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SUBJECT: Display Hardware Technology
 FROM: L. C. Hobbs

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1. Introduction

The ability to present dynamic real-time graphical data and associated alphanumeric characters and symbols, status information, and tabular alphanumeric data is required in displays for Naval Tactical Data Systems. Existing technology is adequate for console type displays, but new approaches to large-screen displays are necessary to meet shipboard operating conditions as well as performance requirements for a future Naval Tactical Data System. The operating conditions, maintainability and logistics requirements encountered in Navy shipboard equipment impose severe limitations on the use of presently available large-screen display techniques. Current cathode-ray-tube technology used in console displays, on the other hand, is satisfactory. The use of CRT console displays will probably continue into the 1970's although continuing improvements in performance characteristics can be anticipated. The mechanical and photographic aspects of film-based projection systems, which constitute the major large-screen display technique in use at this time, do not meet the requirements for mobility, ruggedness, reliability, and ease of maintenance. This is also true of other techniques, such as light valves and mechanical inscriber systems, currently used for large-screen displays. For this reason, most of the study of display hardware technology has been concentrated on new technology for large-screen displays capable of handling real-time data while meeting shipboard operating conditions.

The study of display hardware has concentrated on the major hardware problem facing future Naval Tactical Data Systems - whether technologies will be available for the mechanization of large-screen shipboard displays. The investigation has considered display technology rather than the actual design of display equipment. The basic technologies that can be used in console or large-screen displays have been analyzed, but little attention has been given to the details of how to put these technologies together in a specific piece of equipment. For example, a number of storage techniques discussed in the Memory section of this report are capable of providing storage required in certain types of display equipments, but the use of these techniques in console or large-screen displays is considered an equipment design function. On the other hand, for some display technologies, such as photochromics, the fact that storage capability is inherent in the media has been considered an advantage of this technology over other technologies, such as electro-luminescence, where either computer regeneration or external storage must be provided. Character generation techniques have not been analyzed in detail since a number of satisfactory electronic character generators are available and numerous comparisons have been made in the literature. Emphasis has been placed on basic display technology in this section - not on equipment design.

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Questions such as the kinds of operator functions to provide in a display, how to select the data to be displayed, the types of data to be displayed, and the format or organization of data to be displayed are not dependent upon the hardware technology. Questions of this type are covered by the subsequent discussion of "Displays - User Technology and Software".

The technologies that can be used for the mechanization of display logical components and storage are discussed in other sections on components and memories. This section on display hardware technology is concerned primarily with the media and technologies for achieving the presentation of data. This section considers the question of whether the technology in the present NTDS displays is inherently capable of being improved or replaced by advanced technologies, rather than whether the NTDS displays are satisfactory from the functional and use standpoint. Improvements in technology are possible and a number of advanced technologies applicable to a 1970 shipboard Tactical Data System are discussed and compared.

A number of techniques presently being investigated offer some promise of permitting the design and fabrication of non-mechanical, essentially solid-state, large-screen displays capable of dynamically displaying real-time graphical and alphanumeric data in a mobile, rugged, reliable, easily-maintained unit.

In the remainder of this section, the classification and uses of display technology and the requirements for different types of displays in future shipboard Naval Tactical Data Systems are discussed. Different display technologies are compared and related to Navy requirements. Particular emphasis is placed on the ability to fulfill shipboard operational requirements - environmental conditions, ruggedness, maintainability, reliability, and logistics. Technical descriptions of the major display technologies anticipated for large-screen displays in 1970 are given, conclusions are drawn, and recommendations for display development projects are made.

2. Classification and Functional Uses of Display Technology

Display technology can be classified in a number of different ways that are not mutually exclusive. Associated groupings of display technology will vary with the method of classification. Among the ways in which displays can be classified are:

- | | |
|-----------------------------------|--|
| 1) Functional | Console
Large-screen |
| 2) Nature of data to be presented | Status displays
Real-time or dynamic displays |
| 3) Type of data | Alphanumeric
Symbols
Graphical |

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- 4) Type of Mechanization
- Cathode ray tube - conventional or storage
 - Electroluminescent
 - Character lights
 - Photographic projection
 - Light-valve
 - Thermoplastic
 - Photoplastic
 - Mechanical inscriber
 - Photochromic
 - Electro-chemical
 - Opto-magnetic
 - Laser-luminescent

Displays could also be classified on the basis of factors such as persistence (e.g. self-storage or refreshing required) or ability to provide permanent records. However, these factors are used in later discussions as characteristics to be considered when comparing displays rather than as categories of displays. Other basis for classifying displays include operator functions, computer interface and software requirements, and whether intended for command or operational use. However, classifications of this type are not directly a function of the hardware technology and are more closely related to the user technology and software discussed in a subsequent section.

From a functional standpoint, requirements will exist for situation displays, tabular displays, and special displays that are fixed in format and under computer control. The functional uses of displays will include individual consoles, group displays, intercommunicating individual consoles, and hard copy display units.¹ From a hardware technology standpoint, these functional uses imply three basically different types of display equipments: console (individual users), large-screen (group display), and hard copy. Since present technology can meet requirements for console displays and hard copy displays, the time available for display investigations during this study has been concentrated on the significant problem area -- large-screen or group displays.

For the purposes of shipboard tactical data systems for the 1970 era, large-screen displays capable of presenting alphanumeric characters, symbols, and graphical data in real-time are considered the most critical requirement. This report will classify displays by the type of mechanization with particular emphasis on those techniques capable of meeting this type of requirement.

3. Requirements for Display Technology in a 1970 Naval Tactical Data System

The present Naval Tactical Data System uses real-time cathode-ray-tube console displays that are primarily operator oriented. Requirements for this type of display will continue to exist in future tactical data

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systems and can be handled by existing technology. Requirements will continue to exist for hard copy displays that can also be handled by existing technology.

The major requirement for significant improvements in display capability for a 1970 tactical data system lies in the need for non-mechanical, large-screen displays capable of providing rapid updating of real-time data. Large-screen displays will be needed that can present the same type of data presently handled by console displays and with essentially the same response times. These large-screen displays should also be capable of presenting status information in the form of charts and tables of alphanumeric data. Hence, a large-screen display is required that can present large volumes of rapidly changing real-time data (e.g. moving targets with symbols and alphanumeric characters associated with each target), historical data (e.g. target track history), and static alphanumeric and graphical data. The presentation of status information must be oriented to the commander and ships' officers rather than the operator.

In large-screen displays multi-color capability is desirable. This can be achieved by a number of techniques; but, unfortunately, the technologies that are well suited to multi-color displays (e.g. photographic film) are, in general, not desirable from the standpoint of performance and operational characteristics. Achieving multi-color with some of the more promising future large-screen technologies (e.g. electroluminescence, lasers, light valves, etc.) will require a considerable amount of additional hardware, will increase maintenance and logistics problems, and may impair reliability. As a result, for shipboard tactical data displays, it may be necessary to sacrifice multi-color capability in favor of simpler equipment, easier maintainability, simplified logistics, and higher reliability.

The requirements placed on display equipment in a shipboard tactical data system will differ significantly from those for fixed installation strategic military systems and commercial systems. This is particularly true with respect to operational requirements such as mobility, ruggedness, reliability, and maintainability. These operational requirements impose severe limitations on the use of many of the display equipments and technologies available today. The mechanical and photographic aspects of film-based projection systems, mechanical inscriber systems, and currently available light valves cannot meet these requirements. Although performance characteristics are important, the ability to meet these types of operational requirements are of overriding importance.

Displays for a shipboard tactical data system must have a long mean time between failure, must be capable of being repaired quickly, must not use large quantities of non-reuseable media, such as photographic film, and must be capable of operating under military shipboard

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environmental conditions. Typical characteristics desired for large-screen displays are:

Size	6 x 8 ft.
Brightness	20-25 ft-lamberts
Viewing Angle	$\pm 40^\circ$ at half brightness $\pm 60^\circ$ at one third brightness
Color	2 or 3 colors desirable, but may be sacrificed for size, cost, and maintainability
Linearity	0.2%
Rapid Update (Blink Time)	<1 sec.
Resolution (Optical)	2,400 optical lines (if photos or maps required)
Resolution (Digital)	512 to 2,048 positions in X and Y
Symbol Types	64 to 128 plus vector drawing capability
Symbol Generation Speed	20,000 to 100,000 symbols/sec.
Lumen Output	5,000 lumens
Contrast Ratio	50:1
Reliability	2,000 hrs. MTBF
Environmental	MIL-E-16400

The following comments amplify and explain some of the desirable characteristics listed in the table above:

Size: A 6' x 8' screen has the conventional 4:3 aspect ratio of TV and standard motion pictures. Up to 72 rows of one inch characters will be visible at distances up to 30 feet (one inch at 30 feet equals approximately 10 minutes of arc).

Brightness: 20 to 25 foot-lamberts approximates the brightness of a sheet of newsprint on a properly illuminated deck.

Viewing Angle: A viewing angle of 80° is the best that can be obtained (for half brightness) with a rear projection screen with a gain of one. Lower gain screens are undesirable because the combination of lower gain and higher reflectivity degrades the contrast.

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Color: Three colors plus white are desirable but two may suffice. The use of seven colors (three primaries plus the three complements plus white) is not recommended since blue is not easily legible, and yellow and white are confused. Recommended colors are cyano, yellow green, and orange red, plus white. However, it should be emphasized that the number of colors, and even the use of multi-colors, may be sacrificed to minimize the amount of equipment and hardware desired.

Linearity: It is possible to obtain 0.1% but the added benefits do not justify the costs. The figure of 0.2% is a good compromise between cost and image quality.

Resolution (Optical): 1200 TV lines will permit 80 lines of characters (at 15 lines/character). Since 600 optical lines correspond to 1200 TV lines, the 2,400 optical lines are more than enough for 80 lines of characters. However, if photos or maps are required on the same display, 2,400 optical lines are marginal. Screen width of 8 feet is approximately 100 inches; hence, there are 25 lines per inch on the screen. The eye can resolve 250 lines per inch at 10" distance; hence, at 100 inches (or 8 feet) lack of resolution will be apparent - i.e. 8 feet is the nearest viewing distance. To get 2,400 optical lines on a film with 60 1/mm resolution (typical of color film) requires a 40mm format. It can be done easily on a 70mm film chip.

Symbol Generation Speed: 80 lines of 100 characters requires 8000 characters per second. If the display must be refreshed at 48 cycles/second, (flicker threshold at 20 foot-lamberts), the characters per display must be multiplied by 48 to get the character rate. This gives 384,000 characters per second. Hence, a display that must be regenerated at flicker-free rates would require a higher symbol generation speed or would permit displaying fewer characters. However, for a display with inherent storage or for a regenerated display with graphical type drawings and fewer characters, the rates shown are sufficient.

Lumen Output and Contrast Ratio: 5,000 lumens will produce 100 foot candles on the 50 square foot screen (6' x 8'). With a screen gain of one, the initial brightness is 100 foot-lamberts. Using a 4x neutral density filter coating over the screen will cut this to the 25 foot-lamberts shown. The 4x filter, traversed twice, and the 50% reflectivity factor of the screen will produce a 32x attenuation of ambient light. Thus 16 foot candles of ambient light are permissible since

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the ratio of 25 foot-lamberts to 1/2 foot-lambert (reflected ambient) gives the 50:1 contrast ratio.

Reliability: Xenon lamps used in film-based systems have MTBF of 2,000 hours. Replacement time is 10-15 minutes. It is hoped that some of the new technologies will provide higher reliabilities and better maintainability (MTBF's in excess of 2,000 hours and MTR's less than 10 minutes), but these are minimum goals.

Some of the film-based projection systems under development representing the advanced state of that art can meet or exceed the performance type requirements listed above, but fall short with respect to reliability, maintainability, and environmental conditions. For satisfactory large-screen displays in naval tactical systems, it is necessary to develop display technologies that can also meet the performance requirements but with significant improvements in reliability, maintainability, and environmental conditions that are needed in mobile tactical applications.

Since the large-screen display will be in the same room as the CRT type console displays, a semi-darkened room is anticipated. Several promising large-screen display techniques offer sufficient brightness and contrast for use in this type of environment. The most promising candidates are electroluminescent, light valve, photochromic, and laser generated displays. These are discussed in greater detail in subsequent sections.

4. Comparison of Display Technology

In evaluating and comparing different display technologies, some of the major characteristics that should be considered are:

- Screen size
- Brightness
- Linearity
- Update time
- Resolution
- Character or symbol generation rate
- Contrast ratio
- Reliability
- Color capability and
- Environmental conditions.

The above parameters are important for both console and large-screen displays. Secondary characteristics that should be considered in the case of alternative approaches that are considered acceptable on the basis of the parameters above include:

- Storage and regeneration requirements
- Capacity
- Registration requirements
- Stability
- Physical space requirements
- Weight and power requirements.

Other characteristics of interest (e.g. legibility and image quality) result from some of the parameters listed above (e.g. resolution, registration, contrast, etc.).

In comparing or specifying brightness and contrast ratio, it is necessary to state them within the context of some assumed or specified ambient lighting conditions. For the purpose of the comparisons in this discussion, a semi-darkened environment, such as that necessary for direct viewing of cathode-ray-tube console images, is assumed. This is considered a reasonable assumption for large-screen displays in naval tactical environments since console displays will be used in the same application. Cathode-ray-tubes are expected to be employed in the majority of console type displays in the time frame under consideration. Stocker has also recommended equal readability for hard copy and self-luminous displays as a criteria for brightness and background illumination.²

For any specific application, the systems planner will give greater or lesser weight to particular parameters depending upon the requirements of the application. A systems planner may also need to consider some additional factors that are peculiar to his application. For example, in an airborne display, size, weight, and power become more critical parameters; in shipboard applications, a larger screen size is needed; and in some Marine mobile ground-based systems, portability and ease and speed of set-up are of significant importance.

