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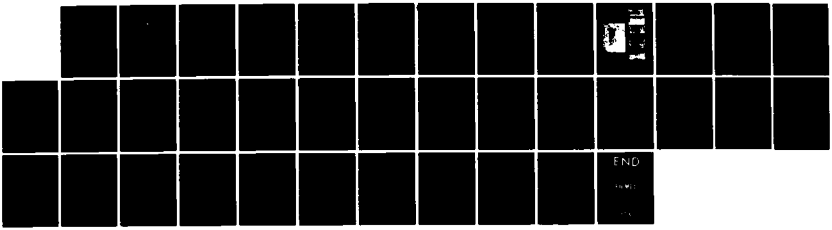

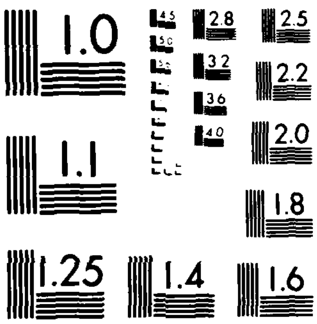
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REPORT NO. NADC-77212-30

AD-A149 692

VOLUME II
DEVELOPMENT OF A COLOR ALPHANUMERIC LIQUID CRYSTAL DISPLAY

Hughes Aircraft Company
El Segundo, California 90245

DECEMBER 1981

FINAL REPORT
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report encompasses efforts directed toward the development of a multicolor display suitable for aircraft command and control applications. The approach taken was to superimpose the images from two 175 x 175 element matrix liquid crystal displays using a dichroic beam splitter such that one display formed a red image while the other display formed a green

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image. The two displays were illuminated by a Xenon arc lamp and the combined image was projected onto a screen.

The resulting display presented red, yellow, and green symbology with high brightness (3300 fL for yellow), high contrast (14:1 for yellow), and good color purity (greater than 90% for all colors).

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SECTION 1

INTRODUCTION AND SUMMARY

The rapidly increasing complexity of aircraft avionic systems has resulted in a growing interest in the use of color for encoding information on visual displays. The advantages of the use of color to categorize information have long been recognized. However, the application of color displays to aircraft cockpits is, with some exceptions, still awaiting the development of a highly reliable, easily visible color display technology. The purpose of this effort, performed under contract number N62269-77-C-0477 for the Naval Air Development Center, was to construct an optical bench demonstration of a multicolored display using two projected liquid crystal matrix display modules.

Since the construction of the liquid crystal display is similar to devices previously developed, the design phase of this program concentrated on the selection, usage, and analysis of the optical projection system, with emphasis on the dichroic beam splitter required to combine the red and green images. Since the reflection/transmission characteristics of a beam splitter are sensitive to the angle of the incident light, the optical system had to be designed such that the angular deviation of the light beam passing through the beam splitter was held to a minimum to prevent objectional color shifts across the display surface. Figure 1a shows the resulting display demonstration system.

Each of the two liquid crystal display modules used on this program had a viewing area of 1.75 x 1.75 inches with a resolution density of 100 elements per inch. However, for compatibility with drive electronics available from a previous program, the displays were electrically connected with the columns connected together in pairs. Thus the effective resolution of each display is 88 by 88 elements, which is sufficient to present seven rows of ten characters. Each character may be selected from 128 ASCII or 256 pseudographic symbols. The ASCII symbols are formed by a 9 x 7 element matrix within a 13 x 8 element block. To form pseudographic symbols, the 13 x 8 element character block is divided into eight sub-blocks which can be individually addressed. The symbol color and the background color are specified independently for each character position.

Figures 1b, c, and d show typical images on the display screen. The defective lines visible on the display are caused by failures in the display modules or the drive electronics. Defect-free displays have been constructed on other, more extensive, development programs.

The goals of this contract were to demonstrate a high brightness, high contrast three color display with a two inch square image area. The performance of the demonstration unit is summarized in Table 1. The performance of this unit showed that the brightness requirements for a multicolor cockpit display can be met by a liquid crystal projection display system.

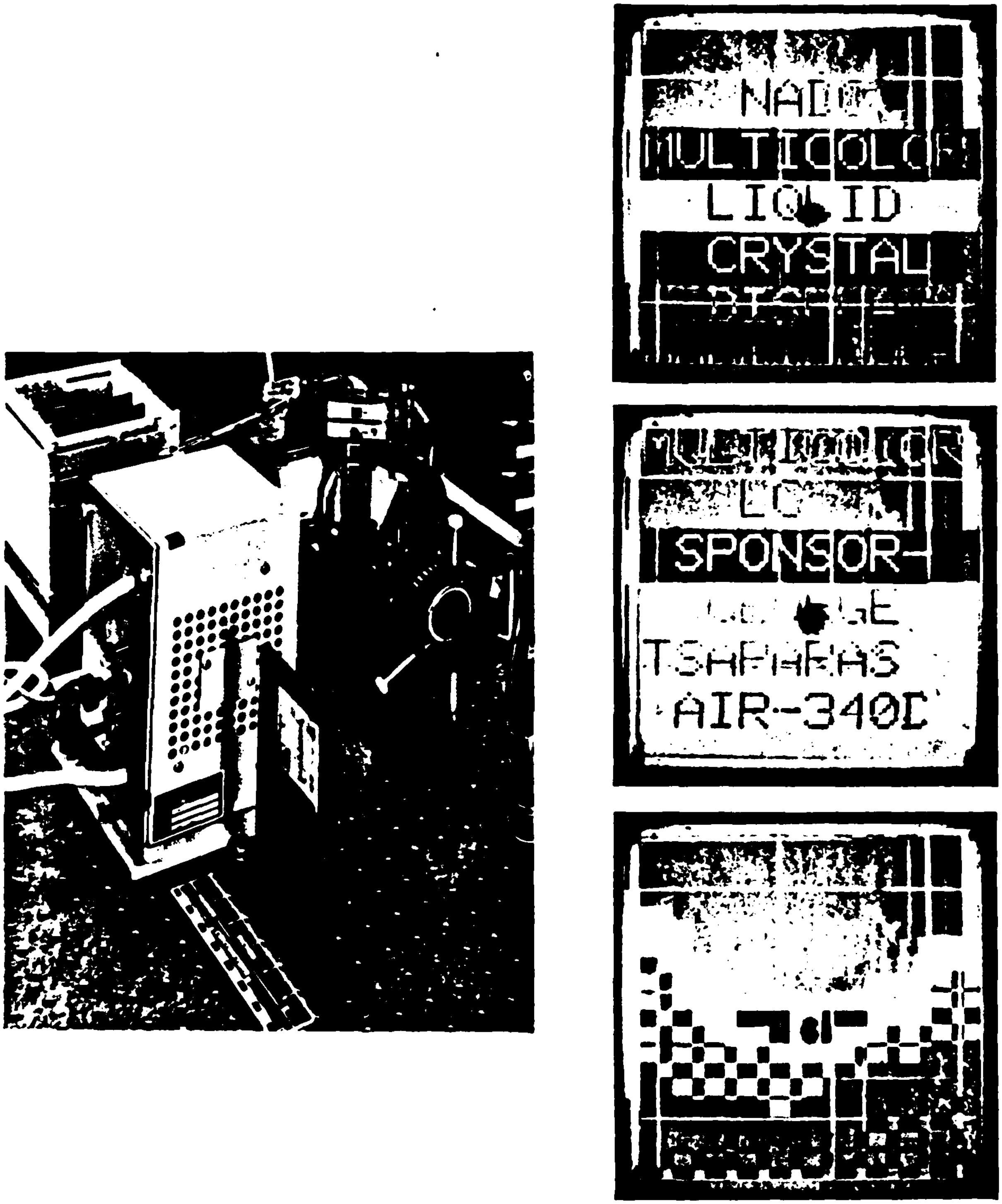


Figure 1. Color Display Demonstration Unit and Typical Images.

