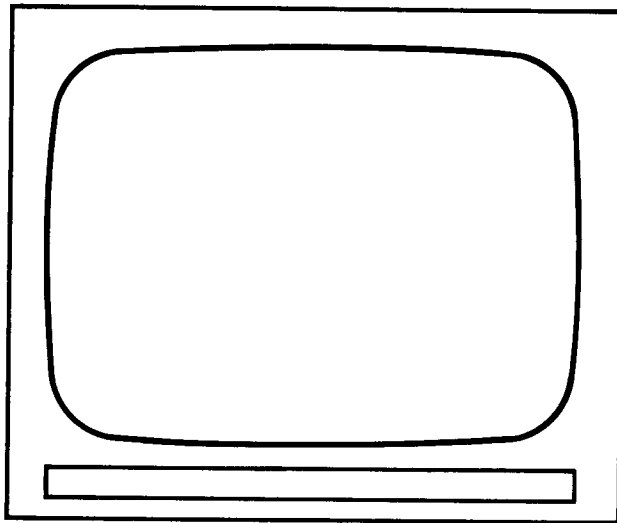# RASTER GRAPHICS HANDBOOK

Conrac Division, Conrac Corporation
600 North Rimsdale Avenue, Covina, CA 91722

CHAPTER

8

THE MONITOR INTERFACE

The monitor interface consists of all the circuitry required to drive a raster-scan CRT monitor. Its principal functions are (1) to convert controller-generated digital data into an analog "display signal," and (2) to coordinate the display of this data by generating appropriate raster-scan synchronization signals. The interface may also include circuits to merge the controller-generated data with information from other sources, or to drive other output peripherals, such as raster-scan hardcopy devices.

Physically, a part or all of these functions may be incorporated into the design of the graphics controller. We have already discussed in the previous chapter, for example, the role of such display-signal sources as shift registers and digital-to-analog converters (DAC's). The same circuits could also be located within the monitor chassis to provide a digital display-device interface. For descriptive purposes, however, we will assume that the design of the interface is a separate task, with its own range of alternatives and options.

The interface design must take into account the output requirements of the controller and, to an even greater extent, the characteristics and signal-input requirements of the raster-scan monitor. The next chapter, Monitor Evaluation and Selection, indicates the wide range of capabilities represented by commercially available monitors. There may be a twenty-to-one difference in cost resulting from often-subtle performance, installation, or maintenance enhancements. Yet the highest performance monitor is, in almost every case, an essentially passive device—without intelligence, memory, handshaking, or status-feedback capabilities.

The monitor can limit, but not expand on the information content of the display. Interface sync signals determine, within limits, the size and aspect ratio of the visible raster pattern, the number of displayed raster lines, and whether the lines are interlaced or non-

interlaced. Display-signal modulations establish the location and intensity of individual pixels along each raster line. The hues and saturations displayed by a color monitor are determined entirely by the display information received across the monitor interface.

In terms of interface design, however, the raster-scan monitor is anything but passive. Specific monitor models are generally restricted to a particular type of signal input—among dozens of possible display, sync, and color-encoding combinations. The monitor dictates, therefore, the form of the signal interface, which may or may not match the preferred output of the graphics controller. There may also be a need to switch or mix display signals from multiple sources with different signal outputs, or to distribute the display information to multiple monitors with different input specifications.

Signal conversion circuits can help to resolve all of these conflicting requirements—at a price in hardware costs and complexity. The result is an iterative design process, with interface decisions affecting the monitor selection and vice versa. The objective, of course, is to achieve a display-system design that delivers optimum performance at a minimum overall cost.

SYNCHRONIZING THE RASTER

Information is displayed on a raster-scan CRT monitor screen as a function of time. The CRT electron beam of a monochrome monitor is in constant motion, tracing a raster pattern on the phosphor surface. The same is true of the multiple beams in a color monitor. Display-signal modulations, controlling the intensity of the emitted light, must be precisely timed relative to the beam motion to produce a meaningful image on the screen.

Synchronization is achieved in two steps. Sync signals generated by the monitor interface establish control over the monitor's raster-scan circuits. Display information is then applied to the monitor's beam-modulation circuits within the timing framework created by the sync-signal input.

The sync signals take the form of voltage pulses and affect *only* the timing of the raster-scan process. Self-oscillating circuits within the monitor will, in fact, deflect the CRT electron beam to form a raster-like pattern on the phosphor screen—whether or not sync information is being received. A horizontal-deflection sawtooth signal (Figure 8-1) sweeps the beam from the left margin of the screen to the right, then returns the beam at an accelerated rate to the left. The scan to the right is called a "raster line;" the return path is a

"horizontal retrace." The time interval between the end of one raster line and the end of the next, including the initial retrace, is identified by the letter H. The frequency or H-intervals per second establishes the "line rate" of the display. Typical values lie in the range of 15 kHz to 31 kHz.

An independent vertical-deflection sawtooth signal sweeps the electron beam from the top of the screen to the bottom (Figure 8-2), then returns the beam at an accelerated rate to the top. The time interval between the end of one "vertical sweep" and the end of the next, including the "vertical retrace," is identified by the letter V. The frequency or V-intervals per second determines the "field rate" or "frame rate" of the display, depending on whether the lines are interlaced or non-interlaced (see below). International television standards have set this value at approximately 50 Hz or 60 Hz, but graphics system designers may elect to use a different figure, such as 80 Hz or 100 Hz, to meet a particular set of system requirements.

When the horizontal and vertical beam deflections are synchronized and occur simultaneously, a raster is generated on the monitor screen. Figure 8-3 shows the resulting pattern in simplified form.
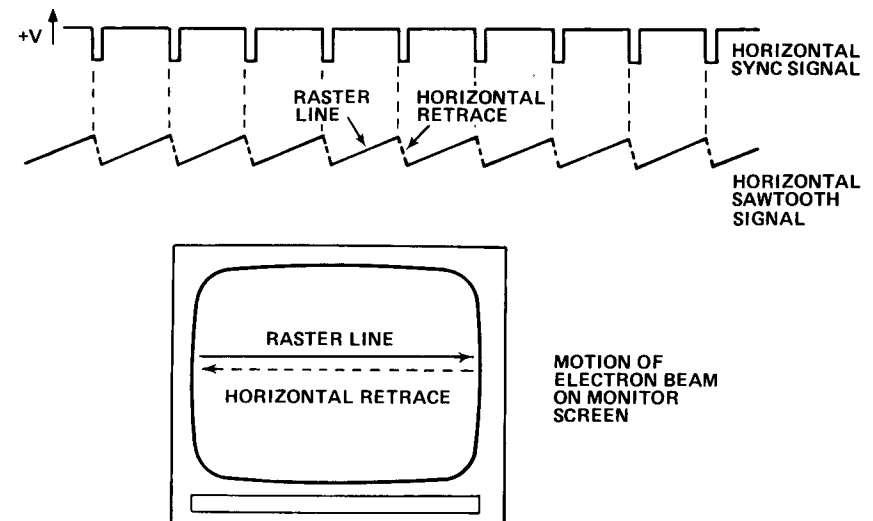

