Communications Research Centre

A REVIEW OF VISUAL DISPLAYS FOR COMPUTER OUTPUT

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EXECUTIVE SUMMARY

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The Image Communications group in DGTS/DTE has undertaken research and development into a network interactive graphics communication system that uses narrowband transmission lines, and one of the prime considerations for an effective operational system is the method of outputting or displaying the graphic information. Technology has provided some traditional methods of graphic display and has pointed the way to many newer innovative techniques.

As part of the overall development of an image communication system an assessment must be made as to which types of display techniques are viable, and which display methods have potential, so that any present software development would not be rendered obsolete by future hardware developments. For this type of image technology assessment the Image Communications group has proposed to set up a laboratory to compare the various output media. However, a more immediate requirement was the consideration of the display technique to be used in a demonstration of the image communication system.

This Technical Note reviews both the traditional and possible future technologies of computer graphics displays and discusses the required attributes of a hardware device. This review is a first step in display device assessment and will be followed by reports on output media evaluation to be carried out in the Image Technology laboratory.

This document has a limited distribution outside of DOC to those agencies and workers in this field who are working on a cooperative basis with DTE and have similar objectives in this research.

SOMMAIRE À L'INTENTION DE LA DIRECTION

N° DU DOCUMENT: Note technique du CRC n° 677

TITRE: Examen des moyens de visualisation pour sortie d'ordinateur

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Le Groupe des communications graphiques du DGTS/DTE a entrepris des travaux de recherche et développement en matière de système interactif de communications graphiques de réseau utilisant des lignes de transmission à bande étroite; le mode de sortie ou d'affichage des informations graphiques constitue l'un des principaux aspects de cette recherche dont il faut tenir compte afin d'obtenir un système opérationnel efficace. La technologie a fourni quelques méthodes classiques en matière d'affichage graphique en plus de préparer la voie à de nombreuses techniques nouvelles et innovatrices.

Dans le cadre du développement global d'un système de communications graphiques, il convient de déterminer d'avance quelles sont les techniques d'affichage viables et les méthodes d'affichage possibles, afin que le logiciel créé aujourd'hui ne soit pas rendu désuet dans un proche avenir par la mise au point d'équipements incompatibles. C'est donc dans ce but que le Groupe des communications graphiques a proposé l'établissement d'un laboratorie pour comparer les divers moyens de sortie. Cependant, il était plus urgent d'examiner la technique d'affichage à utiliser, au moyen d'une démonstration du système de communications graphiques.

La présente note technique du CRC passe en revue les technologies classiques et celles qu'il sera à l'avenir possible d'utiliser en matière d'affichage de graphiques d'ordinateur, et examine les qualités que les équipements doivent posséder. Il s'agit là d'une première étape en matière d'évaluation d'un dispositif d'affichage, qui sera suivie par des rapports sur l'évaluation des moyens de sortie qu'effectuera le laboratoire de technologie graphique.

La distribution du présent document à l'extérieur du MDC est restreinte aux organismes et personnes qui travaillent en coopération avec le DTE dans ce domaine, et qui ont des objectifs semblables en matière de recherche.

COMMUNICATIONS RESEARCH CENTRE

DEPARTMENT OF COMMUNICATIONS

CANADA

A REVIEW OF VISUAL DISPLAYS FOR COMPUTER OUTPUT

by

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(Technology and Systems Research and Development Branch)

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TABLE OF CONTENTS

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ABSTRACT

A descriptive technical comparison of the various types of cathode ray tube devices suitable for visual displays for computer output is made. The plasma panel is considered as a possible potential replacement for the CRT. Recent innovative developments are also described and some specific examples are given. Features such as shading and tone rendition, color, feedback and scrolling are discussed in some detail. Criteria for the selection of a particular type of display device are also assessed.

1. INTRODUCTION

It was inevitable that a display device should be part of a computer installation because most complex data outputs from a computer are better understood if presented in some form of graphical or pictorial format. As the cathode ray tube (CRT) oscilloscope was usually present near computers from the time of the earliest installations, it is understandable that the CRT became the first visual display device. Since then it has met most display requirements because, in general, it is found to be functional, reliable, economical, versatile, bright and efficient. Storage or memory, and color are also available. Increased use of a visual display as an interface between man and computer requires a display particularly suited to a specific application. This requirement may vary from one that calls for a flat panel device capable of displaying a large variety of graphic symbols in bright ambient viewing conditions to another that only displays a small number of alphanumeric characters. However, because the device must interface with man, it must remain a convenient size.

To fulfil the variety of requirements the trend in displays has been to exploit new technologies to develop new devices and improve existing ones. A prime motivation has been to decrease cost, decrease the bulk of associated electronics, make devices more reliable and lower their power consumption. Advances in integrated circuitry have provided the greatest impetus to these requirements.

This report describes briefly the existing and future technologies that can be adapted for graphical output. Desirable features of a visual output device, with particular reference to interactive displays, are also listed. The future potential of various devices is summarized at the end of this report.

2. CATHODE RAY TUBE

The CRT is a device that can generate pictures from electrical signals. Its operation depends on the fact that electric and magnetic fields affect the path of electrons and that certain materials phosphoresce when bombarded by electrons. With acceleration and proper focusing an electron beam can be made to define a fine point on the CRT screen. If the beam were made to deflect then a visible trace indicating the path of the electrons across the screen would be presented.

As shown in the simplified diagram of Figure 1, the basic components of a CRT are:

1. a cathode which emits electrons,
2. a control grid which controls the rate and direction of electron emission,
3. accelerating anodes which produce a high velocity beam,
4. a focusing system which concentrates the electron beam to a fine spot on the screen,
5. a deflection system (magnetic or electrostatic) which positions the beam on the screen, and
6. a phosphor coating on the screen which glows when the beam strikes it.