DISPLAY TECHNOLOGY	CAPABILITY FOR 6x8' SCREEN SIZE	BRIGHTNESS (Ft-Lamberts)	UPDATE TIME (Sec.)	RELIABILITY	COLOR CAPABILITY	POSSIBILITY OF MEETING MIL-E 16400	FEASIBILITY	COMMENTS
Cathode Ray Tube	Poor	40	1/30	Good	Color tube can be used	Good	Readily available	Basic technology for consoles & for image generation in many large-screen systems; Not solid state; Requires vacuum & high voltages; Continued use through early 1970's expected
Mechanical Inscribing Systems	Very good	25	1 to 2	Poor	By use of filters & multiple projectors	Poor	Readily available at present	Permanent record; Flexible; Available; Electro-mechanical
Film Projection Systems	Very good	25	10 to 15	Poor	By use of filters & multiple projectors	Poor	Readily available at present	Permanent record; Flexible; Available; Electro-mechanical; High operational costs due to expending film & processing chemicals; Color film can be used but film and processing costs are even higher
Photo-chromic/CRT Display	Very good	20	<1	Good	By use of filters or different color photochromes but require multiple systems	Good	In prototype stage at present	Direct real-time CRT image generation but requires optical projection system; Material fatigue; Temperature sensitive

SUMMARY OF CHARACTERISTICS OF DISPLAY TECHNOLOGIES
TABLE I

DISPLAY TECHNOLOGY	CAPABILITY FOR 6x8' SCREEN SIZE	BRIGHTNESS (Ft-Lamberts)	UPDATE TIME (Sec.)	RELIABILITY	COLOR CAPABILITY	POSSIBILITY OF MEETING MIL-E 16400	FEASIBILITY	COMMENTS
Oil-Film Light Valves	Good	20	1/30	Poor	By use of filters & multiple systems	Poor	Available at present	TV scan type picture; Present systems require digital to video conversion; Continual vacuum pumping required; Oil contaminates cathode; High maintenance cost and low MTR (e.g. 20-200 hrs.)
Thermoplastic & Photoplastic Light Valves	Good	20	1/30	Good	By use of filters & multiple systems	Good	In prototype stage at present	Needs CRT for image generation and uses optical projection; TV scan type picture at present; Sealed vacuum
Solid State Light Valves	Good	Not available	Not available	Good	By use of filters & multiple systems	Good	Uncertain	CRT or laser needed to control device; Attractive if feasibility is proven
Electroluminescent Displays	Good	20	1/30	Good	Multiple-dot-color using different color phosphors	Good	By 1970	Requires development of cheap integrated storage inherent to display panel; Direct view; No CRT required; Matrix addressing

SUMMARY OF CHARACTERISTICS OF DISPLAY TECHNOLOGIES
TABLE I
Continued

<u>DISPLAY TECHNOLOGY</u>	<u>CAPABILITY FOR 6x8' SCREEN SIZE</u>	<u>BRIGHTNESS (Ft-Lamberts)</u>	<u>UPDATE TIME (Sec.)</u>	<u>RELIABILITY</u>	<u>COLOR CAPABILITY</u>	<u>POSSIBILITY OF MEETING MIL-E 16400</u>	<u>FEASIBILITY</u>	<u>COMMENTS</u>
Opto-Magnetic Displays	Unknown	Not available	Not available	Good	Color is a function of viewing angle	Unknown	Uncertain	Direct view reflective type display; Promising but feasibility is uncertain
Electro-Chemical Displays	Good	Not available	Slow	Good	Multiple-dot-color using different chemicals	Unknown	Uncertain	Direct view reflective type display; Matrix addressing; Interesting but feasibility by 1970 is unlikely
Laser Inscribing Systems	Good	25	41	Good	By use of filters & multiple projectors	Good	By 1970	Digital positioning; Non-mechanical, but requires optical projection; Promising and feasibility by 1970 anticipated
Laser/Luminescent (or Electro-luminescent) Displays	Good	Not available	Not available	Good	Unknown	Good	Uncertain	Digital positioning promising but feasibility is uncertain; Very attractive if proven feasible

SUMMARY OF CHARACTERISTICS OF DISPLAY TECHNOLOGIES
TABLE I
Continued

The major types of displays considered for use in a 1970 era system are compared in Table I. The values shown and the comments made in this Table are based on the technical discussions in Section 6. In viewing Table I, the comments about some of the parameters made in Section 3. (following the list of desirable characteristics) should be considered. In using the comparisons shown in Table I, it is important to remember that the selection of the appropriate display technology is not made on the basis of one or two characteristics but rather on the composite ability of the technology to best meet the needs and requirements of specific applications. It will be necessary to make compromises in some characteristics in order to accept a display that meets other essential requirements that are more important to the particular application. Just as it was noted previously that the relative importance of different characteristics will vary for different applications, it should also be noted that the choice of compromises is a function of the requirements of the particular application.

A decision as to whether to use a multi-color system in a large-screen display is an example of the compromises that must be made. The use of several colors in a display offers definite advantages in terms of the ability to distinguish different types of items (e.g., in a simple case, friendly and hostile ships or aircraft). Hence, from the user standpoint, a multi-color system is desirable. Although most of the technologies discussed are capable of providing multiple colors in one way or another, this usually involves a significantly greater amount of equipment and hardware and may magnify other problems, such as resolution or registration. The increased hardware also implies an increase in space and cost and may imply adverse effects on reliability and maintainability. Hence, the systems planner must balance the need for multi-color displays from the user standpoint against the penalties that may result in other performance characteristics, in cost and size, and in reliability and maintainability. This decision, of course, becomes even more significant if the requirement for multiple colors necessitates the use of a completely different technology than would be used otherwise.

A comparison of present state-of-the-art large-screen displays has been presented in an RADC report prepared by LaSalle.³ A table showing "Status and Features of Group Display Systems and Techniques" in that report is reproduced here as Table II.

The difficulty of establishing quantitative measures of display system effectiveness has been aptly stated by Loewe:

"A thorough understanding of display objectives and criteria is essential to good display system design. Unfortunately, there usually are no quantitative measures of effectiveness for display systems. In fact, it is often difficult to state clear-cut qualitative criteria.Lack of a single all-inclusive objective forces consideration of many display objectives and criteria." ⁴

<u>Class of Display</u>	<u>Status</u>	<u>Applications</u>	<u>Data Capacity</u>	<u>Response Speed</u>	<u>Permanent Record</u>	<u>Optical Quality</u>	<u>Cost Per Update</u>	<u>Remarks</u>
Projection Plotters	Off-the-Shelf	Plotting-Printing Non-Pictorial	Very High clutter-limited	5-20 Symbols per second	If Required	Exc.	50¢/slide	Multi-color
Rapid Process Film	Off-the-Shelf	General Purpose Command & Control	Very High clutter-limited	5-30 Seconds per update	Yes	Exc.	6¢-\$1.20 per frame	Multi-color
Oil Film Light Valve	Off-the-Shelf	General Purpose Dynamic	Up to 1000 TV lines	30 cps display speed	No	Very good	N/A	Multi-color
Projection Cathode Ray Tube	Off-the-Shelf	Low volume dynamic General Purpose	525 TV lines	30 cps display speed	No	Fair	N/A	
Electro-luminescent Matrix Display	In Research	Plotting-Printing Non-Pictorial	Very High	Very Fast Not Established	No	Should be Excellent	N/A	
Scanned Laser Beam Display	In Research	General Purpose	High Not Established	30 cps random or sequential writing	No	Should Be Excellent	N/A	
Reuseable Film Systems	In Research	General Purpose Non-Dynamic	Very High	Not established	If Required	Probably Exc.	Not Established Low	
Alpha Numeric Indicators	Off-the-Shelf	Status Boards limited to symbols	Determined by No. of Indicators	Very Fast for intended use	No	Usually Excellent	N/A	Initial Cost very high

STATUS AND FEATURES OF GROUP DISPLAY SYSTEMS AND TECHNIQUES
TABLE II

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In the referenced article, he identifies and discusses display system objectives and criteria, many of which are non-quantitative.

Table I indicates those technologies that are expected to be feasible for use in a 1970 system. However, some of the other technologies that are not expected to be feasible for an early 1970 system may develop sufficiently rapidly that they can be included in a system becoming operational during the later 1970's. These other technologies should be followed closely to permit their consideration for use in a later system if future developments indicate earlier feasibility or additional advantages. Other display technologies will probably be developed for use in the latter 1970's that are not envisioned at this time. Close attention should be given to the emergence of such new technologies. New laser techniques and applications may well fall in this category.

Finally, in any consideration of display technologies and selection of display media or techniques, display user technology and software considerations discussed later will play an important role. Since the display image is usually generated by a computer initially in a naval tactical system, consideration of hardware technologies cannot be divorced from the accompanying user functions and programming and computer interface techniques. For any selected hardware technology, the requirements of the user and of the computer will place differing requirements on the actual design of specific display equipments or subsystems using the technology. In the same way, the choice of different technologies will affect the requirements placed on the user and the computer.

5. Anticipated Capabilities vs. Navy Requirements

The capabilities of display technologies compared in Section 4. and discussed in Section 6. must be considered in terms of their ability to meet Navy requirements as discussed in Section 3.

In previous discussions, the adequacy and suitability of cathode-ray-tube technology for console type displays have been emphasized. Cathode-ray-tube technology with continuing evolutionary improvements is believed to be capable of meeting the requirements for console displays for naval tactical applications during the 1970's. Hence, there is no urgent requirement for the development of a different technology for console displays. On the other hand, if any of the new display technologies considered for large-screen displays also offer promise of meeting the requirements for console displays, these should be carefully investigated to determine whether they offer advantages over cathode-ray-tubes. Even though cathode-ray-tubes represent an established technology that is adequately meeting the needs of console type displays, other approaches should be considered if they provide equivalent performance and, at the same time, offer other advantages such as smaller size, higher reliability, all-solid state, or lower voltages.

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All of the more important and more feasible types of displays that may be applicable to naval tactical systems in the 1970 era have been analyzed, evaluated and compared. Particular emphasis has been placed on large-screen displays since they represent the major problem area due to the unsuitability of present electromechanical and photographic approaches with respect to the naval environment.

Since military tactics change and functional requirements are difficult to state explicitly, flexibility is an important factor in military display systems. Duffy and Smith have listed four major areas of concern from the standpoint of flexibility -- distribution of information, symbology and coding, format, and growth capability.⁵ Flexibility in such areas should be a strong consideration in planning display equipments and subsystems for naval tactical systems.

Table III presents estimated ratings for each type of display technology for console and large-screen display applications. The ratings shown represent the following categories rather than specific relative values:

1. Devices that will be feasible and that are recommended for serious consideration for use in 1970 naval tactical systems.
2. Devices whose feasibility by 1970 is questionable at this time but that may be feasible if sufficient emphasis is placed on them. Devices in this category are recommended for consideration for 1970 naval tactical systems if available and proven feasible.
3. Devices that will be obsoleted for mobile tactical use by newer technologies by 1970. These devices are not recommended for consideration.

This summary is based on the comparisons in Section 3. and on the technical discussions in Section 6. Fewer types are listed as candidates for console displays because of the difficulty of competing with cathode-ray-tubes. On the basis of these discussions and comparisons, the following are believed to be the most promising technologies for mechanizing large-screen displays in 1970 era naval tactical systems:

Photochromic/CRT displays
Thermoplastic and/or photoplastic light valves
Electroluminescent displays
Laser inscribing systems.

If subsequent developments indicate that they will be feasible and available, consideration should also be given to:

Solid-state light valves
Opto-magnetic displays
Electro-chemical displays
Laser/luminescent (or electroluminescent) displays.

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<u>DISPLAY TECHNOLOGY</u>	<u>CONSOLE DISPLAYS</u>	<u>LARGE-SCREEN DISPLAYS</u>	<u>RATING</u>
Cathode-Ray-Tube (Direct View)	X		1
Mechanical Inscribing Systems		X	3
Film Projection Systems		X	3
Photochromic/CRT Display		X	1
Oil-Film Light Valves		X	3
Thermoplastic and Photoplastic Light Valves		X	1
Solid State Light Valves		X	2
Electroluminescent Displays	X	X	1
Opto-Magnetic Displays		X	2
Electro-Chemical Displays		X	2
Laser Inscribing Systems		X	1
Laser/Luminescent (or Electroluminescent) Displays	X	X	2

NOTE: Numbers in rating column have the following meaning:

- (1) Recommended for consideration for 1970 naval tactical systems.
- (2) Feasibility by 1970 questionable, but should be considered if proven feasible.
- (3) Will be obsoleted by other technologies for naval tactical type applications by early 1970's and not recommended.

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It is difficult to decide whether laser/luminescent displays should be placed in the first or second category. This is a very promising technology, but its feasibility depends upon the development of adequate power lasers in the proper frequency range and the ability to deflect laser beams with high resolution cheaply. These will be developed, but it is not certain that this will occur by 1970.

For large-screen displays, cost, reliability, maintainability, and ability to meet naval environmental conditions are criteria of equal or greater importance than the ability to meet performance requirements. Unfortunately, most of the new technologies recommended for consideration in a 1970 system have not been developed far enough at this time to permit a determination of their relative advantages and disadvantages with respect to these characteristics. It will be necessary to follow these closely during the next year or two to determine whether indications arise that any one of them will be more or less suitable from the standpoint of cost, reliability, maintainability, and ability to meet environmental conditions.

The major need is for a new technology that can provide an all-solid-state large-screen display using batch-fabrication techniques. The development of suitable batch-fabrication techniques is a goal for display systems, but this is more difficult and is not considered as critical as in the case of memories and logic components. If a large-screen display technology suitable for batch-fabrication can be developed, serious consideration should be given to the use of the same technology in console displays as a future replacement for cathode-ray-tubes.