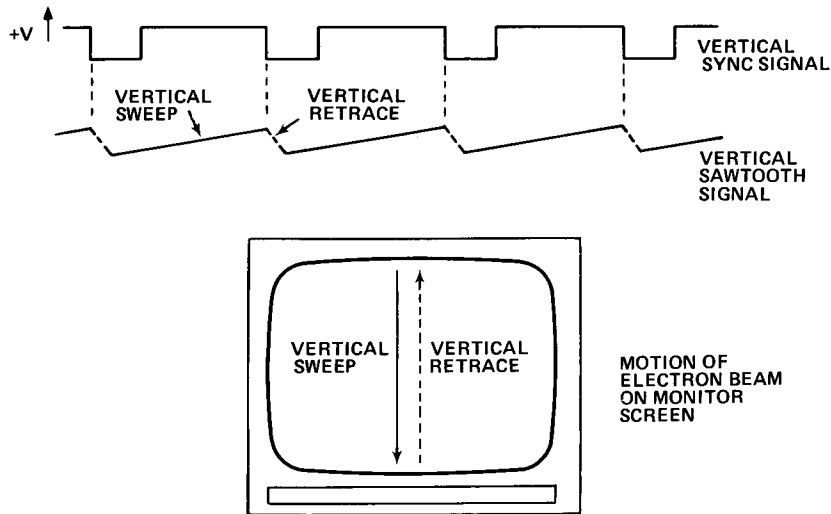Figure 8-1 Horizontal-sync input and monitor beam-deflection waveform.

Figure 8-2 Vertical-sync signal input and monitor beam-deflection waveform.

Raster lines are tilted downward to the right due to the downward vertical sweep of the electron beam. The faster retrace paths are nearly horizontal. During vertical retrace, both sets of lines are tilted steeply upward by the accelerated motion of the electron beam during its return to the top of the screen.
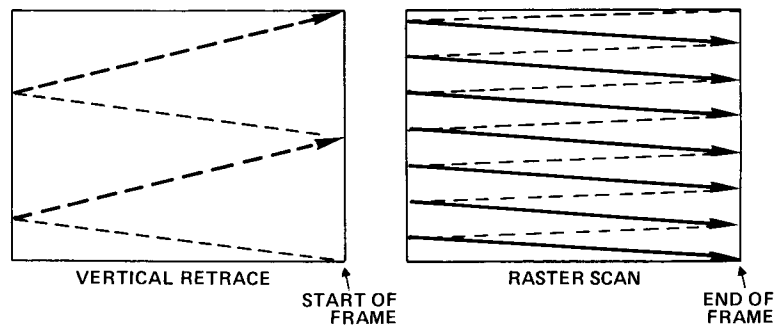
Figure 8-3 Path of electron beam in response to horizontal and vertical deflection signals.

The Figure 8-3 drawings assume that two critical conditions exist. The first is that the V-interval is an exact multiple of the H-interval. The second is that the start of the downward vertical sweep coincides with the end of a raster line and ends with the completion of a raster line. Given these two conditions, the electron beam can start in the lower right corner of the display, zig-zag to the upper margin of the screen for the start of another raster scan, and end the raster pattern in the lower right corner.

Horizontal and Vertical Sync Pulses

The upward and downward slopes of the two beam-deflection sawtooth signals establish the relative deflection rates. Peak-to-peak amplitudes of the sawtooth waveforms determine the width and height of the raster pattern created by the deflections. The relative frequencies of the two waveforms establish the H-to-V ratio, or number of raster lines which are scanned during each vertical retrace-and-sweep interval.

All of these relationships are established by the monitor design, subject to manual adjustment within a set of specified ranges. There is, however, *no* internal synchronization of the horizontal and vertical deflections with each other. Both are controlled by independent, free-running oscillator circuits. A stable and meaningful raster display requires precise coordination of the two deflections and, equally important, a precise time relationship between the deflections and the displayed information.

The negative-polarity pulses shown in Figures 8-1 and 8-2 provide the required synchronization. Generated by monitor-interface circuits, the sync pulses "trigger" the monitor's free-running horizontal and vertical oscillators, locking them into a fixed relationship to each other. Display-data synchronization is typically achieved by using a single graphics-system clock as the timing source for both sync signals and display-memory readout.

Horizontal-deflection sync pulses are very narrow, on the order of 3 to 5 microseconds. Vertical-deflection sync pulses are much wider, ranging up to 200 microseconds. The two pulse widths both represent correspondingly small percentages of the H and V time intervals, but the most important characteristic of the pulse-width difference is that it allows the horizontal and vertical sync pulses to be combined into a single sync signal, as shown in Figure 8-4.

Two parallel filters can then be used by the monitor to separate the pulses. A high-pass filter "differentiates" the leading and trailing

edges of the narrow horizontal-sync pulses. A separate low-pass filter extracts the vertical sync information, typically by "integrating" the signal in a capacitor. The long vertical sync pulses contain enough energy to charge the capacitor to a trigger level. The shorter horizontal sync pulses fall far short of this mark.

A major problem may be created, however, by this combining of the horizontal and vertical pulses into a single sync signal. The monitor's horizontal-deflection oscillator is "running free" during the time interval occupied by the extended vertical-sync pulse. The oscillator may be out-of-sync by the time horizontal-sync pulses reappear. The usual solution is to divide the vertical-sync pulse into "serrated" segments (Figure 8-4). The serrations serve as horizontal-sync markers, maintaining synchronization throughout the vertical-sync-pulse interval.

(a)

COMBINED
SYNC SIGNAL

COMBINED SYNC WITH
VERTICAL-PULSE
SERRATIONS
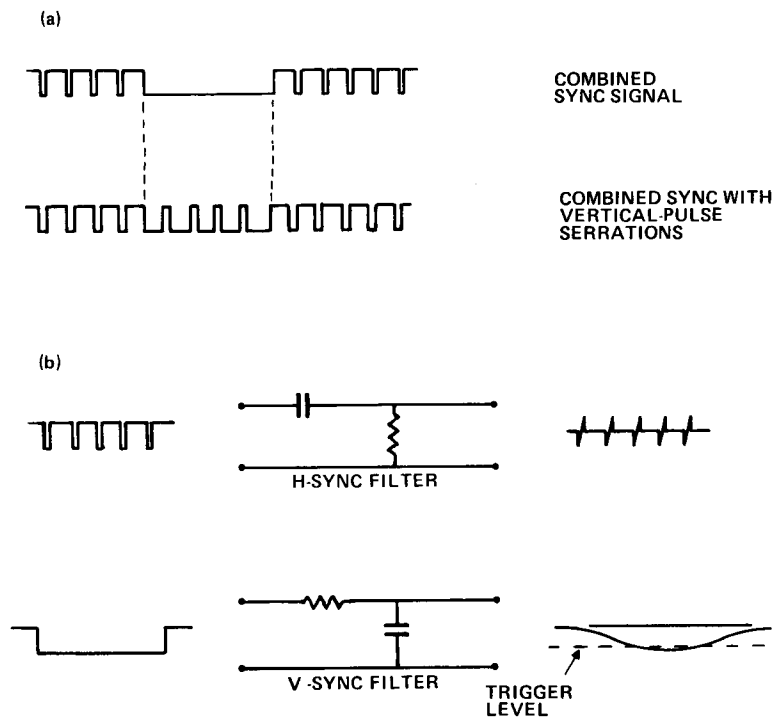
(b)

H-SYNC FILTER

V -SYNC FILTER   TRIGGER
LEVEL

Figure 8-4 Combined sync signals (a) and typical horizontal and vertical sync-pulse filters (b).