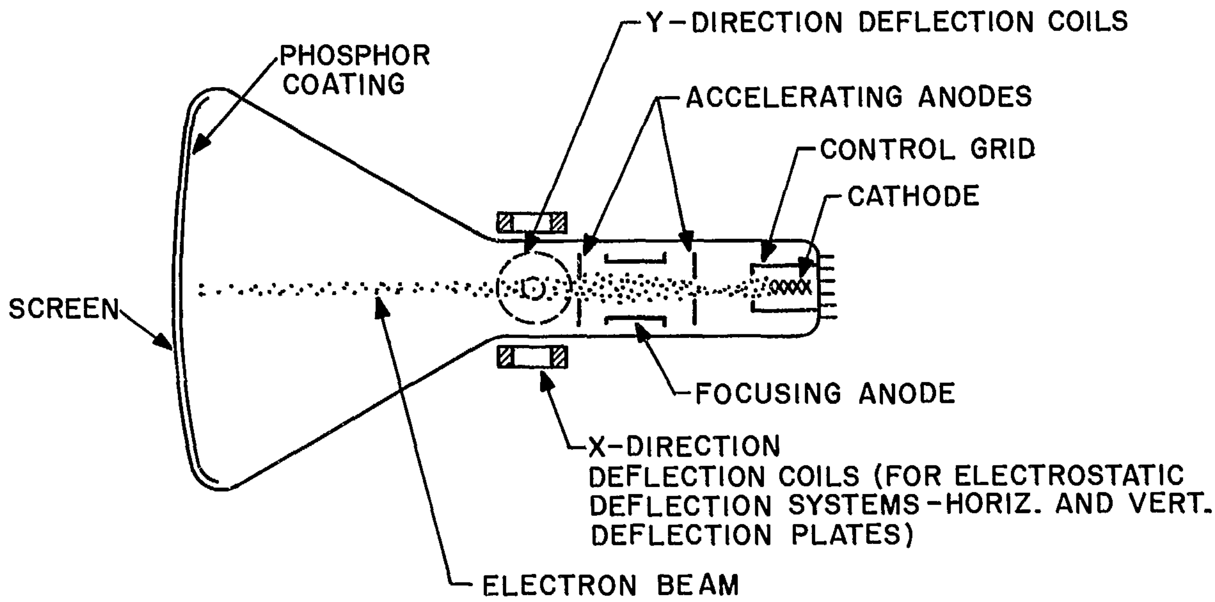

Figure 1. Cathode Ray Tube

2.1 RANDOM SCAN

The organized movement of the electron beam on the CRT can be made to trace out the individual lines and characters that make up a display picture, where the coordinate specifications stored in a computer are used to provide positioning information to the deflection system of the CRT. The display screen can be thought of as a hypothetical grid of points that make up a coordinate system. Characters, special symbols and lines can be built up out of individual intensified points although lines would not be continuous and would be built up much slower than displays equipped with vector generation hardware. To produce smooth lines some modern displays used analog function generators that deflect the electron beam in a continuous fashion from one end of the line to the other. Characters can be built up from a series of strokes. Some display systems include other hardware facilities for producing curves. In all cases it is desirable that the tracing be smooth, and that all items of the display appear with the same brightness; lines or vectors should be straight with the intensity uniform and independent of the length and slope. Thus the beam should move at a constant rate and compensated changes in the rate should be reflected in an accurate adjustment of the electron beam current.

The amount of information that can be displayed is primarily affected by the rate at which the display control electronics can generate the display elements. This depends on whether the CRT operates in a point plotting mode or a vector writing mode, and on the time it takes for a beam to jump from the position of the last element to the start point of another. Typically, the human eye can detect flicker at approximately 40 to 50 frames a second. Persistence of the screen phosphor is the prime determining factor; longer persistence phosphors enable a greater amount of flicker-free items to be displayed, however, they retain "after-images" as the displayed picture changes. The brightness of the display and background light also have an effect on the flicker rate.

The wide range in the quantity of vectors and characters that can be displayed flicker-free is indicated in Table 1 for a number of graphics systems. In general, a graphics system becomes more expensive as the quantity of flicker-free display material increases.

TABLE 1

*Typical Display Capacities of Some Graphics Systems***

System	Characters	Inches of Long Vectors
Communications Research Center Graphics*	900	450
Digital Equipment Corporation GT40	950	1,150
Digital Equipment Corporation PDP15 Graphics	1,700	4,600
Evans and Sutherland Picture System	1,500	13,000
Vector General Vectorgraphics 11	3,500	15,500

Quantities have been normalized to a display rate of 40 frames/second. There will be a flicker-free display whenever the screen is filled up to the maximum number of either characters or vectors. Display will also be flicker-free for any appropriate combination of both items.

* *Based on a DEC PDP9 computer, and magnetic drum buffer and an ITT cathode ray tube.*

** *Data for typical performance obtained from manufacturers' literature; current in 1974.*

2.2 RASTER SCAN

Because the TV monitor is very common and relatively inexpensive, some graphics systems have been designed to use it as an output device. Raster scanning does provide pictures covering a range of tones, shades and color that is not equalled by random scan CRT's.

In a raster display the screen representation is a succession of horizontal lines traced out in a fixed sequence. Individual points on the screen are the result of modulating the intensity of the beam trace. Unlike random scan displays, a raster scan display requires a description of each point on the screen. As is the case with television, flicker is reduced by displaying two successive rasters, each generating alternate lines.

Conversion of line and text information from the computer into a form suitable for raster display can be done through a technique called scan conversion. The basis of one such method (by Princeton Electronics Products (PEP)) is a small diameter tube (about 1 inch) with conventional electron beam focusing supplemented by a mesh electrode close to a silicon dioxide coated target (Figure 2). At a potential of about 200 V this target retains a charge when struck by an electron beam. The variable charges stored at each target point can provide for tonal rendition. This charge pattern can be read by lowering the target potential (to about 10V) and scanning it with the electron beam in a raster fashion. The fluctuating current generated at the target can be amplified and used to drive a TV monitor. Each time the target is scanned there is some deterioration of the picture quality because the deposited charge pattern is slowly drained away. Drawing of new information can be performed during the time of vertical retrace. It is possible to vary the field of view of the scanning process and thus provide for dynamic scaling.

