ESD-TR-86-279

MTR-9915, Volume I

GRAPHICS TECHNOLOGY STUDY VOLUME I: STATE OF GRAPHICS TECHNOLOGY

By

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DECEMBER 1986

Prepared for

DEPUTY COMMANDER FOR STRATEGIC SYSTEMS
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Hanscom Air Force Base, Massachusetts

Project No. 6030

Prepared by

THE MITRE CORPORATION
Bedford, Massachusetts

Contract No. F19628-86-C-0001

REVIEW AND APPROVAL

This technical report has been reviewed and is approved for publication.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release, distribution unlimited.
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) MTR-9915, Vol. I ESD-TR-86-279	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION The MITRE Corporation 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Burlington Road Bedford, MA 01730	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Deputy Commander for (cont.) 8b. OFFICE SYMBOL (If applicable) SCC-3	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F19628-86-C-0001
8c. ADDRESS (City, State, and ZIP Code) Electronic Systems Division, AFSC Hanscom AFB, MA 01731-5000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. | PROJECT NO. 6030 | TASK NO. | WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
GRAPHICS TECHNOLOGY STUDY VOLUME I: STATE OF GRAPHICS TECHNOLOGY

12. PERSONAL AUTHOR(S)
Couture, R.G.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM ____ TO ____	1986 December	53

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Graphic Terminal Technology Video Standards
			Hardcopy Devices
			Video Signals

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This paper is a study of the elements of a graphic display system. It contains a tutorial covering the state of technology in graphic displays and hardcopy devices, including a discussion on video signals and related standards. The report also provides some general comments on the future direction of the graphics industry.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Diana F. Arimento	22b. TELEPHONE (Include Area Code) (617)271-7454 22c. OFFICE SYMBOL Mail Stop D230

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

8a. Strategic Systems.

ACKNOWLEDGMENTS

This document has been prepared by The MITRE Corporation under Project No. 6030, Contract No. F19628-86-C-0001. The contract is sponsored by the Electronic Systems Division, Air Force Systems Command, Hanscom Air Force Base, Massachusetts 01731.

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SECTION 1

INTRODUCTION

This paper is a study of the elements of a graphic display system. Volume I contains a tutorial covering the state of technology in graphic display and hard copy devices, and includes a discussion of video signals and related standards.

This study was performed to assist system engineering personnel better understand the elements of a graphic display system. This includes being knowledgeable of the capabilities offered by state-of-the-art equipment.

1.1 SCOPE

Volume I of this study on graphics technology focuses on:

a. Graphic Terminal Technology
b. Hardcopy Devices
c. Video Signals and Standards.

It presents an overview of current graphics technology. The purpose is to assess the level of performance available in graphics devices today, not to provide a market survey of available products. This study does not present an in-depth, detailed analysis of all aspects of graphics technology; rather, it attempts to provide an easily understood tutorial on the types, techniques, important operating parameters and features of graphics equipment and of their uses.

Section 2.0 on "Graphics Terminal Technology" looks at various design features of graphic terminals including display devices, terminal interfaces, and graphic software. Major performance characteristics of graphics terminals are highlighted.

Section 3.0, "Hardcopy Devices," covers the various technologies employed in graphics hardcopy devices. Salient characteristics, performance features, and advantages/disadvantages of each type are examined.

Section 4.0 discusses "Video Signals and Standards" including the two common video formats used in the U.S. today; namely, composite video and Red, Green, Blue (RGB).

Finally, Section 5.0 briefly summarizes the state of graphics technology, with a few words regarding future direction in the graphics industry.

SECTION 2

GRAPHICS TERMINAL TECHNOLOGY

The graphics terminal, as discussed herein, can be defined as a device that processes and displays both graphic and alphanumeric information. It manipulates and converts digital data into a form that can be easily interpreted by a human being. For purposes of this study, a graphics terminal is considered to be a device containing hardware and software necessary to perform display generation and presentation. This translates into: (1) a graphics processor, which accepts high level commands and translates them into pixel representations or vector commands, (2) a display device, presumably a cathode ray tube, and (3) associated input devices, such as keyboards, mouse, digitizing tablets, etc. This section will analyze graphic hardware and software design issues, as well as terminal interfaces, both physical (device I/O) and visual (display).

2.1 DISPLAY TYPES AND THEIR CHARACTERISTICS

Many display technologies are employed in graphic applications today. Types include the cathode ray tube (CRT), plasma panel, light emitting diodes (LEDs), liquid crystal displays (LCDs), and others. Table 1 compares several types of display devices in terms of relative size, speed of response, and color capability. With respect to graphics terminals, the CRT is by far the dominant display in use today. Although the other types may represent the best choice for a particular display application, no other technology can match the CRT's overall flexibility, resolution, speed, color performance, and price. The CRT provides the greatest number of performance features for the general purpose graphics environment. It is expected to maintain its dominant status for the foreseeable future. As illustrated in table 1, CRTs are virtually the only devices offering cost-effective simultaneous multicolor performance; therefore, the remainder of this section will focus on graphics terminals configured with CRTs and their associated display resolution, color, and alphanumeric characteristics.

TABLE 1. COMPARISON OF DISPLAY TYPES

TYPE	SIZE	SPEED	COLOR
CRT	LARGE	FAST	FULL RANGE
LED	SMALL	FAST	RED
LCD	SMALL	SLOW	GREY
PLASMA PANEL	SMALL	MED/ FAST	ORANGE
ELECTRO-LUMINES-CENT	SMALL	MED	YELLOW

NOTE: THE TERMS LARGE, SMALL, FAST, SLOW, ETC. ARE USED IN A RELATIVE SENSE FOR COMPARING THE TYPES OF DEVICES TO EACH OTHER.

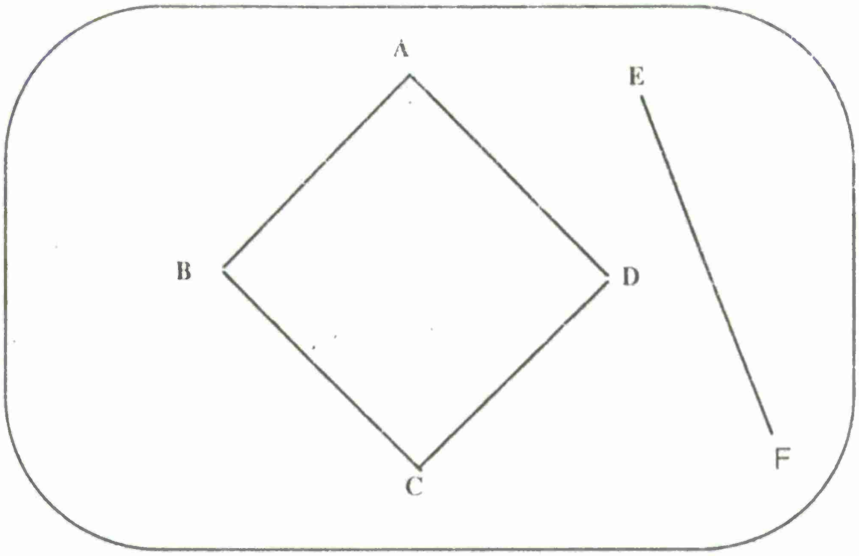
2.1.1 Cathode Ray Tubes (CRTs)

Images are created on the face of a CRT by firing electrons onto the tube´s inner phosphor coated surface. The electron beam is emitted from the tube´s cathode and deflected by means of a magnetic field created by the deflection coil. The electrons striking the surface illuminate the phospor. The manner in which the beam is manipulated forms the basis for the two types of CRTs produced, namely, the stroke writer and the raster scan. Figure 1 illustrates the technique used by both types of devices to create a graphic image.