6. Technical Discussion of Display Techniques

Since a number of satisfactory techniques for console type displays are now available, no problem is anticipated with respect to the availability of console type displays for a 1970 system. Existing cathode-ray-tube technology and anticipated improvements in this technology should meet all requirements for small-screen console type displays, even if none of the new technologies prove to be superior.^{6,7} However, with respect to large-screen displays, the situation is much less favorable. In an RADC Technical Documentary Report⁸ published in 1962, the state-of-the-art and development efforts for large-screen displays were described as follows:

"Display developments are being undertaken in three major technological areas. These areas may be differentiated in terms of the basic processes being applied and on the basis of development time required to provide fully operational subsystems.

The first of these processes is based on projection and employs a stable light modulator, such as film or selenium plate, to provide the display. Operational subsystems of this sort are considered to be achievable within months.

The second process, the light valve, in theory should provide adequate performance for systems applications, and it has the dual advantages of operation at electronic speeds and of the elimination of expensive film. However, the performance potentials have not been realized in practice, and major technological improvements must be made before the light valve can be useful for most systems applications. The presently available models exhibit major weaknesses in their capability to provide high resolution and brightness.

This low brightness makes it impossible to use the light valve in the high-ambient lighting conditions of most of the systems. The interactions of the oil film and the lens systems are such that it is not possible to increase the display brightness level without major improvements in the characteristics of the modulation surface. Improvement, very likely, is contingent on the development of suitable thermoplastic materials. Light valve techniques show considerable promise, and with suitable development may eventually supersede film systems. However, it should be clearly recognized that full realization of the light valve's potential may require years of additional research.

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The third process, electroluminescence, does not require projection since the display surface itself acts both as light source and modulator. Only small laboratory devices for demonstration and experimentation are available at the present time. Electroluminescence is appealing in its apparent simplicity, its capability to eliminate projection, and its characteristic of non-catastrophic failure. In addition, there is a potential for full color operation at high brightness levels, and the large surface reduces the problems of obtaining high resolution. Unfortunately, there is an impressive number of technical obstacles that must be overcome before electroluminescent devices can meet the requirements of the systems. The most immediate problem is that of modulating the display surface, and a number of promising efforts are underway in this area at the present time. This effort is concurrent with others that are aimed at the development and application of new phosphors to obtain high brightness levels and multiple colors. However, even allowing for impressive technological improvements, years will be required to advance the capability of electroluminescent displays to the point where they can serve as dynamic large scale displays for system applications.

Desirable as these advanced displays are, most immediate requirements of Command and Control Systems can only be met by projection techniques using film or xerographic techniques for light modulation."

Unfortunately, developments during the past two years have not significantly altered the status described above, except that improved technologies, such as light valves and electroluminescent displays, are of course somewhat closer to practical realization now than they were in 1962. These will be discussed in greater detail later.

Photographic projection techniques are still the only feasible means available for meeting requirements for large-screen displays in Command and Control Systems. Significant progress has been made in light-valve type displays during the last two years, but the reliability and life of these devices makes questionable their use at this time in an operational system in which minimum down time is an important requirement. However, new and improved light-valve type devices offer great promise for a system to be operational in 1970.

Display techniques that have been developed or that appear promising for the future include individual character lights, cathode-ray-tubes, mechanical inscriber systems, film or photographic projection systems, light-valves, photochromic systems, electroluminescent devices, ferroelectric devices, opto-magnetic devices, electro-chemical and laser systems. Of the above techniques, it is believed that mechanical inscriber systems and photographic type film projection systems will be

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obsolete by 1970. Improved light-valves, electroluminescent panels, photochromic displays and, possibly, laser-luminescent displays appear very promising for that time period. Types of displays, systems considerations and the more promising display technologies that have been investigated are discussed briefly in the following parts of this section.

6.1 Types of Display

Several different methods of classifying displays were discussed in Sub-Section 2. It was pointed out that since this section on display hardware is concerned primarily with technologies available for mechanizing display equipments and systems, those methods of classification will be used that are directly related to technology. Other sections on display user-technology and programming are more properly concerned with classifications relating to the functions included in the equipment, the use for which the equipment is intended, user considerations, and programming and format considerations. There are four major types of displays in a category that directly affect the technologies involved:

- Individual character displays and indicators
- Consoles or individual user display
- Large-screen or group displays
- Hard copy displays.

These can further be subdivided by the technology involved and most of the subsequent parts of this discussion will be on that basis.

A number of techniques are currently available for the mechanization of individual character and indicator type displays. These are perhaps not ideal, but they are certainly adequate for present requirements; and normal evolutionary improvements and developments should permit these devices to meet the requirements imposed by 1970 systems without requiring new technologies or breakthroughs. Hence, these are discussed very briefly.

Console displays are presently mechanized satisfactorily with existing cathode-ray-tube technology. Improved console type displays are desired for future systems, but these improvements are basically a matter of engineering design and better determination of user functions and requirements. Some of the new technologies discussed for large-screen displays (e.g. electroluminescent matrix) may also be applicable to certain types of consoles, and these will be pointed out in subsequent discussions of different technologies. However, continued improvements and evolutionary developments in cathode-ray-tube technologies will permit console displays meeting all of the requirements of a 1970 shipboard tactical data system without the necessity for new technologies or breakthroughs.

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The same is true for hard copy displays - present techniques are in general satisfactory and adequate, but there is of course room for improvement and continuing improvements of an engineering nature are anticipated. Several types of hard copy displays are discussed as printers in the section on input/output.

Little time during the study has been devoted to these three types of displays since existing technology can meet present requirements, and it is anticipated that normal engineering improvements and evolutionary developments in existing techniques and technologies will meet the requirements for a 1970 system. Most of the effort during this study has been devoted to the type of display that presents the major problem from the standpoint of technology -- large-screen or group displays. That is not to say that this is the most important type of display. The console is probably the most important single type of display. However, large-screen displays present the major problems. This is the area in which presently-used systems and approaches are inadequate for real-time shipboard tactical data systems - the area in which new technologies are required to meet the requirements for a 1970 shipboard system.

It should be noted that cathode-ray-tube technology, which is the heart of most console displays, also plays an important role in many current and future large-screen display systems. For example, current photographic film projection displays depend upon cathode-ray-tube generation of the original image on the film.

6.2 Systems Considerations Affecting the Selection and Performance of Display Equipments and Technologies

A display system consists of more than a display media. For example, a typical large-screen film projection system may include:

- A buffer for storing data from the computer
- A symbol generator for converting coded characters into alphanumeric symbols
- An image generator for positioning the symbols and graphical information properly on the face of a cathode-ray-tube to expose the film
- Processing equipment for developing the film and possibly making copies
- Film handling mechanisms for transporting the slides or film strip to the projector at the proper time
- A projector including light source and optical system
- A screen
- Necessary controls.

Some of these are unique to film projection systems but some kind of character or symbol generator and a viewing screen are basic to most types of displays.

Symbol Generation

For almost all types of displays, it is necessary to convert coded information in computer language to shaped characters and symbols on the viewing screen. This operation, usually referred to as character or symbol generation, may be accomplished digitally (e.g. conversion from a 6 bit alphanumeric code to a 35 bit 5x7 dot matrix), or it may be accomplished by beam shaping (e.g. a Charactron tube). In a Charactron tube, the particular alphanumeric coded character causes a deflection of the beam to a particular aperture on a mask through which the beam is passed shaping it into the corresponding character.

Many types of character and symbol generators have been used, ^{See Fig 1.1} including dot matrix generators, stroke generators, raster scan generators, and the shaped beam referred to previously. Since these techniques are well established, it is not necessary to discuss them in detail here, but a table comparing character generation techniques published by Boyd is reproduced as Table IV.⁹ Similar techniques can be used for generating a larger complement of symbols including special military symbols as well as alpha-numeric characters.

Ambient Light Devices

Display devices are of two types: ambient light reflectors (e.g. hard copy or dial settings), and self-luminous (e.g. CRT or projection screens). Devices which have a built-in source of illumination purely to illuminate a reflective type surface (for example, aircraft instruments, or other conventional dial or meter type indicators) fall in the first category, since the purpose of the built-in illuminant is either to replace or supplement ambient lighting. Fluorescent marked dials or indicators do not fall into this category except that they are frequently used as combination ambient-light and darkness viewed devices, (again, as an example, in aircraft instruments.) The advantages of fluorescent indicators are two-fold, first, contrast is increased since the non-fluorescent areas reflect no visible light, and secondly, the illuminating ultra-violet light source, if shielded from direct view, will not affect dark adaptation. In this latter connection, it should be noted that where dark adaptation is important, "ambient-light" reflectors are built with their own self-contained illumination, whose color and intensity characteristics may be adjusted to suit the particular applications.

The important considerations here are the provision of adequate contrast (both color and brightness) and sufficient grossness of detail to provide legibility at the required viewing distance, and viewing angles. The latter requirement imposes the necessity for reducing parallax, and avoiding recessing and distorting glass or plastic housings.

Contrast for ambient light devices is controlled by adjusting the reflectivity of the information and background surfaces. If glass or plastic protective cover surfaces are required, these should be hooded or tilted to prevent distracting reflections from the front surface of

Generation Method	Character Storage	Resolution	Approximate Beam-Utilization Time(%)	Character Change-ability	Typical Character Writing Time (Microsec)
Dot, fixed matrix	Magnetic cores	5 x 7 dot matrix	25	Rewire cores	100
	Storage drum	5 x 7 dot matrix	25	Rewrite program	100
	Weighted resistors	5 x 7 dot matrix	25	Change resistors	200
Dot, quasivariable matrix	Diode matrix	16 dots (max) in 15 x 16 matrix	75	Relocate diodes	8.5
Dot, variable matrix	Weighted resistors	20 dots (max)	85	Change resistors	40
Stroke	Diode matrix	32 lines (max)	70	Rewire diodes	.4
	Diode matrix	16 strokes (max)	70	Rewire diodes	12
	Variable-density mask	-	80	Change mask	20
	Magnetic cores	20 lines (max)	70	Rewire cores	40
	Weighted transformer ratios	-	80	Rewire transformer	30
Raster	Monoscope	20 lines	25	Replace tube	100
	Monoscope	14 lines	25	Replace tube	30
	Core planes	20 lines	25	Rewire cores	20
	Shaped-beam mask	-	100	Replace tube	100

COMPARISON OF CHARACTER-GENERATOR TECHNIQUES
TABLE IV

high brightness or contrast. Since hooding or tilting the protective surface reduces the viewable angle, non-reflective coatings may also be required. Circular polarizing shields will be effective only in the control of specular reflections from the display surface; these are not present, in general, on ambient light devices, or may be eliminated by the application of high reflectivity diffusing paints of the required color.

A special type of "ambient-light" device is available in which the indicator surface (for example a spinning drum containing the characters to be viewed) is in continuous motion, and a flash lamp is synchronized to illuminate the surface at the proper rate. Since this device must be shielded from all extraneous light to avoid blurring of the information, it is more properly classified as a self-luminous device in a special category of its own. Another version of this type of device has the strobe lamp mounted inside an opaque drum with transparent (cutout) characters, and belongs properly in the group of self-luminous devices.

Projection System (Self-Luminous)

The amount of light reaching the projection screen is a function of a number of parameters, but for well designed optical systems certain rules-of-thumb are applicable. Several useful ones are:

- 1) A light valve TV system using a Xenon arc lamp has an output of between 0.7 and 1.5 lumen/watt.
- 2) A 35mm slide projector using an incandescent lamp has an output of between 1 and 2 lumens/watt.

These are typical figures only and the limits may be exceeded by exceptionally well designed or poorly adjusted equipments.

For a uniformly diffusing matte screen the screen brightness in foot-lamberts is equal to the luminous output of the projector divided by the screen area in square feet. For example, the screen brightness produced by a 2000W xenon light valve operating at an output of 1 lumen/watt on a 10 ft. square screen is 20 ft. lamberts. Both front and rear projection screens may appear either brighter or dimmer than a uniform diffuser depending on the nature of the screen and the line of view. The ratio of brightness is a maximum when the line of view extends directly back to the projector for a rear projection screen, or along the reflected ray from the projector for a front projection screen. This maximum value is referred to as the gain of the screen. Typical useful screen gains lie in the range of 0.5 to 2.0, although higher gain screens are used when the restricted viewing angles associated with them are not objectionable or are desirable.

The higher the screen gain the higher the contrast, in general, for both front and rear projection screens. This is true for rear projection screens since the reflection of ambient light from the front surface is low with high gain screens, and for front projection screens, the directivity of higher gain screens is such that off-axis ambient light is not directed into the viewing area. An additional degree of contrast control is available with rear projection screens in that a neutral density frontplate may be incorporated. If the (one way) transmission is $x\%$, the two way attenuation of reflected light is $x^2\%$. A 50% faceplate thus attenuates the projected beam by a factor of 2 and the undesirable ambient reflection by a factor of 4.

Brightness and Contrast

Measures and standards for some display system parameters, such as brightness and contrast ratio, are difficult to establish because of variations in viewing conditions and ambient light. Because of all of the variables introduced by the screen parameters and the ambient lighting conditions, it is not practicable to assign a brightness and contrast value to a projection system without defining the viewing conditions. It is for this reason that projection systems are best defined in terms of lumens output. Brightness in foot-lamberts for a unity gain screen is obtained by dividing by the screen area square feet. Contrast is obtained by multiplying the ambient light in foot candles by the screen reflectivity coefficient, and computing the ratio of "light" to "dark" values.

Typical values of brightness and contrast are given in Table V for several media as an indication of relative levels and variability. In Table V, note that pulsed EL Mosaic panels have brightnesses comparable with TV raster, or open gate theatre screens. If the contrast level shown for white-on-dark textual copy is increased, the legibility of fine detail degrades with increasing contrast if the eye is adapted to darker background level because of the dazzle effect.