A raster display can be driven directly from stored digital information but the data storage requirement is very large. Recently, ELLYARD and MACLEOD (1974) have demonstrated a system for refreshing a 512 x 512 TV image with 16 levels of gray scale; it uses two 32K word memory banks. Alternatively, the data could also be stored in analog form. In whichever format data is stored it is difficult to change selectively. For example, the information that would represent a line on the display screen would not be stored in consecutive memory locations but would be scattered around in memory.

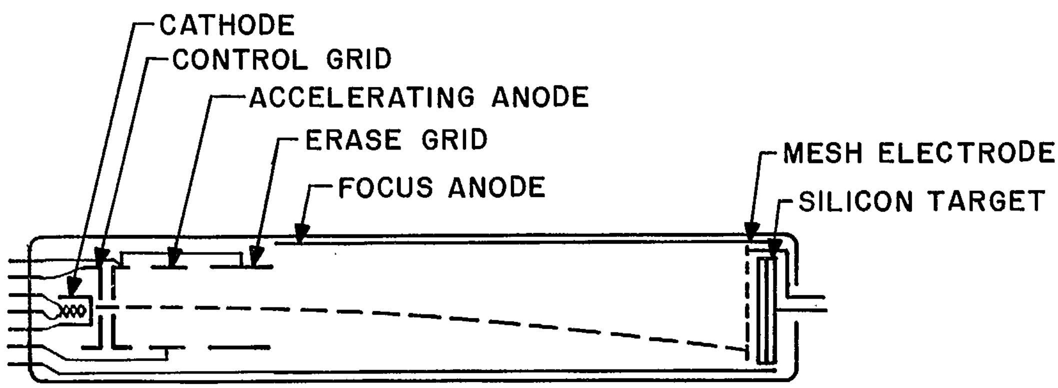

Figure 2. Schematic of a Silicon Target Tube Used for Scan Conversion

2.3 STORAGE TUBE

To maintain a flicker-free display on a CRT the entire picture must be refreshed about 40 times per second. This requires that the data be stored in digital form, usually in a core memory. Fast logic is then required to convert the digital information to beam deflections on a random plotting CRT. An alternative is to store the video information on the face of the tube itself; this is the technique of the direct view storage tube (DVST).

Basically, in a direct view storage tube a writing beam is focused not directly onto the phosphor but on a fine mesh wire grid that is dielectric coated (Figure 3). A pattern of positive charge on a uniform negative background is left on this storage grid. At the same time a continuous low power flood of electrons is emitted by another cathode. This flow of electrons is made smooth by a second grid, the collector, just behind the storage grid. Positively charged parts of the storage grid attract the electrons, whereas, the background repels the rest. These attracted electrons pass right through the grid to the screen where they excite the phosphor. To create a brighter display the screen is maintained at a high potential by means of a voltage on a thin aluminum coating on the back.

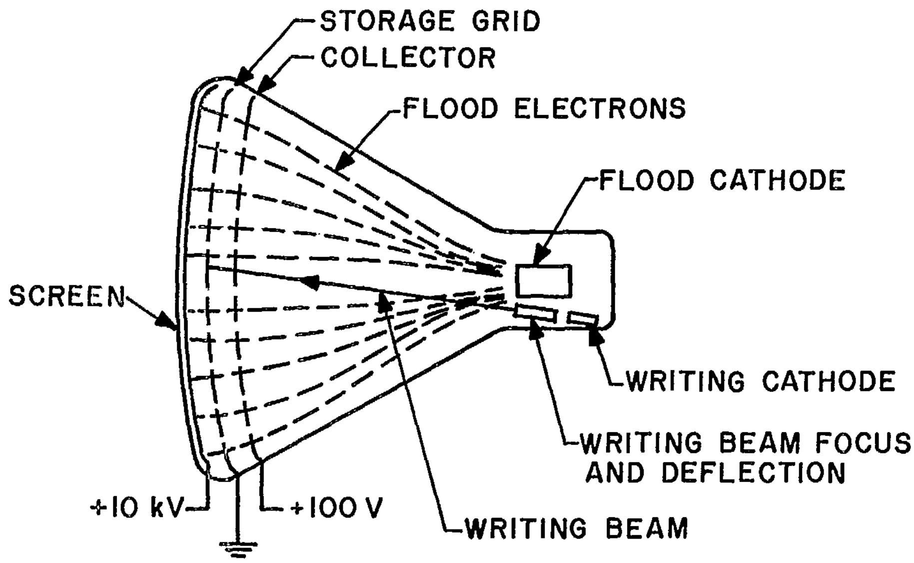

Figure 3. Schematic of a Direct View Storage Tube

The charge on the storage grid cannot be removed rapidly and thus, the written image can be retained for a very long time, an hour or so in most cases. In general, it is the build-up of background glow caused by the flood electrons charging the storage grid that deteriorates the picture and limits the maximum time for which an image can be retained. One consequence is an inferior gray scale capability compared to a raster CRT. The storing feature of the DVST makes selective erasure impossible, thus the writing of highly interactive graphics programs is also impossible. A usual method of erasing the entire display is to apply a positive pulse, lasting a half second or so, to the storage grid. However, this causes a somewhat distracting flash across the entire screen.

A feature of some storage tubes is the "write-through" ability that provides a non-storing mode which neither records new information nor erases old information. Here the writing beam is turned on weakly and, generally, must be kept in some motion. This provides the capability of displaying a screen marker that does not leave a trail of its movements.

2.4 FLAT PANEL CRT

A complete redesign of the conventional CRT geometry (as represented by Northrop Corporation's Digisplay) is under development. This flat panel CRT (GOEDE et al, 1971) has most of the attributes of a CRT except that a flat area electron source has been substituted for the usual point cathode (Figure 4). This device requires no long yoke assembly; it eliminates the need for beam deflection and digital-analog converters; it incorporates the features of digital address, simplified electronics and multibeam operation; and, resolution to 100 points/inch has been demonstrated. Its basic concept can be extended to provide color and reasonable gray scale rendition. At the present time, however, a working prototype of this flat panel CRT has been restricted to alphanumeric display.