A Flicker-Free Refresh Rate

The light emitted by the phosphors on the surface of the monitor screen decays rapidly, allowing a new image to be traced with the next raster "refresh." Light-initiated chemical reactions in the human eye decay at a slower rate, creating the *impression* of a continuous light emission—provided that the raster refresh rate is above the level where perceptible "flicker" occurs. The on-off rate at which flicker becomes perceptible can vary from 20 Hz to nearly 100 Hz, depending on the intensity of the light source (see Chapter 2, Display Principles). The higher the intensity, the higher the flicker-rate threshold.

A similar concern for flickering incandescent lights dictated the choice of ac line-voltage frequencies during the early years of the electrical power industry. U.S. power companies settled on 60 Hz; their European counterparts, expecting the public to use a lower level of illumination, chose 50 Hz. (The 10 Hz reduction translates into nearly a ten-fold decrease in allowable luminance.)

Television system designers in Europe and the U.S. initially matched the refresh rate to the local power-line frequency to avoid power-line "beat" interference on the television screen. Present-day equipment is effectively isolated from power-line noise, but the 60 Hz and 50 Hz conventions have been carried forward in the form of international television standards. The same standards have also dictated the design of most of the monitors now available for raster graphics display.

Interlacing the Raster Lines

The longer image-to-image interval permitted by the European television standard—1/50th versus 1/60th of a second—permits more display information to be transmitted during each refresh cycle without increasing the bandwidth. European systems use the extra time to increase the vertical resolution of the display. Each raster "frame" contains 625 raster lines (including those "lost" during retrace). The U.S. frame is limited to 525 lines.

In both cases, however, only half of the lines are transmitted with each refresh cycle. By dividing the display into two interlaced "fields," each consisting of a separate set of odd or even lines, the horizontal resolution of the raster lines can be doubled without increasing the display-signal bandwidth. At a normal viewing distance, the interlaced lines tend to merge and the refresh rate appears to be a flicker-free 60 Hz or 50 Hz, even though the actual

repetition rate of an individual raster line (and the complete raster frame) is only 30 Hz or 25 Hz.

The interlacing technique resembles the method used to produce a flicker-free motion picture at half the apparent frame rate (and with only half the required length of film). Frames move through the projector at a rate of 24 per second, but the image of each frame is flashed twice on the projection screen to produce a 48 Hz visual refresh rate—well above the flicker threshold for the reflected illumination. The comparison is important because an entire world population has been conditioned to animation based on 24 *new* images a second. An interlaced new-frame rate of 30 Hz or 25 Hz is therefore acceptable.

Interlacing represents a mixed blessing for the designer of a raster graphics system. It reduces by half the rate at which data must be read out of the display memory. Interlacing also reduces by half the bandwidth required to transfer the information to the monitor

screen or, conversely, doubles the amount of information which can be displayed without increasing the bandwidth. The gains are partially offset by a doubling of the number of raster lines lost during the two vertical retraces, increasing the required data-transfer rate while the remaining "active" lines are scanned. A more important concern, however, is the fact that raster graphics displays are often characterized by abrupt color or intensity changes along raster-line boundaries. The result may be an objectionable 30 Hz or 25 Hz line-to-line flicker at close viewing distances.

Interlacing also complicates the form of the sync signals which must be generated by the interface circuitry. Monitor circuits are designed for uniform vertical retrace-and-sweep deflections which end at the top and bottom of the displayed raster pattern. If an even number of lines are interlaced, the upper and lower boundaries will shift with each field and the length of the retrace path will change between successive fields. The preferred alternative is to specify an odd number of lines per frame (e.g., 525 or 625) with half of the extra-odd-line time interval allocated to each field. The resulting sweep-and-retrace patterns are illustrated in Figure 8-5 in simplified form.

Separate horizontal-sync and vertical-sync signals can accommodate the half-line shift in vertical-retrace timing without any problem. Complications are created, however, when the pulses are combined into a single sync signal. As shown in Figure 8-6, there is only a $\frac{1}{2}$H interval between the final horizontal-sync pulse and the forward edge of the vertical-sync pulse at the end of the first field. Energy from the horizontal-sync pulse may be integrated with that of the vertical-sync pulse, producing a premature vertical-deflection trigger.

The conventional solution to this problem is to isolate the vertical-sync pulse with extended zero-signal intervals before and after the pulse. This expands even further, however, the amount of time during which the horizontal deflection may drift out of sync. Brief "equalizing pulses" at $\frac{1}{2}$H intervals are usually added to the waveform, therefore, to maintain synchronization and provide a relatively uniform energy envelope, from field to field, on both sides of the vertical-sync pulse. Serrations within the vertical-sync pulse are also increased to $\frac{1}{2}$H intervals to continue the synchronization pattern. Even-numbered $\frac{1}{2}$H equalizing pulses and serrations maintain the horizontal sync at the end of the first field, odd-numbered at the end of the second field. The remaining intermediate signal transi-
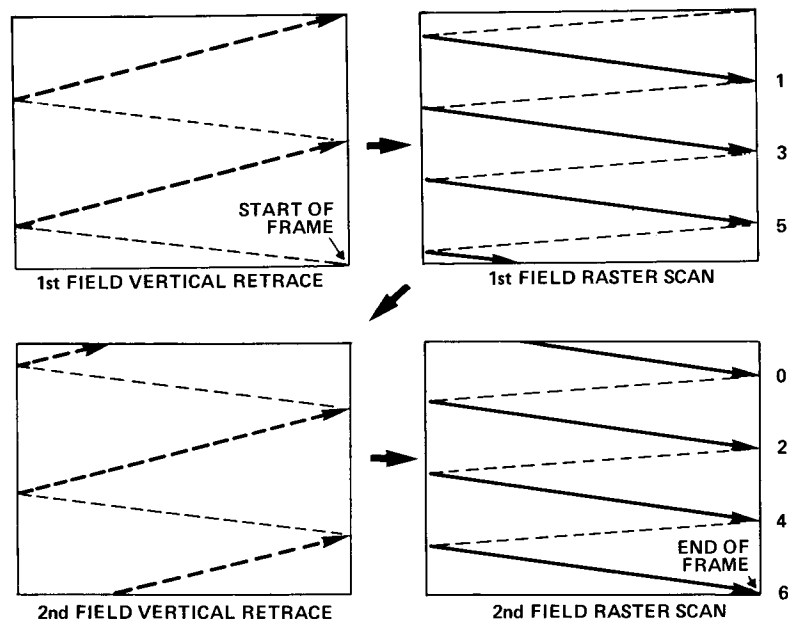

Figure 8-5 Path of electron beam, interlaced raster with two fields per frame.
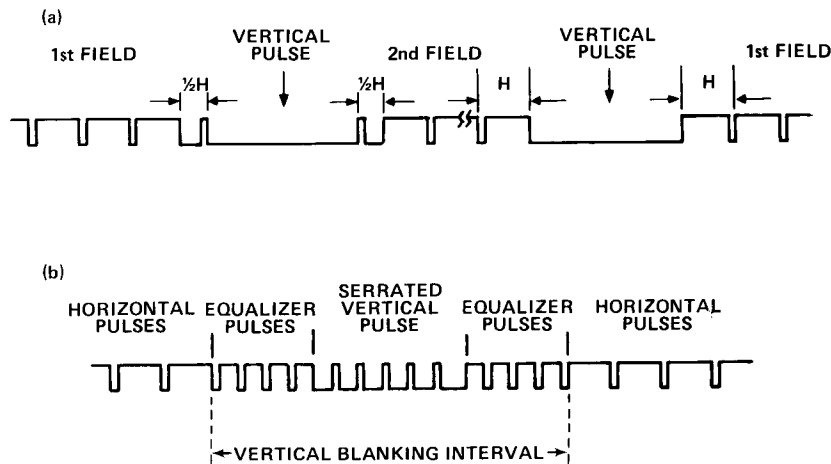
(a)

(b)

Figure 8-6 Interlaced sync signal (a) with added equalizer pulses and vertical-pulse serrations (b).

tions are too removed from the natural period of the horizontal-sync oscillator to have any effect.