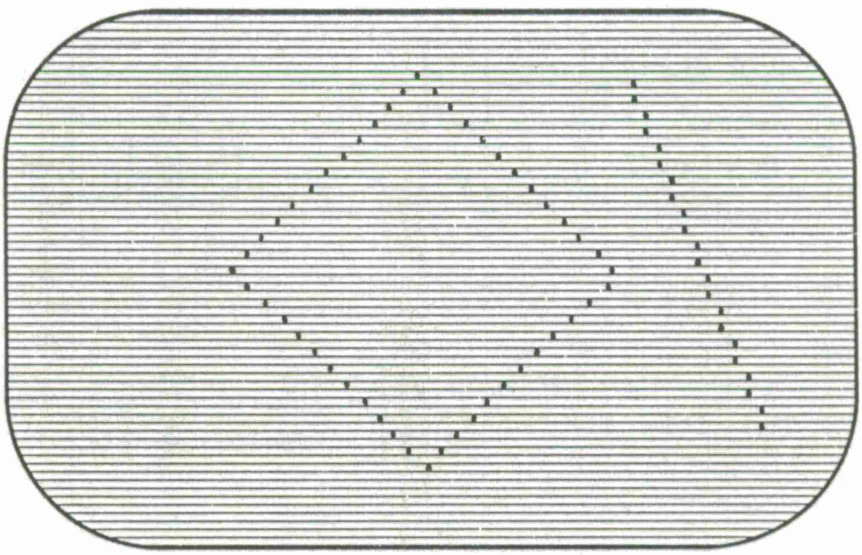
The stroke writer type "draws" a picture randomly on the screen using a series of individual lines extending between any two given points. The electron beam moves from one vector to the next in a sequential manner until the entire image is formed. The amount of time it takes to "draw" a picture is directly proportional to the complexity of the picture. As an example, in figure 1(a), with the electron beam brought into position over point A, the beam´s intensity is increased to the level needed for phosphor illumination. It is then deflected to point B, resulting in line AB being drawn. This process is repeated for every segment of the image.

Conversely, a raster scan CRT will sweep across the entire face of the display in a uniform manner, independent of the complexity of the image to be drawn. In a raster scan CRT, the screen is divided into equal-sized horizontal strips called "scan lines" and each strip is divided into equal-sized blocks called "picture elements" or "pixels." As each line is scanned, the intensity of the electron beam is controlled in accordance with the information stored in a frame buffer to produce light, dark, and gray shades. As such, each pixel is a unique point that is addressed during every scanning cycle. In 1981, only one third of graphic displays in use were raster scan. Today, the figure is approaching two thirds.

One of the primary differences between stroke writers and raster scan devices is that the pixel format of raster displays allows illumination of fixed discrete points only, whereas the stroke writer can illuminate any portion of the screen. The



(a) STROKE WRITER DISPLAY



(b) RASTER SCAN DISPLAY

FIGURE 1. STROKE WRITER versus RASTER SCAN DISPLAY TECHNIQUES

resultant raster scan image can therefore be somewhat jagged in appearance. This phenomenon is referred to as "staircasing" or "aliasing." Aliasing is most evident when diagonal lines are displayed. Figure 1 illustrates an example of aliasing in a raster device. Notice that line EF in figure 1(a) is smooth between points E and F. Conversely, the raster device must select pixels whose fixed locations may not be in the optimum position for smooth image presentation. The line, therefore, in figure 1(b) appears jagged.

Regardless of whether a display uses the stroke writing or raster scan method, it must maintain the image drawn for some finite period of time. This is accomplished by use of either a "storage tube" type of CRT (stroke writer) or by the "refresh" method (stroke writer and raster scan).

A storage tube CRT is constructed using extremely long-persistent phosphor, which enables the image to remain visible for an extended period following a single excitation. Since the image is stored in the display itself and not in a display memory, information presented cannot be selectively manipulated. The entire image must be erased and redrawn. As a result, storage tubes have been inappropriate for an interactive environment where dynamic information must be displayed. Storage tubes are not used in raster scan CRTs, only in stroke writers.

Alternately, with the refresh method, images are continuously redrawn at rates up to sixty times per second, through repeated excitation of short-persistence phosphors. A refresh memory, usually a high speed, dual ported Random Access Memory (RAM), is used to store the current display file that contains specific information regarding each pixel. The refresh approach allows rapid display updating and selective erasure or manipulation of displayed data. Refresh techniques apply to both stroke writer and raster scan devices.

The refresh method may be implemented several ways in a raster scan CRT. The practice of "interlacing" is employed to reduce display flicker. Flicker is the condition where the luminance of the phosphor begins to fade between successive refresh cycles, causing the display to blink slightly. Interlacing involves scanning every other scan line, using the omitted lines for horizontal retrace, then scanning the omitted lines on the next cycle. This essentially divides the image into two separate fields, the combination of which comprises the total frame. Most displays today are of the 60 Hz non-interlaced design, meaning that each scan line is traced sequentially and the total frame is refreshed 60 times each second. Some manufacturers offer 30 Hz interlaced models meaning that each of the two alternating fields is scanned at 60 times per second resulting in a total frame refresh rate of 30 Hz. These displays must use longer persistence phosphors to avoid flicker and jitter, which is a unique problem of interlaced displays. Jitter is the condition where the luminance of the phosphor in one field begins to fade as the other field is being refreshed causing the image to appear to jiggle or vibrate slightly in the vertical direction. Jitter is most evident where data or lines are drawn horizontally on the screen.

Refreshed stroke writer displays can also suffer from flicker. A refreshed stroke writer operates by reading and drawing all vectors in its display file over and over again. Flicker can occur when drawing complex images, since the phosphor may begin to fade before all vectors have been read and drawn onto the screen. As the newer, higher speed stroke writers become more available, the problem of flicker will be less of a concern.

2.1.1.1 Display Resolution

Display resolution is primarily affected by two factors, (1) the size and quantity of the individual picture elements (pixels), and (2) the degree of addressability in memory. Other more detailed factors affecting resolution, such as current density distribution of the electron beam and optical properties of different phosphors, need not be discussed here. Resolution is usually specified as the number of pixels along a display's X and Y axis. Most general purpose color displays offer resolutions of 512 x 512 or 640 x 480. These are generally of the type used in personal computers or general purpose graphic workstations. Due primarily to performance driven requirements of Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) in recent years, color display resolutions of 1280 x 1024 are now readily available. Although greater color resolutions have been demonstrated, technical and economic stumbling blocks must be overcome before these will be producible for the mass market. Monochrome displays are technically far simpler to develop and produce. Resolutions of 4096 x 4096 have been available for some time in monochromatic display systems.

Care must be taken when reading manufacturer's specifications regarding a terminal's resolution. Pixel shifting and manipulation techniques are used that give the illusion of greater pixel addressability. Pixel shifting involves the illumination of phosphor on the periphery of a defined pixel, giving the appearance of a slight shift in the pixel's otherwise fixed location. It is done to try to mitigate the "staircasing" or "aliasing" effect, which plagues raster scan displays. Manufacturers sometimes conclude that pixel shifting translates to increased resolution, since it appears to result in greater addressability on the display screen. Some equipment fact sheets may therefore claim "effective" resolution figures of 2000 or 3000 when in reality, the true resolution is in the order of 1000 pixels.

2.1.1.2 Color

Studies have shown that bright, easy-to-read color images provide five times more information than black-and-white images. Color provides a coding mechanism for separating information, it emphasizes important information by drawing attention to it, and it enhances human pattern recognition.

The simplest case is a display having one electron gun and only two distinct pixel states, black or white. The bit mapped memory could consist of a single memory plane with one bit per pixel indicating only whether the pixel should be black (no intensity) or white (full intensity). Memory planes can be stacked to represent multiple levels of gray scale. N memory planes will yield 2^N levels of gray scale. Gray scale equates to discrete levels of intensity of the electron beam offering a number of shades in the region between black and white. In monochrome displays, the intensity of each pixel is the only information needed in order to faithfully reproduce an image.

Most color displays, on the other hand, utilize three electron beams; one corresponding to red, one green, one blue (RGB). The beams excite corresponding phosphor points that may be only .31 millimeters apart (pitch). To reproduce color images faithfully, the intensity of each of the three beams is varied. Since each pixel contains red, green, blue phosphor, the combination of the three at different intensity levels produces vast color possibilities.

