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COMPARISON TESTING OF 0.7-IN. FIELD EMISSION DISPLAY (FED) AND 0.7-IN. LIQUID CRYSTAL DISPLAY (LCD) FOR USE IN HEAD-MOUNTED DISPLAYS

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Miniature displays for portable electronic devices have tremendous utility potential both in military and commercial applications. Emerging technologies would benefit from the high resolution graphic and video images that the displays could provide, thus enhancing the operator's access to information without disrupting the whole field of vision or requiring hands-on operation. The displays demonstrated little difference in their power consumption, magnetic signatures, size, and usefulness in temperature extremes. However, one of the most promising advantages of the field emission display (FED) is its self-illuminating feature. This puts the liquid crystal display (LCD) at a disadvantage if a low magnetic signature is required since its backlight would also have to be redesigned. Redesigning the circuit board for low magnetic signature should be approximately the same for both displays. Although benchtop testing indicated some measureable differences in color, brightness, and resolution, the opinions of the users were not as clear cut. Both benchtop and user testing however rated the LCD better than the FED for resolution and color accuracy. Neither display was acceptable in bright sunlight; both would require shading. More extensive testing would be required to completely evaluate the displays. Environmental and field testing should be expanded before introduction into the Fleet.

14. SUBJECT TERMS
head-mounted display, heads-up display, field emission displays (FED), liquid crystal displays (LCDs), display technologies

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FOREWORD

Miniature displays for portable electronic devices have tremendous utility potential both in military and commercial applications. Emerging technologies such as advanced imaging devices, universal voice recognition, beltworn computers, and high density information storage devices would benefit from the high resolution graphic and video images that the displays could provide, thus enhancing the operator's access to information without disrupting his whole field of vision or requiring hands-on operation. This report compares advantages and disadvantages of using field emission displays versus liquid crystal displays for such uses.

This report has been reviewed by R. Ramey, Head, Diving Systems Branch and B. Miller, Head, Diving and Life Support Division.

Approved by:

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CONTENTS

ILLUSTRATIONS

EXECUTIVE SUMMARY

This report documents the results of comparison testing performed on a field emission display (FED) versus a liquid crystal display (LCD) for use in head-mounted displays. Both benchtop and user testing were conducted. The analysis was performed to assess the advantages and disadvantages of using each type of display.

The displays demonstrated little difference in their power consumption, magnetic signatures, size, and usefulness in temperature extremes. However, one of the most promising advantages of the FED is its self-illuminating feature. This puts the LCD at a disadvantage if a low magnetic signature is required, since its backlight would also have to be redesigned. Redesigning the circuit board for low magnetic signature should be approximately the same for both displays.

Although benchtop testing indicated some measurable differences in color, brightness, and resolution, the opinions of the users were not as clear cut. Both benchtop and user testing, however, rated the LCD better than the FED for resolution and color accuracy. Neither display was acceptable in bright sunlight; both would require shading.

This test was performed as a quick comparison between two technologies. More extensive testing would be required to completely evaluate the displays. Environmental and field testing should be expanded before introduction into the Fleet.

BACKGROUND

The Defense Advanced Research Projects Agency (DARPA) is presently investigating liquid crystal display (LCD) and field emission display (FED) technologies for future application as miniature displays for portable electronic devices. The potential utility of these displays in commercial and military applications is tremendous when coupled with other emerging technologies such as advanced imaging devices, universal voice recognition, beltworn computers, and high density information storage devices. These miniature displays can provide high resolution graphic and video images that enhance an operator's access to information without disrupting the whole field of vision or requiring hands-on operation.

Several 0.7-in. displays have been fabricated for such uses. DARPA is interested in comparing the basic engineering differences of these technologies and in understanding if these differences affect the technology's operational suitability from a user's perspective. One of the most promising differences between FEDs and LCDs is the self-illuminating feature of the FED. This attribute promises greater operational utility in dark or cloudy environments. It may also provide design simplification, power reduction, and reliability improvements due to the elimination of the normal LCD backlight circuitry.

This study was designed to conduct a quick-look evaluation of FED technology under both laboratory and military field conditions. Laboratory tests included engineering verification and assessments of the displays' technical specifications (e.g., size, power consumption, etc.), magnetic signatures, and some human factor engineering characteristics (e.g., readability, contrast, clarity, color distortion, etc.). The results of this investigation address the relative merits of FED and LCD technology. This report provides a quick assessment of LCD's and FED's abilities in meeting operational requirements.

