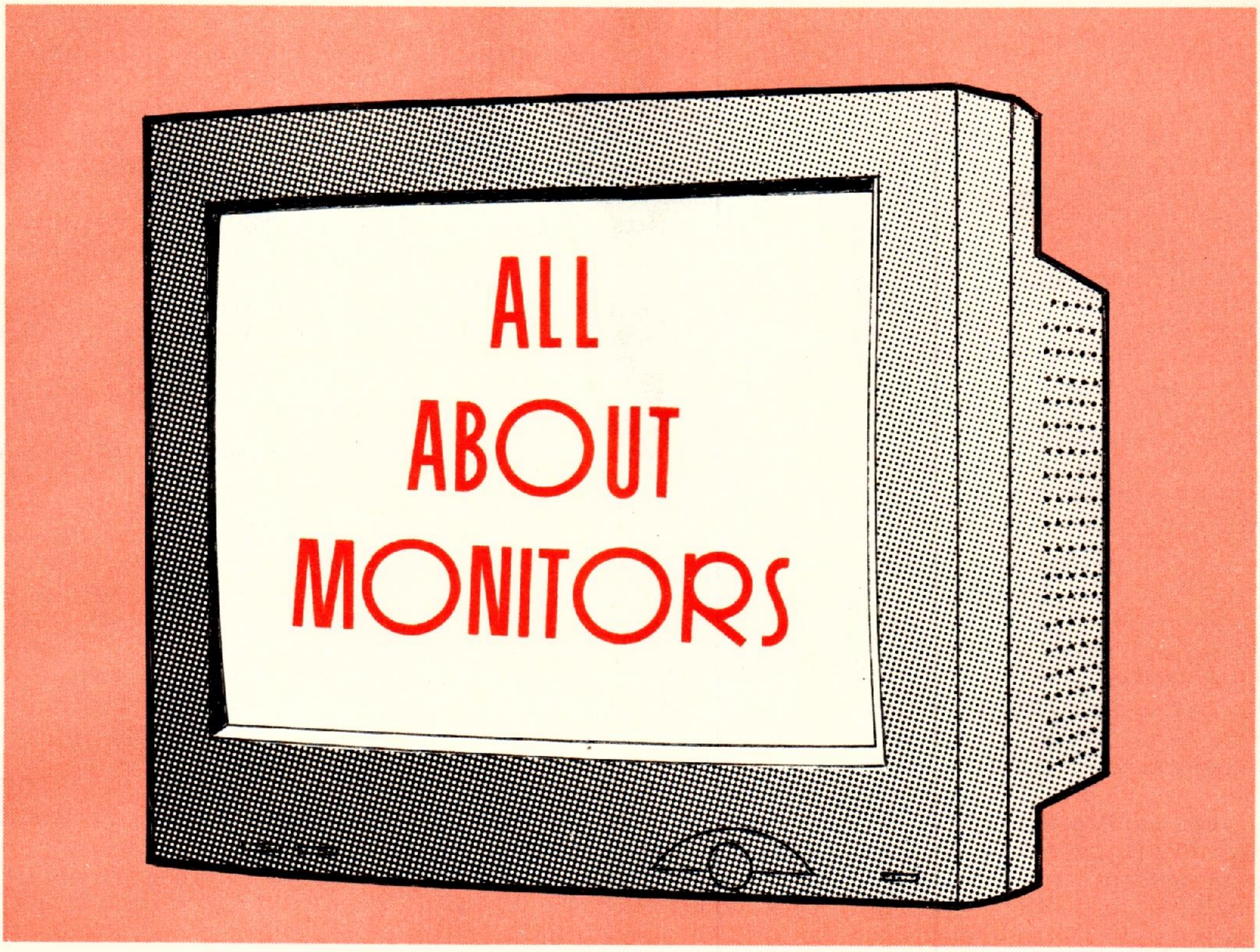

ALL ABOUT MONITORS

Here's a look behind the screens of one of the most important, yet often overlooked, parts of a personal computer

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No matter how fast and powerful your PC may be, it serves little purpose without a monitor. For most computer users, the monitor is usually left as an afterthought, or something that's just "included" with the PC purchase. Yet, monitors play a surprisingly important role in the modern computer. They are the window into a computer's world. Video clips, word processing, web browsing, presentation development—virtually every application we use a computer for will depend on the presence of a working monitor. As a result, we can choose from an astonishing variety of monitor types, sizes, and qualities—all of which have an effect on how long (and how well) we use our computers. This article explains the essential concepts of a computer monitor, and shows you what's inside.

The first step in understanding computer monitors is to understand the terms and concepts essential for monitor operation. Let's go though those next.

The CRT. The *Cathode Ray Tube* (called a "CRT" or "screen") is essentially a large vacuum tube. One end of the CRT is formed as a long, narrow neck, while the other end is a broad, almost-flat surface. A phosphor coating is applied inside the CRT along its front face. The neck end of the CRT contains an element (called the *cathode*) which is energized and heated to very high temperatures (much like an incandescent lamp). At high temperatures, the cathode liberates electrons. When a very high positive voltage is applied at the front face of the CRT, electrons liberated by the cathode (which are negatively charged) are accelerated toward the front face. When the fast-moving electron strikes the phosphor on the front face, light is produced. By directing the stream of electrons across the front face, a visible image can be produced. Of course, there are other elements needed to control and direct the electron stream, but this is CRT operation in a nutshell.

CRT face size (or *screen size*) is generally measured as a diagonal dimension—that is, a 43.2cm (17-inch) CRT is 43.2cm (17 inches)

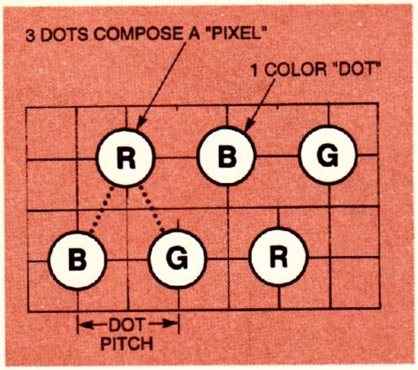

Fig. 1. In a color monitor, red, green and blue phosphor dots are arranged in a "triad" configuration. Each triad is one pixel, and the dot pitch specification of a monitor is the distance between phosphor dots.

between *opposing* corners. Larger CRTs are more expensive, but produce larger images that are usually easier on the eyes. A CRT specification will also list the type of phosphor(s) used (*i.e.* P22), in addition to anti-glare (or any special finish) coatings used during manufacture.