The degree of complexity related to proper alignment and convergence of three color beams has led some vendors to look for alternate methods of color generation using only one beam. The Sony Trinitron CRT fires a single electron beam, which is subsequently broken down into the three red, green, blue components, thereby eliminating convergence problems. Another type of single beam CRT currently being designed is capable of limited color performance using a "penetration" technique. Essentially, several layers of color phosphor are applied to the screen such that electrons penetrate and excite different layers, based on their velocity. The color quality and versatility of current beam penetration CRTs are no rival for conventional color CRTs.

Graphic terminals use multiple memory planes in conjunction with color lookup tables to provide the user with a choice of some limited number of simultaneously displayable colors from a palette of total available color. The color capacity of graphic terminals today ranges from 8 or 16 colors from a palette of 64, to 4096 simultaneously displayable colors from a palette of over 16 million.

2.1.1.3 Alphanumerics

Graphic terminals are capable of producing alphanumeric characters two ways: using a hardware or a software approach. The hardware implementation is based on the use of character generators. In this approach, character sets are stored in firmware and accessed by their corresponding ASCII (American Standard Code for Information Interchange) representation. Terminals having no hardware character option must produce characters through software. Here, each line, arc, or segment of each alphanumeric character is treated as an individual graphic entity, and must be specified separately. Under this approach, for example, four different "draw line" commands would be required to generate an upper case "E" character. It is clear that incorporating an alphanumeric capability in hardware greatly reduces the amount of data exchanged across the terminal interface.

The number of characters per line and lines per page are directly related to the display resolution and character size. The more common character generators utilize a 5 x 7 or 7 x 9 pixel grid to form each character. Standard word processor and VT-100 type terminals offer 80 (5 x 7) characters per line, 24 lines per page. Top-of-the-line graphics terminals having 1280 x 1024 resolutions are capable of 160 (7 x 9) characters per line, 85 lines per page.

2.2 INTERFACING

This section presents information regarding interfaces to graphics terminals. Depending on the application, a graphics terminal may interface to one or more of the following:

a. Standalone display processor
b. Host computer
c. Networks
d. Peripherals.

At least one communications port is normally provided for connecting the terminal to either a standalone processor or host computer. Some terminals are capable of being configured in networking environments through specially provided interfaces. In addition, separate peripheral interfaces are available to accommodate a variety of input and hardcopy output devices. Figure 2 illustrates typical interfaces available for graphics terminals.

2.2.1 Communications Interface

For single user, standalone applications, graphic terminals require some type of display or graphics processor to perform system functions. The typical display/graphics processor offers a VMS, UNIX, or CP/M-86 operating system, FORTRAN compiler, possibly an editor and data base manager, utility programs, and applications software. Such a configuration is normally referred to as a graphics workstation. Communications between the display/graphics processor and graphics terminal are normally through an RS-232-C port operating at speeds between 110 and 19.2K baud. (RS-232-C is an Electronics Industry Association

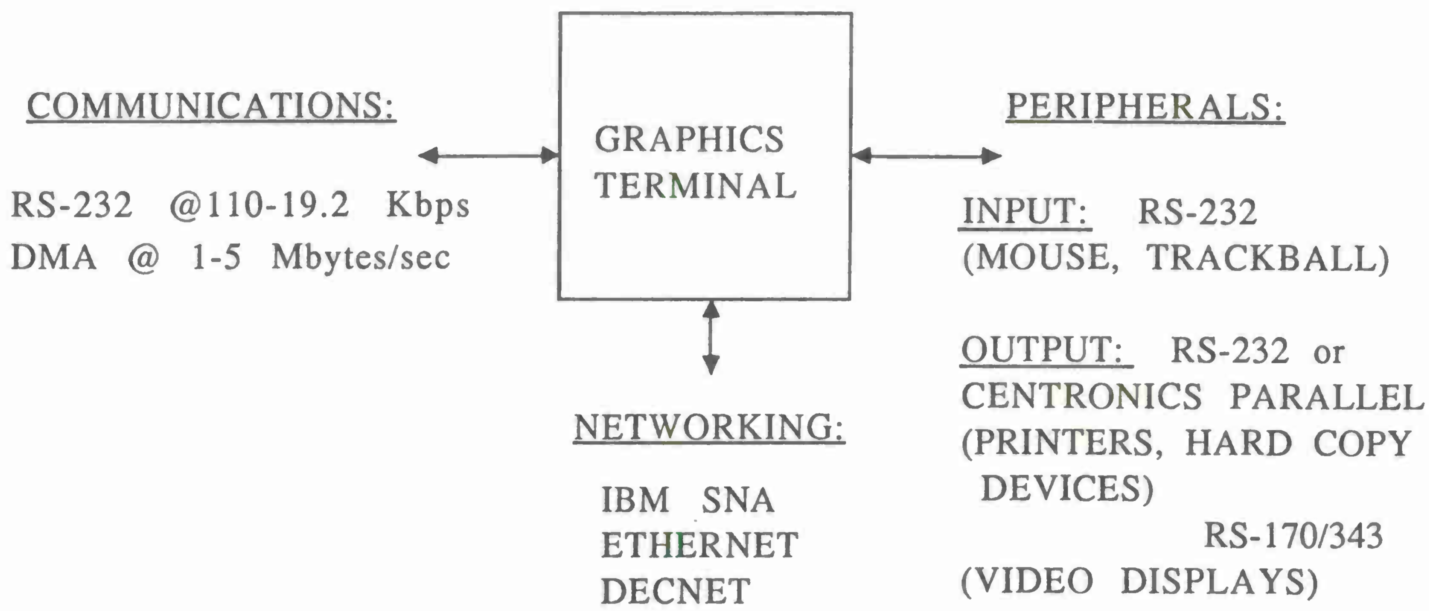


FIGURE 2. TYPICAL GRAPHIC TERMINAL INTERFACES

interface standard for Data Terminal Equipment operating in serial mode.) On-line, this same port could be used for connectivity to a host that normally performs the display processing functions. The serial 19.2K baud graphics data rate is standard in most terminals surveyed, although some support a 38.4K baud rate for communicating alphanumeric data.

In addition to the serial port, a wide variety of parallel interface options is available. A parallel port has the advantage of enabling much more rapid exchange of data between the display processing and display generation functions. A Direct Memory Access (DMA) interface as implemented through Digital Equipment Corporation's (DEC's) UNIBUS, Intel's MULTIBUS, or an IEEE-488 General Purpose Interface Bus (GPIB), provides high speed host communications from 1 to 15 Mbytes per second. Other communications interfaces are being offered by some manufacturers for unique or specialized applications. Examples of these include a 24 bit parallel or Small Computer System Interface (SCSI).

2.2.2 Networking

Although not standard, many terminal manufacturers do offer an interface to a Local Area Network (LAN), or cluster controller affording networking capabilities. The most commonly available LAN interface is to Ethernet, with some terminals handling additional layers of protocol such as the DECNET implementation within the Digital Network Architecture (DNA), or IEEE 802.3 with Transmission Control Protocol (TCP)/Internet Protocol (IP). Cluster controllers available from some manufacturers will allow terminal operation within other network environments, typically IBM's Synchronous Network Architecture (SNA). In addition to resource sharing, networking makes possible features such as electronic mail in terminals so configured.

2.2.3 Peripherals

Graphic terminal peripherals include both input and output devices. Although interfaces to standard input devices such as keyboards or a mouse may be integral in a terminal's design, additional RS-232-C ports may be offered for adding other input devices such as digitizing tablets, touch panels, track balls, light pens, and others. Graphic terminal output may be in digital or video (analog) format. The digital interface to output or hardcopy devices may be either RS-232-C serial or Centronics parallel. The Centronics parallel interface is an 8 bit "de facto" industry standard for peripheral devices. In addition, many terminals produce video output in accordance with standards RS-170 or RS-343-A. (More information on video signals is presented in section 4.)

2.3 SOFTWARE

Graphics software is so diverse that a complete study could easily be devoted to the subject. The short section presented here will, therefore, only highlight major developments in the field of graphics software.

Graphics software is implemented using many different functional components, resulting in many interfaces. Up to now, the approaches to implementing graphics and interfaces between software components have not been standardized. This has resulted in development of non-portable, device dependent software and has complicated the design of application programs.