TYPICAL BRIGHTNESSES - FOOT LAMBERTS

Surface of the Sun	4.8 x 10 ⁸
Surface of a 60W frosted incandescent bulb	36,000
Surface of a 60W "white" incandescent bulb	9,000
Surface of a 15W fluorescent tube	3,000
White paper in direct sunlight	9,000
Clear sky	2,000
Theatre screen open gate	16
Surface of the Moon, bright area	750
White paper on office desk	25
Pulsed EL Mosaic Panel	20
TV Raster on CRT	20
Light valve, 10' x 10' diffusing screen, 2KW Lamp	20

CONTRAST LEVELS

Textual copy (white-on-dark)	10:1
Line drawings and black-on-white text	25:1
Photographs	100:1

NOTE: Figures above were extracted from an unpublished technical manuscript prepared by Dr. H. R. Luxenberg.

TABLE V

Logistics, Maintainability, and Availability

Since some types of large-screen displays, such as silver-halide or Kalvar film-based projection systems use expendable material, logistics can become a serious problem for shipboard applications. Along with considerations of reliability and ruggedness, logistics constitutes one of the major arguments against this type of system for shipboard use. This problem concerns not only the film that is expended, but also the processing materials used in developing and processing the film. In addition to the amount and volume of material used, some of the processing chemicals are expensive and are sometimes of a critical nature.¹⁰ This is a particularly serious problem for silver-halide film, but it becomes much more severe if color film is used, since film costs, processing costs, processing material, and processing time are all increased.

The failure rate and maintainability directly affect the availability of the equipment for operational use. Cathode life in light valves (in the order of 25 to 100 hours at present) and light sources for projection systems (in the order of 25 hours for incandescent lamps and 1,000 hours for xenon lamps) both lead to frequent failures (low MTBF). A directly related consideration is that of mean-time to repair (MTR). Failures are particularly serious if they shut the system down for a significant length of time. Replacing some of these elements may require from several minutes to several hours. This is not satisfactory for shipboard applications where failures may occur during a rapidly moving situation, such as an anti-air operation. Specific reliability figures are difficult to obtain for display equipment, but failure rates are extremely high compared to those for the semiconductor logical components and the memory devices used in the central processor. Certainly, electro-mechanical systems, such as those used in the majority of large-screen displays at present, cannot meet shipboard requirements for high reliability, easy maintainability, and simple logistics.

6.3 Character Lights and Indicators

Status indicators or small displays consisting of a few digits or a few characters are needed for presenting limited amounts of data. Cathode-ray-tubes or other technologies discussed in subsequent portions of this section are not economic for this type of display because of the small size involved. However, it is sometimes feasible to group a number of display items of this type together in a small cathode-ray-tube display. Usually the cathode-ray-tube display in a console is supplemented by a number of small displays of this type, frequently referred to as read-out devices. The major types of read-out devices are:

- Rear projection
- Edge lighted
- Electro-luminescent
- Gas ionization
- Electro-mechanical

The use of devices of this type has an advantage over grouping a number of indicators together in a small cathode-ray-tube in that they can be distributed over the face of the console in positions that are more meaningful or easier to use from the operator's standpoint. A number of read-out devices have been described in a recent series of articles.¹¹

6.4 Cathode-Ray-Tubes

Cathode-ray-tubes, one of the earlier electronic display technologies, are used in almost all present console displays and as a component in many of the present large-screen display systems. Cathode-ray-tubes are so well established and so well known that their principles of operation will not be described here.

Cathode-ray-tubes are used in three basic ways in display systems:

- Direct viewing
- Projection
- Image generation for film systems.

The direct view cathode-ray-tube is used primarily in console type displays, but very large cathode-ray-tubes are being investigated for possible direct view large-screen applications.

Techniques for projecting cathode-ray-tube images onto a screen date back to the Schmidt optical systems of early television. A very high intensity tube capable of developing thousands of foot-lamberts of light at the tube face is required. As the image is enlarged and projected through an optical system onto the screen, only a few foot-lamberts (perhaps in the order of 5) are available on the viewing surface. This level is not sufficient for viewing under ambient light conditions in a shipboard data system environment.

The major use of cathode-ray-tube technology in large screen displays at present is in the generation of an image on the face of a cathode-ray-tube that can then be used to expose film (e.g. silver-halide, Kalvar, photochromic, etc.). After developing, the image on the film is projected onto the screen by means of a high-powered light source and an optical projection system, providing useable light levels on the screen under ambient light conditions.

Mrs. F. R. Darne of the U. S. Navy Bureau of Ships summarized the state-of-the-art for cathode-ray-tubes in the Spring of 1962.¹² This summary gives an excellent picture of cathode-ray-tube characteristics and capabilities and is reproduced here as Table VI .

Normal cathode-ray-tubes have phosphor coating on the inside face of the tube which emits light when excited by the electron beam. The persistence or rate of decay depends upon the particular phosphor, with decay times available from several seconds down to a fraction of

Prepared by
F. R. Darne
(Spring, 1962)

CATEGORY

STANDARD TUBE

PLAIN CRT's

Large raster display (TV rates) magnetic deflection	1,000 TV lines at 100 ft-lamberts, medium persistence 22-in. flat face (prototype 22CP4)
10-in. PPI radar indicators magnetic deflection	0.01-in. spot size, long persistence, low light output (prototype 10KP7A)
5-in. PPI primarily for camera recording, magnetic deflection	1 mil (.001-in. spot size, short persistence, moderate light output
5-in. flying spot scanner tube magnetic deflection	1 mil spot, extremely short persistence relatively high light output
5-in. high writing speed oscilloscope tube, electrostatic deflection	.025-in. spot size at 150 ft-lamberts light output, medium persistence (prototype-5BHP2)
Multibeam tubes, electrostatic	2-gun, 3-gun, 5-gun, various shapes and sizes

PROJECTION TUBES

Theatre TV	25,000 ft-lamberts on tube face at 80 KV, 525 TV lines, 5 ft-lamberts from 20 x 15-ft screen
Projection storage tube	17,000 ft-lamberts at 13 kv, 600 lines 15 ft-lamberts on 4-ft screen
Light valve projector	1,000 TV lines, light from external lamp
Fiber optics faceplate tubes	Record on film for later projection
Wire matrix faceplate tubes	Provide electrostatic printing on paper for later projection

CHARACTER TUBES

Charactron (or scriptron) shaped beam tubes	20,000 characters per second, medium persistence, relatively low light output, sizes 5 to 19 in.
Typotron or storage scriptron	Charactron with storage (brightness and persistence) 25,000 characters per sec. 5-in. and 21-in. sizes
Sympix	Wire matrix tube with charactron gun, 50,000 characters per second
Character generators	Not a tube but peripheral equipment for use with CRT's

CATEGORY

STANDARD TUBE

MULTI-COLOR TUBES

Shadow mask	3-color dot sequential - 500 TV lines at 18 ft-lamberts
Chromatron (Lawrence tube)	3-color line sequential - 300 TV lines at 75 ft-lamberts
Color storage	2-color, 450 raster lines, 90 ft-lambert long-persistence, 10-in. tube

DIRECT VIEW STORAGE TUBES

5-in. high brightness	10,000 ft-lamberts, 50 lines per inch, 75,000 in./sec. writing speed; also available in 3-in., 7-in., 10-in. sizes
5-in. high resolution	200 ft-lamberts, 100 lines per inch, 3,000 in./sec. writing speed
5-in. high writing speed	2,500 ft-lamberts, 50 lines per inch, 250,000 in./sec. writing speed
5-in. multimode storage tube	400 ft-lamberts, 50 lines/in. - light writing mode 100,000 in./sec., 100 lines/in. - dark writing mode
21-in. Tonotron	200 ft-lamberts, 475 lines per diameter, 40,000 in./sec. writing speed

ELECTRICAL OUTPUT STORAGE
TUBES FOR SCAN CONVERSION

Recording type (secondary emission, transmission, storage grid) single and double ended	1,000 TV lines, 0.01 microsec per element writing speed, 20,000 to 30,000 "reads" storage without affecting stored charge
Electron bombardment induced con- ductivity (ebic) type, continuous storage surface double ended	820 TV lines, higher writing speed but shorter storage than recording type; solid storage surface eliminates crosstalk between read and write beams

THREE DIMENSIONAL DISPLAY

Stereoscopic use of two display
tubes with polaroid glasses
Spinning disk in CRT
Moving plate (face) in CRT
Stacked "thin" tubes

a second. Since the normal cathode-ray-tube has a definite decay rate, it is necessary to regenerate or refresh the image on the cathode-ray-tube from the computer or from some storage device, if the image is intended for direct viewing. Refresh rates below 30 per second result in visible flicker and reduce the brightness. Filters sometimes used to help alleviate the effect of flicker on the viewer further reduce the brightness. As an indication of cathode-ray-tube brightness, the light output of a standard television picture refreshed 30 times a second is in the order of 30 to 50 foot lamberts.

Some special cathode-ray-tubes provide a storage mechanism within the tube itself - usually some form of dielectric coating on a metal mesh. Such storage tubes can keep the visible image on the face of the cathode-ray-tube refreshed continuously. These tubes cost approximately two orders of magnitude more than a normal cathode-ray-tube.

(Fig 2)
The Charactron is a special cathode-ray-tube that includes a character generating mask and the necessary electrodes for shaping the beam inside the tube to generate characters and symbols.¹² The electron beam is deflected to the proper position in the character mask corresponding to the character to be generated. As the beam passes through the mask, it is extruded into the shape of the character. The shaped beam is then returned to the axis of the tube by deflection electrodes and deflected to the desired position on the face of the tube.

Random display rates of 50,000 characters per second are possible with this technique. The limiting factor is the time required to position the character on the face of the tube rather than the time required to shape the beam. The Charactron tube is not limited to the generation of alphanumeric characters but can also generate any symbol fabricated in the mask. A typical mask has 64 different characters or symbols, but 144 symbol masks have been used, and several hundred are considered possible.

The Charactron is said to have three major advantages over the stroke or dot matrix method of symbol generation:

- 1) Reliability
- 2) Legibility or definition
- 3) System simplicity

Since the Charactron is basically a cathode-ray-tube, it can be operated as a conventional cathode-ray-tube to generate graphical data and target traces in real time. Any shape and size of symbol can be chosen since this is a function of the fabrication of the mask. Charactron tubes are useful for image generation in photographic projection systems for large-screen displays as well as for direct viewing in console displays. Recent development permits the simultaneous generation of alphanumeric and real-time video information by the use of two electron guns in the tube. Another

recent development provides a rear window in the tube so that a photographic image can be projected through the window and superimposed on the face of the tube with the electronically generated picture.

Some other types of special cathode-ray-tubes worthy of mention are:

Color tubes for generating color displays

Fiber-optic face plate tubes where the image from the inside of the tube is brought to a plane outside the tube through a fiber-optic bundle to avoid parallax and permit direct printing

Electrostatic face plate tubes in which a matrix of fine wires replace the face of the tube so that a charge image can be produced on a dielectric surface (e.g. paper) held in contact with the wire face.

The major type of light valve available today is also basically a cathode-ray-tube, but these are sufficiently different and more complex that they are discussed later under a separate heading.

Because of the length of time they have been in use and the large amount of experience gained in their use, cathode-ray-tubes offer great capability and flexibility in equipment and systems. The capability and flexibility available through the use of cathode-ray-tube technology is illustrated by a list of typical options prepared by James and Dittberner which is reproduced here as Table VII.¹³

6.5 Inscribing Systems

Inscribing display techniques are ones in which a glass slide or mylar film, coated with an opaque material, is "scratched" by some form of stylus. Light from a high-intensity source is then projected through the glass slide, reproducing on the screen the image cut in the opaque material by the stylus. Two basic ways of accomplishing this have been considered. The first of these ~~is by the use of a~~ mechanical stylus controlled by a servo-mechanism. This type is in widespread use and is probably the major method available today for achieving a real-time dynamic tracking type display on a large-screen. The second method, which is only in the research stage at this time, involves the use of a laser beam to evaporate the opaque material from the glass slide.

Mechanical Inscribing Systems

A mechanical inscribing system permits the large-screen display of real-time dynamic information at a relatively slow rate.¹⁴ In this type of display, a glass slide or mylar film coated with an opaque material is inserted into a projection system. A glass plate with a transparent stylus mounted in its center is positioned parallel to the first slide so that tipping the glass plate causes the stylus to

OPTION DESCRIPTION

ADVANTAGES

- | | |
|---|--|
| 1. Quality - Direct view - under 1,000 TV lines/ inch; Display recording - over 1,000 TV lines/ inch. Trade-off between electronics and optics. | Direct view trades quality for greater character selection; display recording trades selection for resolution. |
| 2. Mixing video with fixed graphics - integrates or superimposes CRT images with film images. | Integrated, real-time displays. |
| 3. Color (3-5) - practical uses up to six colors. | Increased information content readability and comprehension. |
| 4. Hard copy of Film Recording. | Information storage, make-up dissemination, delayed reading. |
| 5. Light Pen - hand held. | Permits 'sketching' or line drawing, editing message composition. Hence facilitates computer-aided design. |
| 6. Keyboard - Normally a typewriter keyboard; can be programmed keyboard. | Adds general purpose use of keyboard where computer defines functions of keys. |
| 7. Variable Character Sizes - 7 to 9 TV lines required to form reasonable resolution of character. | Permits reducing or enlarging character geometry. |
| 8. Simultaneous alphanumeric and video display - two gun tube co-displays (computer-generated data and video image). | Permits co-display of data where lacking system time. |
| 9. Time sharing - one tube displays, in series, video or alphanumeric images; can be superimposed. | Greater writing flexibility. |
| 10. Fiber Optics Tube - 'Pipes' image to outside surface of CRT. | Offers undistorted images for photographic reproduction purposes. |

TYPICAL OPTIONS AVAILABLE WITH CATHODE-RAY-TUBES (1968-1970)
TABLE VII

penetrate the opaque material. When the stylus is moved in the X and Y directions by a servo-mechanism under the control of external signals, a trace is inscribed in the opaque material on the face of the slide. The light from a lamp is projected through this trace on the glass slide and focused on a projection screen. Thus, a trace that can be drawn in real-time will appear on the screen.