Pixels and Resolution. The picture element (or *pixel*) is the very smallest point that can be controlled on a CRT. For monochrome displays, a pixel is simply turned on or off. For a color display, a pixel could also assume any of a number of different colors. Pixels are combined in the form of an array (rows and columns), and it is the *size* of that pixel array that defines the display's *resolution*. As a result, resolution is the total number of pixels in width by the total number of pixels in height. For example, a typical EGA resolution is 640 pixels wide by 350 pixels high, while a standard VGA resolution is 640 pixels wide by 480 pixels high. Typical super VGA (SVGA) resolution is 800 pixels wide by 600 pixels high and higher. Resolution is important for computer monitors since higher resolutions allow finer image detail.

While monochrome CRTs use a single, uniform phosphor coating (usually white, amber, or green), color CRTs use three color phosphors (red, green, and blue) arranged as triangles (or *triads*). Figure 1 illustrates a series of color phosphor triads. On a color monitor, each triad represents one pixel (even though there are three *dots* in the pixel). By using the electron streams from three electron guns—one gun for red, one for blue, and another for green—to excite each dot, a broad spectrum of colors can be produced. The three dots are placed so close together that they appear as a single point to the unaided eye.

The quality of a color image is related to just how close each of the three dots are to one another. The closer together they are, the purer the image appears. As the dots of a pixel are spaced further apart, the image quality degrades because the eye can begin to discern the individual dots in each pixel. That results in lines that no longer appear straight and colors that no longer appear pure. *Dot pitch* is a measure of the distance between any two phosphor dots in a pixel. Displays with a dot pitch of 0.31mm or less generally provide adequate image quality for most applications

Shadow and Slot Masks. The *shadow mask* is a thin sheet of perforated metal that is placed in the color CRT just behind the phosphor coating. Electron beams from each of the three "electron guns" are focused to converge at each hole in the mask—**not** at the phosphor screen. The microscopic holes act as apertures that let the electron beams through **only** to their corresponding color phosphors. In that way, any stray electrons are *masked*, and color is kept pure. Without a mask, stray electrons from one electron beam may accidentally excite nearby color phosphors, resulting in unwanted color combinations. Some CRT designs substitute a shadow mask with a *slot mask* (or *aperture grille*) that is made up of vertical wires behind the phosphor screen. Keep in mind that monochrome CRT designs do not use a mask since the entire phosphor surface is the same color.

Convergence. Remember that we said earlier that *three* electron guns are used in a color monitor—each gun excites a particular color phosphor. All three electron beams are tracking around the screen simultaneously, and the beams converge at holes in the shadow mask. That *convergence* of electron beams is closely related to color purity in the screen image. Ideally, the three beams converge perfectly at all points on the mask, and the resulting color is perfectly pure throughout (*i.e.* pure white). If one or more beams do not converge properly, however, the image color will not be pure. In most cases, poor convergence will result in colored shadows. For example, you may see a red, green, or blue shadow when looking at a white line. Serious convergence problems can result in a blurred or distorted image. Monitor specifications usually list typical convergence error as *misconvergence* at both the display center and the overall display area. Typical center misconvergence runs approximately 0.45mm, while overall display area misconvergence is about 0.65mm. Larger numbers than those indicate poorer convergence.

Pincushion and Barrel Distortion. The front face of most CRTs is slightly convex (bulging outward). Images, on the other hand, are perfectly square. When a square image is projected onto a curved surface, distortion results. Ideally, a monitor's raster circuits (discussed below) will compensate for the screen shape so that the image appears square when viewed at normal distances. In actual practice, however, the image is rarely

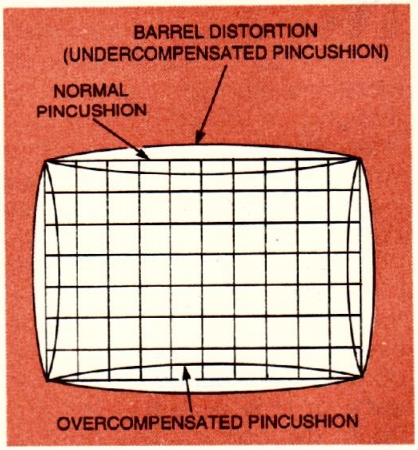

Fig. 2. Pincushion and barrel distortion occur when the displayed image deviates from square. Pincushion is used to describe an inward bend, while barrel is used to describe an outward bend.

square. The sides of the image (top-to-bottom and left-to-right) may be bent slightly inward or slightly outward. An exaggerated view of those effects is shown in Fig. 2.

Pincushioning occurs when sides are bent inward making the image's border appear concave. Other straight lines within the image may also appear to curve toward the image center. *Barreling* occurs when the sides are bent outward making the image's border appear convex. Straight lines in the image may appear to bend outward toward the edges of the screen. In a properly aligned monitor, those distortions should be just barely noticeable (no more than 2.0 or 3.0 mm). Note that barrel distortion is sometimes also referred to as *pincushioning* as well.