DISPLAY CONFIGURATION[1]

A prototype 0.7-in., 240 by 420 pixel FED, serial number P78-59, supplied by Micron Display Technology, Incorporated and a production 0.7-in., 420 by 230 pixel, Seiko-Epson LCD were housed in underwater housings. The housing was originally designed for the LCD and was slightly modified to house the FED driving circuitry. The same optics was used for both displays. The field-of-view was approximately 16 deg in the horizontal direction and 12 deg in the vertical direction. The optical configuration is shown in Figure 1.

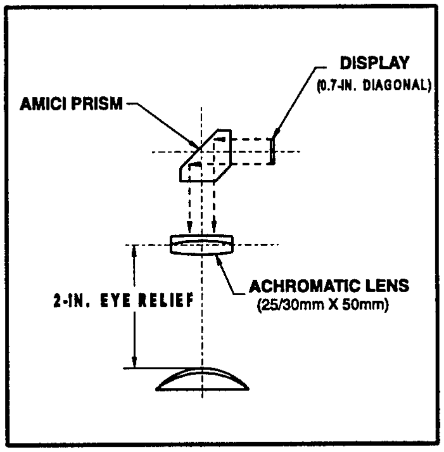


FIGURE 1. OPTICS CONFIGURATION

The LCD unit used a compact vacuum fluorescent backlight with an output of approximately 100 lumens.[2] The system was designed to be viewed by the diver's right eye, since the majority of individuals are right-eye dominant. The optical system is basically a simple magnifier. The magnifier forms a *virtual image* of the display and the diver looks at this virtual image.[3]

The focal distance of the displays was 13 in. When viewed through the optical system, the virtual image appeared to be approximately 1 ft in front of the diver's mask (see Figure 2) and could be viewed simultaneously with the working area in front of the mask. The system gave an approximate magnification of 5X. This was based more on empirical observation than calculation, since the magnification was dictated by a two-lens combination, one of the lenses being the diver's eye. In the case of the eye, the magnification was not easily approximated.[4]

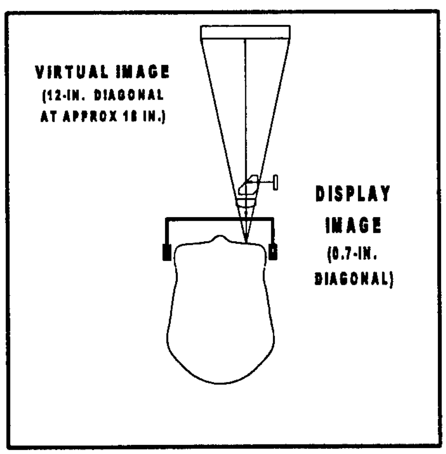


FIGURE 2. VIRTUAL IMAGE

To keep the system inexpensive, commercially available off-the-shelf rather than custom optical components were used. The optical system is comprised of an achromatic lens and an Amici prism.

ACHROMATIC LENS

An achromatic lens consists of two optical components cemented together: a positive low index (crown) element and a negative high index (flint) element. The achromatic lens was selected since it provided noticeable advantages over a simple magnifying lens, such as improved polychromatic imaging, correction of spherical aberration and on-axis coma, brighter images, and better energy throughput.[4] A slightly larger 30 (1.18 in.) by 50 mm (1.97 in.) lens was selected for use with the color LCD.

AMICI PRISM

Since the focal length of the lenses chosen was 50 mm (1.97 in.), the overall housing length became prohibitive. By bending the image through a 90-deg angle, this length was significantly shortened. Using conventional right-angle prisms or mirrors proved unsatisfactory since they reversed the image from left to right. Pentaprisms were considered since they provide the 90-deg bend and did not reverse the image, but they increased the focal length requirements (five reflections within the prism) and were too large. An Amici prism was selected since it bent the image 90 deg and did not reverse the image.[4] This prism did invert the image, but simply installing the display upside down solved that problem. The two reflections within the prism kept the focal length manageable and the prism size small.