Figure 3 illustrates the major functional components associated with the typical graphics application. Software packages to perform these functions are normally resident in the host computer. Standalone workstations contain these in their dedicated display processors. The two most dynamic components examined here include the Utilities/Tools and Device Driver software.

Utilities/Tools software consists of libraries of subroutines dealing with system, graphic and text environments, host file and I/O, and utilities. These routines are usually written in FORTRAN although source code written in other higher order languages, such as BASIC and PASCAL, is available. Utility/Tools software performs the transformation between application program object description and display viewable object description.

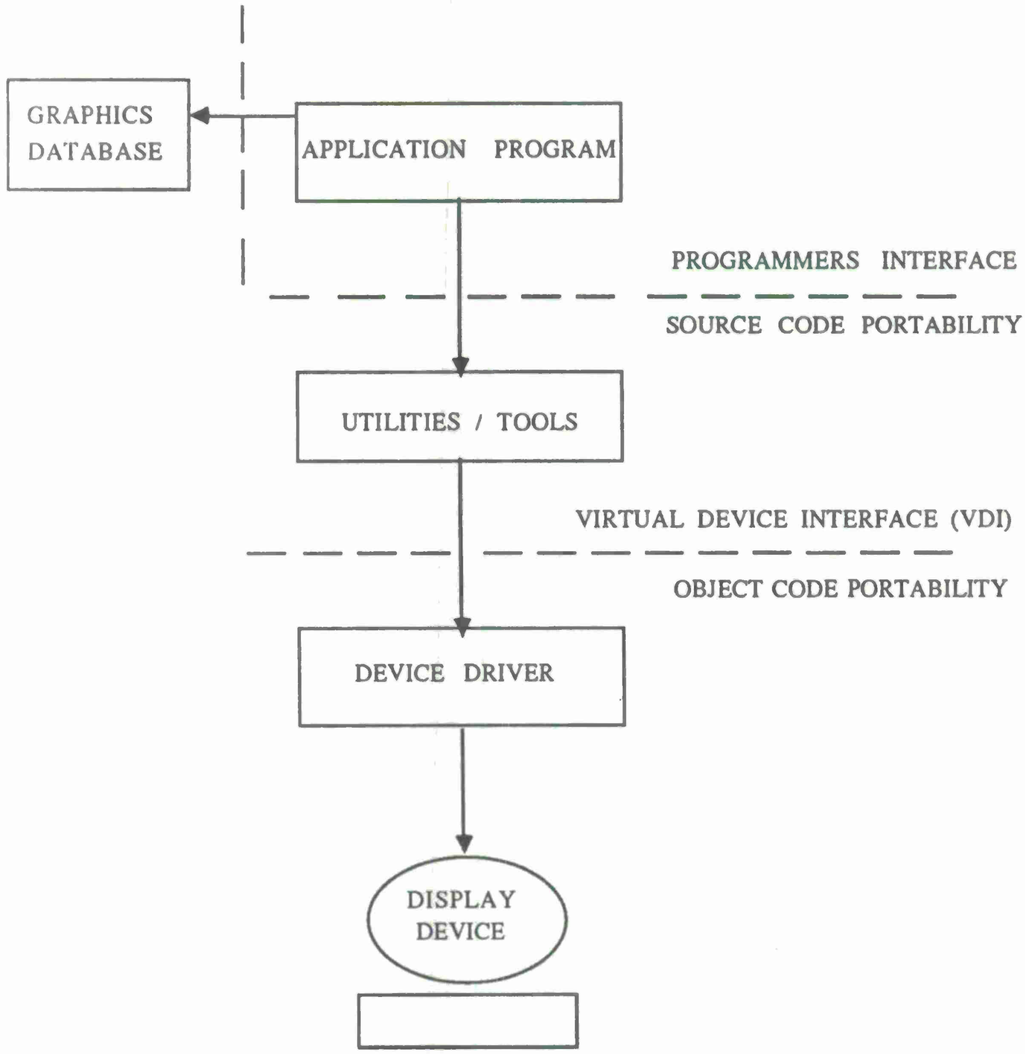


FIGURE 3. GRAPHIC SOFTWARE FUNCTIONAL COMPONENTS AND INTERFACES

The most intense and controversial graphic software standardization effort is occurring at the Utilities/Tools level. One main purpose of Utilities/Tools software is to provide a common method of describing objects to be displayed. This includes a determination of how graphic primitives should be implemented. A Graphical Kernel System (GKS) proposal has been adopted as a national (ANSI) standard. Other systems, such as CORE, enjoy strong support from a large contingent of graphics producers and users, and have been implemented widely in off-the-shelf graphic software products. The major controversy surrounding the GKS standard is that unlike CORE, its object description methodology is based on a two-dimensional representation and does not support 3-D graphics. In addition, GKS does not provide the same level of user control as CORE, and others.

Device drivers are the software interface between the main body of code and the terminal or device, although the function served by device drivers may sometimes be implemented in firmware. They resolve incompatibilities between the device independent data descriptions and the physical characteristics of a particular device. Device drivers therefore allow a program to generate the same display on a wide variety of terminals or peripherals. Even as new graphic devices become available, associated device driver software packages are intended to allow integration with little or no modification to previously developed applications programs.

The interface between the Utilities/Tools and Device Driver components is also experiencing intense activity in the standards arena. Referred to as the Virtual Device Interface (VDI), it represents the epitome of compromise. If the interface is specified to contain too many functions, then device drivers for simple graphic devices will be large in size and difficult to write. If too few functions are contained, the drivers will not be able to take advantage of features offered by high end devices. Generating a VDI standard through a committee whose members represent diverse interests will be a major feat.

Numerous other efforts are ongoing to provide standardization at all levels within the graphics environment. In response to user demand, however, numerous unique software systems have already been deployed, some recognized as "de facto" standards (e.g., Tektronix Plot 10). Since standards represent compromises, manufacturers will continue to be driven by system requirements, implementing non-standard interfaces to optimize performance or cost of their systems. Third party software houses are flourishing in their development of "compatible" software products.

2.4 SECTION 2 SUMMARY

Tables 2 through 4 briefly summarize the information presented in section 2 of this study.

First, table 2 compares the CRT with other display technologies. As table 2 illustrates, the key factors that support the CRT's dominance in the graphics terminal arena are color performance, image quality, and CRT producibility/cost.

Next, table 3 contrasts the stroke writer against the raster scan type of CRT, highlighting the major differences between the two. One can conclude from table 3 that for applications where a wide variety of color is needed, the raster scan CRT is the preferred device. In applications where the "aliasing" effects of raster scan CRTs are not acceptable, the stroke writer CRT provides the better image quality. Technological advancements, however, continue to improve on the undesirable characteristics inherent in each design, bringing the performance of both closer together.

Table 4 cites a few of the capabilities that are available in state-of-the-art graphic terminals. Advancements in the resolution of color CRTs are currently dependent on the ability to produce higher resolution shadow masks. (A shadow mask is comparable to a wire mesh or screen. It separates pixels in a raster scan CRT.) Other CRT capabilities will continue to move forward based on advances in Very Large Scale Integrated circuits (VLSI), reductions in the cost of memory, and increases in the speed of digital logic.

TABLE 2. CHARACTERISTICS OF THE CRT AND OTHER DISPLAY TYPES

	CRT	OTHER TYPES
APPLICATIONS	Widespread application in television,office systems, computer, CAD/CAM, security, and a host of other areas.	Wide variety of specialized applications; usually where small number of displayable elements are used; or low power, size, weight are primary considerations.
PRODUCIBILITY/ COST	Mass production results in economies of scale; lower costs.	Limited production and specialized production techniques result in higher costs.
FEATURES	* Mature product; basic design in place over 40 years. * Unlimited color performance. * Very good image quality. * Larger size, higher power requirements, design not suitable for harsh environments.	* Immature products; most in production less than 10-15 years. * Very limited color options. *Limited graphics capabilities. * Usually smaller in size, less weight, low power requirements, more environmental tolerance.