Horizontal Scanning, Vertical Scanning, Raster, and Retrace. To understand what *scanning* is, you must first understand how a monitor's image is formed. A monitor's image is generated one horizontal line of pixels at a time starting from the upper left corner of the display (see Fig. 3). As the beams travel across the line, each pixel is excited based on the video data contained in the corresponding location of video RAM on the video-adapter board. When a line is complete, the beams turn off (or *horizontal* blank) and are directed horizontally (and slightly vertically) to the beginning of the next line. A new horizontal line can then be drawn. That process continues until all horizontal lines are drawn and the beam is in the lower right corner of the display. When the image is complete, the beams turn off (or *vertical* blank) and are redirected to the upper left corner of the display to start all over again. The rate at which horizontal lines are drawn is known as the *horizontal scanning rate* (sometimes called *horizontal sync*). The rate at which a complete "page" of horizontal lines is generated is known as the *vertical scanning rate* (or *vertical sync*). Both the horizontal and vertical blanking times are known as *retrace times* since the deactivated beams are "retracing" their path before starting a new trace. A typical horizontal retrace time is 5ms, while the typical vertical retrace time is 700 ms (though these times will vary depending on the screen resolution being used). This continuous horizontal and vertical scanning action is known as *raster.*

We can apply numbers to scanning rates to give you an even better idea of their relationship. A typical VGA monitor with a resolution of 640 × 480 pixels uses a horizontal scanning rate of 31.5 kHz. That rate means that 31500 lines can be drawn in 1 second, or a single line of 640 pixels can be drawn in 31.7 µS. Since there are 480 horizontal lines to be drawn in one "page," a complete page can be drawn in (480 × 31.7 µS) 15.2 ms. If a single page can be drawn in 15.2 ms, the screen can be refreshed 65.7 times per second (65.7 Hz)—this is roughly the vertical rate that will be set for VGA operation at 640 × 480 resolution. In actual practice, the vertical scanning rate will be set to a whole number such as 60 Hz, which leaves a lot of spare time for blanking and synchronization. It was discovered early in TV design that vertical scanning rates under 60 Hz resulted in perceivable flicker, which causes eye strain and fatigue. You can start to see now that horizontal scanning rates are **not** chosen arbitrarily. The objective is to select a horizontal frequency that will cover a page's worth of horizontal pixel lines for any given resolution at *about* 60+ times per second. Newer monitor designs are now using vertical scanning rates of 72 to 80 Hz. Table 1 compares the scanning rates for current monitor resolutions.

Interlacing. Table 1 introduces another important concept of horizontal scanning known as *interlacing.* Images are "painted" onto a display one horizontal row at a time, but the sequence in which those lines are drawn can be non-interlaced or interlaced. A *non-interlaced* monitor draws all of the lines that compose an image in *one* pass (such as the pattern in Figure 3). This is preferable since a non-interlaced image is easier on your eyes—the entire image is refreshed at the vertical scanning frequency—so a 60-Hz vertical scanning rate will update the entire image 60 times in 1 second. An *interlaced* display draws an image as *two* passes. Once the first pass is complete, a second pass fills in the rest of the image. The *effective* image refresh rate is only half the stated vertical scanning rate. The typical 1024 × 768 SVGA monitor of Table 1 shows a vertical scanning rate of 87 Hz, but since the monitor is interlaced, *effective* refresh is only *43.5 Hz* and screen flicker is much more noticeable.

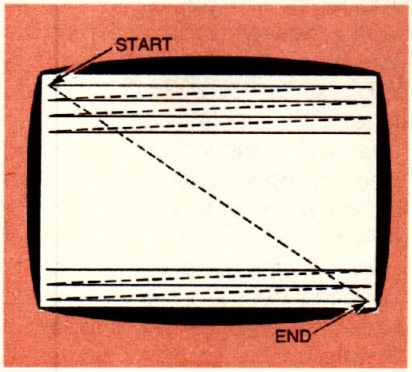

Fig. 3. A typical raster pattern is shown here. The scan pattern begins in the upper left-hand corner, ends in the lower right-hand corner, then returns to the beginning during the vertical blanking interval.

Bandwidth. In the very simplest terms, the *bandwidth* of a monitor is the absolute maximum rate at which pixels can be written to the display. Typical VGA displays offer a bandwidth of 30 MHz. That is, the monitor could generate up to 30 million pixels per second on the display. Consider that each scan line of a VGA display uses 640 pixels, and the horizontal scan rate of 31.45 kHz allows 31450 scan lines per second to be written. At that rate, the monitor is processing (640 pixels/scan line × 31450 scan lines/second) 20,128,000 pixels/second—well within the monitor's 30-MHz bandwidth. The very newest high-resolution color monitors offer bandwidths of 135 MHz. Such high-resolution 1280 × 1024 monitors with scanning rates of 79 kHz would need to process at least (1280 pixels/scan line × 79000 scan lines/second) 101,120,000 pixels/second (101.12 MHz), so enhanced bandwidth is truly a necessity.

Swim, Jitter, and Drift. The electron beam(s) that form an image are directed around a display using variable magnetic fields generated by separate vertical and horizontal *deflection coils* mounted at the CRT's neck. The analog signals that drive each deflection coil are produced by horizontal and vertical deflection circuitry (which you will learn more about later). Ideally, deflection circuitry should steer the electron beam(s) precisely the same way in each pass. This would result in an absolutely rock-solid image on the display. In the real world, however, there are minute variations in the placement of images over any given period of time. *Jitter* is a term used to measure such variation over a 15 second period. *Swim* (sometimes called Wave) is a measure of position variation over a 30 second period. *Drift* is a measure of position variation over a 1 minute period. Note that all three terms represent essentially the same problem, but over different amounts of time. Swim, jitter, and drift may be expressed as fractions of a pixel or as physical measurements such as millimeters.

Brightness. When an electron beam strikes phosphor, light is liberated. The *brightness* of an image indicates how much light is generated when an image is formed. Brightness is measured in foot-Lumens (*fL*). While the actual physics of fL and brightness are beyond the scope of this article, simply consider that most monitors provide visible brightness levels of 50 to 60fL depending on the CRT's brightness setting, and how much white is contained in the overall image. Larger numbers indicate brighter displays, while smaller numbers suggest dimmer displays (*i.e.* background raster is usually about 0.3fL). Keep in mind that brightness is typically measured with a pure white square shown in the center 20% of the display. Not all monitors provide a specification for brightness, since it is a difficult and rather subjective quantity to measure—precise scientific instrumentation is needed for an accurate measurement.

