT monitor with a Trinitron mask. The horizontal line pitch of the Trinitron mask is 0.31 mm , whereas the horizontal pixel pitch is 0.28 mm for a $1,280 \times 1,024$ matrix. This results in clearly observable aliasing in the lower figure, and the MTF cannot be judged around the Nyquist frequency. The CRT is not suited for a $1,280 \times 1,024$ pixel matrix.

higher harmonics are folded back into the region below the horizontal Nyquist frequency. In case of the dot mask, the spectrum is repeated in horizontal as well as in vertical directions.

Figure 16 shows vertical MTF curves. The measurements have been performed at 50% video level. We do not present the horizontal MTF curves because they are for a $1,280 \times 1,024$ matrix already aliased. Examining Fig 16, one recognizes that the vertical MTF curves are very comparable for all color CRT monitors investigated. In our experience, the MTF of a color monitor does not have the same importance as that of a monochrome monitor. The image impression basically is determined by the dot or line structure rather than by the MTF. This is attributable to the following arguments. For a 20" to 21" CRT monitor, the human observer typically has a viewing distance of 50 cm or more. Consequently, in case of a $1,280 \times 1,024$ image matrix, the Nyquist frequency corresponds to about 15 cycles/degree of viewing angle. Here the MTF of the human visual system is already low. If the observer wants to resolve small gray-scale details at the Nyquist frequency, he or she would come closer to the monitor. But then the viewer would, for the current dot/line pitches, begin to identify the colored screen structure and lose the gray-scale impression. Therefore, it is most important for the display of monochrome medical images to select an image matrix that corresponds to the dot matrix. For the current CRT technology with dot pitches of 0.26 to 0.28, a matrix of $1,280 \times 1,024$ is the absolute maximum.

A separate problem is the convergence of the

Fig 16. Typical vertical "MTF" curves derived from profiles of horizontal lines of color CRT monitors.

three electron beams. As long as only medical gray-scale images are presented, small convergence errors between the three guns are almost negligible. This is due to the fact that approximately 70% of the luminance stimuli are coming from the green gun and that the other two guns provide basically the gray impression, but have minor impact on the perceived resolution. However, if text information is presented on the same screen, convergence between the three guns becomes a very sensitive image quality criterion. A misconvergence will be recognized immediately and be judged as a poor performance. This can be checked easily by the reader with a simple experiment. Display a medical gray-scale image and simultaneously a text window. Then change the convergence control of the monitor slightly. One will easily observe the misconvergence on the text but hardly in the medical image.

CONCLUSION

There are four factors that mainly determine the perceived image quality of a monitor: luminance, contrast, resolution, and noise. With respect to medical viewing, monochrome CRT monitors still provide the highest image quality. For color CRT monitors, the shadow mask sets significant limitations, particularly for luminance, intrinsic contrast, and resolution. Typically, color CRT monitors have a maximum luminance of only 80 to 100 cd/m^2 , whereas monochrome monitors can achieve more than 800 cd/m^2 . Because of electron back-scatter processes between phosphor screen and shadow mask, color CRT monitors show significantly higher veiling glare for small objects, and thus poorer small detail contrast perceptibility than monochrome CRT monitors. Color display systems, particularly if operated under high ambient light conditions, require an adaptation of the LUT to optimize the gray-scale rendition of medical monochrome images. The structured color screen can reduce the amount of reflected ambient light because the space between the phosphor dots (stripes) is covered with a black layer (black matrix). The dot pitch of the shadow mask determines the useful image matrix that can be displayed on the screen. For screen diameters of approximately 20", present technology comes with dot pitches of 0.26 to 0.28 mm. To avoid aliasing and other artifacts, not more than $1,280 \times 1,024$ pixels should be displayed on a standard 20" color CRT. Modern monitors have a

digitally controlled convergence correction and high-performance video amplifiers that allow a $1,280 \times 1,024$ image to be displayed with a refresh rate of more than 80 Hz.

Although flat panel display systems are improving rather quickly, there is also a great deal of development in color CRTs and color monitor technology. The major part of the industry focus here is on cost reduction, digital control, flat screen, and reducing the bulkiness of the monitor. These

features are driven by the high-volume computer desktop monitor market and will become available for the medical application without special request. Particularly, the digital control of the monitor will allow optimal implementation of image quality maintenance procedures.

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