WATERPROOF HOUSING

The material used for the waterproof housings and mounting bracket assemblies was polyoxymethylene - acetal plastic (Delrin). The LCD housing (Figure 3) used an eyepiece containing the 30-mm lens, an elbow piece with the Amici prism, and a short cylindrical cap containing the LCD and backlight. This was assembly mounted to the diver's mask with a flat bracket. A slide bar/swivel link design provided flip-up/flip-down capability to the diver. Adjustments were made via a single knurled knob. The LCD driver electronics were enclosed in a separate cylindrical housing located at the diver's waist or backpack area. A 3-ft flexible whip connected the electronics housing to the display. This minimized the bulk on the diver's mask and shifted the umbilical strain from the mask to the waist or backpack area.

The FED housing was a modified LCD housing (slightly modified so that the FED driving electronics could be placed into it). Connection to the mask, optics, and cable were identical.

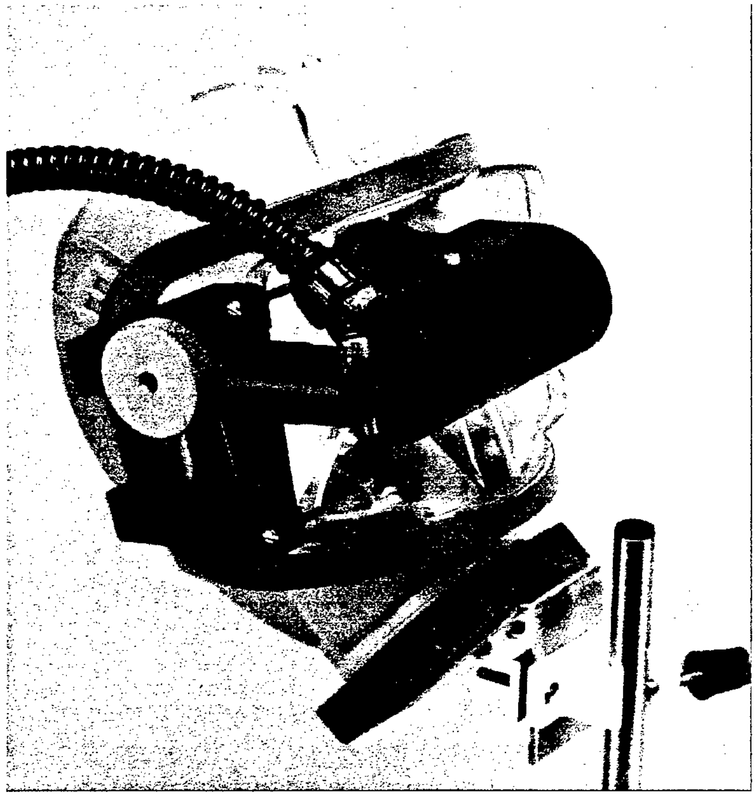


FIGURE 3. CYLINDRICAL HOUSING FOR LCD DISPLAY

TESTING PROCEDURES

OPTICS 1 TESTING

OPTICS 1 Incorporated completed the optical performance characterization and image quality measurement for the FED and LCD. Since the purpose of the testing was to compare LCD and FED performance in terms of color, contrast, resolution, and brightness, the procedures used differed from the standard testing procedures used for LCDs and FEDs during their manufacturing and testing. Some unique test configurations were arranged to properly evaluate the performance and image quality of each display. A standard National Television System Committee signal generator was used to generate standard color bars and fields. Resolution targets in the form of black and white bars varying sinusoidally in their brightness were obtained from a video disc *A Video Standard* for display onto the LCD and FED.

A high resolution Cohu camera with a 1X magnification microscope objective and a Colorado video frame integrator were used to display images onto a computer screen. OPTICS 1's *OPTIMA* software was used to characterize the image quality and optical performance of the displays, and a Photo Research TR 650 colorimeter was used to measure color tristimulus and the brightness/contrast of the displays. Figure 4 shows the basic setup.