The use of color filters in the light path permits color traces to be generated. A composite multi-input or multi-color display can be generated by superimposing the images from several projection systems. Additional projectors can be used to superimpose static information, such as maps, on the dynamic information. Since the inscribed trace remains on the glass slide, no external memory is required for this type of display.

With a trace width of 0.001 inches on the slide, the projected trace will be about 0.1% of the screen size. Recent systems require approximately 50 milliseconds to inscribe a trace across the full width of the screen. Alphanumeric characters can be inscribed at a rate of approximately 20 characters per second.

Laser Inscribing

A laser inscribing system can permit the large-screen display of real-time dynamic information at a fast rate. This technique is similar in concept to a mechanical inscribing system except that in place of a mechanical stylus, a laser beam is used to inscribe by vaporizing metallic film on the glass plate. The vaporization of the metal on the glass plate by the laser beam permits light to shine through, projecting the image onto the screen. The satisfactory development of this technique depends upon the ability to deflect laser beams. Binary digital deflection by crystals has been satisfactorily demonstrated in the laboratory for 256 positions in each direction. For a practical display system, 2^{10} positions in each direction (X and Y), are desirable. Digital deflection of laser beams is discussed further in a later discussion of laser displays. The display department of the U. S. Army Electronics Research and Development Laboratory at Ft. Monmouth, New Jersey is quite interested in this approach and has planned to issue a Request for Proposals for the development of such a system. This approach may provide the first use of lasers in large-screen display systems since it requires neither the intensity needed in a direct viewing laser system nor the generation of an ultra-violet laser beam needed for a photochromic system.

6.6 Film Projection Systems

Large-screen display systems based on projection of film images have been used in a number of existing Command and Control Systems and several specific systems have been described in the literature.^{15,16,17} In essence, these systems involve:

- 1) A symbol generator for converting the digital information

to a shaped symbol or character on the face of a CRT.

- 2) An image generator for positioning the symbols and generating graphical data on the face of the CRT.
- 3) Processing equipment for exposing film to the image on the CRT, developing the film, and, if necessary, making prints.
- 4) Slide or film storage and selection equipment for storing the film images and making them available upon call.
- 5) A projector and screen for projecting and displaying the selected image.

Cathode-ray-tube displays may be imaged on film in three ways,- optical projection, optical contact printing through a fiber optics face plate, and direct charge deposition through wires embedded in the face-plate. These methods and the recording media used with them have been summarized in a table by Luxenberg which is reproduced as Table VIII.¹⁸

Usually, a multiple projection system is used to permit the simultaneous projection and superimposing of multiple images to generate multi-color displays ~~for to~~ superimpose multiple overlays over a map background. Color film could be used, but the film cost is greater and the processing is more difficult. For additive color, a positive image (clear symbols on an opaque background) is required. Where the initial CRT recording is a negative, a contact print onto a suitable material (Kalvar for permanence or a photochrome for reuseability) may be made.

Systems that superimpose three or four independently selected images encounter difficult registration problems in the final projected display. Other systems that contain the multiple images on a single film chip overcome the registration problem, but the image size is reduced and flexibility in selecting the combination of images to be displayed simultaneously is lost. A recently revived approach involves the use of a lenticular film in which the three separate color images are line-interlaced (at 25 line triples per millimeter) into a single frame of reversal processed silver-halide film. This approach completely eliminates registration problems, and requires a much simpler optical system than the triple frame methods.

Most of the film projection systems in current use employ discrete slides, but a few use a continuous film strip to provide more rapid updating of the display and to permit a simpler mechanical system than one in which individual slides are selected independently.¹⁵ The flexibility offered by random slide selection is sacrificed. The continuous film strip type projection system is more suitable to rapid updating (approximately 15 seconds) of pseudo-real-time displays where the same type of information is displayed continuously but updated rapidly. It uses a much larger amount of film if the display is updated rapidly. The individual slide approach is more suitable to situation displays where a large number of different kinds of situations or pictorial combinations are available, any of which may be required at a given time and in any sequence.

PRINTING TECHNIQUE	MEDIUM	PROCESSING	COMMENTS
Optical Projection (Variable magnification)	Silver-halide	Chemical (Full color is available)	Permanent Fastest Either negative or positive
	Photoconductive plate	Toning (Color is selectable)	Permanent or eraseable Either negative or positive
	Photothermo-plastic	Heat	Permanent or eraseable Requires Schlieren optics for projection Usually a positive
Contact Printing (Fiber optics faceplate and UV phosphor)	Kalvar	Heat	Permanent Negative only
	Photochromes	None	Eraseable Negative only
Direct Charge Deposition	Any dielectric, mylar film, etc.	Toning (Color is selectable)	Permanent or eraseable Either positive or negative
	Thermoplastic dielectric	Heat	Permanent or heat eraseable Requires Schlieren optics for projection Usually a positive

METHODS OF RECORDING CRT DISPLAYS FOR PROJECTION
TABLE VIII

Silver-Halide Film

Most film projection systems use conventional silver-halide film similar to that used in amateur and commercial photography, but Kalvar and photochromic films and xerographic techniques have also been used. The use of silver-halide films is well established and well understood. Handling and processing techniques are well developed. Silver-halide films are very fast and require energy levels for exposing that are compatible with cathode-ray-tube output levels. However, they possess several disadvantages. Three of the major drawbacks of a silver-halide film projection system are:

- 1) The logistic requirements for continual replenishment of the film and processing materials.
- 2) The relative complexity of the chemical processing, as compared to electrostatic and heat processing films.
- 3) The inability of the film emulsion to withstand the heat of projection, particularly where the projection image consists of small areas of clear symbology on a predominantly dark background.

It is the third difficulty which has made the use of Kalvar so widespread as the projection medium in the majority of current command and control projection display systems.

Kalvar Film

The use of Kalvar is very attractive from the processing standpoint since it can be developed simply by means of heat (approximately 120°C for 1 to 2 seconds).¹⁹ Unfortunately, Kalvar (like the diazos and photochromes) is sensitive only to a narrow band in the ultra violet region and is much slower than silver-halide film. The energy required to expose Kalvar is 2×10^5 erg/cm² (0.2 watt-seconds) at 3850Å for Kalvar vs. 0.2 ergs/cm² at 4300Å for Plus-X film. This energy level ("speed" in photographic terms) makes direct photography of the face of a cathode-ray-tube impractical when using Kalvar.

In some systems, silver-halide film is used first to develop a negative from the face of a cathode-ray-tube. Multiple positive copies are then printed on Kalvar using a high-intensity xenon or mercury arc lamp. The temperature of 120°C required for developing presents no serious problem and good resolution can be obtained from Kalvar. In the ARTOC display subsystem, the image from the cathode-ray-tube face is recorded on silver-halide photographic film which is developed, fixed, washed, and dried within 8 to 10 seconds.¹⁶ Positive prints are then made automatically from the negative in less than one second by contact printing of the negative on the Kalvar film. The Kalvar film is exposed by high-intensity U.V. and the image is developed by heat.

Photochromic Film

The exposure and developing processes for both silver-halide and Kalvar film are non-reversible. Hence, these film cannot be reused, and they cannot easily be used in a dynamic or plotting type display. One of the most attractive features of photochromic film is that the process is reversible. Hence, the film can be reused and can be used in a dynamic or plotting type display. Since there is a finite decay rate at normal temperatures and since some fatigue occurs, there is a limit to the number of times the photochromic film can be used. Photochromic material will withstand the heat of projection as well as Kalvar, and is self-developing. Its speed is comparable to Kalvar; but since it is heat eraseable, it has not been used in command and control systems where the permanency of Kalvar is a requirement. The reversible process and the relative insensitivity to ambient light are special properties that also permit photochromic film to be used in other types of display systems where silver-halide and Kalvar cannot be used. Special types of photochromic displays are discussed later.

Other Film Techniques

Xerographic techniques have been used for developing an image on film from an electrostatic image. The electrostatic image can be created on the film by a cathode-ray-tube with a metal fiber face plate. Electrostatic photography and photochromic material both offer the advantages of reuseability and simplicity of processing. In addition, panchromatic photoconductive materials have been developed with an ASA rating of 15 (comparable to Kodachrome I-type A). There are a large number of other photographic and reproductive processes that can be considered for film projection display systems. Robillard has compared a large number of these, some of which meet certain requirements that cannot be met by silver-halide.²⁰ He describes the general scheme for photographic systems consisting of exposure of a latent image and the development of this by local energy sources resulting in the final image. He presents one table classifying existing photo and reproduction processes and another classifying new photographic systems for the three-steps of photosensitive system, amplification, and image formation. These tables are reproduced here as Table IX and Table X to illustrate the large number of possible systems and the range of characteristics. The potentials of film based systems have not been fully exploited. Processing time for all film media is in the order of seconds. Even full color film can be processed in less than a minute. It is reported that one company will shortly announce a color film for display application which can be processed in 15 seconds.

The film projection type systems are currently the most practical solution to large-screen displays where continuous operation is required. However, because of the relatively slow response time, the inability to display dynamic information, and the mechanical equipment involved, this is not a desirable long-range solution for shipboard tactical data systems. It is believed that film projection systems will be obsolete for this type of application before the 1970 period and should not be considered for a 1970 system.

NOTE: Numbers in parentheses refer to References at the end of Robillard Paper.

Prepared by
J. J. Robillard

Type of Process	Process (Examples)	Nature and Color of the Image	Spectral Response	Uses	PHOTOSENSITIVE SYSTEM		AMPLIFICATION (Development)			IMAGE FORMATION			Fixation
					Phenomena Involved	Material Involved	Phenomena Involved	Nature of Energy Added	Material Involved	Phenomena Involved	Material Involved	Image Forming Material	
Silver Halide	Photography	Negative - Black	Visible - UV - IR	All Photographic applications	Photo-reduction	AgBr	Chemical Reaction	Chemical	Reducing Agents	Chemical Reduction	AgBr + Reducing Ag	Ag	Chemical (Hypo)
Print out Emulsions		Negative - Brown	Visible - UV	Recording Photocopy	Photo-reduction	AgBr	Photolysis	Radiation (UV)	None	Photolysis	AgBr	Ag	Chemical (Hypo)
Diaz	Quatid	Positive - Blue Brown	UV	Recording Blueprint Photocopy	Photo-reduction	Diazonium Salt + Coupling Compound	Chemical Reaction	Chemical	NH ₄ OH	Chemical Reaction	Diazonium Salt + Coupling Compound	Coupling Product	-
Diaz	Kalvar	Negative - Brown	UV	Recording Microfilm Data Process	Photo-reduction	Diazonium Salt + Coupling Compound	Chemical Reaction	Heat	None	Chemical Reaction	Diazonium Salt + Coupling Compound	H ₂	UV
Electrostatic	Electrofax	Positive - Black	Visible - UV	Recording Photocopy Data Process	Photo-conductivity	ZnO	Material Transport	Electrostatic	Carbon Black or Dyes	Selective Deposit	Carbon Black or Dyes	Carbon Black or Dyes	Heat Fixing
Electrostatic	Xerography	Positive - Black	Visible - UV	Photocopy Recording Data Process	Photo-conductivity	Se	Material Transport	Electrostatic	Carbon Black or Dyes	Selective Deposit	Carbon Black or Dyes	Carbon Black or Dyes	Heat Fixing
Electrolytic	IM	Negative - Black	Visible UV	Microfilm Repro. Data	Photo-conductivity	ZnO	Electrolysis	Electrical	Silver salt or Silver	Selective Plating	Metallic Salts	Ni, Au or other Metals	None
Electrostatic	Photo-plastic Recording (1)	Light scattering image	Visible UV	Experimental	Photo-conductivity	Plastic film	Electrostatic deformation	Heat	Plastic film	Electrostatic deformation	Plastic film	Plastic film	None
Electrolytic	Redox	Negative or Positive Black	Visible	Experimental	Photo-conductivity	CdS or CdTe, Sb ₂ S ₃	None	None	None	Electro-reduction or Oxidation	-	Sb	None
Electrolytic	(2)	Positive - Black	UV	Experimental	Photo-polarization	InSb	Electro-oxidation	Electrical	KOH	Electro-oxidation	InSb + KOH	InO ₂	None
Electrolytic	(3)	Negative - Gray	UV	Experimental	Photo-polarization	Al	Electro-oxidation	Electrical	PO ₄ NH ₄	Electro-oxidation	PO ₄ NH ₄ + AL	Al ₂ O ₃	None
Photopolymerization	Photopolymerization (4)	Negative - Black	Visible UV	Experimental	Photopolymerization	Vinyl monomers	Chain Reaction	Chemical (Self Contained)	Vinyl monomers	Polymerization	Vinyl Compounds	Polyvinyl Compounds	Heat
Free Radicals	Free Radical Photo System (5)	Negative - Yellow & Black	UV	Experimental	Photo-chemical Reaction	Styryl Base + CBr ₄	Chemical Reaction	Chemical	Styryl Base + CBr ₄	Chemical Reaction	Styryl Base + CBr ₄	Styryl Hydrobromide + Quaternary Diester	Heat
Dichroism	Photo-Dichroism (6)	Positive - Brown	Visible	Experimental	Photo-Dichroism	O-NITRO Benzaldehyde	Chain Reaction	Chemical (Self Contained)	O-NITRO Benzaldehyde + TiO ₂	Chemical	O-NITRO Benzaldehyde	O-NITRO Benzoic Acid on TiO ₂	Electrical
Thermal	Thermofax	Positive - Brown or Black	IR	Photocopy	IR Absorption	Lead Salt + Thiocarbamide	None	None	None	Chemical	Lead Salt + Thiocarbamide	Pb	None
Mechanical	(7)	Negative - Gray	UV	Experimental	Photo-conductivity	Se	Allotropic Transform	Mechanical	Se	Plastic Deformation	Se	Se	None