Superimposed Fields

A raster-scan CRT electron beam cycles between the top and bottom borders of the raster pattern at a constant rate—regardless of whether the raster lines are interlaced or non-interlaced. It is the ½H shift in the vertical sync pulses generated by the interface circuits which interlaces the lines. This raises, then, the question whether a monitor designed for interlaced operation can be used to generate a non-interlaced display by simply changing the sync-signal input. The answer is a qualified "yes."

Two design features distinguish an interlace-type monitor. The first is the H-to-V frequency ratio of the beam-deflection oscillators. The ratio for an interlaced monitor is half the value of a non-interlaced monitor with the same number of lines per frame. For example, the H-to-V ratio for an interlaced 525-lines-per-frame monitor operating at a *field* rate of 60 Hz is 262½:1. The ratio is 525:1 for a non-interlaced monitor with the same number of lines per frame but operating at a *frame* rate of 60 Hz. Twice as many lines must be scanned during each vertical sweep interval—doubling the line rate of the display.

A second and more important difference lies in the physical design —and expense—of the horizontal-deflection circuits. Twice as much deflection power is expended when the line rate is doubled to produce a non-interlaced display. The power ratings for all circuit components must be higher, and significantly more heat must be dissipated.

Any interlaced-display monitor can be adapted to lower-resolution, non-interlaced operation, however, by reducing the lines per frame to an even number. Both fields would return, in this case, to the upper right corner of the display and trace identical raster patterns. The superimposed fields become, in effect, separate "frames" with half the vertical resolution of the original display. The change can be accomplished by simply decreasing the V interval for each frame by ½H. The monitor's vertical-deflection oscillator normally has sufficient adjustment range to accommodate the slight shift in vertical-deflection timing. Black stripes between the superimposed lines can be minimized by reducing the vertical deflection or expanding the electron-beam spot size.

Any application which can tolerate the reduction in vertical resolution would be a candidate for this type of monitor operation. The major advantage is that all line-to-line flicker is eliminated without the extra monitor costs and data-transfer rates imposed by a standard non-interlaced display. Typical would be a large-screen vector-graphic or alphagraphic application in which line-to-line flicker at the horizontal borders of graphic elements would be highly objectionable.

THE DISPLAY SIGNAL

Raster-scan display signals perform two functions. One is to provide "display" information in the form of a positive-polarity, amplitude-modulated voltage. The second function is to "blank" the electron beam during the horizontal and vertical retrace intervals so that no visible retrace paths appear on the monitor screen. Both functions require precise synchronization with the sync signals which control the generation of the raster pattern.

Typical display signals encountered in a raster graphics system are illustrated in Figure 8-7. The output of a shift register, for example, consists of discrete pulses with a constant amplitude that corresponds, we can assume, to the full-scale luminous output of the CRT monitor. The output of a DAC is a stairstepped signal, with each step generated by a binary-coded value at the DAC input. A
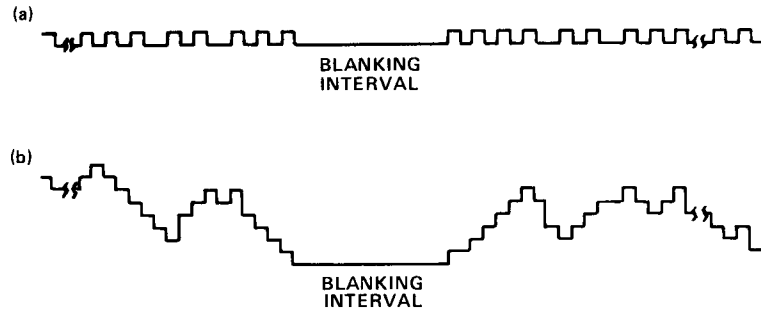
(a)

(b)

Figure 8-7 Display signals generated by shift register (a) and digital-to-analog converter (b).

4-bit DAC can generate a 16-step signal, corresponding to 16 monochrome luminosities or gray-scale values. An 8-bit DAC increases the gray-scale range to 256. "Gray-scale," as used here, applies to any graduated variation in the luminous output produced by a single electron beam. This would include both the grays displayed by a single-beam monochrome monitor and the intermediate red, green, or blue intensities produced by modulating one of the electron beams in a three-beam color monitor. (By contrast, a "video" signal is neither pulsed nor stair-stepped. It is, instead, a true analog signal representing, for example, the light intensities reflected into the optical system of a television camera.)

Each digitally generated pulse or stair-step is related to a specific pixel location on the display screen. To maintain this relationship, the controller must read information out of display memory at exactly the same rate as the electron beam scans an active raster line. Display information for the first pixel location along a raster line must be delivered to the monitor at the precise moment when the electron-beam retrace has been completed and the blanking interval ends. Display information for the last pixel on the line must be received just before the start of the next retrace blanking interval.

The duration of the display time for each pixel, the display-memory readout rate, and the required display-signal bandwidth can all be calculated from three known values: (1) the horizontal resolution as defined by the number of pixel codes stored in the display memory for each raster line, (2) the H-interval determined by the horizontal-sync pulses, and (3) the duration of the horizontal-retrace blanking interval.

Figures 8-8a and 8-8b list the H-intervals and horizontal-retrace blanking intervals specified by several widely applied interlaced-monochrome standards. The time values allow us to make a sample calculation of the signal parameters. For example, the H-interval for an 875-line interlaced display is 38.1 microseconds. From this we must subtract a 7-microsecond retrace blanking interval, resulting in an active-raster-line duration of 31.1 microseconds. If the line is to contain 1024 addressable pixel locations, the per-pixel display time can be calculated as 31.1 microseconds divided by 1024, or 30.4 nanoseconds. Dividing this value into one second, we can conclude that during the time the electron beam is tracing an active raster line, pixel data must be read out of each display-memory plane at a rate of 32M bits per second. Allowing a half-cycle per bit, the bandwidth of the interface and monitor circuits would have to be at least 16 MHz,

Monochrome Standards				
	U.S. Broadcast	European Broadcast	U.S. Closed-Circuit	U.S. High-Resolution
Lines/Frame	525	625	525	See Figure 8-8b
Field Rate (Hz)	60	50	60	60
V-Interval (us)	16,667	20,000	16,667	16,667
V Blanking (us)	833	1,200	1,250	1,250
V-Sync Pulse (us)	190.5	192	150	150
H-Interval (us)	63.5	64	63.5	See Figure 8-8b
H Blanking (us)	11.4	12.8	10	See Figure 8-8b
H-Sync Pulse (us)	5.1	5.8	4.8	2.8

Figure 8-8a Display-signal parameters established by international standards.