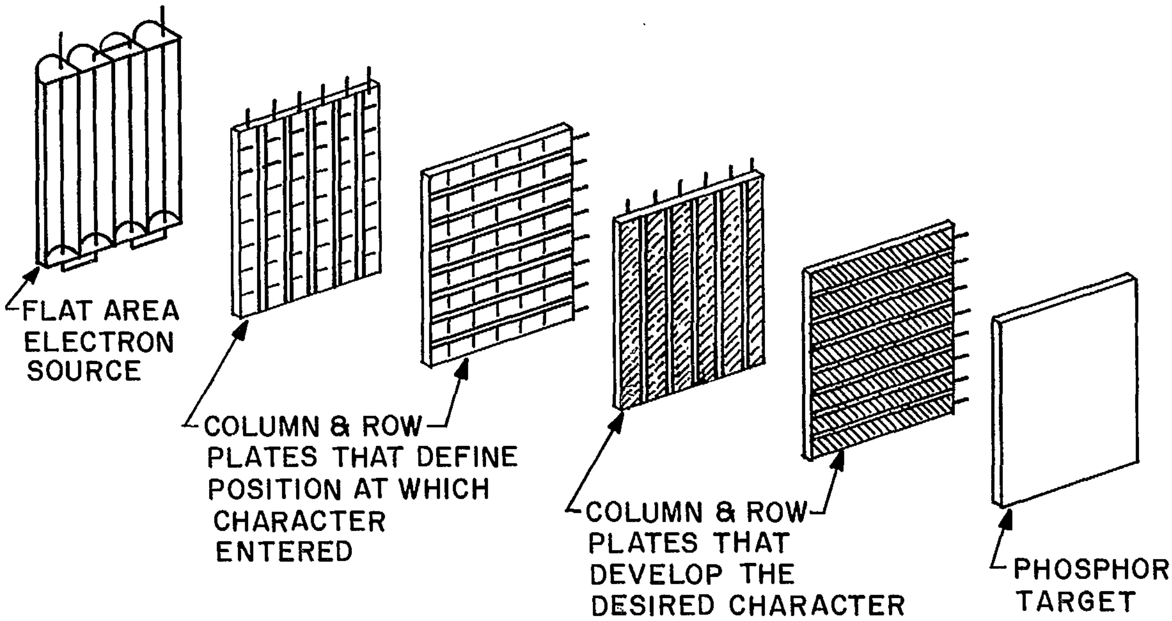

Figure 4. Exploded Schematic View of a Flat Panel CRT Display

3. PLASMA PANEL

The plasma panel has been designed as one alternative to the CRT but it still does not provide the same quality of display or high performance. Many design variations have been used, but typically the plasma panel's construction consists of two sheets of glass spaced a few thousandths of an inch apart with the enclosed space sealed and filled with a neon-based gas (Figure 5). Each sheet has thin, closely spaced, transparent electrodes attached to the inner face and covered with a thin dielectric material. The two sheets may contain up to 500 or more parallel electrodes and each set of electrodes is arranged orthogonal to the other.

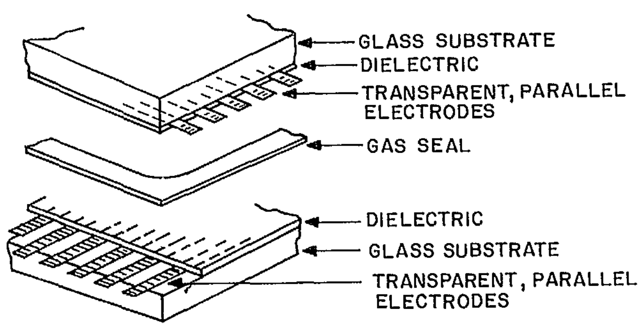

Figure 5. Exploded Schematic View of a Portion of a Plasma Panel

The gas within the panel can be considered to be made up of individual tiny cells at the point of electrode intersection, each one independent of its neighbors. Each cell can be made to glow by discharge whenever there is a high frequency alternating voltage of the correct amplitude in those two conductors that intersect at the desired cell. A voltage lower than the 'turn-on' potential is required to sustain the glow. Lowering the sustaining voltage causes the glow to cease. Thus a general sustaining voltage can be applied to all electrodes with the state of a particular cell determined by the change in potential at that intersection. With present technology only a single brightness level is available but various states at different intensities are possible and color display also appears feasible.

Selective writing and erasure is still relatively slow, approximately 20 microseconds per cell, i.e., about 5 seconds for a 500 x 500 element display. Parallel addressing techniques could increase the write and erase rates. A problem may occur during erasure when there is a sharing of points by different display items; if one item is erased, gaps may be left in those remaining. A solution for this is difficult except perhaps to store the individual elements of each item in a manner analogous to that in a random scan graphics display.

A shortcoming of the plasma panel is the requirement for substantial electronics to provide complex signals for control and for sustaining voltages of individual cells. The thickness of the panel is potentially an inch or so thick, but driving electronics mounted around its perimeter increases its thickness and also the side dimensions. The largest currently available panel is only 8½ inches square, but larger panels are under development.

The basic construction of the plasma panel makes it a potential replacement for the CRT in certain graphics applications. It presents a sharp image that does not deteriorate with time; it has a reliable selective erase mechanism; it has an inherent memory; and, it is compact. Media mixing with the panel is possible because of its transparent, flat surface.

4. OTHER OUTPUT DEVICES

4.1 CLASSIFICATION OF DEVICES

The major new developments in display technology have been in such devices as liquid crystals, light emitting diodes (LED), thin film electroluminescent displays, plasma panels, electrophoretic devices, and various projection light valve technologies. At present, most of the technological newer devices are very limited as to the type of display they can support. Much more development is required to make them useful as an interactive graphics display medium.

Basically all display devices can be catagorized as either light emitters or light controllers (Table 2). Light emitters are self-luminous such as a CRT, LED, plasma panel and electroluminescent films. Light controllers, or light valves as they are often called, modulate in transmission or reflection the viewing light provided by an external source such as a projection lamp, or just the ambient light. Examples of light controllers are various film displays, liquid crystal displays, cathodochromic tubes, various electrooptic systems, and the Ediphor TV system for theater projection.