Synchronization and Polarity. After a line is drawn on the display, the electron beams are turned off (blanked) and repositioned to start the next horizontal line. However, no data is contained in the retrace line. In order for the new line to be "in sync" with the data for that line, a *synchronization* pulse is sent from the video adapter to the monitor. There is a separate pulse for horizontal synchronization and vertical synchronization. In most current monitors, synchronization signals are edge triggered TTL (transistor-transistor logic) signals. *Polarity* refers to the edge that triggers the synchronization. A falling trigger (marked "-" or "positive/negative") indicates that synchronization takes place at the high-to-low transition of the sync signal. A leading trigger (marked "+" or "negative/positive") indicates that synchronization takes place on the low-to-high transition of the sync signal.

Putting the Basics to Work. It is a popular misconception that monitors "make" an image. That's not the case at all. Actually, it is the *video board* that generates the image. A monitor is little more than a "converter" or "interpreter" that takes the color signals produced by your video adapter and places the proper colors in the corresponding locations on a CRT to produce a visible picture. In order to accomplish that feat, a monitor must perform several distinct functions:

(1) produce power and high voltage

(2) generate and focus electron beams

(3) modulate the electron beam strength based on color signals from the video board, and

(4) sweep the electron beams across the CRT in a synchronized fashion.

The block diagram in Fig. 4 shows you what's needed for a monitor to work.

The Color CRT. It is the design and construction of the CRT itself (Fig. 5) that really makes color monitors possible. Low voltage from the power supply heats a cathode in the CRT's neck. That causes electrons to "boil" off the cathode and

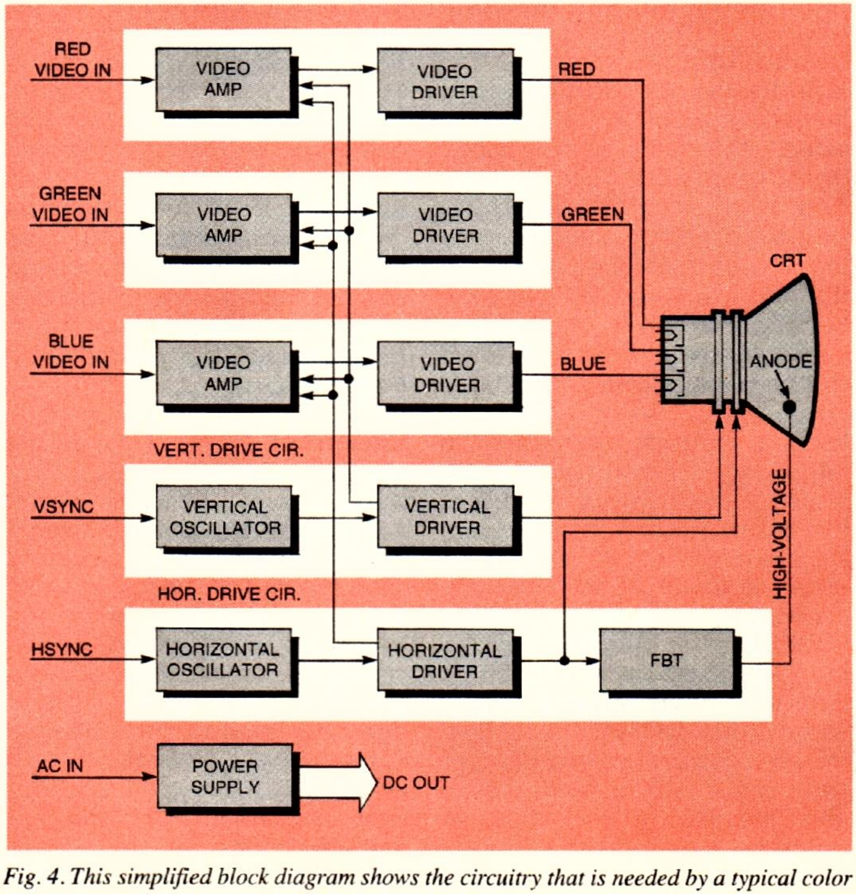

Fig. 4. This simplified block diagram shows the circuitry that is needed by a typical color computer monitor.

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San Jose, CA 95134
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AST Research
16215 Alton Parkway
Irvine, CA 92713
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ATI Technologies
3761 Victoria Park Avenue
Scarborough, Ontario, Canada, M1W 3S2
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CTX International, Inc.
20530 Earlgate Street
Walnut, CA 91789
Tel: 714-595-6146

Diamond Computer Systems
470 Lakeside Drive
Sunnyvale, CA 94086
Tel: 408-736-2000

Eizo NanaoTechnologies, Inc.
5710 Warland Dr.
Cypress, CA 90630
Tel: 800-800-5202

Epson America, Inc.
20770 Madrona Avenue,
Torrance, CA 90503
Tel: 800-922-8911

Everex Systems
48431 Milmont Drive
Fremont, CA 94538
Tel: 800-821-0806

GoldStar Technologies
3003 N. First Street
San Jose, CA 95134-2004
Tel: 800-777-1194

Hewlett-Packard Company
California Personal Computer Division
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Sunnyvale, CA 94086
Tel: 800-752-0900

Idek/Iiyama North America, Inc.
650 Louis Drive, #120
Warminster, PA 18974
Tel: 215-957-6543

Leading Technology
10430 S.W. Fifth Street
Beaverton, OR 97005
Tel: 503-646-3424

MAG Innovision, Inc.
4392 Corporate Center Drive
Los Alamitos, CA 90720
Tel: 800-827-3998

Magnavox
Philips Consumer Electronics
One Phillips Drive
Knoxville, TN 37914
Tel: 423-521-4316

Mitac USA, Inc.
42001 Christy St.
Freemont, CA 94538
Tel: 510-656-3333

Mitsubishi Electronics America, Inc.
Information Systems Division
5757 Plaza Drive
P.O. Box 6007
Cypress, CA 90630
Tel: 800-843-2515