TABLE 3. COMPARISON OF THE STROKE WRITER AND RASTER SCAN CRTs

	STROKE WRITER	RASTER SCAN
COLOR	LIMITED & EXPENSIVE (BEAM PENETRATION)	UNLIMITED (COLOR TRIAD)
IMAGE QUALITY	VERY GOOD (STRAIGHT LINES)	SUFFERS "ALIASING" (JAGGED LINES)
FLICKER	YES (LARGE DISPLAY LIST)	YES (REFRESH < 60 HZ)
JITTER	NO	YES (INTERLACING)

TABLE 4. FEATURES AND CAPABILITIES OF CURRENTLY AVAILABLE GRAPHIC TERMINALS

FEATURE	PERFORMANCE
RESOLUTION	State-of-the-art in production color CRT s is 1280 X 1024 pixels. Monochrome CRT s is 4096 X 4096.
COLORS	Only limited by amount of memory planes employed. Greatest number of colors currently available is 4096 simultaneously displayable colors from a palette of 16.7 million.
REFRESH RATE	Most offer 60 Hz non-interlaced, resulting in no flicker or jitter. Some 30 Hz interlaced models available.
INTERFACES	* Communications: Either RS-232-C serial with speeds up to 38.4K baud, or parallel DMA with speeds typically 1-3 Mbytes per second. * Networking: Ethernet, DECNET, and IBM SNA interfaces available. * Peripheral: Either RS-232-C serial with speeds up to 19.2K baud, CENTRONICS parallel, or video (composite or RGB).

SECTION 3

HARDCOPY DEVICES

This section will examine types and performance features available today in computer graphics hardcopy devices. These devices produce a permanent record of what appears on a display console. This study will assume that the hardcopy device receives its information in a logical manner (as opposed to a photographic process, for example). The technologies and innovative methods for generating hard copy are numerous. To begin, equipment will be segregated into two major categories: impact and non-impact devices.

One feature of hardcopy devices, which is discussed in subsequent paragraphs and requires further clarification, is "copy rate." There exists no standard method for measuring the rate at which a graphic image is produced. Variables such as image size, resolution, color density, and information density all greatly affect the rate at which many devices generate hard copy. Therefore, the copy times cited for the different devices discussed herein are subjective, based on averages and estimates, assuming an image of "medium" size, color, and information density.

3.1 IMPACT DEVICES

Impact devices produce images on hard copy through physical contact with the medium. Most common among these types are:

a. selectric ball
b. daisy wheel
c. band/belt/drum
d. dot matrix
e. pen plotters.

The first three are inappropriate for graphics hard copy since they contain pre-formed alphanumeric characters and are used exclusively in printing textual data. Dot matrix devices, however, print individual points to form characters or graphic images, similiar to how individual pixels form characters or images on a visual display. Pen plotters use pens or other writing instruments to draw an image onto the recording medium.

3.1.1 Dot Matrix

The dot matrix print head is normally constructed with electromagnetically controlled pins arranged in a 1 x 7 or 1 x 9 vertical matrix, although many other variations exist. Individual pins are fired as the head is stepped horizontally across the page, usually in a bi-directional manner. Pins fired strike the paper through an inked ribbon. Many variations on this technique are utilized to achieve greater resolution or high print throughput. Some heads are constructed with a 2 x 9 pin matrix, while others "tilt" or "nod" in the vertical direction on successive passes to fill in between dots drawn on a previous pass. Recent advances include the use of multicolored ribbons for color performance and multiple print heads for increased throughput.

The major advantages of dot matrix devices are that they can print on standard paper, can produce simultaneous multiple copies, are capable of both graphics and alphanumerics, and are inexpensive. Disadvantages include the fact that they are noisy (as are all impact devices), offer limited resolution, produce images of fair quality, and are relatively slow. Resolutions of dot matrix printers average in the 65 to 85 dots per inch (dpi) range although some are offering around 150 dpi. Factors affecting speed include head construction, number of pins, number of heads, desired resolution, color, and speed of paper feed stepper motor. A typical dot matrix printer can print 120 characters per second. This translates into 16 seconds to print one page of 24 lines, 80 characters per line. Devices employing a 2 x 9 dot matrix head generally achieve speeds of 240 characters per second, equaling 8 seconds to print a page of text. Approximately 500 characters per second is the upper limit in print speed today using character serial dot matrix print heads. It is clear to see that in graphics mode, where a far greater amount of printing is required, compared to text mode, an average of 3 minutes per black-and white-copy is typical. A state-of-the-art color dot matrix printer requires, on the average, about 8 minutes to produce a full page (8 1/2-x 11-inch) graphic image. The price of a color dot matrix printer is in most cases less than $5 thousand (K).

3.1.2 Pen Plotters

Pen plotters have been the dominant desktop graphics output device, outselling all other technologies combined. These devices use mechanical control systems to direct the motion of a pen or other writing instrument. The types of pen plotters available differ only in the manner in which the pen and/or paper moves. For example, in the basic flatbed system, the pen moves in two directions over the paper, which remains stationary. Drum and beltbed units simultaneously move pen and paper to achieve faster drawing speeds.

The speed of these devices is directly related to the complexity of the drawing. Color pen plotters use each color pen serially, which greatly increases draw time. Writing alphanumeric characters is also very time-consuming with throughputs of 3 characters per second typical. Axial line (along the X or Y axis) drawing speeds of over 30 inches/sec are possible.

The advantages of pen plotters are that they can accommodate a wide range of copy sizes, produce better quality in line drawing applications (since drawing is in continuous strokes vice dot matrix technique), and are relatively inexpensive for the average application. Disadvantages are the slow copy rate, limited color options, and poor quality in producing images with high color content or fill areas.

These devices are most appropriate for applications involving drafting, simple business graphics, line drawings, or large copy sizes. A wide variety of pen plotters is available in prices ranging from $1K to $100K.

3.2 NON-IMPACT DEVICES

Non-impact devices utilize printing techniques in which there is no physical contact between paper and print mechanism. Non-impact printing methods include:

a. ink jet
b. thermal
c. electrostatic
d. laser.

By the very nature of their design, non-impact devices are more quiet and better suited for the office environment. They characteristically operate much faster than impact devices since they tend to be less mechanical, and in many cases print in a line vice character format. Character printers produce data one character at a time in serial fashion. A good example of this is the manner in which a standard typewriter prints. In contrast, line printers generate a total line, or portions of a total line of data, all at one time. Obviously, this results in much greater data throughput when compared with character printing.

3.2.1 Ink Jet

Ink jet technology is enjoying a revival in recent years. The early ink jet printers produced about 30 years ago employed a "continuous stream" technique. Statically charged ink droplets were emitted from a nozzle and deflected to "write" in a manner comparable to the operation of a stroke writer CRT. These types are no longer produced. They were highly unreliable due to clogging and frequent maintenance required of the jets. Subsequent ink jet applications were mostly in areas outside of Automatic Data Processing (ADP) such as product manufacturing and labeling.

Current systems use "drop on demand" technology in which drops of ink are individually projected onto a printing surface under the control of electrical pulses. Usually, the print head moves across the page as tiny ink drops are ejected by the compression action of piezoelectric crystals that surround the ink in each jet.

Color systems usually contain the three primary colors of ink (magenta, yellow, cyan) with some also supplying a separate black ink. The color of each pixel is obtained by mixing ink drops on the page to produce any of seven solid colors. These devices also generate multi-dot patterns to achieve levels of shading. Most ink jet products today are capable of 125 useable color shades, although common standards for defining color shades do not exist. One product data sheet claims 4913 shades.

Reliability of the early "continuous stream" devices was a real problem. However, reliability of current products has increased dramatically over early models with figures such as 3900 hour mean-time-between-failure (MTBF) (100% duty cycle) with 6000 hour MTBF (50% duty cycle) being the norm.

Resolutions offered in most ink jet devices, expressed as the number of ink dots per inch (dpi), range from 85 to 154 in both the horizontal and vertical directions, although several top of the line units are capable of over 200 dpi.

Again, many factors come into play when attempting to quantify a unit's print speed. Most ink jet devices today can generate an image of medium resolution on 8 1/2-x 11-inch paper in about 90 seconds. All colors are usually applied during a single pass of the print mechanism. Therefore, the color density of the image being drawn usually is not a factor in print speed. The only variable in print speed is related to the amount of actual image area over the entire copy area. For example, some ink jet devices are designed with an "image seeking" feature. During generation of an image, this feature causes acceleration of the print head in areas of the copy where no data is present.