TABLE 1. TWO COLOR LXD DEMONSTRATION UNIT PERFORMANCE

Brightness, Foot Lamberts	
Red	1170
Yellow	3380
Green	2210
Contrast Ratio	
Red	5:1
Yellow	14:1
Green	9:1
Dominant Wavelength, nm	
Red	623
Yellow	575
Green	563
Color Saturation, %	
Red	100
Yellow	93
Green	91

SECTION 2

DESIGN

BASELINE TECHNOLOGIES

The matrix liquid crystal display technology dates to September 1973, when the first video liquid crystal display was demonstrated. A 100 x 100 element, one inch square, defect free device was built in June of 1975. In December of the same year, a two inch square "quad" display, constructed of four one inch chips, was demonstrated. In November of 1977, the first 175 x 175 element, 1.75 inch square display was completed. Two similar display devices were used in the two color display demonstration.

Figure 2 illustrates the construction of a matrix liquid crystal display. The liquid crystal material is sandwiched between a semiconductor chip and a cover glass coated with a transparent electrode. The surface of the chip is covered with an array of highly reflective electrodes. This chip also

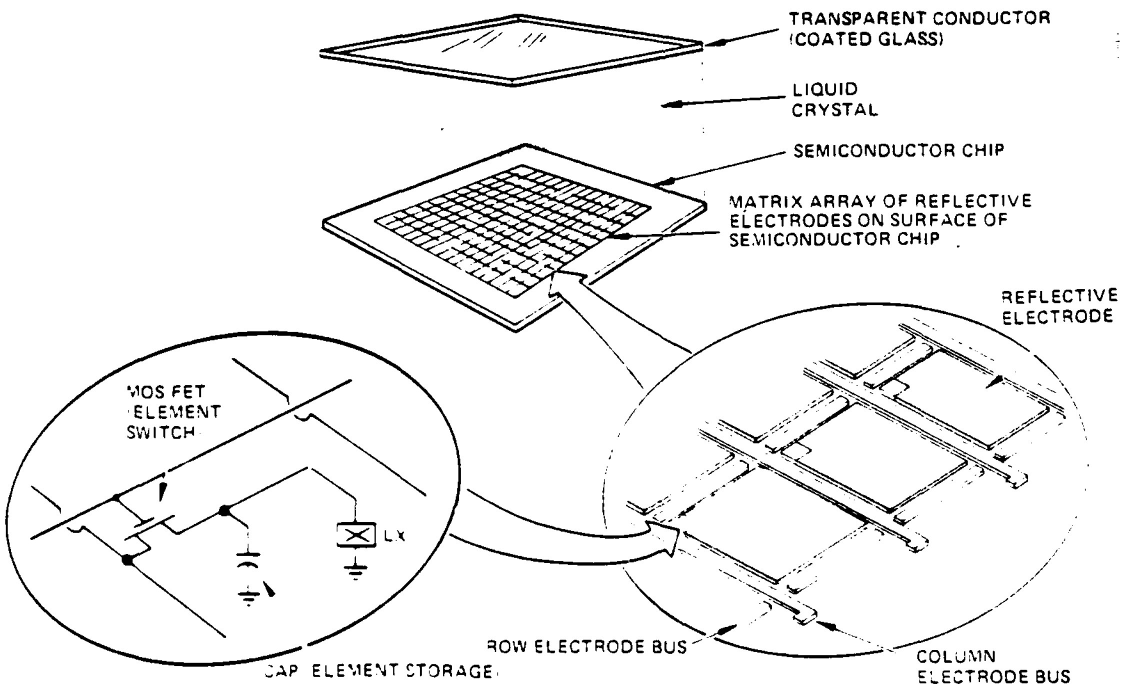


Figure 2. Liquid Crystal Display Module Construction.

contains one storage capacitor and one switching field effect transistor for each display element, in addition to row and column bus electrodes. Each column electrode connects to the drain of every transistor in its respective column. Similarly, each row electrode connects to the gate of each transistor in its corresponding row.

Line-at-a-time addressing is used to form an image on the display. To write one line, voltages proportional to the amplitudes of each element are placed on the column electrodes. A voltage is applied to the appropriate row electrode, the transistors conduct, and each elemental storage capacitor charges to the voltage applied to the corresponding column electrode. The storage capacitors hold sufficient charge to energize the liquid crystal layer until the row is rewritten through a 100 hertz refresh.

The liquid crystal material in the display described above modulates ambient illumination by dynamic scattering. With no voltage applied to the liquid crystal layer, the material is clear, and ambient light is specularly reflected from the mirror electrodes. With a voltage applied, the liquid crystal layer becomes turbid and scatters the reflected ambient light. Figure 3 illustrates the use of a dynamic scattering liquid crystal display in a projection system similar to the two-color display demonstration. Light which is specularly reflected by an unenergized element is gathered into a projection lens and appears as a bright area on a screen. On the other hand, scattered light from an energized element is virtually blocked by a small aperture in the optical system and appears as a dark area on the screen.

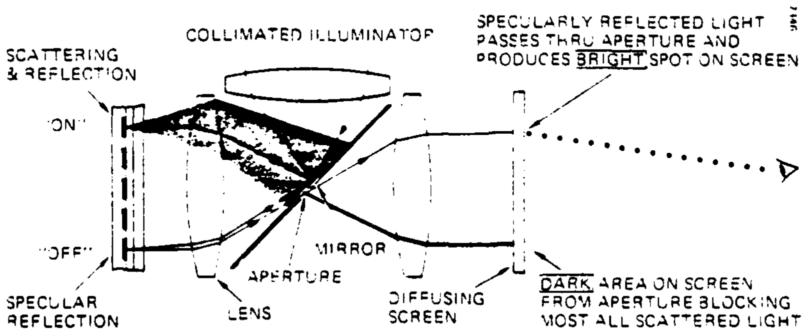


Figure 3. Basic Liquid Crystal Projection Display System

PROJECTOR DESIGNS AND LIMITATIONS

The projection system design chosen for the optical bench demonstration unit is shown in Figure 4. This design was selected because all of the optical components are located on the axis of the projection lens, and because it can be constructed using only off-the-shelf optics. Additionally, the incoming illumination to the display modules is collimated when it passes through the beam splitter. Thus, this design does not have any perceptible color shifts across the display area. However, this simple design has the disadvantage that the system aperture is located in the middle of the bending mirror where it causes a shadow on a small portion of the center of each display. Hence, a dark spot is visible in the center of the screen at all times.

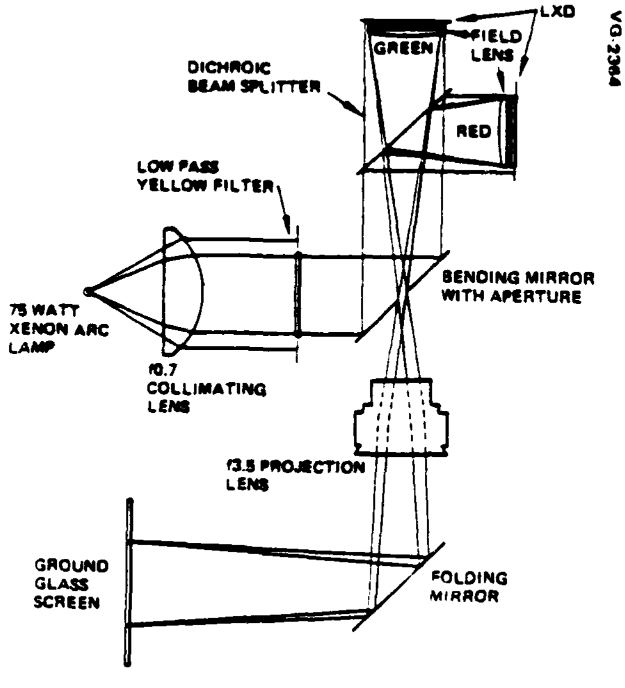


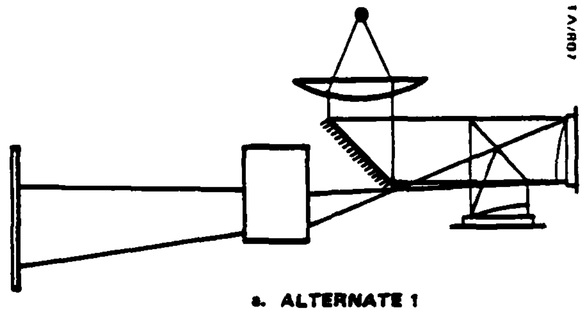
Figure 4. Optical Schematic of Color Display Demonstration Unit

Three other designs were considered which did not have this disadvantage and are shown in Figure 5. Each design, nevertheless, was rejected for other reasons. The first design (Figure 5a) required a low f-number projection lens whcih was not avaiable as an off-the-shelf item. The second design (Figure 5b) was successful in removing the dark spot while using only the off-the-shelf optics. Unfortunately, the converging and diverging beams passing through the dichroic beam splitter produced objectionable color shifts across the screen. The third design (Figure 5c) was similar to the preceding design except that the field lenses on each display were replaced by a single field lens placed before the beam splitter. Since only collimated light passes through the beam splitter, this design has no color shift across the display screen. However, the placement of the field lens caused noticeable distortions and abberations and increased the optical path length.