NEC Technologies, Inc.
1255 Michael Drive,
Wood Dale, IL 60191
Tel: 800-388-8888

Packard Bell Electronics
9425 Canoga Avenue
Chatsworth, CA 91311
Tel: 818-773-4400

Panasonic
2 Panasonic Way
Secaucus, NJ 07094
Tel: 800-346-4768

Princeton Graphic Systems
2801 S. Yale St. #110
Santa Anna, CA 92704
Tel: 800-747-6249

Relisys
320 S. Milpitas Boulevard
Milpitas, CA 95035
Tel: 408-945-9000

Sampo Corp. of America
5550 Peachtree Industrial Boulevard
Norcross, GA 30071
Tel: 404-449-6220

Samsung Electronics America
105 Challanger Rd.
Ridgefield Park, NJ 07660
Tel: 201-229-4132

Seiko Instruments USA, Inc.
Color Graphics Group
1130 Ringwood Court
San Jose, CA 95131
Tel: 800-888-0817

Sony Computer Peripheral Products Co.
655 River Oaks Parkway,
San Jose, CA 95134
Tel: 800-352-7669

Tatung Co. of America, Inc.
2850 El Presidio Street
Long Beach, CA 90810
Tel: 800-829-2850

Toshiba America Consumer Products, Inc.
1010 Johnson Drive
Buffalo Grove, IL 60089-6900
Tel: 708-541-9400

ViewSonic
12130 Mora Drive
Santa Fe Springs, CA 90670
Tel: 800-888-8583

those are accelerated toward the phosphor-coated front screen by a high positive potential. Color CRTs use three cathodes and video control grids—one for each of the three primary colors. The *control grid* regulates the overall brightness of the electron beams, the *screen grid* begins accelerating the electron beams toward the front face of the CRT, and the *focus grid* narrows the beams. Once the electron beams are focused, vertical and horizontal deflection coils (or deflection yokes) located around the CRT neck will apply magnetic force to direct the beams across the screen.

You will also notice a *shadow mask* in the color CRT. A shadow mask is a thin plate of metal that contains thousands of microscopic perforations—one perforation for each screen pixel. The mask is placed in very close proximity to the phosphor face. Rather than a single homogeneous layer of phosphor as with a monochrome CRT, the color CRT uses phosphor *triads* as shown in Figure 1. Red, green, and blue phosphor dots are arranged in sets such that the red, green, and blue electron beams will strike the corresponding phosphor. Of course, the electron beams are invisible (and color is determined by the phosphor itself), but each electron beam is intended to excite only one color phosphor. In actual operation, the color dots are so close together that each triad appears as a single point (or pixel) to the human eye.

Color CRTs must also be very precise in how the three electron beams are directed around the screen. Since there are three phosphors, it is critical that each electron beam strike only its corresponding phosphor color, not adjoining phosphors. How well that task is accomplished is known as *color purity*. A *purity magnet* added to the CRT neck helps to adjust fine beam positioning. By using a shadow mask, the electron beams are only allowed to reach the phosphors where there are

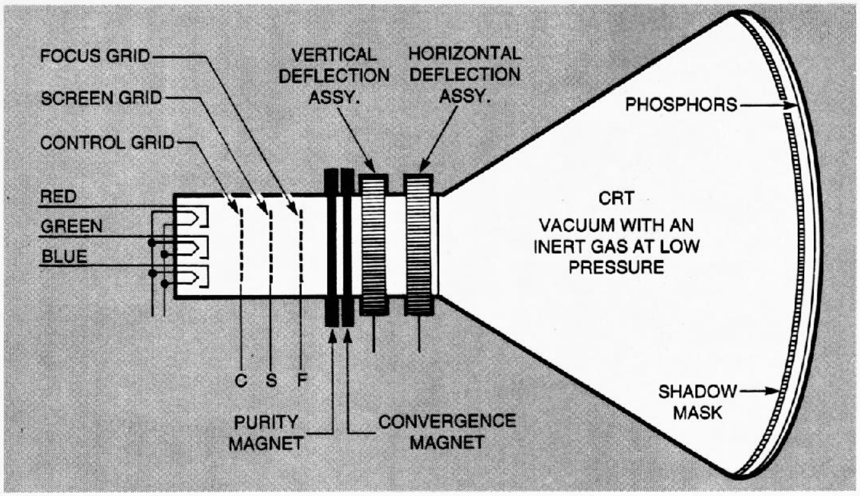

Fig. 5. The monitor's image is displayed on a cathode-ray tube, or CRT. A diagram of a typical CRT is shown here.

holes in the mask. Also realize that each of the three electron beams must converge at each hole in the shadow mask. A *convergence magnet* added to the CRT neck adjusts beam convergence in the display center (known as *static convergence*), while a convergence coil driven by the raster circuitry handles beam convergence at the edges of the display (known as *dynamic convergence*). It is that delicate balance of purity and convergence adjustments, as well as the presence of a shadow mask, that give today's color monitors such rich, precise color.

Video-Drive Circuits. A *video drive circuit* is used to regulate the strength of an electron beam by adjusting the signal strength on the corresponding video control grid in the CRT. The video drive circuit must convert a small video signal from the PC's video adapter (usually no more than 0.7 volts peak-to-peak) into a signal large enough to drive the CRT (typically between 30 to 50 volts). For color monitors with three analog video lines, three separate video drive circuits are required.

The initial video amplifier of each stage (often referred to as a *pre-amp*) is a linear, high-gain amplifier that translates the low-level analog color signal into a clear, solid analog level of several volts (usually about 3 volts). A common *contrast control*, which affects each of the three video amplifiers simultaneously, is typically added. Unfortunately, the amplified analog signal is not enough to drive the CRT's video control grid. Additional amplification is required, so a secondary amplifier stage is added. Some monitor designs use a three-stage amplifier circuit for each color; a high-gain *pre-amp* for lots of amplification at little power, a second *amplifier* that provides less amplification but more power to the signal, and a *driver* that offers almost no amplification but provides enough signal power to drive the CRT.