U.S. High-Resolution Standards			
Lines/Frame	Active Lines	H-Interval	H-Blanking
675	650	49.5 us	7 us
729	702	45.7	7
875	842	38.1	7
945	909	35.3	7
1023	985	32.5	7

Figure 8-8b Parameters established by U.S. high-resolution standard (EIA RS-343, Appendix II).

with 20 to 30 MHz as a more conservative estimate of the bandwidth requirement.

The horizontal and vertical blanking intervals listed in Figures 8-8a and 8-8b are minimum values and assume that the visible raster pattern is to occupy most or all of the CRT screen. One way to adjust the size and aspect ratio of the raster is to change the amplitudes of the beam-deflection sawtooth waveforms. Another and more flexible method is to alter, potentially under software control, the duration of the blanking intervals. Lengthening the vertical blanking interval, for example, has the effect of reducing the number of visible raster lines. A lengthened horizontal blanking interval will shorten the visible raster lines. The blanking intervals can also be shifted relative to the sync signals to place the visible raster anywhere on the surface of the monitor screen. The only constraint is that the blanking intervals must also coincide with and mask the retrace paths of the electron beam.

Composite Display Signal

Just as the horizontal and vertical sync pulses can be combined into a single sync signal, display and sync information can be merged into a single "composite signal" (not to be confused with the composite-sync term often used for a combined horizontal-and-vertical sync signal).

Figure 8-9 illustrates a typical composite waveform and the terminology used to identify the signal voltage levels. The blanking level serves as the benchmark for the other voltage values. By definition, a blanking-level voltage at the monitor input will reduce the CRT electron-beam current below the "cut off" point, assuring that no visible trace of the electron beam will appear during the blanking intervals.

All of the display voltage levels have a positive polarity with respect to the blanking level. The lowest display level is reference black, defined and specified as a lower limit for "peak black" excursions. The highest positive level is reference white, defined and specified as an upper limit for "peak white" excursions. The display-signal "setup" is the ratio between the reference-black and reference-white voltage levels when both are measured from the blanking level. It is typically expressed as a percentage (e.g., 7.5%).

The vertical-retrace and horizontal-retrace blanking intervals are referred to as "pedestals" (for reasons that will become clear when we examine a modulated-RF composite signal). The horizontal-

retrace pedestal has a "front porch" ahead of the sync pulse and a "back porch" following the pulse.

Sync voltage levels are negative with respect to the blanking level. The furthest negative excursion of the horizontal and vertical sync pulses is the sync level, also called the sync tip. The negative sync level is typically 40% of the reference white level when both are measured from the blanking level.

Display and Sync Signal Amplitudes

Because the display and sync signals may vary in amplitude as they are processed through the interface and monitor circuits, an "IRE" scale has been established for defining the relative voltage levels of the signals, independent of their absolute voltage values. Reference white is given a value of +100 IRE units. The blanking level is set at 0 IRE units. Sync tips would typically have a value of –40 IRE units. A composite signal would therefore have a peak-to-peak (p-p) value of 140 IRE units.
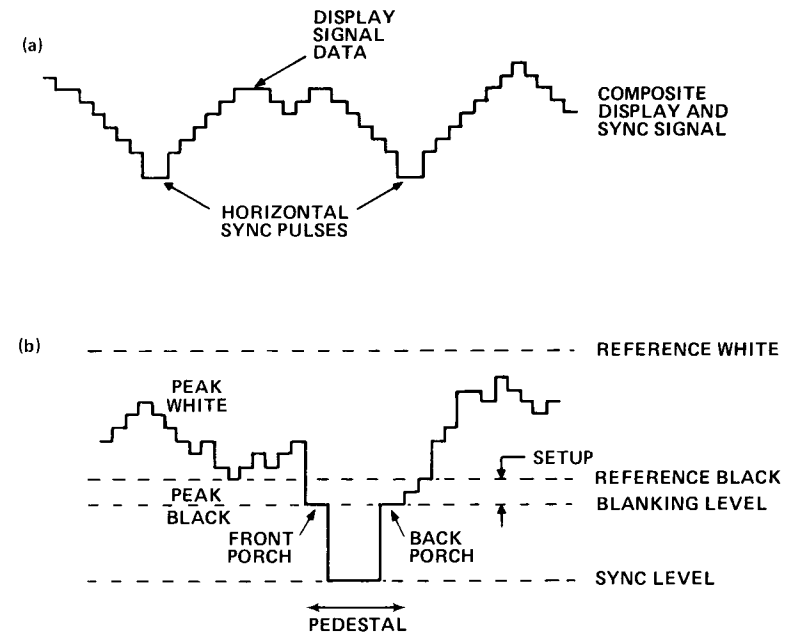

Figure 8-9 Composite display signal (a) and waveform nomenclature (b).

Voltage levels at the monitor input can vary within wide limits and are specified in different ways. A typical practice is to define a nominal value and a range. The specification for a composite display /sync signal might be 1.0 V p-p nominal, 0.3 to 3.0 V p-p acceptable. A non-composite display signal could be specified as 0.7 p-p nominal, 0.3 to 2.0 V p-p acceptable, while the accompanying sync signal is specified as 4 V p-p nominal, 1 to 8 V p-p acceptable.

The input circuits of conventional monitors are designed to "terminate" a 75-ohm or 100-ohm coaxial cable. If the signal is "looped through" to one or more monitors, provision must be made for terminating the last monitor on the line. Monitors are also available with input-impedance and signal-level characteristics which are directly compatible with transistor-transistor-logic (TTL) circuits. A full-scale TTL-compatible signal input voltage level would typically be +5V.

dBmV	mV	dBmV	mV
-40	.010	2	1.259
-30	.032	3	1.413
-20	.100	4	1.585
-19	.112	5	1.778
-18	.126	6	1.995
-17	.141	7	2.239
-16	.159	8	2.512
-15	.178	9	2.818
-14	.200	10	3.162
-13	.224	11	3.548
-12	.251	12	3.981
-11	.282	13	4.467
-10	.316	14	5.012
-9	.355	15	5.623
-8	.398	16	6.310
-7	.447	17	7.079
-6	.501	18	7.943
-5	.562	19	8.913
-4	.631	20	10.00
-3	.708	30	31.62
-2	.794	40	100.0
-1	.891	50	316.2
0	1.000	60	1000
1	1.122		

Figure 8-10 Conversion table, dBmV to millivolts.

Modulated-RF signal voltages (see below) are held to a much lower value to avoid radiation which could interfere with television receivers in the neighborhood. FCC regulations generally limit the peak-to-peak signal value to less than 500 microvolts. The RF signal levels are often specified in dBmV—the ratio between the signal level and 1 millivolt, expressed as dB. Figure 8-10 is a conversion table for dBmV signal values.

A number of monitors (and all television-receiver antennae terminals) are designed for a "floating" or "differential" input. Unless specified otherwise, however, it is assumed that the signal inputs are single-ended, with the coaxial-cable shields tied to the monitor ground. With a non-composite input, the display-signal blanking level and the sync-signal tips would therefore be at ground. With a composite input, only the sync tips would be at ground. In both cases, care must be taken to avoid ground-loop or common mode noise which could interfere with the sync and display signals.

Gamma Correction

There is a direct relationship between the display signal and the voltage applied to the monitor CRT. The luminous output of the phosphors on the CRT monitor screen is not, however, directly proportional to either of these values.