TABLE 2

Catagorization of Display Devices

LIGHT EMITTER

BEAM ADDRESSED

ELECTRON

Cathode ray tube

LIGHT

Laser-scanned screen

MATRIX ADDRESSED

Flat panel CRT — Northrop Digisplay

Dc plasma panel — Burrough's Self-Scan

Ac plasma panel — Owens — Illinois Digivue

Electroluminescent film

Light emitting diodes (LED's)

LIGHT CONTROLLER/LIGHT VALVE

BEAM ADDRESSED

ELECTRON

Electrooptic birefringent light valve — Philips Titus tube

Storage and project display device — Lumatron

Cathodochromic dark trace tube

Oil film diffractive light valve — Eidophor, Toshiba

LIGHT

Film systems — bismuth film; Dylux; Kalvar; dry silver

Electrooptic medium with photoconductive layer — Phototitus
— PLZT ceramic

MATRIX ADDRESSED

Liquid crystals

Electrophoretic suspensions

For output devices an important distinction can be made as to whether they can be beam addressed or matrix addressed. In beam addressed displays each element of the display is addressed sequentially and the element is excited only during the address time. This technique is used for the larger and higher resolution displays of which the electron beam scanned CRT is an example. Beam addressing works well with those display media that require no threshold and respond quickly and linearly to brief excitations without saturation. Electron beam addressing of light valve devices is still in the exploratory stages and further improvements as to speed and reliability are needed. Use of a laser beam to scan across a screen or a responsive device has also been demonstrated but at the present time this technique is expensive and inefficient.

One could conceivably have a separate connection to each element of a display in order to address it. Clearly, this method becomes uneconomical and cumbersome for displays with a large number of elements. An alternative is matrix addressing. In this technique there is an arrangement of two sets of mutually orthogonal conductors (such as discussed in Section 3) and any one element is excited by a signal to its corresponding row and column conductors. This technique is useful for devices that require threshold voltages for excitation, i.e., a fixed potential at which a picture element changes state.

4.2 DESCRIPTION OF DISPLAY TYPE

The catagorization of the types of displays as listed in Table 2 has been summarized from an article by GORDON and ANDERSON (1973). Since diverse technologies are involved, a brief explanation of each follows. Of related importance to a description of each device is its characteristics, i.e., resolution, currently available size and potential for the future. These parameters are listed in Table 3.

4.2.1 Laser-Scanned Screen

The technique of using acoustic deflection and modulation of laser light to scan across a screen has been demonstrated (KORPEL et al, 1966). However, the required power of $\sim 1 W/m^2$ of screen area cannot be achieved cheaply and efficiently enough at present. A more promising concept is to use lasers in a beam addressing mode to create an image on a light valve device.

4.2.2 Electroluminescence and Light Emitting Diodes

Electroluminescence is the nonthermal generation of light by the application of an emf directly to a material. Dc electroluminescent devices operate in a resistive mode, whereas, ac devices operate in a capacitive mode.

Light emitting diodes (LED's) are injection electroluminescent devices which rely on band-to-band recombination as results at a p-n junction of a semiconductor (BERGH and DEAN, 1972). The application of a potential at the junction in a forward direction causes a recombination of the injected and majority carriers with the emission of light (Figure 6). LED materials are primarily used for segmented numeric displays although large LED panel arrays are possible; the latter are not economically justifiable at the present time.

TABLE 3

Characteristics of Display Devices

Device	Resolution	Size	Potential for Future
Cathode ray tube	50–100 points/in	~30" max dia	Improved resolution, reliability, driving electronics.
Flat panel CRT	50 points/in	2.5" x 2.5"	Expect 100 points/in. & up to 12 x 12". Large power consumption.
Dc plasma panel	1.5 mm	256 5 x 7 char	Alphanumeric but potential for TV display.
Ac plasma panel	33 points/in	8 1/2" x 8 1/2"	60 points/in at 8 1/2 x 8 1/2" size demonstrated.
Electroluminescent film	20 points/in	6" x 6"	Westinghouse. Expensive & complicated to manufacture. Potential for long life, low power, color, gray scale. 100 points/in feasible. 5 x 7 character size. Complex interconnection. Cost per element is high.
Electrooptic light valve	500 lines/in on device target. Projected–750 elements/line	~2" x 2" target	Nonuniform decay time. Quality of crystal critical. Cooling required for crystal. Large screen projection.
Storage/projection	1800 lines/in	1.5" x 1.5"	High resolution projection & storage potential.
Cathodochromic tube	2500 lines/in on device target	3" x 4"	Contrast ratio < 10:1 at 25 KV beam. Fatigue of material. Slow speed of writing.
Film systems	1400 lines/in to 2500 lines/in	~1 cm x 1 cm	Laser addressed. Very high resolution for projection. Bismuth film has limited gray scale.
Electrooptic/photo-conductive	1000 lines/in on device target. Projected -1500 elements/line	~2" x 2"	Large screen projection. Cooling of crystal.
Liquid crystal			Numeric displays current. Degradation with time, response time slow, expensive, complex circuitry.
Electrophoretic			Numerals demonstrated.

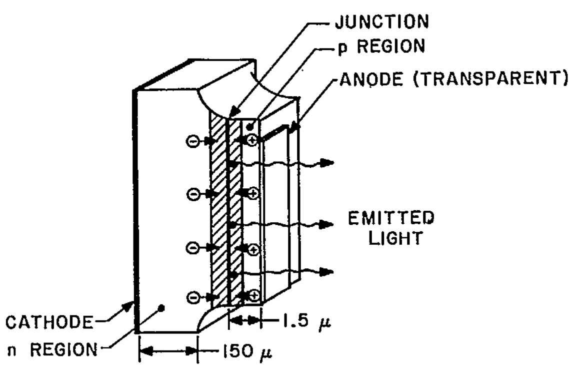

Figure 6. Light Emitting Diode

4.2.3 Electrooptic Birefringence

An electrooptic light valve works on the principle of electrically induced birefringence in the crystal target (SALVO, 1971). Birefringence is the double refraction or the splitting of a ray of incident light into two components which travel at different velocities. One example of a device utilizing this affect is the Titus tube (Figure 7). A video modulated electron beam from a type of CRT deposits charge on the target. An external polarized light source, that normally would be blocked from reaching the screen, illuminates the target and is modulated by the optical changes caused by the charge pattern on the target. With the aid of a suitable optical system the modulated light then can be projected onto a display screen. An erase capability can be incorporated by flooding the target surface with low energy electrons which charge it to the potential of the anode.