The cost of ink jet printers is falling to below $10.0K per unit, with one manufacturer offering a unit for $5.5K.

Advantages of ink jet devices include good image quality on paper or transparencies, low noise, and low cost. Factors such as moderate copy rate and moderate resolution may or may not be considered disadvantages, depending on the intended application.

3.2.2 Thermal

Until recently, thermal printer operation was based on the chemical reaction of special heat sensitive paper when exposed to the heated elements of a thermal print head. Copy quality was poor due to characteristics of the paper. Besides its high cost, paper would become opaque if not stored properly and copy usually began fading with time.

Today, the thermal process is referred to as "thermal transfer." It does not depend on heat sensitive papers. Basically, printing is achieved by "melting" ink pigments off an ink sheet or ribbon onto plain paper. Low end thermal heads may be dot matrix types having 5 x 7 or 7 x 11 array elements, while high end units may consist of one or two rows of closely spaced styli extending horizontally across the total width of the page. Individual head elements are heated at appropriate times to result in ink dots being deposited on the paper. Either the head or paper is moved such that the entire page is scanned. Printers of this type are sometimes referred to as "raster scan" since image composition is based on individual dots much like pixels of a video image.

Multicolored ink sheets or ribbons have just recently been utilized in the printer's design to achieve color performance. Resolutions as high as 400 dpi are currently available in off-the-shelf thermal transfer devices, although the average is 100 to 200 dpi. Generally, print speeds for this type device are characterized as the rate at which the paper is receiving the processed image, in inches per second. The average print speed of a thermal transfer device is 1 to 2 inches per second. Therefore, a black-and-white image on 8 1/2- x 11-inch paper can typically be produced in 10 to 15 seconds. Color printers that require a separate scan and paper rewind cycle for each color, average 1 minute per copy. The price of color thermal transfer hardcopy devices averages $10K-$15K.

Advantages of thermal printers include very good image quality on paper or transparencies, high resolution, relatively fast copy time, and low noise. The only apparent disadvantage is that thermal printers are a bit more costly to buy and operate. Efforts are ongoing to develop less costly color ribbons.

3.2.3 Electrostatic

Electrostatic printing is a process where minute static electrical charges are deposited on a paper surface and then exposed to liquid toner to create hard copy. The printing head is typically one or more rows of closely spaced styli or writing nibs that extend horizontally across the width of the paper or other medium. The individually controlled styli generate electrostatic charges that are transferred to the medium in a raster scan manner. Paper is then exposed to a liquid toner where suspended carbon particles are attracted to the point charges. A final fusion process assures adherence of toner to paper.

A wide variety of electrostatic products are being marketed today for use in numerous printing and plotting applications. Paper widths from 8 1/2 to 72 inches are accommodated.

Color electrostatic printing has just been introduced. Here, paper is scanned more than once with a different colored toner being applied after each scan. The only known color unit in production as of this writing is a 42-inch-wide color plotter. It is expected that desktop electrostatic color printers will be available shortly.

As with thermal transfer devices utilizing heads of closely spaced styli, resolutions of 400 dpi are available in off-the-shelf products, although the majority fall in the 100 to 200 dpi range. Here again, print speeds are normally specified as the rate at which the paper is receiving the processed image, in inches per second. Typically, figures range from 1 to over 3 inches per second, resulting in color images in about 60 to 90 seconds.

Electrostatic printer advantages are fast copy speed, very good image quality, high resolution, low noise, and a wide choice of paper widths. Disadvantages include the fact that the average electrostatic printer is a bit more costly than other printer types. Also, the number of producers offering electrostatic units is limited, with marketing directed primarily toward drafting operations.

Prices for these devices range from $1K-$100K, reflecting the diverse product options available.

3.2.4 Laser

Laser printers employ electrophotographic imaging and xerographic printing technology to achieve very fast print speeds. Compared to other hardcopy devices, laser printers are generally differentiated in the areas of speed (fast), size (large), and cost (expensive). Advancements in the thermal and electrostatic technologies, however, are narrowing the gap in print speed. The primary application of laser printers has been as a high speed computer output device. Vendors are now attempting to offer smaller units aimed at applications such as typography, graphic arts, CAD, and office automation.

The key element in a typical laser printer is the drum that is coated with photoconductive chemicals. The printing process usually begins by uniformly charging the drum with a large DC voltage. The laser subsequently scans the surface of the drum in a raster scan manner, selectively discharging areas of the drum corresponding to image elements. The drum then turns through a developer where slightly charged metal particles in the carbon toner are attracted to the discharged areas of the drum. At the transfer station, the toner particles are rolled onto paper. The fusion station then applies heat and pressure to bond the toner to paper, yielding the final image. A bright light is used to discharge the photosensitive drum, following each image production.

Resolutions of 240 to 300 dpi are typical in laser printers, with print speeds averaging 5 to 6 seconds per page. At the time of this writing, there are no known laser devices offering color performance. This may be the result of economic or marketing considerations as opposed to any technical limitations. With the advent of color electrostatic printing and color reproduction devices that use xerographic printing techniques, color laser printing certainly is feasible.

Advantages of laser printers include fast copy rates, good image quality, good resolution, and low noise. Disadvantages are the higher initial cost (typically, over $20.0K although slower, lower cost desktop units are available), and the fact that color laser printers are not available as yet.

3.2.5 Other Technologies

One new technology, which is rivaling laser printers in terms of speed and reliability, is the "ion deposition" printer. Similiar to laser printing, ion deposition involves high voltage coronas and an ion pool cartridge to deposit charged particles on an anodized aluminum drum. An ion printer, with resolution in the 240 dpi range, can print at a typical rate of 1 page per second. These devices are just now being produced, and, like laser printers, do not offer color performance at this time.

Probably one of the fastest printing devices today is the electron beam recorder (EBR). An EBR converts electrical signals into images on electron sensitive film. The device is analogous to a CRT except that the lens and phosphor are replaced by the recording medium. However, even though actual draw speed is virtually instantaneous, the recording media must undergo subsequent processing using chemicals, heat, or toners. Therefore, overall response speed to a finished image may take much longer than by other means.

3.3 SECTION 3 SUMMARY

In summary, there exist two major categories of hardcopy devices, namely, impact and non-impact types. Of the impact type, only dot matrix and pen plotter devices are capable of producing color graphic hard copy; however, both possess major limitations. In the category of non-impact types, the ink jet, thermal, and electrostatic devices all produce quality, color, hardcopy images.

In terms of print speed, the current state-of-the-art device is capable of producing a color image in approximately one minute. Factors that must be considered in any evaluation of print speed include image complexity, color density, copy size, and resolution offered (in dots per inch). The maximum resolution available in state-of-the-art hardcopy devices is 400 dpi.

Table 5 summarizes and compares salient characteristics of all types of hardcopy devices discussed in section 3.

TABLE 5. CHARACTERISTICS OF GRAPHIC HARD COPY DEVICES

CATEGORY	TYPE	COST	SPEED	IMAGE QUALITY	COMMENTS
Impact	Ball, wheel, drum	Inex-pensive	N/A	N/A	No graphics capability.
	Dot Matrix	Inex-pensive	Very slow	Fair	Noisy print-ing process.
	Pen Plotter	Wide range	Slow	See comment	Appropriate for line drawings, not typical images.
Non-Impact	Ink Jet	Inexp.-mod	Medium	Very good (Up to 200 dpi)	Quite a few prod-ucers making ink jet devices. Good cost/performance balance.
	Ther-mal	Mod.	Med.-fast	Very good (Up to 400 dpi)	Several producers.
	Electro-static	Wide range	Med.-fast	Very good (Up to 400 dpi)	No desktop color units currently available. Several producers.
	Laser	Mod.-Expensive	Fast	Very good (200-300 dpi)	No color units currently produced.