Vertical-Drive Circuit. The *vertical-drive circuit* is used to operate the vertical-deflection yoke, and is part of the color monitor's overall raster circuitry. The heart of the circut is a *vertical-sweep oscillator*, which is little more than a free-running oscillator set to run at either 60, 70, 72 Hz (or more—depending on the design of the particular monitor). Older color monitors typically used transistor-based oscillators, but virtually all current color monitors use an integrated-circuit oscillator, since ICs provide a very linear and precise signal. The vertical oscillator, is forced to fire when a vertical-synchronization trigger pulse is received from the video-adapter board. When the oscillator is triggered, it produces a sawtooth wave. The start of the sawtooth wave corresponds to the top of the screen, while the end of the sawtooth wave corresponds to the bottom of the screen. When the sawtooth cycle is complete, there is a blank period for blanking and retrace. One vertical sweep will be accomplished in less than 1/60th of a second (or 1/70th or 1/72nd of a second depending on the monitor).

However, the sawtooth signal generated by the vertical-oscillator circuit does not have enough power to drive the vertical-deflection yoke directly. The vertical deflection sawtooth signal is amplified by a *vertical-output driver* circuit (or vertical amplifier). The vertical amplifier provides the significant current needed to induce a strong magnetic field in the vertical-deflection yoke. The amount of power needed to operate the deflection yoke demands the use of a high-power transistor arrangement, but many current monitor designs are using high-power amplifier ICs instead of discrete transistors.

There are a number of adjustments in the vertical-drive circuit that you should be familiar with. The *vertical linearity* optimizes the shape of the sawtooth waveform. Ideally, the wave's upward ramp should be perfectly straight (or linear). In actual practice, however, the slope of the line may vary a bit from start to finish. That translates to the display. Since the ramp defines the spacing between individual lines, any variation in the ramp "slope" will effect the spacing between horizontal lines. Typically, you need not adjust vertical linearity unless you replace a component in the oscillator circuit. The *vertical-size* control adjusts the slope of the ramp signal, which effects the final amplitude of the sawtooth. That effectively compresses or expands the screen image in the vertical direction. By applying a DC offset to the vertical-deflection signal, the raster can be centered in the display with a *vertical-centering* control.

Horizontal-Drive Circuit. The *horizontal-drive circuit* is the second part of the color monitor's raster circuit, and it is designed to operate the horizontal-deflection yoke. The heart of this circuit is a *horizontal oscillator*, which is little more than a free-running oscillator set to run at a frequency between 15 kHz and 48 kHz (or higher). A CGA monitor will typically use a horizontal sweep frequency of about 15.75 kHz. The actual oscillator may be based on a transistor, but is usually designed around an integrated circuit which is more stable at the higher frequencies that are needed. When a horizontal-synchronization trigger pulse is received from the video-adapter board, the oscillator is forced to fire. When the oscillator is triggered, it produces a squarewave. The start of the squarewave corresponds to the left side of the screen. When the cycle is complete, there is a blank period for blanking and retrace. At an operating frequency of 31.5 kHz, one horizontal sweep will be accomplished in about 31.7 μS.

As with vertical-oscillator circuits, the signals generated by the horizontal oscillator do not have enough power to drive the horizontal-deflection yoke directly. The horizontal-deflection pulse signal is amplified by a *horizontal-output driver* circuit (or horizontal amplifier), which provides the significant current needed to induce strong magnetic fields in the horizontal-deflection yoke. The amount of power needed dictates the use of a high-power transistor arrangement. Transistors are still popular today as horizontal output drivers.

There are a number of adjustments in the horizontal drive circuit that you should be familiar with. The *horizontal linearity* optimizes the shape of the horizontal sweep. Ideally, the left-to-right sweep rate should be perfectly even, but the actual sweep rate may vary a bit from start to finish. That variation will affect the spacing between pixels in a line. Typically, you need not adjust horizontal linearity unless you replace a component in the oscillator circuit. The *horizontal-size* control adjusts the signal magnitude, which affects the amount of sweep applied to the electron beam. That effectively compresses or expands the screen image in the left-to-right orientation. A third control allows the adjustment of *horizontal centering* by introducing a slight delay between the time an Hsync (horizontal-synchronization) pulse is received and the time a horizontal pulse is generated. By default, there is always some delay needed to produce a centered display image. Reducing the delay moves the screen image to the left, while increasing the delay moves the screen image to the right. Centering and size controls are most useful for optimizing the image size and position for a particular video mode, and should not need to be readjusted unless the video mode changes.

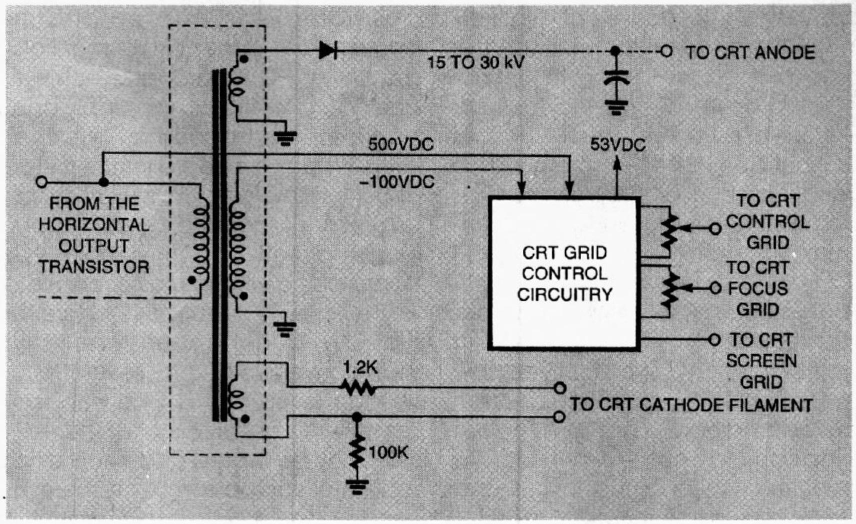

Fig. 6. The high voltages required by the CRT are generated by the monitor's flyback transformer.