ELECTRONICS

As illustrated in Figure 6, the electronics required to generate an image on the multicolor liquid crystal projection display includes a simple symbol generator and video and sweep driver circuits. The symbol generator consists of two 2048 x 8 programmable read-only-memories which store character codes and color select information, a character generator read-only-memory which stores 128 alphanumeric and 256 pseudographic symbols, and appropriate timing and addressing logic.

The sweep driver LSI circuit, as illustrated in Figure 7, is simply a thirty-five bit serial input shift register with thirty-five buffered outputs. A start-of-frame sync pulse is applied to the Enable-In input. The circuit is clocked by the start-of-line sync pulse, and successive lines on the display are enabled as the Enable-In pulse propagates from stage to stage in the shift register. Five sweep driver LSI circuits are mounted on a single printed wiring board having provisions for attaching two flat capton cables to drive the two display modules.



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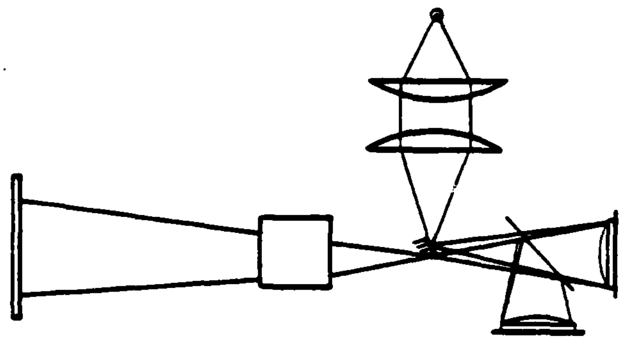

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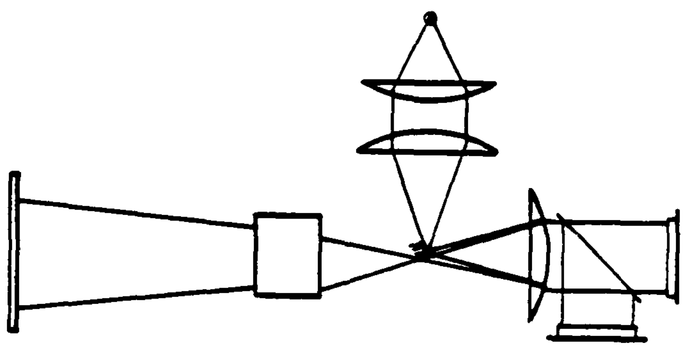

c. ALTERNATE 3

Figure 5. Alternate Two-Color Projection Display Designs

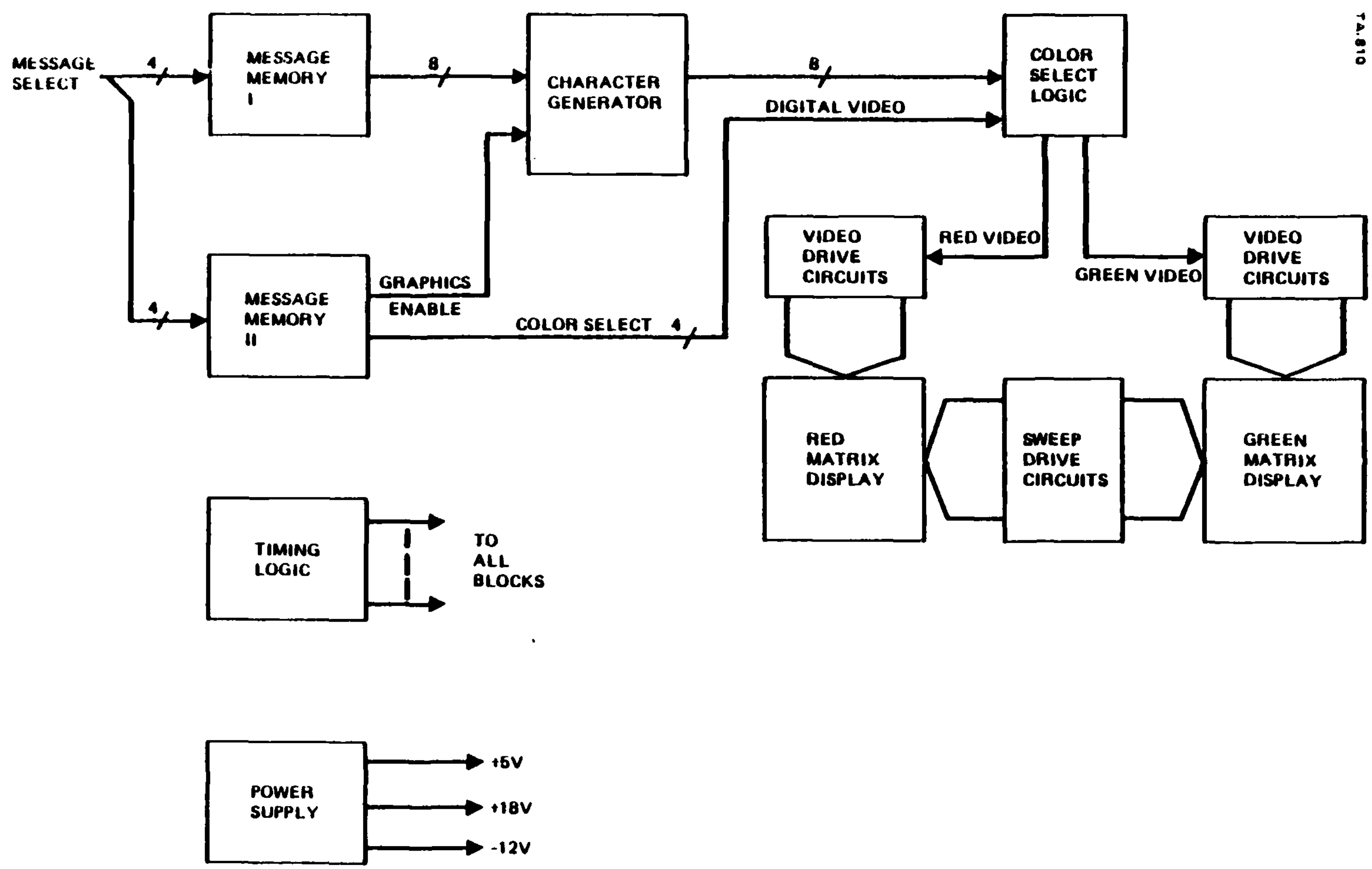

Figure 6. Two Color Display Electronic Block Diagram.

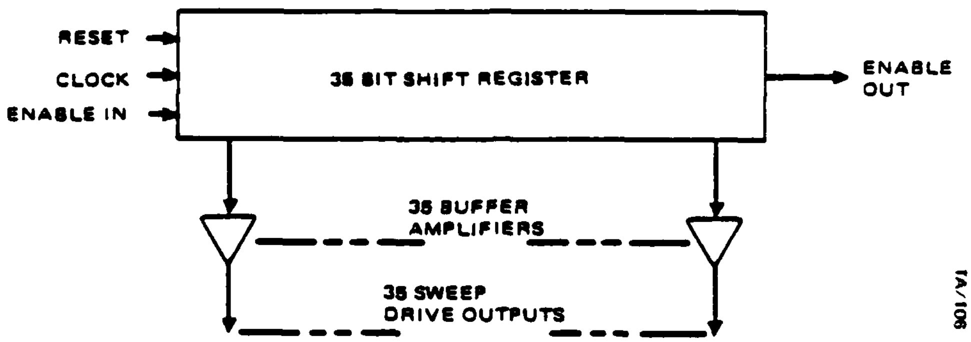

Figure 7. Sweep Driver LSI Circuit Block Diagram.