KEY: N/A = NOT APPLICABLE

SECTION 4

VIDEO SIGNALS AND STANDARDS

This section on video signals and standards is applicable to all graphic display terminals, large screen displays, display monitors, and even home television systems, which are designed to operate by raster scan techniques. Video signals contain analog picture and scanning information, which drive the intensity of the CRT beam(s) as well as control the sweeping and retrace actions. This section will examine the structure and application of video signals and discuss standards that specify video interfaces.

4.1 VIDEO DEFINED

The video signal consists of five components, as follows:

a. Blanked Video Intensity
b. Horizontal Blanking
c. Horizontal Sync
d. Vertical Blanking
e. Vertical Sync.

The first component, Blanked Video Intensity, is that portion of the signal that contains the actual picture luminosity information. This signal controls the intensity of the electron beam as it scans horizontally across the display screen. The variations in amplitude of this signal correspond to variations in electron beam intensity and, therefore, control the brightness of the phosphor being excited. Following each sweep, the Horizontal Blanking signal effectively reduces the intensity of the electron beam to a level that produces no visible illumination of the phosphor on the display surface. The Horizontal Sync signal then retraces the beam to the start of the next scanning line. Upon reaching the bottom of the display screen, the Vertical Blanking and Vertical Sync signals likewise blank the beam and retrace it to the top of the screen where it will begin its next scanning cycle. Figure 4 correlates the physical manifestation of the video signal on a cathode ray tube with components of the video waveform, as illustrated in video standards RS-170/343 (discussed in subsequent paragraphs). A single signal, which contains all five components previously discussed, is referred to as a "Composite Picture Signal" or "Composite Video."

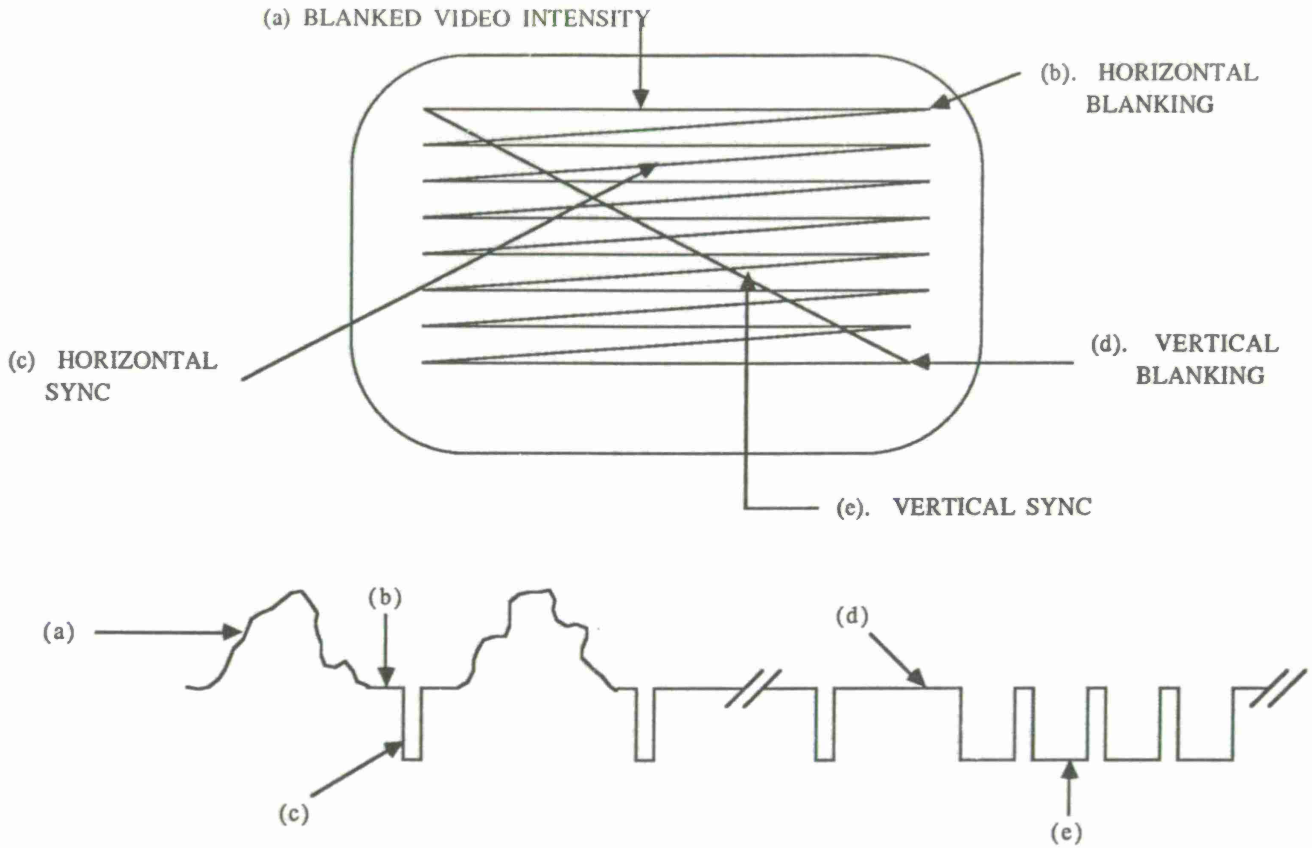


FIGURE 4. THE VIDEO WAVEFORM AND ITS IMPLEMENTATION

All raster scan displays operate basically as described previously, however, certain design factors affect performance and impose special requirements on the video signal. These factors are presented here:

a. Interlacing. As discussed in section 2, interlacing is the practice of dividing the image to be displayed into two or more fields. In recreating the picture, the electron beam alternately scans the odd numbered lines from top to bottom, then following vertical retrace, scans the field comprised of even numbered lines. Thus, in 2:1 interlacing, two scanning cycles are required to recreate the total picture image. Obviously, if the display employs interlacing, the video signal must be structured accordingly.

b. Aspect Ratio. This is a ratio of frame width to frame height, a frame being the total area occupied by the picture. The standard aspect ratios used in display devices are 4:3 and 1:1. Again, signal timing and bandwidth must accommodate aspect ratio, otherwise image distortion can result.

c. Vertical Resolution. Vertical resolution is related to the number of lines per frame. Standard television in the U.S. is based on 525 lines per frame. High resolution displays of over 1000 lines per frame are available today. Not all lines are used for picture scanning however. Active lines per frame equal total lines less lines occurring during vertical blanking and retrace. For example, a display of 1023 lines per frame would actually possess only 946 active scan lines. Vertical resolution is a measure of how many picture elements can be reproduced along a vertical line by a given number of horizontal scanning lines. In reality, it equals approximately 0.7 (Kell Factor) times the number of active lines. The Kell Factor is a multiplier that accounts for limitations in analog television, such as low bandwidth channels. Thus, the 1023 line display would convey a vertical resolution of about 650 lines per frame. (Note that vertical resolution as defined here by the Electronic Industries Association (EIA) differs from the way computer graphics manufacturers currently specify vertical resolution, as strictly a pixel count.) Video signal timing parameters directly translate into the number of scan lines that are possible during each refresh cycle.

4.2 VIDEO FORMATS AND STANDARDS

There are basically two ways to drive a video device. One is using a single coaxial cable that carries all picture, color, and sync information, commonly referred to as a Composite Video signal. The other, is using separate cables for the red, green, blue, and sometimes sync signals, commonly referred to as Red, Green, Blue (RGB). The characteristics of these two video formats, as well as the standards that apply to each, are discussed in the following sections.

4.2.1 Composite Video

As stated previously, composite video is the incorporation of all picture and sync information over a single coaxial cable. Standards (NTSC, EIA) for composite video are available for low resolution (525 scanning lines) monochrome or color pictures, or higher resolution (up to 1023 scanning lines) monochrome pictures only. The low resolution signals are commonly referred to as NTSC, meaning that they follow criteria as established by the National Television Systems Committee (NTSC).

The NTSC was established by the Radio, Electronic, and Television Manufacturer´s Association (RETMA) over thirty years ago. One of NTSC´s objectives was to develop guidelines or standards for television signal composition and broadcasting. NTSC methods for coding and broadcasting the video signal have become standard in the U.S., Canada, and Japan. The two other standard formats employed throughout the world are the Phase-Alteration Line (PAL) used by western Europe, Australia, and S. America, and Sequential Couleur Avec Memoire (SECAM) used by France, USSR, and Africa. The manner in which color information is coded within the video signal, as well as timing and other signal characteristics, differs among the three formats.