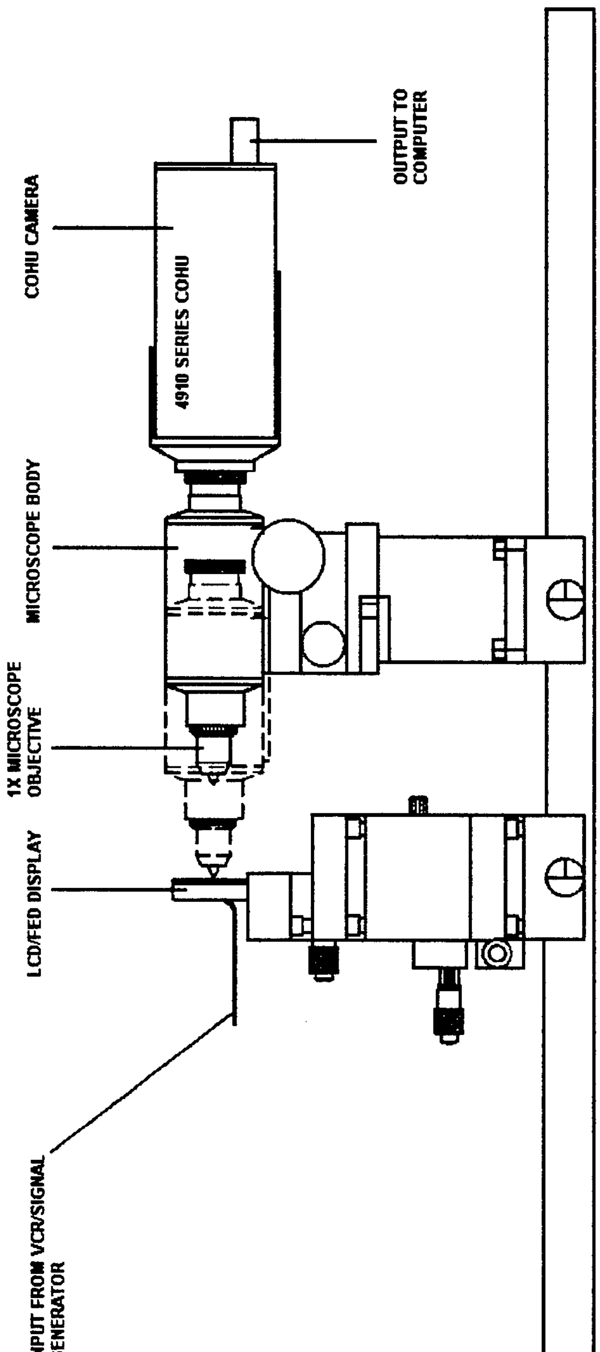


FIGURE 4. OPTICS 1 TEST SETUP

Since the purpose of this testing was to compare the resolutions of the LCD and FED, both standards (pixel and measured resolution) were included. To measure the resolution, the video disc referenced was used to generate the standard resolution bar targets. The video from the disc was displayed electronically as a sinusoidal wave, providing alternate black and white images with different frequencies in the display. Both displays resolved as small as 2.0-MHz multiburst frequency produced by the video disc. This translates to a resolution bar with about 120 μm peak-to-peak separation on the LCD and the FED. Three different multiburst frequencies were measured: 2.0 MHz, 1.5 MHz, and 0.5 MHz (which represent 120 μm, 245 μm, and 500 μm in peak-to-peak separation, respectively).

When performing the tests for modulation transfer function (MTF), a very low spatial frequency square wave bar target was placed on each display. Then a scan window (the region within which data is extracted in the form of gray levels) was outlined over the pattern. The bright bars had a high gray level and the dark bars had a low gray level. The modulation was calculated as follows: (Imax-Imin) / (Imax + Imin), where Imax is the maximum light intensity level and Imin is the minimum light intensity level. Since the bars were of very low spatial frequency, there was no degradation due to pixelization, electronic adjacency effects, or other factors; therefore, the modulation was, in effect, the modulation at 0 lp/mm. The sinusoidally varying bar patterns referenced were then used, and the modulation from each of these was computed. The net MTF was the modulation from each of the sinusoidally varying bar patterns divided by the modulation of the very low frequency bar pattern. Both displays could resolve the 2.0-MHz sinusoidal black and white multiburst bar patterns. This translates to about 150 μm peak-to-peak separation in the bar patterns.