A somewhat similar but an optically addressed device called a Phototitus (MARIE and DONJON, 1973) employs a target made with a dielectric mirror, photoconductive layer and a second transparent electrode added to the crystal and electrode (Figure 8). Writing on the target is by projecting an image onto the photoconductor while a dc voltage is applied between the electrodes. The picture is then projected on a screen similar to the Titus tube. For erasure the photoconductor is flooded with light at the same time that the electrodes are short circuited.

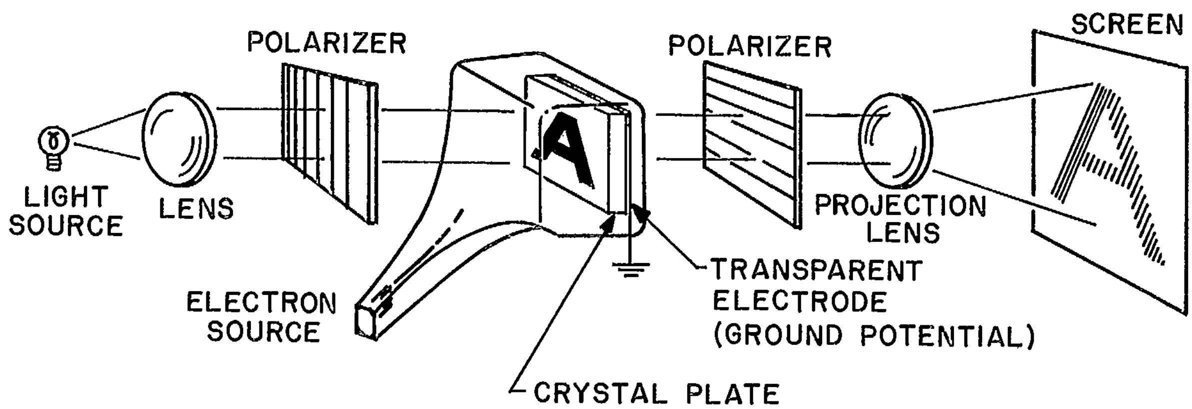

Figure 7. Projection Setup Using an Electrooptic Birefringent Light Valve

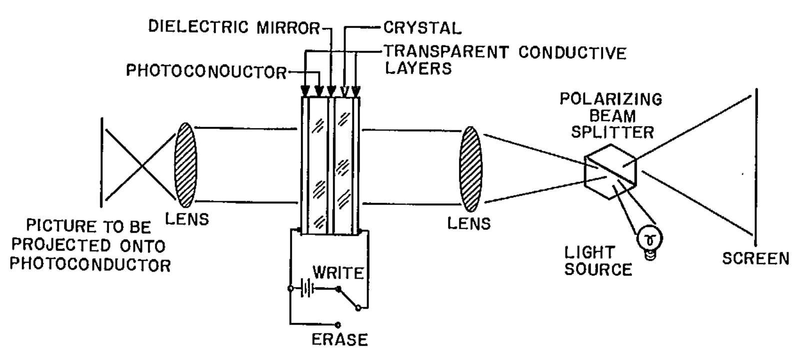

Figure 8. Phototitus — An Electrooptic Light Valve with a Photoconductive Layer

4.2.4 Storage and Projection Display Device

One such device, the Lumatron (DOYLE and GLENN, 1971), is a storage and projection display unit that separates the functions of light generation and modulation which are combined in a normal CRT or DVST. The modulation is achieved by creating a deformation pattern on a thermoplastic coated faceplate by an electrostatically focused and deflected electron beam (Figure 9). The configuration on the faceplate will determine the amount of light that will pass from a light source, coaxially located, through a schlieren optical system to the screen. Once an image is formed on the faceplate only a light source is required for display. To remove the image the faceplate is heated to an erase temperature to restore the surface to smoothness.

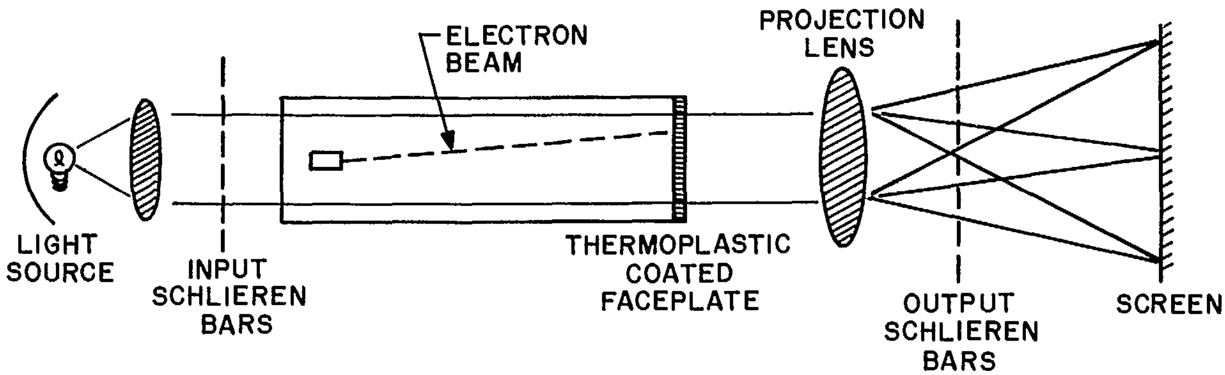

Figure 9. Lumatron in a Schlieren Optical System

4.2.5 Cathodochromic Tube

A display tube of this type is basically a CRT in which a cathodochromic material is substituted for the usual screen phosphor (FAUGHNAN et al, 1973). In this material an absorption band in the visible spectrum is generated by electron beam bombardment, and the gray tones thus obtained are reversible either by bleaching with light or by heating. A direct view storage display can be achieved by a change in the transmission and reflection properties of light striking the cathodochromic material.