As illustrated in Figure 8, the video driver circuit design can be broken down into three functional areas: the shift register, the data storage, and the line drivers. The shift register serves to propagate an enable signal such that the video samples for each column of the display are taken at sequential time intervals. The sample data is stored in two banks of data bins: one bank accumulates the new line while the other outputs the samples accumulated for the previous lines. Switching between the two banks is controlled by a single flip-flop which is toggled by the start-of-line sync. The line drivers provide impedance matching: their high input impedance prevents discharging the voltage on the data storage capacitor while their low output impedance assures that the display responds properly to new signals.

Four LSI driver circuits, mounted on a wire wrap circuit card, were used to drive each display module. Since each LSI driver has 22 outputs, the 175 columns of each display were connected as 88 pairs.

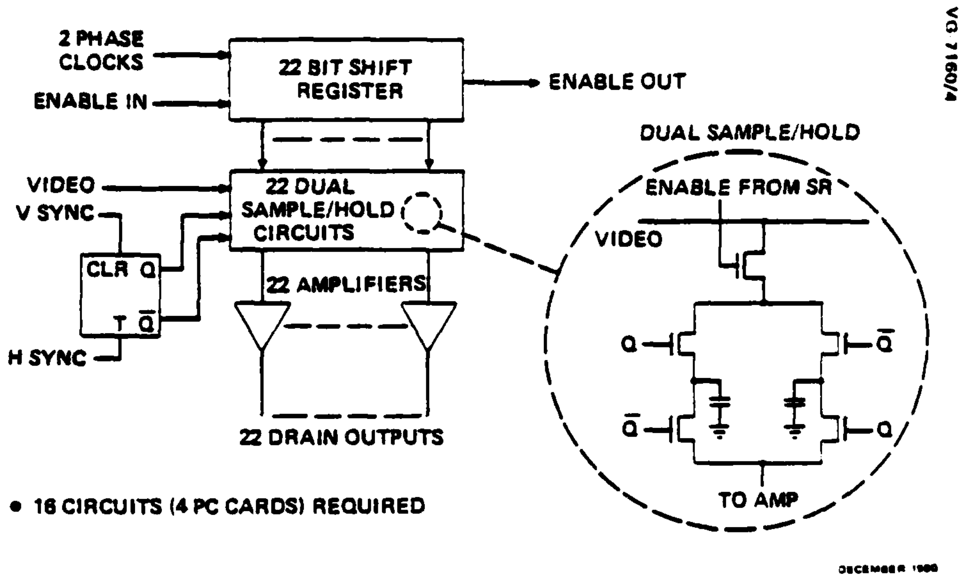

Figure 8. Video Driver LSI Circuit Block Diagram.

SECTION 3

OPERATION AND PERFORMANCE

OPTICAL LAYOUT

Figure 4 shows, to scale, the actual optical layout of the projector system used in the demonstration unit. Seven basic elements in the design are discussed in detail in this section: (1) the xenon arc lamp and collection optics, (2) the low-pass yellow filter, (3) the bending mirror with aperture, (4) the dichroic beam splitter, (5) the liquid crystal display modules with field lenses, (6) the projection lens, and (7) the ground glass screen.

Xenon Arc Lamp and Collection Optics

The xenon arc lamp is a relatively flat, white light source as compared, for example, to a mercury source with strong peaks at 436 nm, 546 nm, etc. Figure 9 compares the two sources. The arc lamp used was a 75 watt (operated at about 13 volts and 6 amps) XBO-75W made by Osram. The bulb was contained in a laboratory lamp house which contained an f0.7 condensing lens system. The source was collimated and directed through the filter opening.

Low-Pass Yellow Filter

A two-inch square yellow filter was placed in front of the collimated beam in order to eliminate the UV and blue parts of the incoming xenon spectrum. Figure 10 shows the actual change in spectral radiance as a function of wavelength between the arc lamp with and without the filter. The cutoff wavelength of the yellow filter is 495 nm which produces a yellow with a dominant wavelength of 570 nm and a purity of 93 percent. The selection of the proper yellow filter was dependent on the 50-50 cutoff wavelength of the dichroic beam splitter and brightness considerations. The colorimetry of the system is explained in part 3 of this section.

Bending Mirror with Aperture

As previously explained, an aperture is required in a dynamic scattering liquid crystal projection system to increase the contrast between the reflecting and scattering states of the displays by effectively blocking scattered light.

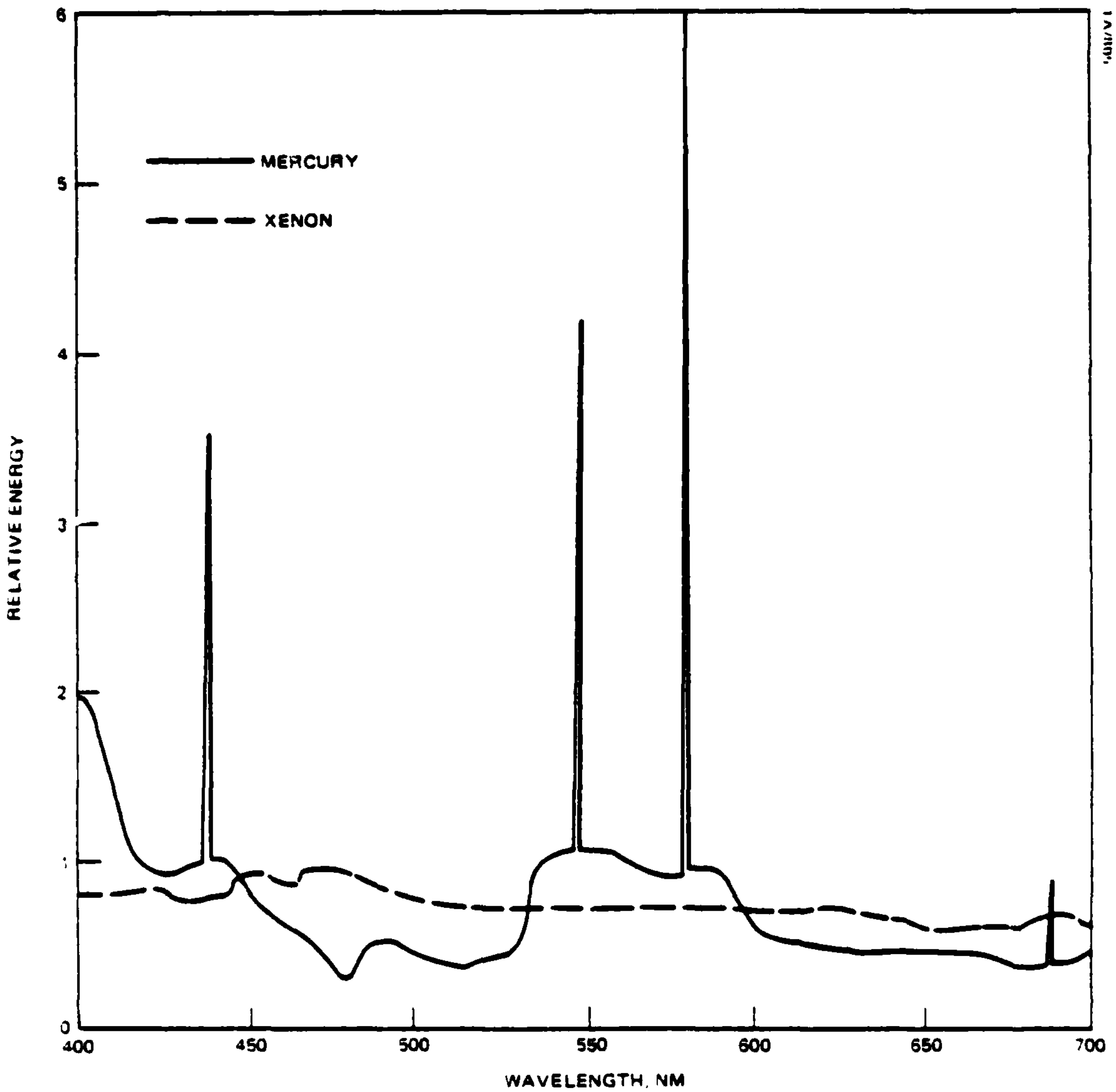

Figure 9. Spectrum of Xenon and Mercury Arc Lamps.