Figure 8-11 plots the luminous output of the monitor as a function of the display-signal voltage. Both are shown as fractions of their full-scale values. The monitor output is less than linear at low display-signal values, more than linear at high display-signal levels. Monitors differ, but the international convention is to assume that the value of the luminous output can be approximated by raising the display-signal input to the 2.2 power. Thus, a 60%-of-full-scale input voltage will result in 33%-of-full-scale luminous output ($0.6^{2.2}$ equals 0.33).

The practice in the television industry is to correct for this "gamma" non-linearity at the signal source: the television camera. The signal output of the camera tube (or each of the three tubes in the case of a color camera) is modified by taking the 2.2 root of its full-scale fractional value. The correction results in a linear *system* relationship, from camera to monitor screen.

There is considerable disagreement on the most appropriate "general-purpose" value for gamma. Values up to 2.8 have been cited, with 2.5 suggested as an average figure.

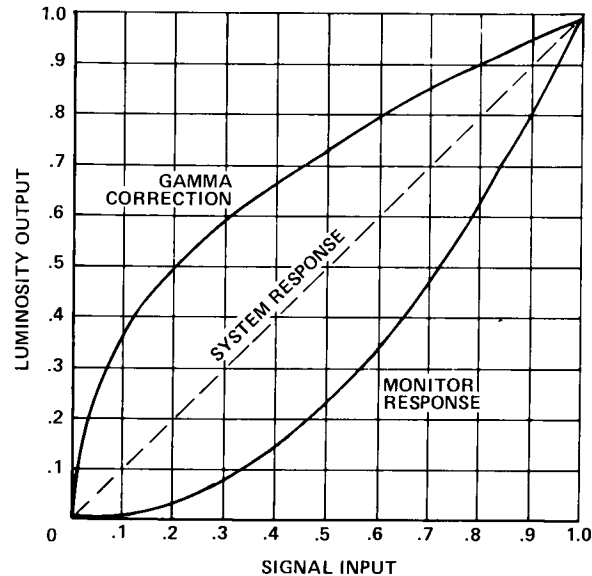The designer of a graphics system with a DAC-generated display

Figure 8-11 "Gamma" monitor response and correction, based on a gamma value of 2.2.

signal has three choices with respect to gamma. The gamma correction can be performed in software by recalculating the display-data values before they are stored in display memory or entered into a lookup table. As a second alternative, an analog gamma correction can be applied to the display signal generated by the graphics controller. The third option is to ignore the whole subject and accept the luminous output of the monitor screen as an inherent characteristic of the system.

COLOR SIGNALS

The discussion on visual perception in Chapter 10, The Human Interface, summarizes the experimental evidence for the theory that the human eye perceives color as a three-dimensional quality. One characteristic of three-dimensional systems is that any three independent parameters can be used to define the complete system specifications. A rectangular box, for example, can be fully described by its length, width, and height, or by the length of a single side and its area and volume. In similar fashion, color information can be specified, coded, and communicated in a variety of three-

APPENDIX
II

DISPLAY-SIGNAL STANDARDS

Display-signal standards assure compatibility between signal-information sources and display or recording devices.

The principal standards applying to both television and graphics systems have been established by the Electronic Industries Association (EIA). They nominally apply to monochrome display systems, but the same standards are widely used to establish the characteristics of each of the three color-input signals which drive a non-encoded (e.g., RGB) color monitor.

There are three basic standards for encoded-color display signals: NTSC, PAL, and SECAM. These are described briefly at the end of this section, with special emphasis on the NTSC standard which applies to all government-regulated broadcast color systems in the United States.

EIA RS-170 STANDARD

(The following paragraphs are edited excerpts from EIA RS-170, which provides performance standards for monochrome display systems. The waveform drawing is derived from EIA RS-170A, a tentative standard for color display systems.)

These standards are intended to apply only to locally generated signals where control can be exercised over display quality.

Impedance

Impedance is defined as the complex ratio of voltage to current in a two-terminal network, expressed in ohms.

The standard load impedance of the source shall have a value of 75 ohms ±5% over the frequency range of 0 to 4.5 MHz and shall be connected for single-ended operation. The internal impedance of the source shall be 75 ohms ±10% at those frequencies where the

impedance of the output condenser (if used) may be neglected. The time constant of the internal impedance combined with the standard load impedance shall be 0.1 second or greater.

Direct Current in Output

The open circuit dc voltage of the display source shall not exceed 2 volts. The short-circuit dc current shall not exceed 2 milliamperes. These dc values are presumed to be independent of the output signal.

Polarity

Polarity is defined as the sense of the potential of a portion of the signal representing a dark area of an image relative to the potential of a portion of the signal representing a light area. Polarity is stated as "black-negative" or "black-positive." The standard polarity of the output of the source shall be black-negative.

Composite Display Signal

Display Signal—The signal resulting from the scanning process.

Sync Signal—The signal employed for the synchronization of scanning.

Sync Level—The level of the peaks of the sync signal.

Blanking Level—That level of a composite display signal which separates the range containing display information from the range containing synchronizing information.

Black Peak—A peak excursion of the display signal in the black direction.

White Peak—A peak excursion of the display signal in the white direction.

Reference White Level—The display signal level corresponding to a specified maximum limit for white peaks.

Reference Black Level—The display signal level corresponding to a specified maximum limit for black peaks.

Setup—The ratio between reference black level and reference white level, both measured from blanking level. It is usually expressed in percent.

Composite Display Signal—The signal which results from combining a blanked display signal with the sync signal.

Blanked Display Signal—The signal resulting from blanking a display signal.

Level—Signal amplitude measured in accordance with specified techniques, or a specified position on an amplitude scale applied to a signal waveform.

It shall be standard that the display signal as measured from blanking level to reference white level across the standard load impedance of the source be 1.0 ±0.05 volt.

It shall be standard that the synchronizing signal as measured across the standard load impedance of the source be 40 ±5% of the display signal.

It shall be standard that throughout a given transmission the synchronizing signal be maintained constant within ±4% as measured across the standard load impedance of the source. This variation may take place on a long-time basis only and not during successive cycles. The allowable amplitude variation over one frame should be considerably smaller.

The amplitude of blanking level referred to the ac axis of the signal at the source output shall not vary more than ±5% of the sync signal amplitude during one field. The ac axis of the signal shall be determined by averaging the signals over one field. The sync amplitude is designated in IRE units in Figure A2-1. It shall be standard that the minimum setup be 7.5±2.5%.
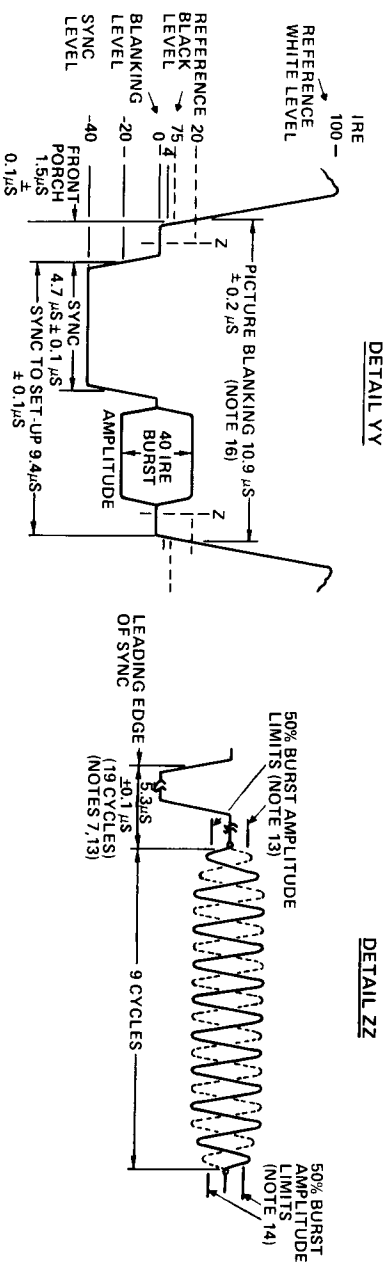
Geometric Distortion

Geometric distortion is defined as any aberration which causes the reproduced image to be geometrically dissimilar to the perspective plane projection of the original image.