Some parametric values defining timing and structure of the NTSC waveform are specified in the Electronic Industries Association (EIA) standard RS-170 titled "Electrical Performance Standards-Monochrome TV Studio Facilities." RS-170 timing restrictions limit the video signal to approximately 525 horizontal scan lines per field. As discussed earlier, a display having 525 lines per field would in reality produce vertical resolution in the order of 330 lines. Today, this is considered a fairly low resolution display. A new standard, RS-170A, is being developed by EIA, which will address color performance. At this time, however, EIA cannot project a date when the new standard may be adopted. A portion of it, "Color Television Studio Picture Line Amplifier Output Drawing," has been released in the interim. The drawing incorporates a burst color reference subcarrier signal into the video waveform. The phase of the reference subcarrier is used to extract color information from the video signal. Timing parameters cited, however, still limit applicability to lower resolution displays.

Another characteristic of the NTSC signal is its bandwidth utilization. The analog NTSC video signal is designed to occupy a 6 MHz television channel. Within the bandwidth are contained the luminance and chrominance signals. The luminance conveys the intensity information for the composite color signals; the chrominance defines the color information. Human optical limitations have been taken into account in the implementation of the NTSC signal in order to compress the color signal into the available 6 MHz bandwidth. For example, for very small areas of picture information requiring maximum visual acuity, the eye sees brightness variations only and not color. The NTSC approach is, therefore, to reproduce these areas in monochrome only. As such, color resolution is not comparable to that possible in the higher bandwidth, high performance graphic display terminals, where color content of each pixel can be fully exploited.

To summarize, when the video signal is specified as being NTSC, the following signal or display characteristics apply:

a. Composite video, single coax
b. 525 scanning lines per frame
c. Low signal bandwidth (6 MHz)
d. Monochrome or color
e. 2:1 interlacing
f. Field rate (refresh) of 60 Hz
g. RS-170/170A signal timing.

Composite video signals, which drive higher resolution displays of greater than 525 scanning lines/frame, are governed by EIA Standard RS-343-A titled "Electrical Performance Standards for High Resolution Monochrome Closed Circuit Television Camera." This standard is written to encompass equipment that operates in the range from 675 to 1023 scanning lines with a field rate of 60 Hz, interlaced 2:1. With the greater resolution comes greater bandwidth requirements. For example, close to 30 MHz of bandwidth is needed to transmit a high resolution picture of over 1000 lines, with 60 Hz refresh and 2:1 interlacing. RS-343-A contains all system parameters associated with the high resolution video signals.

Therefore, to summarize, when the low or high resolution video signal is specified as being "composite" it is understood that:

a. sync and picture information are combined on a single coax
b. the field rate is 60 Hz
c. 2:1 interlacing is employed.

In addition, the following characteristics also apply to composite video:

	Low Resolution (NTSC)	High Resolution
Scanning lines/frame	525	675-1023
Monochrome or color	Both	Monochrome only
EIA Standard	RS-170/170A	RS-343-A
Signal Bandwidth	Less than 6 MHz	6 to 30 MHz

4.2.2 RGB

Red, Green, Blue (RGB) is the second type of video interface commonly used. As the name implies, RGB signals drive color displays where video information for each primary color is carried on separate coaxial cables. The reason for utilizing separate signals for each color component is that RGB is normally employed in higher resolution displays where higher frequencies can be more effectively transmitted and processed as separate color signals.

The structure and timing of the video waveform on each of the RGB cables is normally in accordance with specifications found in EIA standard RS-343-A titled "Electrical Performance Standards for High Resolution Monochrome Closed Circuit Television Camera." Again, this standard is intended to encompass equipment operating in the range from 675 to 1023 scanning lines, with a field rate of 60 Hz, interlaced 2:1. Notice that the standard applies to monochrome signals only. RS-343-A is adapted to RGB by treating each of the three color signals as a monochrome signal whose timing parameters correspond to those of RS-343-A. In this adaptation, another factor to consider is how sync information should be integrated with picture information. The signal waveform illustrated in RS-343-A is a composite video signal consisting of all intensity, blanking, and sync components. It is not necessary to transmit sync information on each RGB cable since the same sync signal applies to all three signal components. However, since no standard exists on the implementation of high resolution color composite video signals, many options exist for the systems designer. These options, all used commonly today, include:

a. separate sync (a fourth cable dedicated only for sync signals)
b. sync on green (combining sync information with the green component to achieve a true composite signal on that cable only)
c. composite sync (an ambiguous term meaning sync is combined with one or more color components).

It should be noted that although RGB is normally associated with RS-343-A, due to its applicability to higher resolution displays, it is also possible to design an RGB interface whose signal parameters are in accordance with portions of RS-170. Signal timing constraints of RS-170, however, would limit applicability to low resolution displays.

To summarize, when the video signal is specified as being RGB, the following signal or display characteristics "normally" apply:

a. 3 or 4 separate coaxial cables carrying picture and sync information
b. medium to high resolution image
c. higher signal bandwidths
d. color
e. RS-343-A timing specifications.

4.3 SECTION 4 SUMMARY

In section 4, video signals were defined and their composition examined. The signals combine blanking and synchronization components to control the movement and intensity of electron beams within a cathode ray tube.

The video signal may be implemented in two ways, namely, in composite or RGB format. The composite signal is appropriate for low resolution monochrome or color signals and high resolution monochrome signals. The RGB format is appropriate for low and high resolution color signals. EIA standards RS-170 and 170A govern timing and other parameters of the low resolution composite video waveform. EIA standard RS-343-A governs timing and other parameters of high resolution composite or RGB video waveforms.

Table 6 summarizes the characteristics of each signal type and identifies the standards that apply to each.

TABLE 6. VIDEO SIGNALS AND STANDARDS

	LOW RESOLUTION (525 LINES OR LESS)	HIGH RESOLUTION (MORE THAN 525 LINES)
BLACK & WHITE OR MONO-CHROME	COMPOSITE VIDEO (NTSC) RS-170 BANDWIDTH: 6 MHz	COMPOSITE VIDEO RS-343-A BANDWIDTH: 6-30 MHz
COLOR	COMPOSITE VIDEO (NTSC) RS-170-A BANDWIDTH: 6 MHz OR RGB RS-170	RGB RS-343-A BANDWIDTH: 6-30 MHz per RGB color component

SECTION 5

SUMMARY

Graphics equipment today offers a wide range of capabilities to satisfy the needs of a diverse and growing population of graphic users. Hardware has advanced to the point where the focus is now on integrating the right capabilities for a given application, not on whether the capabilities exist. Future advances in the graphics industry will center around standardization of graphic software interfaces (to enhance portability and device independence), and tailored workstation design (to achieve more powerful and efficient performance, particularly for real-time interactive applications). Also, it is expected that more graphic software functions will be implemented in firmware.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADP	Automated Data Processing
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Interchange
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
COTS	Commercial Off-the-Shelf
CRT	Cathode Ray Tube
DEC	Digital Equipment Corporation
DECNET	Digital Equipment Corporation Network
DMA	Direct Memory Access
DNA	Digital Network Architecture
dpi	Dots per inch
EBR	Electron Beam Recorder
EIA	Electronic Industries Association
GKS	Graphical Kernel System
GPIB	General Purpose Interface Bus
Hz	Hertz
I/O	Input/Output
LAN	Local Area Network
LCD	Liquid Crystal Display
LED	Light Emitting Diode
MHz	Megahertz
MTBF	Mean Time Between Failure
NTSC	National Television Systems Committee
PAL	Phase-Alteration Line
PIXEL	Picture Element
RAM	Random Access Memory
RETMA	Radio, Electronic and Television Manufacturers Association
RGB	Red, Green, Blue
SCSI	Small Computer Systems Interface
SECAM	Sequential Couleur Avec Memoire
SNA	Synchronous Network Architecture
VDI	Virtual Device Interface
VLSI	Very Large Scale Integrated circuit