COASTAL SYSTEMS STATION (CSS) TESTING

In addition to the benchtop evaluation at OPTICS 1, CSS performed benchtop evaluations of the power consumption, physical dimensions, magnetic signature, and tolerance to temperature extremes. The temperature testing was performed last to prevent damage to displays, which would prohibit other testing. Only one display of each type was tested.

Power Consumption

Each unit was connected at room temperature. A nominal voltage of 5 V was applied to each unit. Voltage and current were measured for each unit three times over a 10-min period. Measurements were taken immediately after power-up, at 5 min, and at 10 min. Average power consumption was calculated. Only power consumption for the total assembly was measured.

Physical Size of Displays

The display elements were measured using calipers. Except for the length of the ribbon cable, dimensions were rounded to the nearest 0.010 in. Both displays generate a 0.7-in. diagonal image. The FED generates its own light, and therefore has no backlight dimensions.

No physical measurements were made of the driver boards. The number, size, and complexity of components required to drive each display type is approximately the same. Neither technology's driver board holds a dimensional advantage.

Magnetic Signature

The displays, circuit board, and various components were tested for their magnetic signature in accordance with MIL-M-19595C[5] at both the contact (2 in.) and non-contact (5 in.) ranges. Because both LCD and FED technologies share many driver board components, those electronic components common to both systems are listed together.

Temperature Extremes

The FED assembly (inside its housing) was turned on and placed in a warm water bath. It was powered through the head-mounted display underwater cable by a power supply. The start temperature was 91.8 °F and the temperature at the end of 10 min was 88.8 °F. The FED was removed and carefully observed. The LCD assembly (inside its housing) was turned on and placed in a warm water bath. The start temperature was 88.6 °F and the end temperature was 85.4 °F. Power supply problems caused the display to be left in for 19 min and 4 sec.

While operational, the LCD assembly was placed in an ice water bath. The start temperature was 34.8 °F and the temperature at 10 min when the display was removed was 33.8 °F. The display was viewed and carefully observed. While operational, the FED assembly was placed in an ice water bath. The start temperature was 33.0 °F and the end temperature (after 10 min) was 32.4 °F. Image quality was carefully observed.

The displays were also tested for their ability to withstand storage temperatures. Both displays in their housings (but without power connected) were placed in an oven for 10 min and 40 sec. The start temperature was 145 °F and the end temperature was 148 °F. Immediately after being removed from the oven, the display was connected to power and video, and videotape images were displayed. Image quality was observed. Both displays were placed in a commercial freezer in housings (but without power connected) for 10 min and 40 sec. The start temperature of the freezer was 7.8 °F and the end temperature was 15.8 °F. Immediately after removing the unit from the freezer, the display was connected to power and video, and videotape images were displayed. Image quality was carefully observed.

Human Factors

Users were asked to fill out a questionnaire on their sight and color blindness. The users were then tested on their near and far vision. Although color blindness was indicated by the questionnaire (Data Sheet 1, Appendix A), no testing was done to verify their answers.

A videotape was produced containing three segments. The first segment was a series of facial pictures and outdoor scenery from both a television show and a recent movie. The second contained five sets of lettering ranging from size 6 to 16. Size 6 lettering corresponds to approximately 3.33 percent of the screen height or 24 min of arc and 2.5 percent of screen width or 24 min of arc. Size 11 lettering corresponds to 5.55 percent of screen height or 40 min of arc and 4.17 percent of screen width or 40 min of arc. Size 16 lettering corresponds to 13.88 percent of screen height or 100 min of arc and 10.42 percent of screen width or 100 min of arc. The third segment was a typical sonar display with a wide variety of colors and a compass.

The videotape was played and viewed on a Sony Hi-Fi 8 mm Video Walkman (LCD, color 4-in. screen) to familiarize the subjects with the testing process. Then a housing containing either an FED or LCD was attached to each diving mask. Each display was centered over the right eye. Each individual was told to place the mask on his face and adjust the display for best visibility. Several users asked if they could remove the mask. This was not allowed. The first set of testing was performed inside under florescent office lighting. The users were allowed to close one eye if they desired. The tape was played and questions were asked. A single person asked all questions and recorded all answers on the data sheets shown on Data Sheet 2 in Appendix A. At the end of the test, each user was directed to step outside and look up toward bright sunlight. They were asked to rate display brightness as acceptable, marginal, or unacceptable. Then they were directed to turn away from the sun and rate the display brightness.