It shall be standard that no image element be displaced from its true position referred to the original by more than 2% of the display height. It is desirable that the distortion be held as much below this minimum standard as conditions permit. The instantaneous apparent scanning velocity, since it is a measure of the magnification of the system, shall vary from the mean velocity in a gradual fashion.
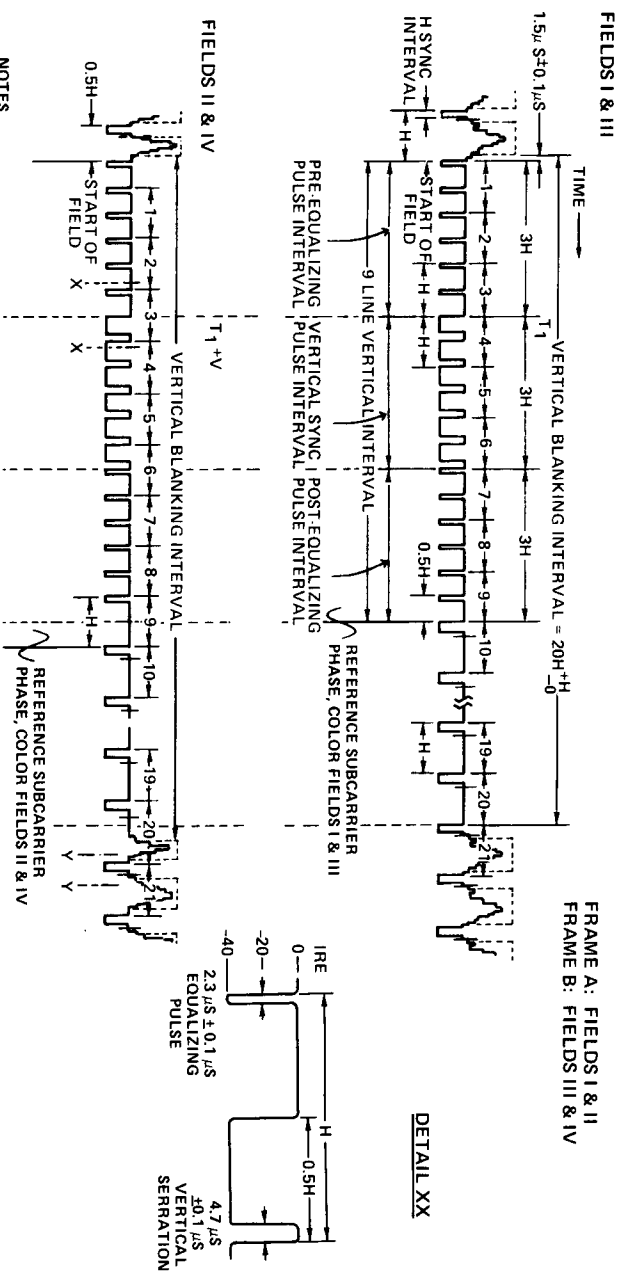
Resolving Power

The resolving power of a display system or a portion thereof is a measure of its ability to delineate detail. It is expressed in terms of the number of lines resolved on a test chart. For a number of lines N (normally alternate black and white lines) the width of each line is 1/N times the picture height.

It shall be standard that the resolving power of the overall system be at least 350 lines in the vertical direction and 400 lines in the horizontal direction, both measurements to be made near the center of the display.

NOTES

1. Specifications apply to local system facilities. Common carrier and transmitter characteristics are not included.

2. All tolerances and limits shown in this drawing permissible only for long time variations.

3. The burst frequency shall be 3.579545 MHz ± 10 Hz.

4. The horizontal scanning frequency shall be 2/455 times the burst frequency [one scan period (H) = 63.556 µS].

5. The vertical scanning frequency shall be 2/525 times the horizontal scanning frequency [one scan period (V) = 16.683 µS].

6. Start of color fields I and III is defined by a whole line between the first equalizing pulse and the preceding H sync pulse. Start of color fields II and IV is defined by a half line between the first equalizing pulse and the preceding H sync pulse. Color field I: That field with positive going zero-crossings of reference subcarrier most nearly coincident with the 50% amplitude point of the leading edges of even numbered horizontal sync pulses. Reference subcarrier is a continuous signal with the same instantaneous phase as burst.

7. The zero-crossings of reference subcarrier shall be nominally coincident with the 50% point of the leading edges of all horizontal sync pulses. For those cases where the relationship between sync and subcarrier is critical for program integration, the tolerance on this coincidence is ± 40° of reference subcarrier.

8. All rise times and fall times unless otherwise specified are to be 0.14 µS ± 0.02 µS measured from 10% to 90% amplitude points. All pulse widths are measured at 50% amplitude points, unless otherwise specified.

9. Tolerance on sync level, reference black level (set-up) and peak to peak burst amplitude shall be ± 2 IRE units.

10. The interval beginning with line 17 and extending through line 20 of each field may be used for test, cue and control signals.

11. Extraneous synchronous signals during blanking intervals, including residual subcarrier, shall not exceed 1 IRE unit. Extraneous non-synchronous signals during blanking intervals shall not exceed 0.5 IRE unit. All special purpose signals (VITS, VIR, etc.) when added to the vertical blanking interval are excepted. Overshoot on all pulses during sync and blanking, vertical and horizontal, shall not exceed 2 IRE units.

12. Burst envelope rise time is 0.3 µS + 0.2 µS − 0.1 µS measured between the 10% and 90% amplitude points. Burst is not present during the nine line vertical interval.

13. The start of burst is defined by the zero-crossing (positive or negative slope) that precedes the first half cycle of subcarrier that is 50% or greater of the burst amplitude. Its position is nominally 19 cycles of subcarrier from the 50% amplitude point of leading edge of sync. (see Detail ZZ)

14. The end of burst is defined by the zero-crossing (positive or negative slope) that follows the last half cycle of subcarrier that is 50% or greater of the burst amplitude.

15. Monochrome signals shall be in accordance with this drawing except that burst is omitted, and fields III and IV are identical to fields I and II respectively.