CLASSIFICATION OF EXISTING PHOTO AND REPRO PROCESSES
TABLE IX

Prepared by
J. J. Robillard

Type of Process	Process	Spectral Response	Quantum Yield	Nature and Color of the Image	PHOTOSENSITIVE SYSTEM		AMPLIFICATION (DEVELOPMENT)			IMAGE FORMATION			Fixation
					Phenomena Involved	Material Involved	Phenomena Involved	Nature of Energy Added	Material Involved	Phenomena Involved	Material Involved	Image Forming Material	
Catalytic	Barrier Layer	Visible-UV	10^5	Negative - Black	Photo-Conductivity	Cds or CdTe or Sb_2S_3	Material Transport & Chain Reaction	Chemical & Electrical	$Cu + SiO_2 + Cobalt$ Complex	Catalytic Reaction	Cobalt Acetyl Acetonate or Others	Co	None
Catalytic	Electro-Dissociation of a Catalyst Compound	Visible-UV	10^5	Negative - Black	Photo-Conductivity	Cds or CdTe or Sb_2S_3	Electro-Dissociation + Chain Reaction	Chemical & Electrical	$CuX + Cobalt$ Complex	Catalytic Reaction	Cobalt Acetyl Acetonate or Others	Co	None
Catalytic	Photo-Dissociation of a Catalyst Compound	UV	10^5	Negative - Black with Blue Background	Photo-Dissociation	$CuSCN$ or Others	Chain Reaction	Chemical	Cobalt Complex	Catalytic Reaction	Cobalt Acetyl Acetonate or Others	Co	Electrical
RF	Photo-Dielectric	Visible-UV	10^2	Negative - Black or Brown	Change in Dielectric Constant	ZnS	Dielectric Heating	RF	$ZnS + Binder$	Thermo-Sensitive Reaction	Lead Xanthate or Other Thermo-Sensitive Materials	Pb or Others	None
Electro-Optical	Two Steps Reduction	Visible-UV	10^7	Negative - Black	Photo-Excitation	CeO_2	Ionic Migration in Crystals	Chemical	$Ag + CeO_2$	Reduction	CeO_2	CeO	None
Electro-Optical	Photo-Reduction	Visible	10^2	Negative - Black	Photo-Conductivity	TiO_2	Electron Trapping + Ionic Migration in Crystals	UV Radiation	$Ag + TiO_2$	Reduction	TiO_2	TiO	None
Color Centers	Color Centers	Visible-IR	10	Positive - Various Colors	Quenching Color Centers	KCl or $CaCl$	Return to Ground States	X-rays (previous to exposure)	KCl or $CaCl$	Quenching Color Centers	KCl or $CaCl$	Color Centers	Electrical

CLASSIFICATION OF NEW PHOTOGRAPHIC SYSTEMS
TABLE X

6.7 Photochromic Displays

Photochromics have been discussed briefly previously as one type of media for use in film projection systems as an alternative to silver-halide and Kalvar. Three properties of photochromic film that permit it to be used in other types of display systems, where silver-halide and Kalvar cannot be used easily, were considered. These properties are:

- 1) A reversible process, hence eraseable and re-useable
- 2) Self-developing, hence requires no processing
- 3) Relatively insensitive to ambient light, hence can be exposed without light shielding (if the ambient light does not contain significant amounts of ultraviolet or infrared)

These properties permit photochromic material to be used in real-time dynamic or plotting type displays that offer promise for future display systems.

Photochromic materials are organic dyes which become opaque when exposed to ultraviolet light, and return to the transparent state when exposed to heat or infrared light. By coating a transparent film with a thin layer of photochromic material, a "photographic" type media can be produced in which the chemical process is reversible. An image can be exposed with ultraviolet light and erased with infrared light. A number of new photochromic materials with different characteristics are in the research stage at this time. One of these can be written upon by light in the blue range of the spectrum and is not bleached by visible light. Another is bleached by visible light and is not bleached by heat.

The exposed image will decay at room temperature at rates depending upon the particular chemical compound. Typical persistency times for photochromic materials used in display systems range from approximately 2 seconds to 15 minutes. Faster decay times can be obtained, but for display purposes, this requires regeneration of the image. Longer persistence times can be achieved by cooling the image since the decay is inhibited by cold temperatures.

Photochromic materials exhibit a fatigue characteristic at present, after a few hundred cycles of a particular spot. Red, blue, or green colors can be obtained with a resolving power capability in excess of 1,000 lines per millimeter. The sensitivity varies with the photochromic material but is about 1/3-watt-second per square centimeter. The persistency of the image can be controlled by varying the temperature, the material, or the method of applying the material to the base.

Early work on photochromic display systems generated a dynamic display by focusing an ultraviolet light through a lens system onto a photo-

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chromic film; the ultraviolet light being mechanically positioned by a servo-mechanism.²¹ This approach is conceptually similar to inscribing systems discussed previously, but it generates a reverse image (i.e., a dark trace on a light background). Since the photochromic material becomes opaque at the point at which the ultraviolet strikes, projection type displays can be generated by inserting the photochromic material between the lamp and the lens of a projection system. Moving the lens through which the ultraviolet light is focused causes the opaque spot on the photochromic film to move, generating a dynamic display on the screen. Shining an ultraviolet light beam through a character-matrix mask can generate alphanumeric characters or special symbols on the display screen. This type of display is interesting for tracking a limited number of targets or for generating displays that change relatively slowly. However, the speed of the photochromic material and the mechanical motions involved in deflecting the ultraviolet light limit the useful speed.

In a newer development, a cathode-ray-tube is combined with the photochromic film to permit the electronic generation of an image. In this approach, a fiber-optic face plate cathode-ray-tube is used to generate an image on the outer surface of the face of the tube by conventional techniques.^{22,23} The ultraviolet light from the phosphor on the inner surface of the face of the cathode-ray-tube is transmitted through the fiber-optic face plate to generate an opaque image on the photochromic film. A dichroic mirror that transmits ultraviolet light and reflects visual light is sandwiched between the fiber-optic face plate and the photochromic film. Visual light from an external source is projected through the photochromic film onto the dichroic mirror which reflects it back to a viewing screen. The opaque image on the photochromic film prevents the light from the projector from striking the dichroic mirror. Hence, this image is reflected onto the screen. Since the light passes through the photochromic film twice, the optical density is effectively doubled. For target track type applications, this technique not only provides a real-time target track, but also provides target track history in the form of a trace with "intensity" decreasing with time. The time period covered by the visible target track history can be changed by replacing the photochromic film with another of a different persistence photochrome. For example, a long persistence material used for an ASW operation could be replaced with a short persistence one for an AA operation. It should be noted that this approach provides a dynamic real-time display where the photochromic material is reused. This is in contrast to the film projection systems discussed previously which are not dynamic and where film is continuously processed and expended.

At the present time, the speed of photochromic materials limits the character generation rate to 20 to 50 characters per second in this type of display. If work on faster photochromic materials is successful, this approach could provide an attractive electro-optical dynamic large-screen display with no mechanically moving parts.

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The Army and the Navy have supported similar photochromic display system developments at two different companies using photochromic materials with different persistencies. The development effort supported by the Navy, uses a photochromic material that has a shorter persistence which is further accelerated by permitting the infrared in the visual light to strike the film rather than filtering out the infrared. The computer is expected to regenerate the display periodically to compensate for the short persistence. The development effort supported by the Army, on the other hand, uses a longer persistence material and filters out the infrared in the visual light. The appropriate light colors must then be recombined to get white light on the screen without infrared. This approach gives a longer persistence picture with less requirement for computer regeneration, but the picture cannot be changed as rapidly unless infrared is used to erase the previous image.

A more advanced, but somewhat similar, photochromic display has been proposed that may be feasible in 3 to 4 years. This is a combination photochromic-laser display in which an ultraviolet laser beam is digitally deflected to write on the photochromic material. This combination can provide a very high resolution since a 10 to 20 micron spot size can be obtained with a laser beam compared to a 1 mil spot size for a cathode-ray-tube.

Photochromic display systems combining electronic, photochromic, and projection techniques are promising for future display systems but, in the long run, will probably be superseded by other techniques such as electro-luminescent, magneto-optic, or laser displays. Photochromic displays are more attractive as an interim large-screen display technique that can be operational within the next two to four years. Their use is more questionable for systems to become operational during the 1970's. Photochromic displays using cathode-ray-tube writing and optical projection, similar to the ones discussed in this section, are being developed. This appears to be a feasible technique for the next generation of large-screen displays if development efforts are adequately supported.

6.8 Light-Valve Systems

The term "light valve" in a generic sense refers to any system in which light passing through the system is modulated. The CRT/photochromic system discussed in the preceding subsection is a light valve in that sense. However, the term is usually used in a narrower sense to refer to a cathode-ray-tube projection display system using a Schlieren optical system or to certain types of liquid or solid crystal devices.

Oil-Film Light Valves

The most common example is the "oil-film" light valve used in theatre projection TV systems. In a typical system of this type, a metallic mirror-like surface covered with a thin film of oil is placed inside an evacuated cathode-ray-tube type device. The oil film is scanned with

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an electron beam to generate a television type image, (raster scan), on the oil film. This is similar to the operation of a normal cathode-ray-tube except that the image is generated on the oil film rather than on a phosphor face. The electrons impinging on the oil film create electrostatic forces that cause a temporary deformation of the oil film. When a high intensity light source is focused on the oil film, the light is reflected at a different angle for those areas that have been deformed by the electron beam than for the remainder of the oil film. Passing the reflected image through a ladder-like grating (a Schlieren optical system) permits selective passing of the light, depending upon whether it was reflected from a deformed area or a non-deformed area of the oil film. Hence, the desired image is displayed on the viewing screen.

At present, oil-film light valves suffer from the severe disadvantage of a short cathode life (20 to 200 hours MTBF). Since it is necessary to have an oil film inside the vacuum, it is difficult to maintain a good vacuum. As a result, there is a tendency for the cathode to be poisoned by evaporated oil. Light-valve systems of this type are in common use in large-screen theatre-television systems. However, these systems are operated for short periods of time for special events, and considerable time can be allotted prior to the event for bringing the system up to proper operation. Unfortunately, in the military command and control environment, the system is required to be in almost continuous operation.

Another disadvantage is that multi-color displays require multiple projection units with consequent cost and registration problems. One company has combined several colors in one frame by using two scan rasters at right angles to each other with a dual Schlieren optical system.

Considerable development efforts are being expended toward improving the performance, reliability, and life of light-valve systems. The Rome Air Development Center, in particular, is sponsoring extensive efforts toward improving light-valve systems. It is their belief that light-valve projection systems will constitute the next generation of large-screen display systems. Although oil-film light valves are promising for future display systems, size, reliability, and maintainability considerations are likely to restrict their applications to fixed-site land-based strategic command and control systems. Their use in mobile tactical systems, such as those required for Navy ship-board and Marine ground applications, is not promising. In any event, they offer only an interim solution. However, it will be a number of years before some of the other newer display techniques (e.g. electroluminescence) can provide the same brightness, resolution, and gray scale capability. These factors must be balanced against other factors such as size, cost, reliability, and maintainability. Although oil-film light valves will be used for a number of years for TV presentations wherever group viewing of TV is required, such systems will be surpassed by other techniques by 1970.

Thermoplastic Light Valves

The problems of cathode contamination caused by the presence of an oil film in the vacuum system can be avoided by the use of thermoplastic and photoplastic media in somewhat similar light-valve systems.

The thermoplastic media is used in a manner almost identical to the oil film. An electron beam in an evacuated cathode-ray-tube type device is used to write on the thermoplastic media by depositing electrons on the surface. If the film has been heated to the softening point, the electrostatic forces cause the surface of the film to become distorted in a pattern corresponding to the image. This image is projected with a Schlieren optical system, as in the case of the oil-film light valve. In a thermoplastic system, a permanent record could be retained by permitting the surface of the media to cool and harden while holding the distorted pattern. However, this is not desirable in a light valve since it would require the ability to remove the thermoplastic media from the evacuated chamber.

Other thermoplastic techniques have been investigated. One is the use of a tube with a wire matrix face plate to place the electrostatic charge on the thermoplastic media external to the tube. Another is the use of a crossed matrix of conducting lines which deposit charges at the line intersections.

Thermoplastics can also be used as the media in a film projection system by using powder-dust toning to produce a visual image that can be projected like silver-halide or Kalvar film. Some advanced work in this area indicates the possibility of a single frame multi-color picture using different colored powders for dusting.

Photoplastic Light Valves

A photoplastic media is a combination of photoconductive and thermoplastic techniques in which a conducting layer, a photoconductive layer, and a thermoplastic layer are combined. If the thermoplastic layer is transparent and the media is exposed to a light pattern in the form of an image, the charge from the conducting layer can move through the photoconductor in the areas corresponding to the light pattern. If the surface of the thermoplastic layer is first charged with respect to the conducting layer prior to the exposure to the light image and then discharged to the conducting layer after exposure, a charge pattern is retained on the surface of the thermoplastic film. This charge pattern on the thermoplastic film corresponds to the light image as a result of the charge pattern in the photoconductive layer. Briefly heating the plastic permits the electrostatic forces to deform the thermoplastic surface. This deformation can be retained by cooling (hardening) the plastic if desired.