High-Voltage Circuit. The *high-voltage system* is actually part of the horizontal drive circuit. We discuss it separately because of its importance in computer monitors. A monitor's power supply generates relatively low voltages (usually not much higher than 140 volts). That means that the high positive potential needed to excite the CRT's anode is *not* developed in the power supply. Instead, the 15 to 30 kV needed to power a CRT anode is generated from the horizontal output. The amplified, high-frequency pulse signal generated by the horizontal-output driver circuit is provided to the primary winding of a device known as the *flyback transformer* (or FBT). It is the FBT that produces the high-voltage.

You can see the diagram for a typical FBT in Fig. 6. Three secondary windings are shown. The lower winding is a simple step-down winding that provides a low AC voltage (typically about 6.2 to 15 VAC depending on the particular CRT) that heats the color CRT's three cathodes. The middle winding provides about 100 volts to the CRT control circuit. A 500-volt signal from the horizontal output and a 53-volt input from the monitor's power supply also power the CRT control circuit (the actual voltage levels will vary slightly from monitor to monitor). Adjustable control-grid voltage (brightness), the adjustable focus-grid voltage (focus), and the fixed screen-grid voltage are all generated by the FBT circuit.

The FBT's top winding is the high-voltage winding that steps up the horizontal signal to the required 15- to 30-kV level (the actual voltage level will depend on the particular monitor—larger CRTs require greater voltages to operate). Notice that a high-voltage diode is placed in series with the high-voltage winding to *rectify* the high AC level to a DC level. The 500 pF of effective capacitance found in the CRT assembly acts to *filter* (or smooth) the high-voltage into a useful form. In effect, that arrangement forms its own power supply. The high positive voltage applied to the CRT anode causes the electron beams to stream toward the phosphor-coated face.

Power Supply. The operation of every color monitor relies on the proper performance of a power supply, where commercial AC is converted into a series of relatively low DC voltages that power the monitor. A color monitor will typically use a power supply that delivers +135, +87, +20, +12, and +6.3 volts DC, but be aware that there will be variations in the supply's outputs depending on the design of each particular monitor.

A Complete Assembly. Now that you know the major circuits needed for a color monitor, you can see how everything fits together in the exploded diagram of Fig. 7. The first thing you may notice when looking inside a monitor is the layout and position of the printed circuit boards. As a general rule, monitors use three PC board assemblies—one board for the power supply, one board for the video and CRT drive circuits, and one board for the raster circuits. However, many monitor assemblies place the power supply circuit directly on the main PC board along with the raster circuits.

The *power supply PC board* is typically a hand-sized assembly that converts AC into several DC voltage levels that will be needed by other monitor circuits. The AC itself may be filtered and fused by a separate small assembly. If there is no stand-alone power-supply board in your particular monitor, the supply is probably designed into the main monitor board. The only voltage that is *not* produced in the power supply is the high-voltage source. The power-supply board is mounted vertically to a metal frame. The metal frame not only provides a rigid mounting platform, but it serves as a chassis common, and helps to contain RF signals generated by the monitor.

The *CRT-drive PC board* attaches directly to the CRT pins through a circular connector at the neck. Control (brightness), screen, and