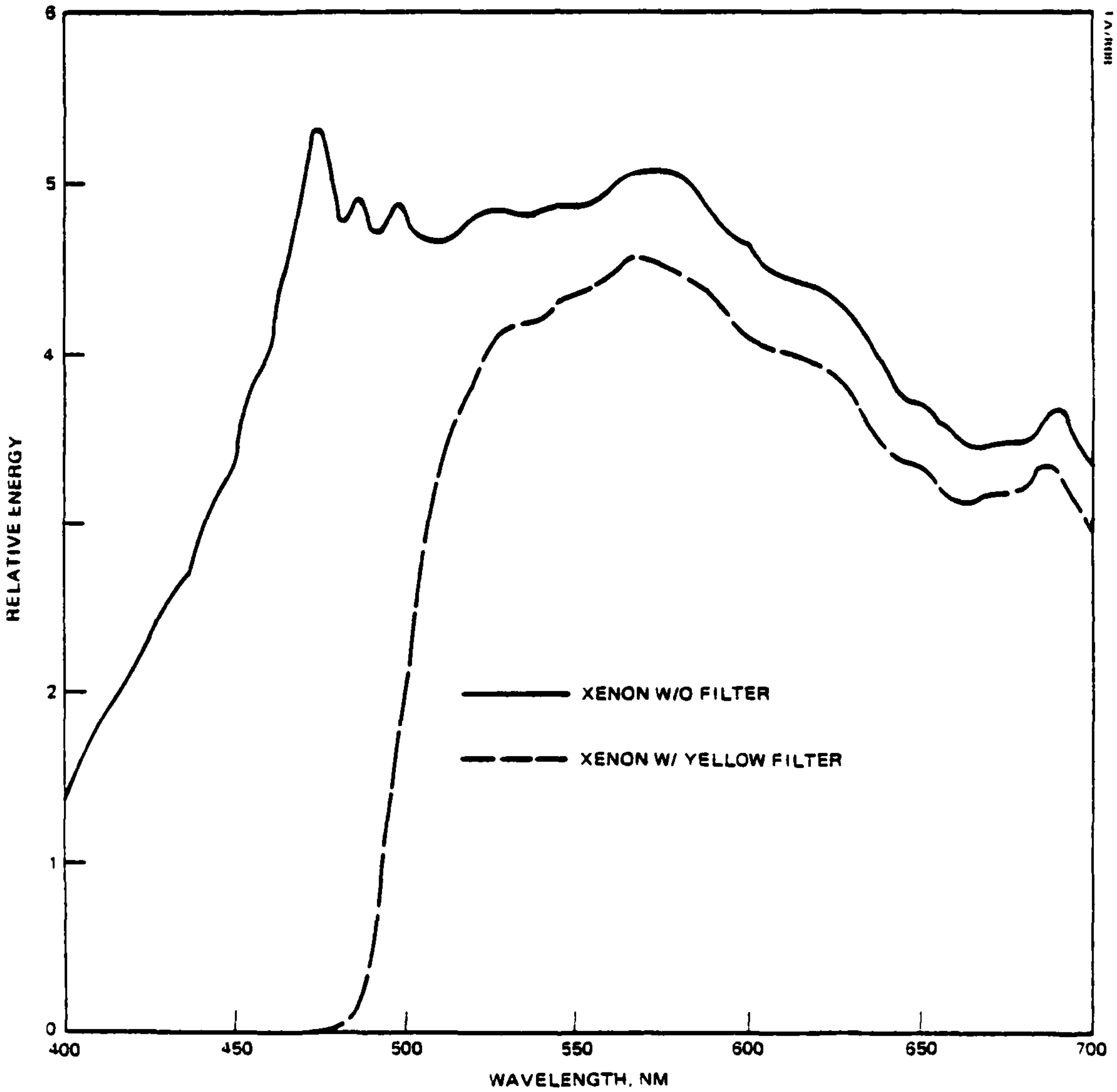

Figure 10. Spectral Distribution of Xenon Lamp after Filtration.

The size of the aperture was determined by test data which showed that an angular aperture of two degrees is needed for high contrast ratios. As illustrated in Figure 11, the shape of the aperture was selected to be a 45 degree ellipse since the aperture was at an angle of 45 degrees with respect to the cone of converging light.

Dichroic Beam Splitter

In the two-color LXD demonstration unit, the incident yellow light must be divided into two primary colors (red and green), and then recombined with minimal losses. An all-dielectric color-selective beam splitter (dichroic) was chosen because it was practically lossless (on the first pass) and the transition wavelength could be selected at will. These types of beam splitters

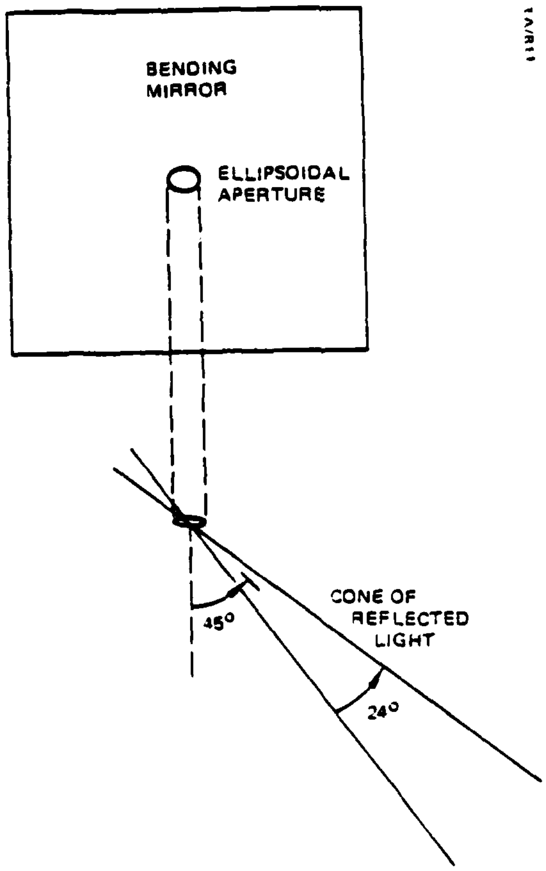

Figure 11. Aperture Geometry.

are essentially cut-off color filters which transmit a given range of the visible spectrum and reflect the rest and are designed to be used at 45 degrees incidence. In the demonstration unit the incident yellow light was divided by the beam splitter into a transmitted green (about 500 to 600 nm) and a reflected red (about 600 to 700 nm) onto two LXD's. The modulated light was reflected off the displays and recombined by the beam splitter into areas of yellow, green, red, and black. The colorimetry and analysis of the dichroic beam splitter is discussed in part 3 of this section.

Liquid Crystal Displays and Field Lenses

In the optical path the LXD's can be thought of as a matrix of mirrors which either reflect or do not reflect. The reflectivity of each display is dependent upon the materials used for the mirror matrix. In the demonstration unit the display modulating the red light had an aluminum mirror matrix with a reflectivity of 60 percent, and the display modulating the green light had a chromium mirror matrix with a reflectivity of 35 percent. The reason two different reflecting displays were used was to produce the sufficient color contrast between yellow and green with the dichroic beam splitter used. This is discussed in more detail in part 3. The 300 mm focal length field lens on each display was used to converge the specularly reflected light through the aperture in the bending mirror. Since the lenses were placed close to the image plane (less than 0.25 inch), the distortion in the image caused by the lenses was minimized. Nonetheless, the spherical and chromatic abberations of these simple lenses increased the spot size at the aperture. If this system were redesigned with custom lenses, the field lens on the green display module would have a slightly longer focal length than the lens on the red module to correct for chromatic abberations.