This image can be projected by a Schlieren optical system also, but it has an advantage over the straight thermoplastic media in that the

recording is by light rather than by electron beam. Hence, it is not necessary to place the photoplastic media inside the vacuum chamber, nor to use the lower density of matrix techniques such as a wire mesh face plate tube. This permits an "open-air" light-valve system that avoids many of the disadvantages of the oil-film and thermoplastic light valves.

Using the light from the face of a cathode-ray-tube to write on a photoplastic media, when combined with a Schlieren optical system for projection, provides a dynamic, real-time, large-screen display with a sealed vacuum system. The media is reuseable and heat is utilized for both instantaneous development and for erasure. Resolutions of 360 line pairs per millimeter, spot size of approximately one millimeter, and contrast ratios of 30:1 have been achieved with photoplastic light valves.

Although photoplastic light valves are not as far along in the development cycle at this time as oil-film light valves, they offer more promise for use in tactical display systems because of the use of more conventional cathode-ray-tubes and the fact that it is not necessary to place the media inside the evacuated chamber. A sealed light valve is achieved that avoids problems of maintaining the vacuum, re-evacuating the chamber after maintenance, and low reliability and poor maintainability due to cathode contamination. Many display experts and users believe that photoplastic sealed light valves are the most important current display development from the standpoint of feasibility in the near future.

Many of the adverse comments made about oil-film and thermoplastic light valves will not be applicable to photoplastic light valves. As a result, if light valves of this type are satisfactorily developed, they will be competitive with, and probably faster than, the dynamic real-time photochromic displays discussed previously.

Photoplastic light valves should be considered one of the major competitors for the next generation large-screen display systems and , for use in systems during the early 1970's if other techniques, such as electroluminescent, magneto-optic, or laser displays, are not perfected as rapidly as might be expected.

Solid State Light Valves

Solid state light valves are an interesting and promising technique for long-range consideration since many of the problems associated with oil-film, thermoplastic, and even photoplastic light valves, are avoided. In some approaches, even the necessity for a cathode-ray-tube may be avoided.

One approach that has been proposed uses a solid-state crystal for light modulation, but it is not really an all-solid-state device since an electron beam is used to control the crystal.²⁴ In this approach, an electron beam in a cathode-ray-tube is used to control the passage

Illustration Fig 6

of light through a birefringent KDP crystal in the face of the tube. A polarized light is projected through a rear window in the cathode-ray-tube, through the crystal modulating element in the face of the tube, and onto a screen. The electron gun in the cathode-ray-tube generates an image on the crystal modulator; the polarized light passing through the modulator then projects this image onto the screen. The electron gun serves as a control element but is not required to supply the light output.

The crystal light modulator is but one example of a class of light modulators where electrical or magnetic fields are used to modify the optical properties of an electro-optically active crystal (or liquid in some approaches) - to modify its transparency, index of refraction, plane of polarization, color, etc. Such crystals can be used to modulate laser beams in both direction and intensity.

Although the media controlling the light is solid state, the media must be controlled by some method to generate the image. Unfortunately, the most practical method of accomplishing this at present is with a cathode-ray-tube. In the more distant future, a practical solid-state combination may use a low-power laser to control the crystal, which in turn controls the light from a high power optical projection system.

These approaches are being followed with interest, but there is no indication at this time that they will be feasible for use by 1970.

6.9 Electroluminescent Displays

Electroluminescent displays offer the advantages of an all-solid-state display without moving parts or projection optics, a flat display requiring very little depth, and sufficient brightness for viewing under properly controlled room lighting conditions. An electroluminescent element consists of a thin layer of phosphor powder that is embedded in a dielectric medium and sandwiched between two parallel plate electrodes, one of which is transparent. The application of an alternating voltage to the electrodes causes the phosphor to emit light. 25, 26

Alphanumeric and Symbol Lamps

The major applications of electroluminescent materials in display equipment so far have been in the form of individual character or symbol indicators.^{26, 27} In these devices, each character position in an alphanumeric display is represented by an electroluminescent panel which can be caused to display any one of a predetermined set of characters depending upon the electrical signals applied to the device. However, extensive research and development efforts have been devoted to the use of electroluminescent materials to fabricate a complete display screen capable of displaying graphical data as well as alphanumeric characters.

Crossed-Grid Display Panel

Aside from the discrete character display, the electroluminescent display which has been developed further than others to date has been the electroluminescent cross-grid display.^{27,28} This display uses a continuous electroluminescent sheet with the electrodes on one surface subdivided into parallel strips in the X direction and with the electrodes on the other surface subdivided into parallel strips in the Y direction. Applying excitation to an X and a Y strip will cause the electroluminescent material to emit light at the intersection, and, to a lesser degree, along each strip. The contrast ratio between the light output at the intersection and that along each line is approximately ten to one. To reduce this "cross-effect," a continuous sheet of non-linear resistor material is coated on the electroluminescent material between the two sets of electrodes. This results in an increase to 10,000 to 1 in the contrast ratio between the light output at the intersection and that along each line. The non-linear resistor material also reduces the capacitance and hence the driving power required.

This approach is useful for both large-screen and console type displays. Real-time dynamic displays, such as target tracks, can be generated by properly sequencing the selection of X and Y grids. Alphanumeric characters and symbols can be drawn on the same display. However, it is necessary to regenerate each spot on the display periodically since it has no storage characteristic. As a result, this type of display requires either an external storage or computer controlled regeneration. To avoid noticeable flicker, the picture must be regenerated in excess of 30 times per second. The frame rate of 30 per second, and the fact that approximately 5 microseconds are required to energize each spot on the display, limit the total number of positions that can be activated. If many spots are to be energized, it may not be possible to regenerate each spot for a long enough period to maintain the desired level of light output. This will decrease if each spot is not energized for a long enough period and sufficiently frequently. Periodic action is required for active spots that remain static as well as for those that are changing. A typical mosaic panel operated at 250 v, 10 kcs with pulses of 20 usec duration repeated at 30/s intervals (to avoid flicker) provides an average 20 foot-lamberts of luminance.

One display of this type that is being built provides a 256 x 256 matrix in a 16 x 16 inch display panel. This display panel is $3\frac{1}{2}$ inches thick. The spot size is approximately 1/10 of an inch. It is expected that spot sizes of 1/40 to 1/50 of an inch are realizable in the near future, and that 1/100 of an inch is feasible.

Analog Display Panel

In another type of electroluminescent display, a continuous sheet of electroluminescent material is deposited over a sheet of piezo-electric ceramic.²⁹ With the proper voltage applied to the electroluminescent material, a mechanical shock wave travelling through the piezo-electric ceramic can generate sufficient voltage to energize the electroluminescent material in the vicinity of the shock wave.

Introducing a shock wave to one edge of the ceramic causes a light signal to propagate across the electroluminescent material as the shock wave propagates across the ceramic beneath it. A reduced shock wave on one edge, combined with a shock wave on a perpendicular edge, can cause a point of light corresponding to the intersection of the two wave motions to propagate across the display. A non-linear resistor material is again used to suppress partial excitation. Controlling the time of the two shock waves provides the ability to position the spot of light as it moves.

Electroluminescent/Storage Panels

In a crossed-grid electroluminescent display, the necessity to regenerate the entire display periodically limits the number of spots that can be energized and may decrease the light output. To overcome these problems, considerable attention has been given to the development of matrix addressed electroluminescent display panels that include a storage capability for each spot on the display. Providing an external storage such as a core matrix is not satisfactory since it does not eliminate the necessity for scanning through the display periodically. A method is required that provides separate storage directly coupled to each spot or position so that individual spots can be turned on and will remain on until intentionally turned off.

Two different approaches have been taken to this problem. The first is to fabricate a display panel with a matrix of discrete electroluminescent elements, each having an associated semiconductor storage circuit. An XY selection matrix is used to turn on the storage element that energizes a specific electroluminescent element. This storage element then maintains the electroluminescent element in that state until it is cut off by another XY selection operation. At present, the addressing rate is limited to a switch-on time of approximately 10 microseconds per element. The switch-off time is approximately 30 microseconds, but it is not necessary to maintain the electrical signal for this length of time. It is anticipated that the switch-on time can be reduced to 5 microseconds in the near future. Resolving powers of 10 lines per inch can be realized now with 16 - 20 lines per inch considered feasible by 1970.

This approach provides a true dynamic large-screen display with exact registration and positioning, without mechanically moving parts, and without an optical projection system. Since the individual storage elements eliminate the necessity for periodically regenerating the picture, only those elements that change must be activated and energized or de-energized.

This type of display is quite expensive due to the electronic selection of individual elements and the electronic storage associated with each element. However, it is a practical display in that a dynamic large-screen display of this type can be built in

a relatively short time with a high assurance of success. Development of an integrated circuit storage array may lower the cost of the electronic elements, but it would still be necessary to make physical connections between each bit of storage on the semiconductor chip and the corresponding electroluminescent element.

The major fabrication and cost problems associated with the type of electroluminescent storage panel discussed above result from the fabrication of a semiconductor storage circuit for each spot on the display. A more desirable solution is one in which the storage is provided by overlaying a sheet of electroluminescent material with another sheet of material that provides storage in conjunction with the electroluminescent material. Electroluminescent elements and photoconductive elements have been combined for this purpose. The electroluminescent element provides sufficient light to keep the photoconductive element in the conducting state, while the photoconductive element provides a path for keeping the electroluminescent element energized. The result is an EL-PC storage element with both electrical and optical feedback. Electroluminescent panels with this type of storage have been built with a resolution of 5 lines per inch. Approximately 20 lines per inch resolution is anticipated in future devices. ²⁷

One company has placed over the layer of electroluminescent material a layer of Cadmium Selenide (CdSe) that provides two stable states with an 8-1 change in resistance between the two states. With a layer of CdSe in series with the layer of electroluminescent material, the hysteretic effect in the CdSe can be used to provide both switching and storage for an array of electroluminescent cells. It is said that this approach can produce 100 foot-lamberts for approximately 1500 hours with a turn on time of 5 microseconds.

It is too early to determine whether the technical problems in this approach can be overcome, but it is particularly attractive if it proves feasible. It may provide a means of batch-fabricating a complete electroluminescent display panel with associated storage. The ability to fabricate the storage media directly on the electroluminescent panel without the necessity for making connections between each spot and its storage element is very advantageous.

Matrix addressed electroluminescent display panels with semiconductor integrated circuit storage for each spot or position on the display definitely will be feasible for use in a 1970 system, but the cost may be prohibitive for a large display screen. Electroluminescent display panels with storage material fabricated on the panel itself are attractive and will be economic if the techniques prove feasible. However, it cannot be stated with certainty at this time that this will prove feasible by 1970.

Multi-Colored Electroluminescent Displays

A multi-colored electroluminescent display is difficult but can be achieved by segmenting each element of the display into three elements corresponding to a three color system. Green, blue, yellow, and white electroluminescent phosphors are available, but the green has approximately twice the light output level of the other colors.

6.10 Opto-Magnetic Displays

fill
A different approach to solid-state displays is based on the magnetic properties of certain thin-film materials that affect their reflection of light. If a thin-film of magnetic material of this type is deposited on a substrate, areas that have been magnetized will reflect light in a different way than other areas of the film. An XY matrix selection can be used to generate a magnetic image on the surface. If a high intensity light is projected on the magnetic film, a visual image will appear as the result of the effect of the magnetic image on the reflection of the light.

Contrast ratios of 75 to 1 under "normal" room ambient light conditions have been obtained. Only a few percent of the incident light is reflected. Resolutions in the order of 5 mils have been obtained in the laboratory. The intensity varies with the viewing angle in one axis and color varies with viewing angles in the other axis. There is very little intensity variation within angles of approximately 90°.

The U.S. Navy Bureau of Ships has awarded a study contract for a display of this type. This is an interesting approach to a dynamic large-screen display, but it is too early in the development stage to determine with confidence whether it will be available and feasible for a 1970 system.

6.11 Electro-Chemical Displays

A number of display techniques based on electro-chemical phenomena have been investigated. Several electro-chemical devices are available in which the color, the opacity, or the reflectivity of liquids or solids are changed by the application of local voltage or current signals.

One approach uses reversible electroplating techniques. Each cell or spot on the display panel consists of an electrode in a silver solution. The silver can be plated or deplated on the surface of the electrode under the control of an electrical signal to give a reflective type display. Another approach uses a liquid in a honeycomb like structure where the pH of the liquid can be changed chemically by an electrical signal to provide selective color. Most of the devices of this type are ambient light viewing devices although some self-luminance devices are experimentally available.

One type of electro-chemical display that has been under development for several years is Electroflors.³⁰ These use liquid phase materials

that either exhibit fluorescence or change color when activated by electrical signals. Three elements comprise Electroflor liquids - carriers, indicators, and activators. Basically, an electric potential across two electrodes emersed in an Electroflor liquid sets up an ion unbalance that causes color change. The ions represent a localized increase in pH of the solution that results in a color change in the pH sensitive indicator. A reverse polarity current can be used to neutralize the color. This action is relatively slow requiring approximately 1 millisecond to provide a useable color change. Such cells have inherent storage. It takes several minutes for diffusion effects to dissipate the color indication.

Individual Electroflor cells have been built but the most promising approach from the standpoint of large screen displays is a matrix selection technique in which a matrix of horizontal and vertical electrodes are used with each cross-over corresponding to a spot or display element. An experimental display with 120 lines in each direction of the matrix has been constructed under an Air Force contract. This experimental project uncovered problems with smearing of the image by spurious side currents from surrounding electrodes. Further investigation revealed that these effects can be overcome by the use of anodic electrodes which act as rectifiers. However, the use of anodic electrodes made it impossible to erase the image electrically. The image will decay and fade with time, but this seriously affects the speed of the display if it is necessary to change the image frequently. Selective colors can be produced that are visible under bright ambient light.