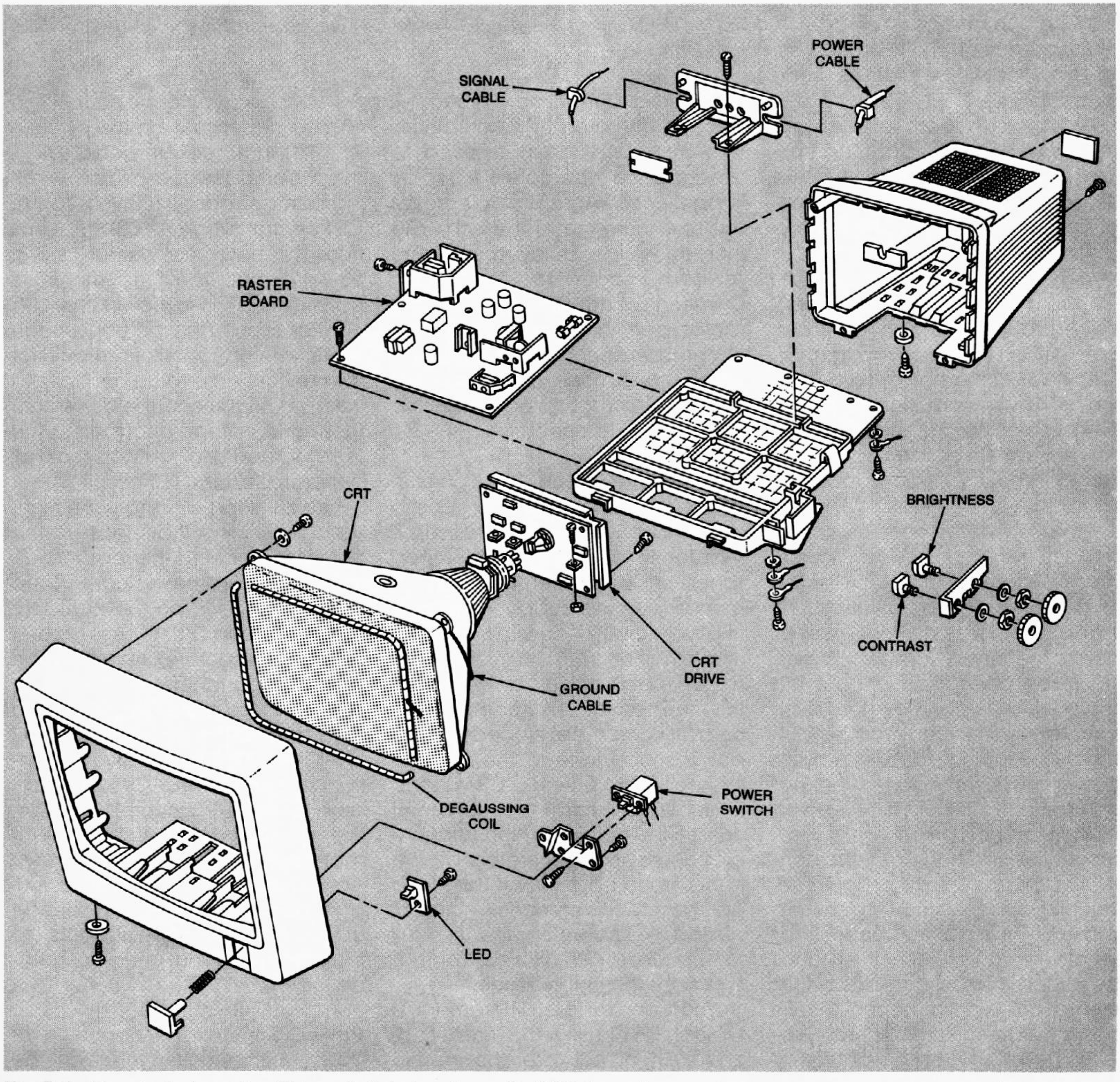

Fig. 7. Inside a typical monitor. This exploded view shows the CRT, the main or raster board, the CRT-drive board, and more. (Illustration Courtesy of Tandy Corporation).

focus grid voltages are applied to the CRT through that board. The CRT drive board also usually contains the RGB video amplifiers and drivers. Since more video-drive circuitry is needed for a color monitor than a monochrome monitor, the CRT-drive PC board for a color monitor is usually much larger than that of a monochrome monitor. Once the monitor is unplugged and discharged, make sure that this board is attached evenly and securely to the CRT.

The main *monitor PC board* (often called the *raster board*) contains the vertical-raster, horizontal-raster, and high-voltage circuits that drive the CRT and direct the electron beam(s) around the screen. Depending on the design of your particular monitor, the main monitor board may contain part or all of the power supply circuit as well. Just about all monitors mount the main PC board to the metal frame horizontally below the CRT neck. That assembly can be difficult to remove, since it is obstructed by the CRT neck and yoke, as well as by the interconnecting wiring that connects to the power supply, front panel controls, and flyback transformer.

There are some other assemblies in Fig. 7 that you should be familiar with. Note the thick wire surrounding the CRT screen. That is known as a *degaussing coil*, and is required on all color monitors. Since magnetism influences the path of the electron beams, and all three electron beams must be aligned precisely to achieve proper color, any stray magnetic influence will upset the display's color purity. It is not uncommon for small areas of the metal shadow mask to become magnetized. When this occurs, the color in those magnetized areas will be distorted. The degaussing coil plugs into the power-supply circuit. When the monitor is first turned on, a temporary AC voltage in the coil creates a strong alternating magnetic field that acts to clear any magnetized regions in the shadow mask. After a moment, AC is cut off in the coil, and the CRT will operate normally.

The *horizontal-output transistor* can be mounted on a separate heat sink or mounted to a heat sink on the main monitor PC board. The horizontal-output transistor is a key component, since it not only drives the horizontal deflection yoke but the flyback transformer as well. You may also notice the *high-voltage anode*, which originates at the flyback transformer and is little more than a metal prong covered by a large red plastic insulator. That anode must be inserted fully in the CRT. **Never touch the anode wire or connector (even when the monitor is turned off)**. That conductor is carrying 15 kV or higher, so a VERY dangerous shock hazard exists. The monitor must be UNPLUGGED and the CRT must be safely discharged before working with the high-voltage anode.

Finally, you should take note of any metal shrouds or coverings that are included in a monitor. Metal shielding serves two very important purposes. First, the oscillators and amplifiers in a computer monitor produce radio-frequency (RF) signals that have the potential to interfere with radio and TV reception. The presence of metal shields or screens helps to attenuate any such interference, so always make it a point to replace shields securely before testing or operating the monitor. Second, large CRTs (larger than 17 inches) use very high voltages (25 kV or more) at the anode. With such high potentials, X-radiation becomes a serious concern. CRTs with lower anode voltages can usually contain X-rays with lead in the CRT glass. Metal shields are added to the larger CRTs in order to stop X-rays from escaping the monitor enclosure. When X-ray shielding is removed, it is vital that it be replaced before the monitor is tested and returned to service. X-ray shields will usually be clearly marked when you remove the monitor's rear cover.

Conclusion. Computer users are often so obsessed with clock speed, system RAM, and hard-drive size, they overlook the importance of their monitor. But the monitor is a very vital part of the PC as it is what converts video data into a visible image. This article explains the important ideas behind monitor operation, shows you the major parts involved, and illustrates a typical monitor assembly.

The author welcomes comments and questions about this article. He can be reached via Fax at 508-829-6819, by BBS at 508-829-6706, on CompuServe at 73562,3205, or via e-mail at sbigelow@cerfnet.com. You can also visit his Dynamic Learning Systems Web site at www.dispubs. com. Ω

REACT-TIME

(Continued from page 32)

piece of clear plastic to the inside of the lid.

Testing. Install batteries into the holder and turn on the power. The display should read 00. Squeeze both buttons and the 3—2—1 countdown should start. If it doesn't, check the wiring and component placement, measure the supply voltage, and check that the PIC clock is running at 4 MHz by connecting an oscilloscope to the crystal.

Using the React-Time. A lower score means a quicker reaction time. It is possible to score as low as four or five, if you're quick! Most people can score about 10—12 after a dozen tries. Overly intoxicated people will have a very hard (if not impossible) time trying to score below 13. Older individuals might not score lower than 20.

The best way to test someone's reaction time is to first demonstrate how to use the React-Time. The person being tested must cooperate. After the demonstration, they should have about a dozen attempts to lower their score. The score will steadily decrease until there is a point at which they cannot get lower. That score best represents the person's reaction-time performance.

While the unit is intended for entertainment only and should not be used in place of blood-alcohol level testers, the React-Time tester can be used in practical applications. For example, bartenders or party hosts can use the unit to screen those that have had too many. Ω