Projection Lens

After passing through the aperture, the light was directed into the projection lens on axis. The projection lens used was a f3.5, four-element, off the shelf achromatic and anastigmatic lens. All lenses were anti-reflection coated. The focal length was five inches.

Ground Glass Screen

A high-gain ground glass, rear-projection screen was used to increase the brightness of the image. Brightness non-uniformities across the image occur due to the angular variation of the rays striking the screen. Table 2 lists the angular dependence of the screen gain (with respect to an ideal lambertian diffuser) as a function of viewing angle. The actual angular range of the image was designed to be about 0 ±3 degrees, and hence, the brightness non-uniformity across the screen was predicted to fluctuate no more than 30 percent.

PERFORMANCE

The projection system design allowed the magnification of the image to be adjusted between two limits. At high magnification the image was 2.5 inches across (compared to the LXD which is 1.75 inches across), and at low magnification the image was 2.25 inches across. In both cases the brightness (and contrast ratio with respect to the black state) was measured at three positions across the screen. This data is presented in Table 3.

TABLE 2. GAIN OF GROUND GLASS SCREEN AS A FUNCTION OF VIEWING ANGLE

Angle*	Gain
0	15.4
1	14.6
2	13.5
3	11.9
4	11.3
5	9.4
10	4.2
15	1.5
20	0.6

*Degrees from normal.

TABLE 3. OPTICAL PERFORMANCE VERSUS SCREEN POSITION

Low Magnification Brightness (Contrast Ratio)			
Color	Left Side	Center	Right Side
Yellow	3250 (11:1)	4120 (13:1)	3200 (12:1)
Red	910 (3:1)	1420 (5:1)	1140 (4:1)
Green	2340 (8:1)	2700 (8:1)	2060 (8:1)
High Magnification Brightness (Contrast Ratio)			
Color	Left Side	Center	Right Side
Yellow	2750 (12:1)	3380 (14:1)	2980 (10:1)
Red	800 (4:1)	1170 (5 :1)	1100 (4:1)
Green	1950 (8:1)	2210 (9:1)	1880 (6:1)

The spectral distribution of the colors at the screen was also measured and is shown in Figure 12. The dominant wavelengths and purities of the green, red, and yellow are given in Table 4.

COLORIMETRY

One of the main objects of the two color LXD demonstration unit was to show three bright, distinct colors. Two of the colors were considered the primary colors, red and green, and the other color was the mixture of the two, yellow. A fourth state, black, was also possible as it was the absence of the two primary colors.

Color Characteristics

In order to get distinct colors, their respective dominant wavelengths had to be as widely separated as possible, and their respective purities had to be as high as possible. The dominant wavelength of a color is defined as the wavelength in the visible spectrum that, when additively mixed in suitable proportions with a specified achromatic (white) color, yields a match with the color desired. In the calculations of this section, the achromatic color was assumed to be produced by illuminant standard C (daylight) since the

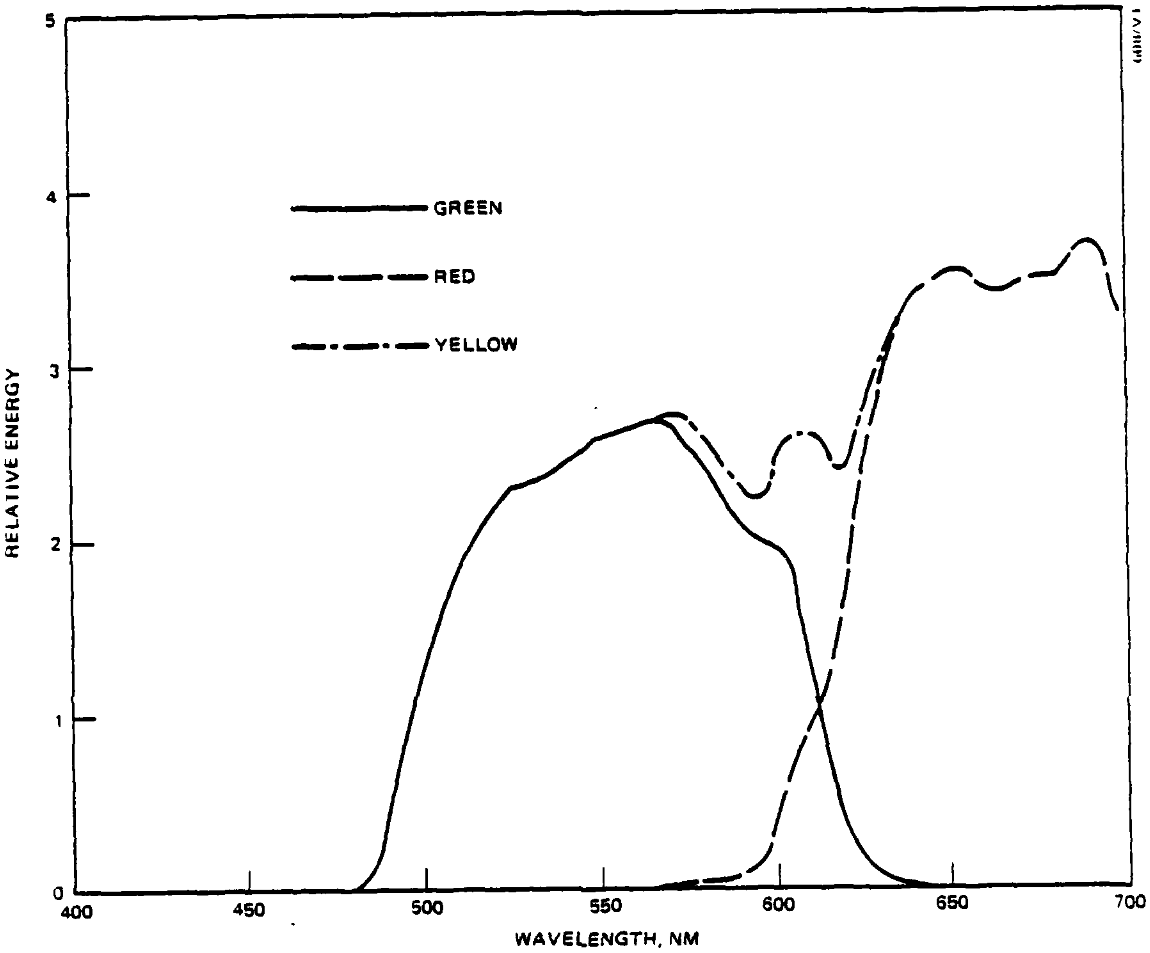

Figure 12. Spectral Distribution of the Colors on the Screen.

TABLE 4. DOMINANT WAVELENGTHS AND PURITIES OF COLORS AT SCREEN

Color	Dominant Wavelength, nm	Purity, Percent
Green	563 ± 2	91
Yellow	575 ± 2	93
Red	623 ± 2	100

usage of this type of demonstration unit would be inside an airplane cockpit. The purity of a color is defined as the ratio of two lengths on the chromaticity diagram. The first length is the distance between the point representing the chromaticity of the specified achromatic color (illuminant C) and that representing the chromaticity of the color considered. The second length is the distance along the same direction and in the sense from the first point to the edge of the chromaticity diagram (the coordinates of the dominant wavelength). Purity, in other words, gives a measure of the saturation of monochromatic color in the white light background of the color sample. Figure 13 shows the chromaticity diagram with the coordinates of the measured LXD colors and areas that give standard colors.

In the demonstration unit, the main element in setting the colors was the dichroic beam splitter. Due to its high cost, only one was purchased, which then dictated the cut-off wavelength between the red and green. Figure 14 shows the spectral transmission and reflectivity of the beam splitter as a function of wavelength. At 45 degrees incidence the 50-50 cut-off wavelength between red and green was measured to be 615 nm. Unfortunately, the desired cut-off was 600 nm. The affect of this 15 nm shift toward the red was to dim the red output and to increase the dominant wavelength of the green toward the yellow.