16. Occasionally, measurement of picture blanking at 20 IRE units is not possible because of image content as verified on a monitor.
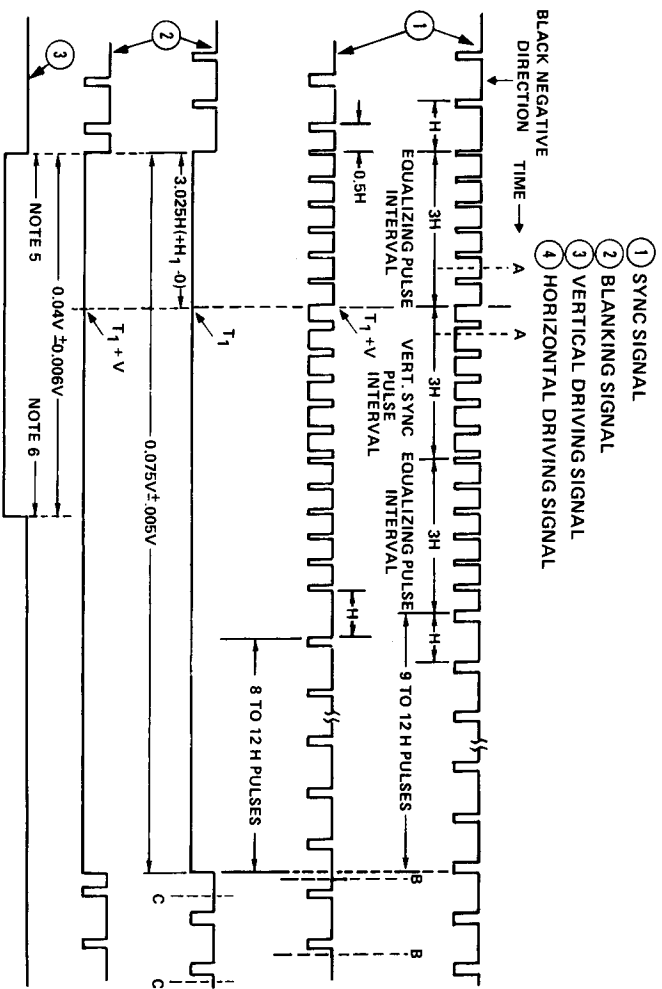
Figure A2-1a RS-170 waveforms, composite display signal, 1 of 2.
(Source: EIA)

Figure A2-1b RS-170 waveforms, composite display signal, 2 of 2.
(Source: EIA)

NOTES:

1. H = time from start of one line to start of next line.

2. V = time from start of one field to start of next field.

3. Leading and trailing edges of vertical driving and vertical blanking signals should be complete in less than 0.1H.

4. All tolerances and limits shown in this drawing are permissible only for long time variations.

5. Timing adjustment, if any shall include this condition.

6. The vertical driving pulse duration shall be 0.04V, ± 0.006V. The horizontal driving pulse duration shall be 0.1H, ± 0.005H.

7. The time relationship and waveform of the blanking and sync signals shall be such that their addition will result in a standard RETMA signal. The time relationship shall be adjustable in order to satisfy this relationship for the condition where the blanking signal is delayed with respect to the sync signal over the range from 0.0H to 0.05H.

8. The standard RETMA values of frequency and rate of change of frequency for the horizontal components of the sync signal at the output of the picture line amplified shall also apply to the horizontal components of the output signals from the recommended sync generator.

9. All rise and decay times shall be measured between 0.1 and 0.9 amplitude reference lines.

10. The time of occurrence of the leading edge of any horizontal pulse "N" of any group of twenty horizontal pulses appearing on any of the output signals from a standard sync generator shall not differ from "NH" by more than 0.0008H where H is the average interval between the leading edges of the pulses as determined by an averaging process carried out over a period of not less than 20 nor more than 100 lines.

11. Equalizing pulse area shall be between 0.45 and 0.5 of the area of a horizontal sync pulse.

12. The overshoot on any of the pulses shall not exceed 5%.

13. The output level of the blanking signal and the sync signal shall not vary more than ±3% under the following conditions:

   A. The a.c. voltage supplying the sync generator shall be in the range between 110V and 120V and must not vary more than 5V during test.

   B. A period of 5 hours continuous operation shall be considered adequate for this measurement, after suitable warm-up.

   C. The room ambient shall be in the range between 20 deg. and 40 deg. C. and shall not change more than 10 deg. C. during this test.

14. Adjustment shall be possible between minimum and maximum limits so that aspect ratio can be set to the normal value.

① SYNC SIGNAL
② BLANKING SIGNAL
③ VERTICAL DRIVING SIGNAL
④ HORIZONTAL DRIVING SIGNAL

All signal amplitudes shall be adjustable over the range from 3.5 to 4.5 volts across a load impedance of 75 ohms ± 5%. Negative signal polarity shall be available for all pulses. Source impedance for all output circuits shall be 75 ohms ± 10%.
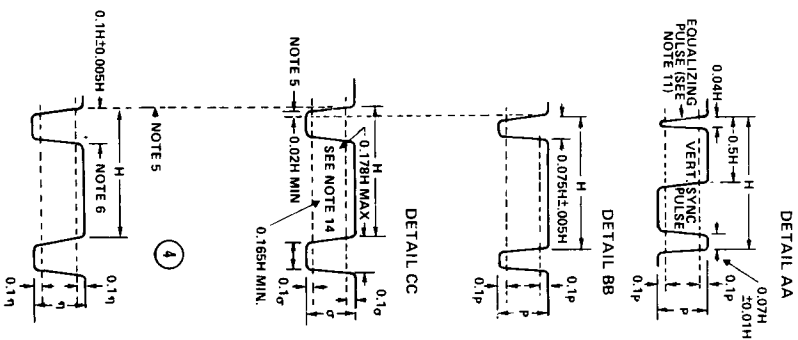
Figure A2-2a RS-170 waveforms, composite sync-signal generator, 1 of 2. (Source: EIA)

Figure A2-2b RS-170 waveforms, composite sync-signal generator, 2 of 2. (Source: EIA)

Aspect Ratio

Aspect ratio is defined as the ratio of the frame width to the frame height. "Frame" is defined as the total area scanned while the display signal is not blanked.

The standard aspect ratio of a frame shall be 4:3 on condition that the horizontal blanking interval be 17.5% of the line period and the vertical blanking interval be 7.5% of the frame period. No specific tolerances are assigned to this ratio but it is understood that the tolerance allowed for geometric distortion will provide adequate limits for permissible variation in the aspect ratio.

Sync Signal Tolerance

It shall be standard that the synchronizing signal waveform conform with Figure A2-2.

It shall be standard that the time of occurrence of the leading edge of any horizontal pulse "N" of any group of twenty horizontal pulses not differ from "NH" by more than 0.001H where "H" is the average interval between the leading edges of horizontal pulses as determined by an averaging process carried out over a period of not less than 20 or more than 100 lines.

It shall be standard that the rate of change of the frequency of recurrence of the leading edges of the horizontal sync pulses appearing in the source output be not greater than 0.15 per cent per second, the frequency to be determined by an averaging process carried out over a period of not less than 20 or more than 100 lines, such lines not to include any portion of the vertical blanking signal.

It shall be standard that the frequency of horizontal and vertical scanning pulses not vary from the values established by the standards of frame frequency and number or scanning lines by more than ±1% regardless of variations in frequency of the power source supplying the system.

EIA RS-330 STANDARD

(The following paragraphs are edited excerpts from EIA RS-330, which provides performance standards for high-performance raster-scan systems.)

It shall be standard that the blanked picture signal with setup (non-composite), as measured from blanking level to reference white level across the standard load impedance of the source, be 0.714±0.1 volt (100 IRE units).