Electroflors and other electro-chemical displays are of interest for the long-range future, but it is unlikely that they will be developed to a sufficient point for use in a 1970 system.

6.12 Laser Display Systems

The use of lasers to evaporate opaque material on a glass slide in an inscribing type display and the use of ultraviolet lasers to write on photochromic material have been covered in previous discussions. However, lasers have the potential of being used in other ways that offer promise for future large-screen displays.^{31, 32, 33} For example, a laser beam may be used to write directly on a large luminescent screen. This is somewhat equivalent to an "outdoor" cathode-ray-tube in which the laser beam replaces the electron beam and the luminescent screen replaces the phosphor coating on the face plate of the tube. This offers advantages over a CRT in that a vacuum is not required and a large-screen image can be generated directly.

The major development problems associated with laser displays are:

Obtaining sufficient power at the desired wave length to provide adequate luminance at the desired color, and

Obtaining deflection and intensity modulation devices with sufficiently fast response to provide the necessary resolution.

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The nature of these development problems can be illustrated by considering the raster scan type of presentation (the random positioning method offers higher luminance but requires equally fast modulation response). The luminance L on a screen of area A and gain G provided by a laser of output power P_λ at wave length λ for which the luminous efficiency is E_λ is given by

$$L = \frac{680 P_\lambda E_\lambda G}{A}$$

L is in foot lamberts if A is in square feet. Assuming a screen of $G = 2$ and $A = 100$ square feet, a laser for which $P_\lambda = 1$ watt, $\lambda = 550$ mu (for which $E_\lambda = 1$) the luminance L is 13.6 foot-lamberts. While this luminance is comparable with the open gate screen brightness of the average motion picture theatre, it should be recalled that the most powerful laser available today, operating at $\lambda = 633$ mu (for which $E_\lambda = .25$) has a power output on the order of .05 watts rather than 1 watt. With these values of P_λ and E_λ , and with $A = 100$ square feet and $G = 2$ as before, the luminance is only 0.13 foot-lamberts.

To provide a resolution of 1 part in 1000 along each of the two axes of the screen at a flicker-free rate in the order of 30 cycles requires a horizontal deflection sawtooth frequency of 30KC for deflection and an intensity modulation square wave response of 30MC. These requirements are not believed to be within the current state-of-the-art in lasers. Hence, improvements in power and efficiency available from lasers at the desired wave lengths (particularly ultraviolet) and adequate laser deflection techniques must be developed before laser-controlled luminescent screen displays will be feasible.

Binary digital deflection of lasers by crystals has been satisfactorily demonstrated for 256 positions in each direction, but 1024 positions in each direction are needed for a practical display system.³⁴ The results accomplished to date indicate an 85% to 90% transmissivity of light through the deflectors. Calcite and Sodium Nitrate are the two crystal materials that have been used for deflecting laser beams. Deflection angles are in the order of 6% to 8% for each crystal.

A recently-developed display panel appears very attractive for use with an ultraviolet laser in a system similar to that described above. This panel provides an electroluminescent screen controlled by a variable impedance dielectric material. The exact nature of this material is proprietary and has not been disclosed in detail. This variable impedance material is used in series with the electroluminescent material between the plates of a capacitor formed by two thin-film electrodes. The result is a four layer panel (a thin-film electrode, the variable impedance material, the electroluminescent material, and another thin-film electrode) in which the impedance material layer controls the voltage across the electroluminescent layer. Hence, the energizing of the electroluminescent layer can be controlled by changes in the impedance layer since the energizing voltage is applied across the series combination of impedance layer material and electrolumines-

cent material. The impedance of the material is changed by ultraviolet and infrared light. An image can be written with an ultraviolet light and erased with an infrared light.

The variable impedance material does not provide an on-off type storage but has a finite decay time -- up to approximately two hours. A very interesting property of this display panel is that the decay time is a function of the frequency of the supply voltage across the electrodes. The image is actually stored in the impedance layer which controls the electroluminescent layer. Changing the excitation frequency does not change the stored image but rather changes the effect of the impedance layer on the electroluminescent layer. This type of display media has some interesting possibilities from the standpoint of Navy applications. For example, a display could be viewed showing only the immediate real-time image, but historical data such as target track history could be recaptured by changing a switch setting to change the frequency. A dial controlling a continuous frequency range could permit varying the time period covered by the historical data linearly. The persistence can be varied from 5 or 10 seconds to 1 or 2 hours.

This display panel is a proprietary development by one company and very little information has been released on it to date. Apparently, effort has been concentrated on the panel itself with little work yet on the development of a display system using the panel. It is necessary to develop methods of addressing, writing, and erasing. One possibility is the use of an ultraviolet laser beam for writing and an infrared laser for selective erasure. The screen could be flooded with infrared for complete erasure. It appears that the display panel can be developed satisfactorily, but that the feasibility and the timing of its use in a high-speed real-time display system depends upon developing ultraviolet lasers and the ability to adequately control the deflection of a laser beam. Addressing and writing could be accomplished with a servo-controlled ultraviolet optical system, but this would limit the speed to approximately that of mechanical inscribers discussed previously.

6.13 Three-Dimensional Displays

Some types of applications have lead to an interest in the development of a three-dimensional display. There are two major types of three-dimensional displays. The first are volumetric displays that use intersections (e.g., of light beams, of fine wires, etc.) in three-dimensional space to produce light at the intersection points.³⁵ The second are illusory displays in which the illusion of three dimensions is produced on a two-dimensional screen by techniques such as the viewing of stereoscopic pairs.³⁵ Approaches that have been investigated include:

The use of a three-dimensional wire matrix grid in a gas-filled tube to produce localized glow discharges at selected grid intersections.³⁶

A "fish-bowl" tank of clear, colorless Electroflor liquid with a fine mechanically-controlled electrode (probe) moving through

the liquid forming a colored trajectory.³⁰

A cathode-ray-tube mechanically oscillated in the axial direction with axial position information synchronized with the axial displacement.

A projection cathode-ray-tube optically projecting an image onto a rotating or oscillating screen with the image position synchronized with the screen motion.

Stereoscopic viewing of two direct-view storage tubes presenting stereoscopic pairs.

Holograms in which a gas laser is used to illuminate a specially-prepared photographic plate.³⁷

In general, the techniques listed above are limited to relatively small displays, have poor resolution, have poor light intensity, and are relatively slow. None of them are currently suitable for large-screen displays, nor have they been proven feasible on other than an experimental basis.

The hologram deserves special mention because it is a new and significantly different technology.³⁷ In preparing the photographic plate, a laser beam is used to illuminate the subject directly. The beam is also reflected onto the photographic plate by mirror to establish a reference. The coherent light establishes an interference pattern on the photographic plate which bears no visual resemblance to the subject. However, if the developed photographic plate is illuminated by a laser beam, a three-dimensional image of the subject is created. The laser beam passing through the hologram on the photographic plate creates the illusion of a three-dimensional reproduction -- even to the extent that moving the viewing point permits seeing around corners. No lens or optical system is required.

Holography is very interesting from the standpoint of long-range potential for three-dimensional displays. However, it has several disadvantages: long exposure time (e.g., 5 to 20 minutes), light inefficiency, and power requirements. Although holography is discussed here because of its potential long-range value, it is not expected to be feasible for use in display systems in the early 1970's.

6.14 Other Potential Display Techniques

There are a number of other possible techniques for achieving large-screen displays.³⁸ One of these is a research contract sponsored by the U. S. Navy Bureau of Ships to develop a low-voltage, high-resolution solid state display panel using electroluminescent diodes (injection electroluminescence). In this approach, the display panel would consist of an array of gallium-arsenide-phosphide electroluminescent diodes controlled by an array of silicon integrated circuit flip-flops.³⁹ Another approach uses a self-luminous gas matrix discharge panel with external storage. Other approaches that have been considered or investigated include gas-discharge matrices and matrices of mechanically-controlled moving elements. Of these approaches, only the use of a matrix of electroluminescent diodes controlled by a semi-

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conductor integrated circuit array is believed to offer promise for large-screen displays in the 1970 era. At present, it is too early in the development cycle to determine with confidence whether even this one will be feasible or economically competitive with other technologies discussed previously.

7. Conclusions and Recommendations For Display Hardware Technology

Existing cathode-ray-tube technology and continuing engineering improvements that can be anticipated will be adequate for console type displays and for image generation in the 1970's. Although some breakthrough may occur that will provide a better method of mechanizing consoles, there is no strong requirement for a new technology.

On the other hand, present approaches to large-screen displays are not satisfactory for naval tactical use and a new approach is needed for the mechanization of large-screen displays during the 1970's. Several technologies presently under investigation and development offer promise of meeting these needs. Present approaches to large-screen displays are primarily electromechanical and photographic in nature. Such approaches may meet performance requirements, but they are not well suited to meeting the operating conditions for naval tactical equipment -- particularly environmental conditions, ruggedness, reliability, maintainability, and logistics requirements. Approaches are needed that offer relatively long life, that involve a minimum of mechanical parts and motions, that are easy to maintain, and that do not require the use of expendable media or processing chemicals that pose difficult logistics problems.

Several technologies offer promise for new large-screen displays meeting the requirements of naval tactical applications. The following are the most promising that are believed to be feasible by 1970:

- Photochromic displays with cathode-ray-tube or laser image generation
- Thermoplastic and photoplastic light valves with cathode-ray-tube or laser image generation
- Crossed-grid electroluminescent displays with integrated storage
- Laser inscribing systems.

Several additional technologies under investigation offer promise, but at this time it is too early in their development to predict whether or when they will be feasible. These include:

- Solid-state light valves
- Opto-magnetic displays
- Electro-chemical displays
- Laser/luminescent (or electroluminescent) displays.

Of this latter group, laser/luminescent displays are particularly attractive, but their feasibility depends upon the development of

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adequate power lasers in the proper frequency range and the ability to cheaply deflect laser beams with high resolution. These will be developed but it is not certain that this will occur by 1970. Injection electroluminescent matrix displays using light-emitting diodes also appear promising for some time after 1970. These approaches should be followed closely in the event that further research and development prove that any of them will be feasible for 1970 era systems.

Some of the technologies recommended for large-screen displays may prove applicable to console displays as well. Although there is less pressure for a new technology for consoles since present cathode-ray-tube technology can provide the necessary characteristics, other approaches should be followed carefully in the event that any develop to the point that they are more desirable or advantageous than cathode-ray-tubes for console displays. For example, crossed-grid electroluminescent displays with integrated storage are one of the techniques that offer promise for large-screen displays. Since this is an all-solid-state approach that provides image generation inherent in the display itself, smaller, higher resolution panels might also be useful for console displays. There is probably little reason for considering any of the technologies that require a cathode-ray-tube for image generation for use in consoles since the cathode-ray-tube can be viewed directly.

In considering future large-screen displays, it is necessary to consider not only the display presentation viewed by the user, but also the method of image generation required, the method of addressing and selecting individual positions on the display screen, and the required interface with the computer. For example, systems based on cathode-ray-tube image generation are basically analog in nature while other techniques, such as crossed-grid electroluminescent display panels, are strictly digital. An approach that is basically digital in nature will be more desirable from the standpoint of computer interface, reproducibility, and maintainability. However, this is not an overriding consideration since some of the analog approaches may be more desirable in terms of cost or complexity.

It is essential that the final selection of a display technology be closely coordinated with the determination of user functions and software implementation.

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8. Sources of Information and Reference Bibliography

Organizations Contacted

Display techniques and systems have been discussed with personnel of a number of different companies and governmental agencies in the course of this study. The following list indicates the companies and governmental agencies with whom display technology has been discussed and the type of displays discussed with each:

Bunker-Ramo Corporation Canoga Park, California	Light-valve displays Continuous-strip photographic projection displays CRT displays
General Dynamics/Electronics San Diego, California	Charactron CRT displays Light-valve displays
General Telephone Laboratories Bayside, Long Island, N. Y.	Continuous-sheet electrolumines- cent displays with XY matrix addressing Acoustic/electroluminescent displays
RCA Laboratories Princeton, New Jersey	Ferroelectric displays
Laboratory for Electronics Boston, Massachusetts	Magnetic thin-film displays
NCR El Segundo, California	Electro-mechanical photochromic displays CRT-Photochromic projection displays
Sylvania Waltham, Massachusetts	Discrete alphanumeric character displays Continuous-sheet electro- luminescent displays with XY matrix selection
Stanford Research Institute Menlo Park, California	Magnetic thin-film displays Modulated crystal filter displays
Rome Air Development Center Rome, New York	Light-valve displays Modulated crystal interference- filter displays Thermo-plastic displays Laser displays

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USAER&DL Fort Monmouth, New Jersey	Photochromic displays Laser-luminescent displays Electroluminescent displays Fiber-optic CRT displays Lenticular film Photographic projection displays Display memories
U.S. Navy Bureau of Ships Washington, D.C.	Display equipment Display systems Photographic projection displays Lenticular film Light valves Electroluminescent displays CRT displays Large screen displays
Hughes Ground Systems Fullerton, California	Large screen displays Console type displays
U.S. Marine Corps, Bureau of Ships, Washington, D.C.	Tactical displays Large screen displays
Librascope Glendale, California	Libracote display panel

Discussions with personnel of these organizations provided a basis for much of the information presented in this report. In addition to discussing techniques and approaches that have not been adequately described in published literature, the opinions of experts in specific areas in these organizations were solicited concerning the advantages, disadvantages, limitations and future prospects for different display techniques.

Literature

An extensive list of references pertinent to the study of display technology is given in the Bibliography. A study of many of these references has contributed to the material presented in this report. Some of the more pertinent and important of these referred to in the text have been extracted from the bibliography and listed in this section as specific numbered references. These numbers correspond to numbered citations in the text. Direct quotations have been used where noted.

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