In order to readjust the dominant wavelengths to get the necessary color contrast between green and yellow, two other degrees of freedom were changed: (1) the yellow input filter and (2) the reflectivity of the green display module. The purpose of the yellow filter was to set the dominant wavelength and purity of the yellow and green. (The red characteristics were set by the beam splitter.) Increasing the cut-off point of the yellow filter causes the dominant wavelengths of the yellow and green to increase but not to separate. Therefore, the yellow filter was selected on the basis of producing the best color characteristics of the green.

With the filter selected, the dominant wavelength of the yellow was then shifted upwards by placing a neutral density filter into the path of the green light. This effectively decreased the percentage of green light to red light in the yellow mixture and increased the dominant wavelength of the yellow.

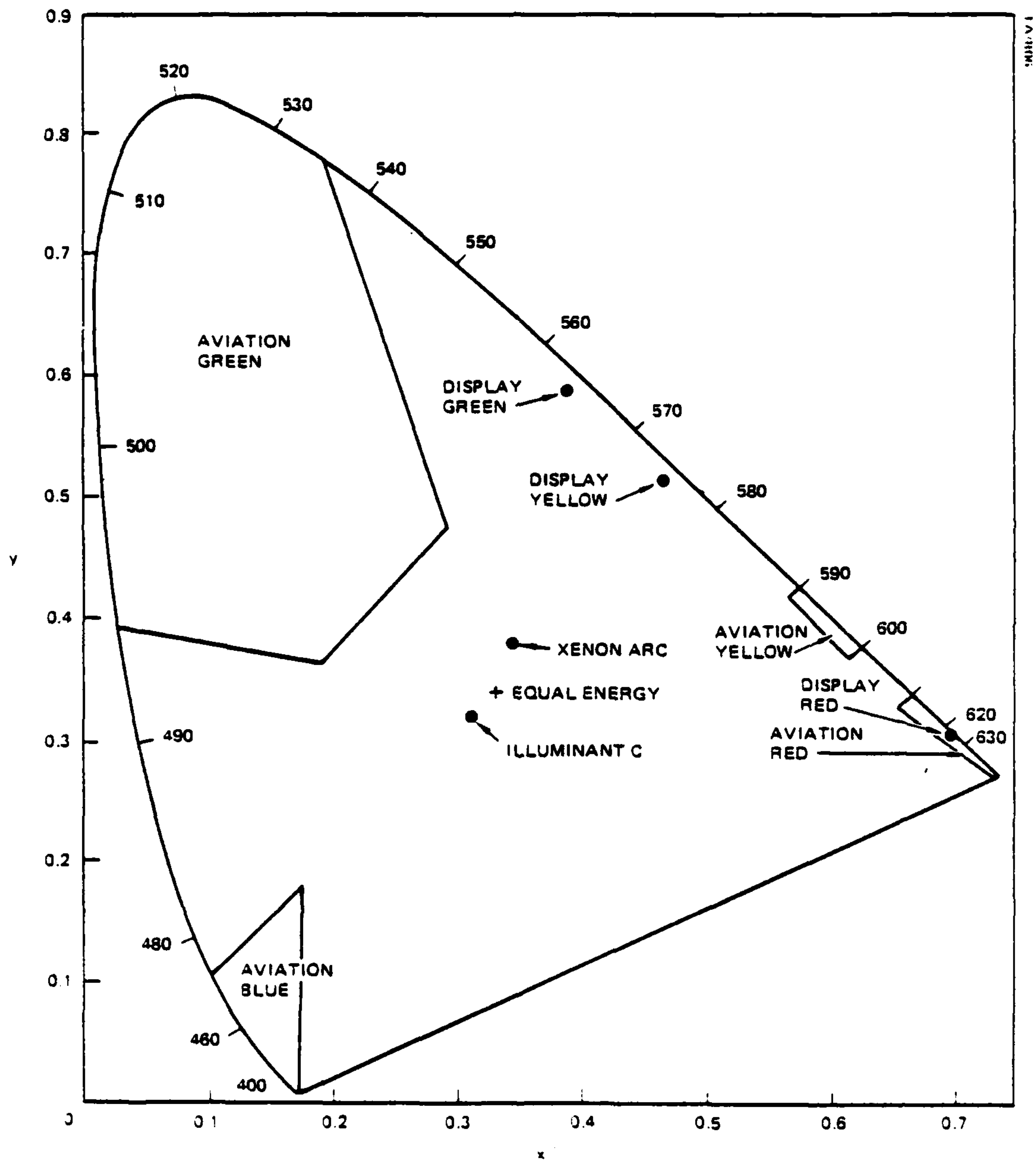

Figure 13. Chromaticity Diagram Showing Location of Display Colors.

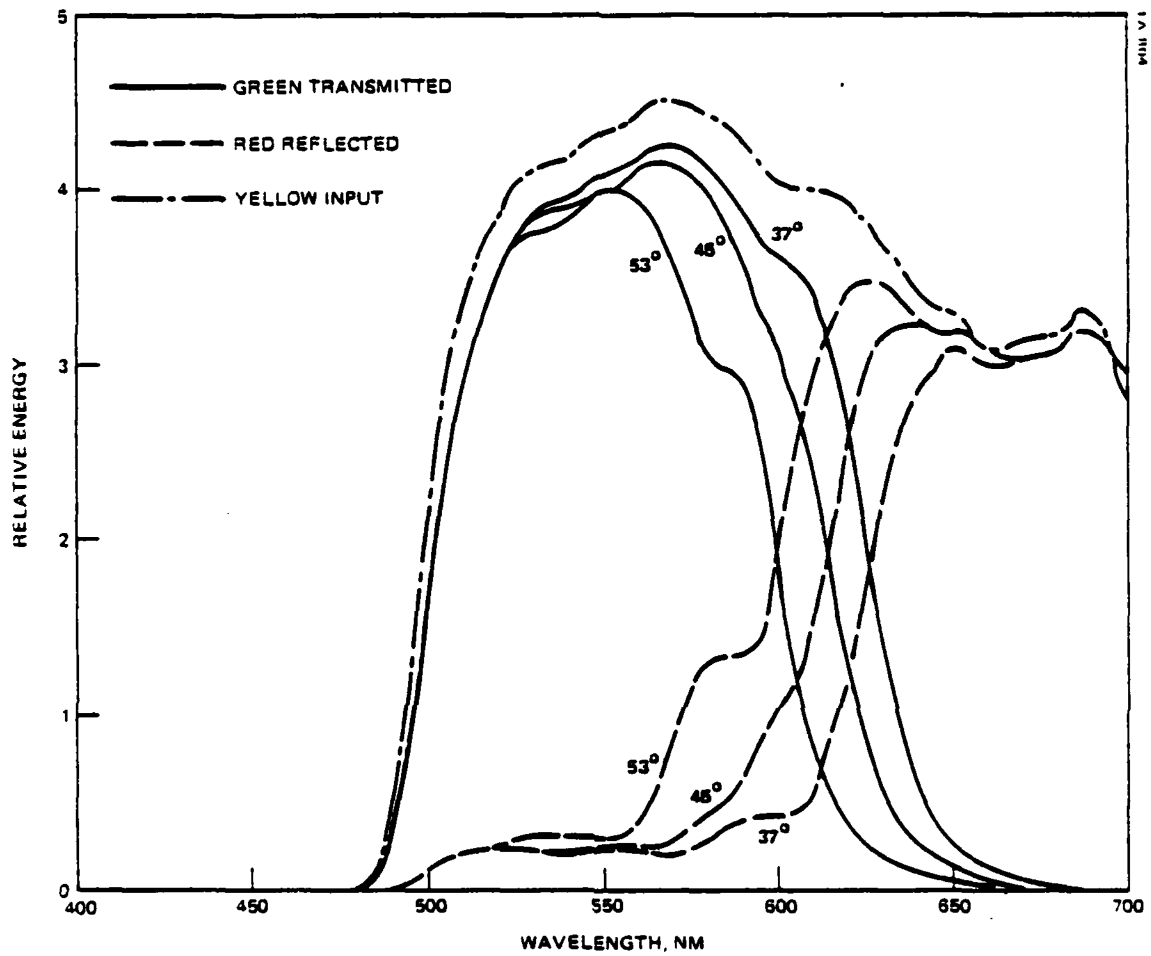

Figure 14. Beam Splitter Characteristic as a Function of Angle.