4.2.6 Oil Film Diffractive Light Valves

A large screen projection system is exemplified by a Eidophor type system which uses an oil film diffraction technique. The Eidophor system consists of a schlieren lens placed between two sets of bar gratings which are positioned between a light source and a screen. Normally no light can pass through the system to the screen (Figure 10). The light valve placed between the gratings has one face coated with a transparent oil layer. The surface of the oil layer is deformed by an electron beam under the control of a video signal; the deformation refracts the light passing through the first grating and thus controls the light transmission through the second grating to the screen. A drawback of this system is the requirement for a large, dynamically pumped vacuum tube that contains the apparatus and the source of the electron beam.

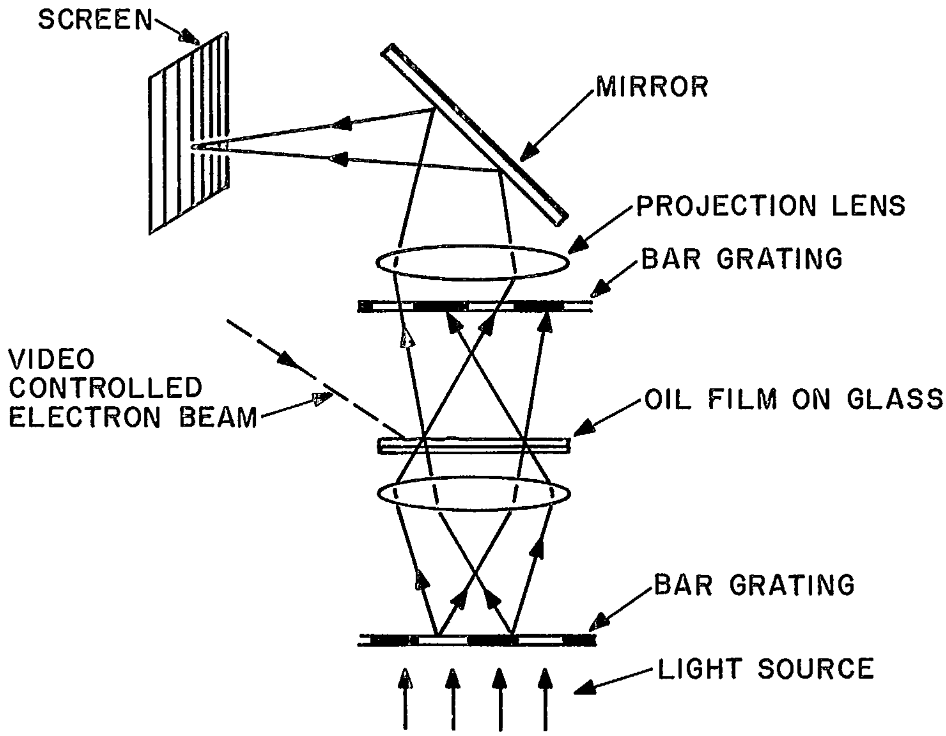

Figure 10. Schematic of Eidophor Projection System

Toshiba in Japan have developed a similar light valve system except that it employs a small sealed tube with no moving parts. Also, they use a design technique that eliminates direct electron bombardment of the oil film which otherwise would cause oil degradation. The design intent of the Toshiba system is to accommodate small group viewing.

4.2.7 Film Systems

It is possible to direct a spatially coherent laser beam to focus on a small spot of high intensity such that the beam can be scanned and modulated to record video information on various types of recording materials. Such a technique can be considered analogous to electron beam writing of a CRT screen. The information recorded on the material can now serve as a light addressed light valve where the image is projected on any size screen. Systems that use metallic films (bismuth) and Dylux require no development, whereas the Kalvar and dry silver systems require short thermal development before the image can be viewed. Except for the Dylux system, the images are permanent and the film may be used as hard copy.

4.2.8 Liquid Crystals

Liquid crystals are organic substances and certain classes of these crystals interact with electric, magnetic and ultrasonic fields to exhibit optic effects (CREAGH, 1973). As a display element a common arrangement is a transparent (nematic) liquid crystal layer up to 50 microns thick between two glass plates provided with transparent electrodes. The liquid crystal essentially becomes the dielectric of a parallel plate capacitor. When a potential is applied the liquid crystal becomes turbulent and loses its transparency through one of the electrooptic effects which depend on the alignment of the twisted rod-like molecules. Transmission displays are illuminated from the rear by a light source hidden from the viewer. The light scattered by the selected display elements then appears bright against a dark background. For some arrangements a reflective back electrode is used because an electrically active layer can scatter the incident ambient light which otherwise would be specularly reflected by the back electrode away from the observer. In a simple numeric display seven segment electrodes are used. By energizing some or all of the segments, numerals can be made visible.

4.2.9 Liquid Suspensions and Electrophoresis

Electrophoresis is the movement of charged pigment particles suspended in a liquid under the influence of an electric field (OTA et al, 1973). A dc voltage applied across a suspension layer of 25 to 100 microns changes the reflective color of the suspension as a result of electrophoretic migration of the particles. For numerical indication a segmented electrode arrangement can be used.

A somewhat similar phenomena is the suspension of submicron dipoles in a transparent fluid or plastic medium (MARKS, 1969). The random dipole orientation due to Brownian motion torque can be overcome by an electric field. This alignment of dipoles can cause a large change in the transmission, absorption and reflection properties of the light passing through the medium.

5. FEATURES OF OUTPUT DEVICES

5.1 SHADING AND TONE RENDITION

Realism of a visible surface of a displayed object can be enhanced with shading. This provides the visual effect of texture, shadows, specular reflection or reflection of scattered light. Many variables affect the shading algorithms, although quite adequate images can be displayed without considering many of the complicated parameters. Most of the shortcomings in the rendition of tones are of a software nature; existing algorithms are time consuming, inefficient and expensive.