The action of the neutral density filter did not change the color characteristics of the green, even through the brightness of the green (and hence the yellow) decreased. Finally, the neutral density filter was eliminated by using a chromium-reflecting display which reflected less than the aluminum-reflecting display used in the red channel.

As was illustrated in Figure 13, the chromaticity coordinates of the yellow and green colors did lie within the standard areas. The required colors cannot be obtained by simply splitting the output from a broadband light source into two components. One must either develop an arc lamp with the proper green and red spectral lines, or a special subtraction filter (cutting out approximately 560 to 590 nm) must be used on a flat source to separate the green from the red. Nevertheless, the colors on the screen of the demonstration unit are easily distinguished.

Color and Brightness Uniformity

The dichroic beam splitter used in the demonstration unit is intended to separate red and green illumination when placed in a collimated beam incident at 45 degrees. In the demonstration unit the incoming collimated beam strikes the screen at 45 degrees, but the light reflected from the display modules is focussed by the field lenses into a 16 degree diameter cone. Thus the angle of incidence of the reflected light on the second pass through the beam splitter varies with position on the display surface. Light reflected from the left edge of the green display module (corresponding to the right side of the projected image) strikes the beam splitter at 53 degrees; light reflected from the right edge of the module strikes the beam splitter at 37 degrees. Since the transmission/reflection characteristics of the dichroic are dependent on incident angle, these angular variations cause slight, but detectable, variations in both brightness and dominant wavelength across the width of the projected image.

The transmission/reflection characteristics of the beam splitter were measured at 37, 45 , and 53 degree incidence and the results were used to calculate the variations across the projected image. Table 5 lists the calculated dominant wavelength, purity, and relative brightness of each color as a function of screen position.

REGISTRATION

The demonstration unit optical system was designed so that the images of the red and green display modules were superimposed on the projection screen. This was accomplished by making sure the virtual image of the red display folded over perfectly onto the green display. The importance of registration was clear when yellow characters were presented on a black background, where both displays were generating the same characters. Without proper registration, the yellow characters appeared multicolored and shadowed. Proper

TABLE 5. CALCULATED COLOR CHARACTERISTICS AS A FUNCTION OF SCREEN POSITION

Dominant Wavelength			
Color	Left Edge	Center	Right Edge
Green	564 nm	562 nm	558 nm
Red	625 nm	621 nm	617 nm
Yellow	575 nm	575 nm	573 nm
Purity			
Color	Left Edge	Center	Right Edge
Green	92%	92%	90%
Red	100%	100%	100%
Yellow	93%	93%	92%
Relative Brightness with Respect to Center Yellow			
Color	Left Edge	Center	Right Edge
Green	0.88	0.84	0.75
Red	0.12	0.16	0.21
Yellow	0.99	1.00	0.96

registration was defined as no more than a one-quarter (0.0025 inches) of a basic pixel element difference between the superimposed green and red images over their entire active area. Given this requirement, the yellow characters were easily legible.

To register the two displays, the demonstration unit was provided with enough degrees of freedom for adjustment. The displays themselves were set on tilt stages such that the beam spot could be directed through the aperture. The red display also had x-y-z adjustment along with rotation to match the stationary green display.

In the demonstration unit, the registration procedure was quickly mastered and only a few minutes was needed to adequately register the two displays. The registration was measured to be accurate within 0.003 inch on both axis at all locations on the screen. This slight amount of misregistration was not visible to an observer. The cause of the residual misregistration was determined to be a slight curvature in the beam splitter which introduced an undesired optical power into the path of the red beam.

OPTICAL EFFICIENCY

The commercial lamp house used in the demonstration unit includes a high quality condensing lens with a relative aperture (f-number) of 0.7. Thus this lamp house collects as much light from the lamp as is practical, and the brightness of the system can be increased only by improving the efficiency of the other optical elements. For reference, the collimated light from the lamp house was used to illuminate a ground glass diffusing screen identical to that used in the demonstration system and a brightness of 25,000 foot-lamberts was measured. Since the brightness of the color display was 3400 foot-lamberts, the efficiency of the system was about eight percent. The efficiencies (transmittance or reflectivity, as appropriate) of the elements in the system were measured and are tabulated in Table 6.

As can be seen from Table 6, the major inefficiencies in the system are due to losses in the beam splitter and the display modules. As was previously discussed, the red/green crossover wavelength of the beam splitter used in the demonstration system was about 15 nanometers too high, which forced the use of a low reflectivity display in the green channel. The beam splitter introduced additional losses since it had a relatively large reflectivity for green light which should have been transmitted. Analysis indicates that, with an ideal beam splitter and a high reflectivity display in the green channel, the brightness of the demonstration unit would have increased by a factor of over two with no decrease in color purity or contrast. Additional smaller increases in efficiency could be obtained by applying antireflective coatings to all optical surfaces and by using higher reflectivity dielectric mirrors.

TABLE 6. OPTICAL EFFICIENCY OF THE DEMONSTRATION UNIT

Factor	Efficiency, Percent
Bending Mirror	90
Aperture Shadow	96
Over Illumination of Displays	85
Beam Splitter and Display Reflectivity	27
Glass Surfaces (at aperture)	92
Four-Element Coated Projection Lens	96
Folding Mirror	90
Calculated Brightness at Screen: 3900 foot-lambert	
Actual Brightness at Screen: 3400 foot-lambert	

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

The two color LXD demonstration unit was a highly successful demonstration of the feasibility of contructing high brightness color displays using matrix liquid crystal display technology. The unit performed to its theoretical limits and produced an easily-readable, three color information display.

The most important accomplishment was the high brightness produced by the demonstration unit (3400 ft. lamb. in the yellow). Nevertheless, the brightness could have been further increased by at least a factor of two if the proper beam splitter with the correct 50-50 cut-off wavelength had been used along with an aluminum-reflecting display for the green.

The contrast ratio of the display was lower than would be ultimately required. This was primarily due to the older and less reflective displays used in the effort and not the optical system. If the brightness were increased as described in the preceding paragraph, the contrast ratio should also double. Even with the limited contrast ratio exhibited by the demonstration unit, the clarity between the three colors and the black state was more than adequate in room ambient lighting and the color images were visible in a 10,000 foot candle ambient.

Excellent registration was achieved between the red and green images with little effort. Once the displays were aligned, the observer was unable to note any misregistration in the characters from a normal viewing distance. If this program moves on to the miniature displays where the resolution is increased almost nine-fold, the registration will have to be more precise. Nonetheless, from what has been learned from the demonstration unit and larger displays, registration does not appear to be a problem if an equivalent optical system (single projection lens) is used.

Since the demonstration unit achieved the goals of this program, the development of a multicolor liquid crystal projection display should be continued with emphasis on increasing the display resolution. This goal can be accomplished by replacing the 175 x 175-element, 100 element per inch, display modules with the 240 x 320-element, 321 element per inch, display modules which were developed for NADC, NVEOL, and AFWAL on the Miniature Flat Panel Display Program (contract number DAAK70-78-C0137).

The initial step should be to replace the existing display modules with miniature displays that are electrically connected for compatibility with the existing drive circuitry. The optical system in the color demonstration unit would also be modified to accommodate the smaller image area on the display modules. The projected image would have the same resolution as the current demonstration unit. These changes will prove the feasibility of using the higher density display modules in a color projection system and will demonstrate a more compact optical system.

The second step should be to incorporate 240 x 320-element miniature display modules with hybridized drive circuits (presently under development under company sponsorship) and to upgrade the present symbol generator to accommodate the increased display resolution. The demonstration unit would then be capable of presenting up to 20 rows of 40 characters.

Finally, the demonstration system of the previous step should be redesigned in flight-quality hardware form and a flyable color display unit should be constructed and evaluated.

In conclusion, the success of the program, as evidenced by the genuine excitement generated by the demonstration unit, has proved the feasibility of developing multicolor displays having sufficient brightness and contrast for viewing in the most adverse cockpit ambients. We believe that if the steps outlined above are followed, a multi-colored, aircraft-packaged display with a performance unmatched in today's cockpits will be achieved.

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