For random scan CRT's the intensity of a point is proportional to the dwell time of the beam. This method is not compatible for raster scan displays which operate at a fixed scan rate. Here, the intensity of a point can be varied by changing the potential used to excite the screen phosphor. Response of phosphors is non-linear and the short dynamic range of most of them restricts the number of distinguishable intensity levels. As many as 256 levels of intensity may be required to provide all the nuances of shading for high quality monochrome images or effective color displays.

5.2 COLOR

Color can provide a realism unequaled by monochrome displays, particularly when dealing with tones or shades. Early color displays made use of the commercial shadow mask tube but this had drawbacks in brightness and resolution. Also, there is difficulty in keeping the electron optical system aligned and adjusted. Some of these difficulties have been overcome by the availability of a new color tube by Sony called a Trinitron (YOSHIDA et al, 1968). Unlike the conventional color tube with three independent electron guns, the Trinitron has a three beam single gun. This enables a common electron optical system for each beam. Instead of a shadow mask for defining the color spots, the Trinitron uses an aperture grill of vertical strips. Together, these improvements provide more brightness, a sharper picture and simplified adjustments.

Although the standard commercial color television monitor is available for use in graphics, some of the color displays use the newer single gun Penetron tube. It offers essentially the same resolution as the monochrome displays except at a somewhat higher cost, perhaps some $7,500 more. However, this tube does not have the brightness of commercial shadow mask CRT's.

A Penetron uses two or more layers of phosphor and each layer emits a different color over the range from red, through orange and yellow to green, when excited by the electron beam. Even blue light can be emitted but at a low brightness. By switching the anode potential, usually over a range from 6000 to 20000 volts, beam penetration depth can be controlled, and thus the resulting color of the CRT. There are difficulties associated with the requirement for high speed, high voltage switching of several thousand volts. Switching time is currently the order of 15 microseconds for each color. Precise color hue is not a prime requirement for a color display of vectors or text, hence switching between colors can be minimized by executing all the display items of each color in turn.

5.3 FEEDBACK

Input devices that are not pointed at the screen generally must rely on visual feedback to provide the operator with some response on the display. This technique can be considered equivalent to character echoing on the alphanumeric terminal. Depending on the type of function performed the feedback will be different. There are:

1. the "rubber band" line drawing technique where one endpoint of the line is fixed and the other follows the coordinate input device;

2. "inking" a free-hand curve by connecting with short vectors a collection of screen points as they are being generated; and,

3. "dragging" an object on a screen where repositioning is performed very rapidly until it is correctly positioned and then "fixed".

Feedback of the above types can be provided by refresh terminals only. For other terminals its total effect is difficult to achieve unless the graphical output process is modified. To perform these functions it is necessary to include in the display file instructions to be executed once every refresh cycle. This method, however, begins to interfere with the philosophy of device independence of a graphical system.

A simpler approach is to restrict the visual feedback to a display of crosshairs or a cursor. This limitation would be compatible with the use of storage tube displays, although the cursor would need to be displayed in a non-storing mode to prevent a large number of them from being written onto the stored image. Although this technique will limit interference with the output process, programmers may find this dynamic constraint too restrictive and would feel bound to devise more powerful presentations for specific applications. In this instance appropriate account can be taken of the types of terminal and graphics input available.

5.4 SCROLLING

A scrolling capability of a display allows for the addition of a new line to existing text by deleting the top line of text and raising up each succeeding line by one position. This technique is not difficult with a random scan CRT for scrolling can be achieved by merely rearranging a few pointers in the display processor. A similar operation can take place with raster scan CRT's. For direct view storage tubes scrolling necessitates the erasure and then the rewriting of every text line.

5.5 RESOLUTION

One criterion for choosing a particular type of display is whether the display will be viewed by one individual, a small group, or a large number of people. For the latter case projection techniques may be more suitable. A display parameter that is important is the resolution of the display, i.e., the total number of picture elements on the screen. Table 3 summarizes the present day limits of the various technologies. The resolution of most categories of displays is variable up to a certain limit. Raster displays utilizing the television monitor usually operate in a 512 x 512 format; some systems utilizes a 1024 x 1024 matrix. Random scan displays can present 4096 discrete points along each of the two orthogonal directions although the 10-inch 1024 x 1024 displays are the most common.

The useful resolution is not necessarily the number of addressable points which are available because the spot size on the screen may be larger than the distance between grid points. Typical spot diameter for a CRT is .010 to .020 inches and it is brightness dependent. A good criterion for spot size is for it to be $\sqrt{2}$ times the grid spacing measured at a contrast ratio of >25, typical of present day CRT's. The result is that adjacent spots on a diagonal line will just touch and appear to be a continuous line.

At present, resolution for flat panels is limited to 60 points/inch in each direction although 100 points/inch systems are under development. Resolution of LED displays is somewhat coarser; a density of 50 points/inch is about the best that has been demonstrated.

6. SUMMARY

All of the various devices described in this report have their own unique properties and graphic display potential but most have not progressed much beyond the experimental laboratory stage. Because some are prototype devices they are still restricted as to the size of the available viewing area. Even with such a wide diversity of display technologies under development, and more forthcoming, it does not appear that any of these new devices will economically replace the CRT in the near future (DOBRINER, 1972; JURGEN, 1974). A more probable occurrence is that flat panel devices with their advantage of less bulk will be improved to where they could conceivably replace the CRT in certain applications; before then, more development is required in the panel driving and addressing circuitry.

Nevertheless, further improvements are expected in the CRT itself. Factors such as display quality, information quantity and reliability are certain to be improved, and there will be an increasing trend towards the greater use of color displays.

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8. ABSTRACT:

A descriptive technical comparison of the various types of cathode ray tube devices suitable for visual displays for computer output is made. The plasma panel is considered as a possible potential replacement for the CRT. Recent innovative developments are also described and some specific examples are given. Features such as shading and tone rendition, color, feedback and scrolling are discussed in some detail. Criteria for the selection of a particular type of display device are also assessed.

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