The other housing with the other display was attached to the face mask and the test was repeated. The users were not told until after the testing which display was the FED and which was the LCD.

The testing was repeated with nine of the earlier subjects in a test pool. The testing was performed as the divers breathed SCUBA at a shallow depth. The users were asked questions by topside personnel and their answers were recorded.

TEST RESULTS

OPTICS 1 RESULTS

Performance Evaluation

Figures 5 through 7 are the MTF measurements for the LCD without a depixelizer at 2.0, 1.5, and 0.5 MHZ multiburst frequencies, respectively. Figures 8 through 10 show the same measurements for LCD with the depixelizer. The peak heights are approximately the same gray level, indicating uniform illumination across the video screen.

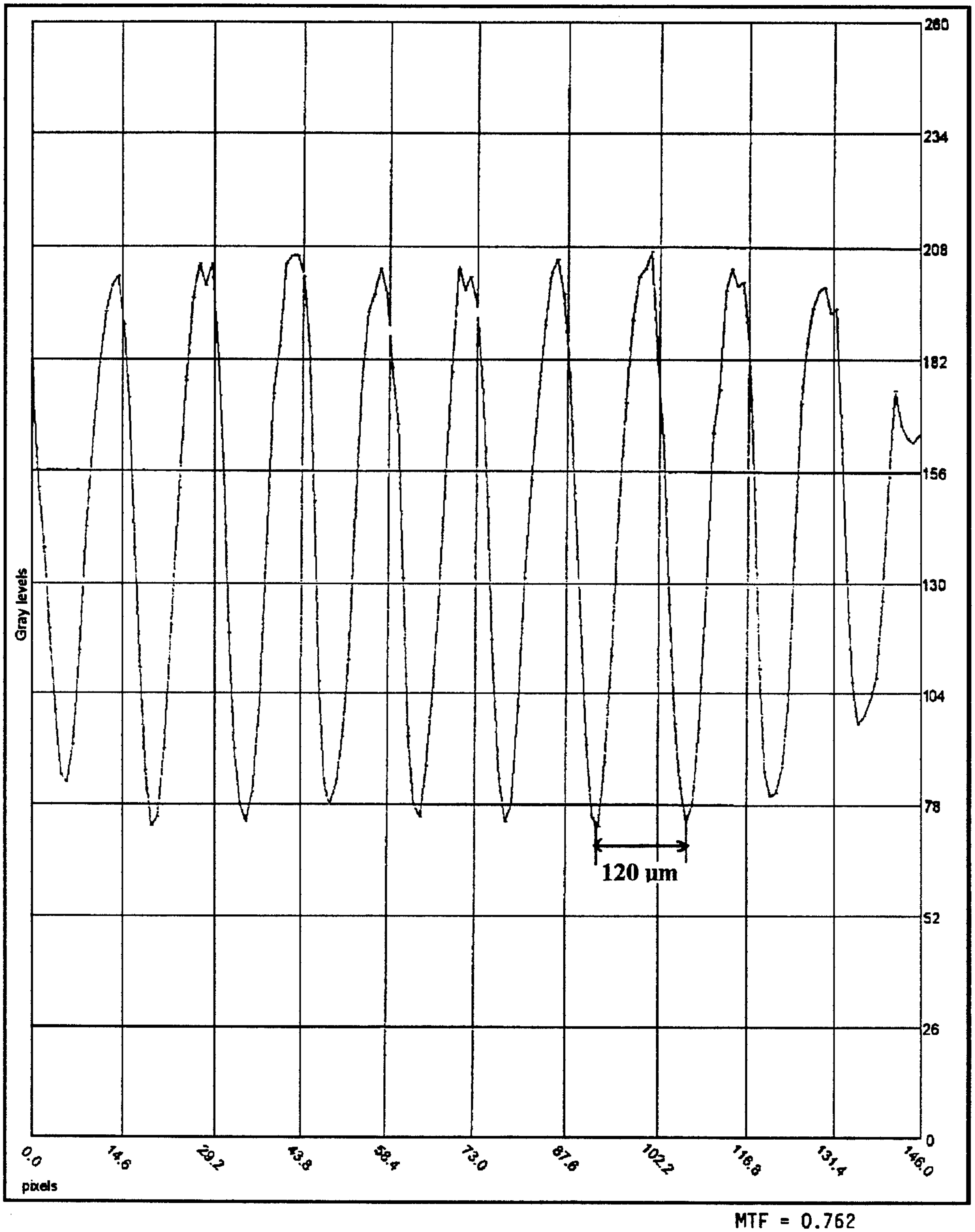


FIGURE 5. MTF FOR LCD WITHOUT DEPIXELIZER, 2.0 MHz

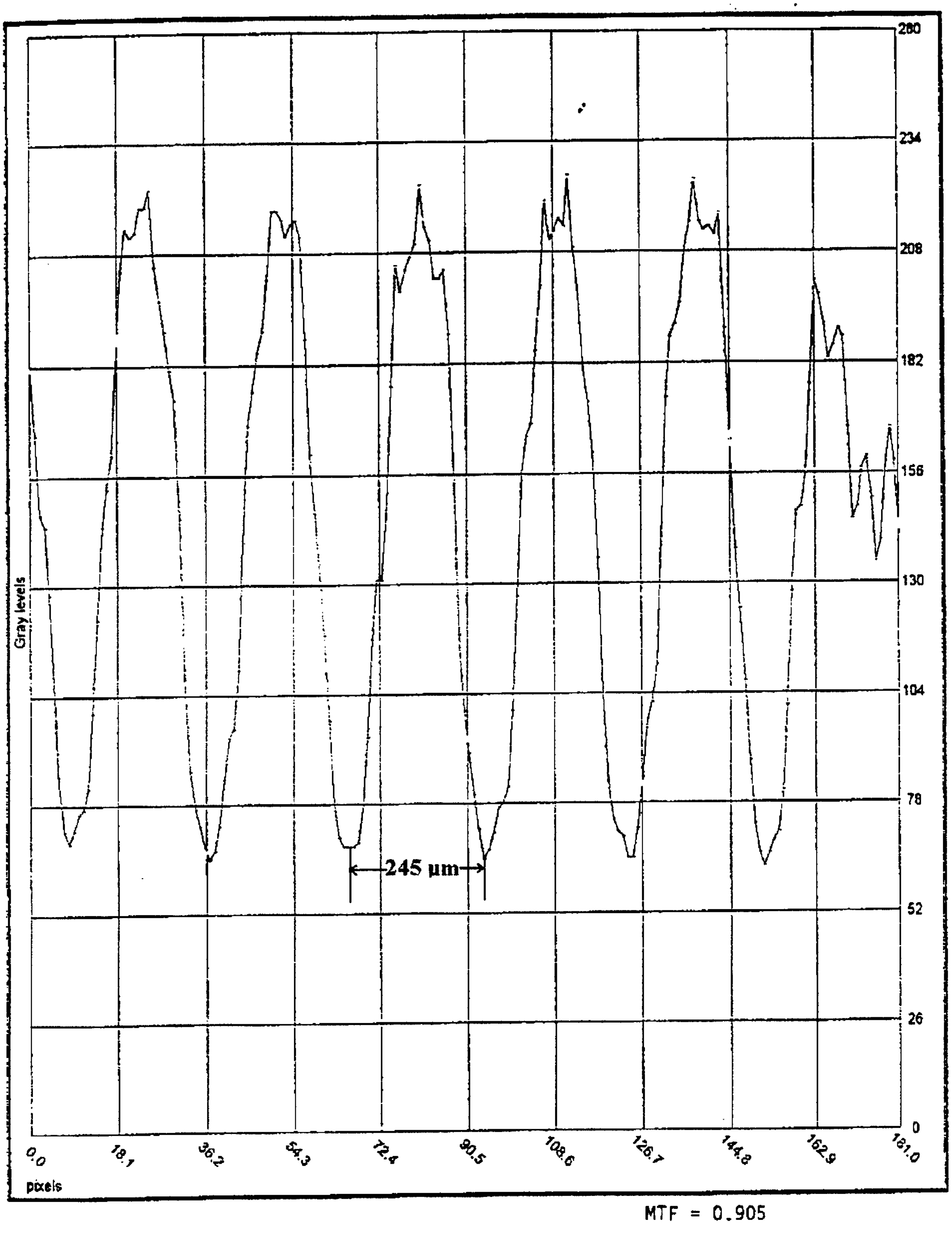
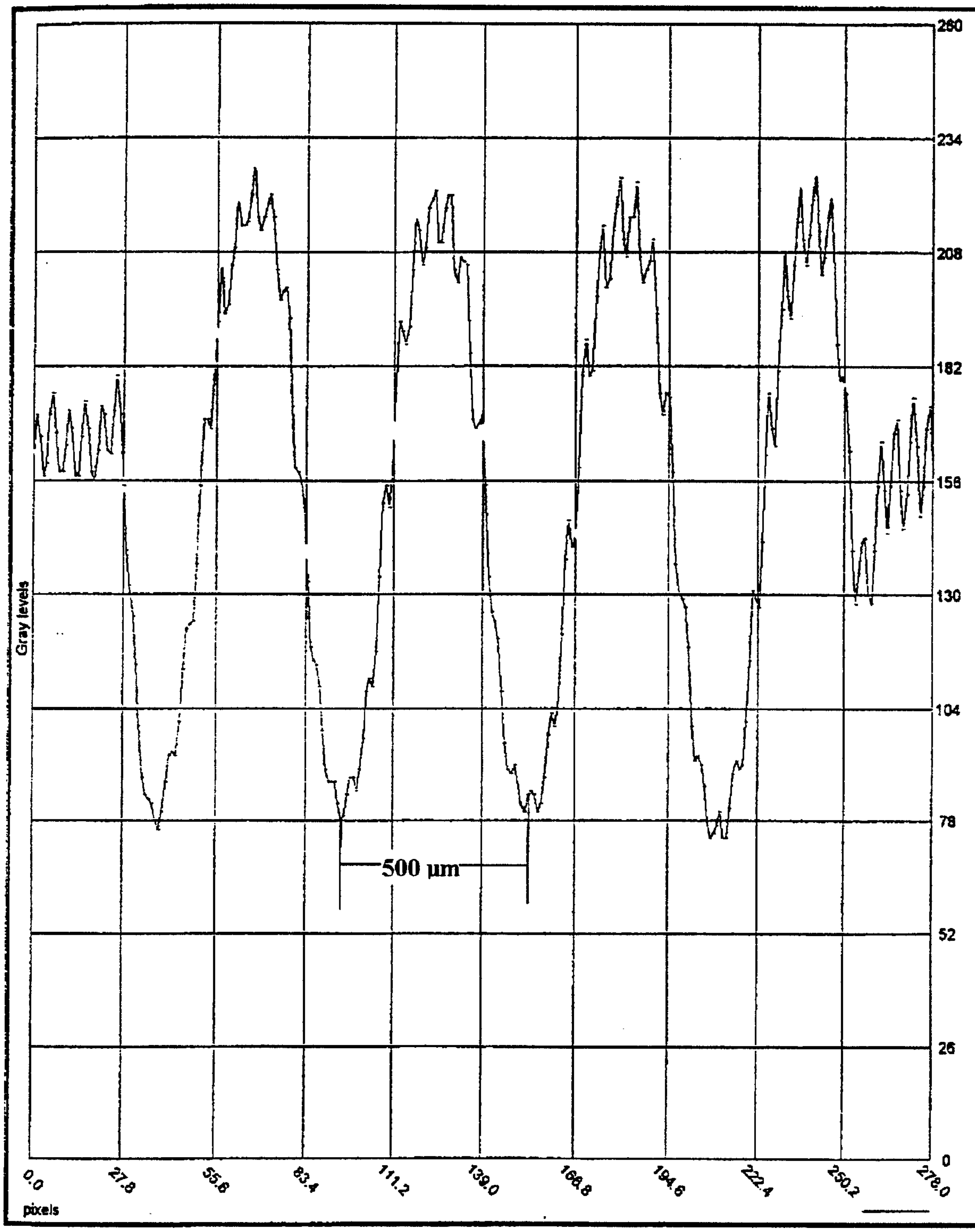


FIGURE 6. MTF FOR LCD WITHOUT DEPIXELIZER, 1.5 MHz



MTF = 0.821

FIGURE 7. MTF FOR LCD WITHOUT DEPIXELIZER, 0.5 MHz

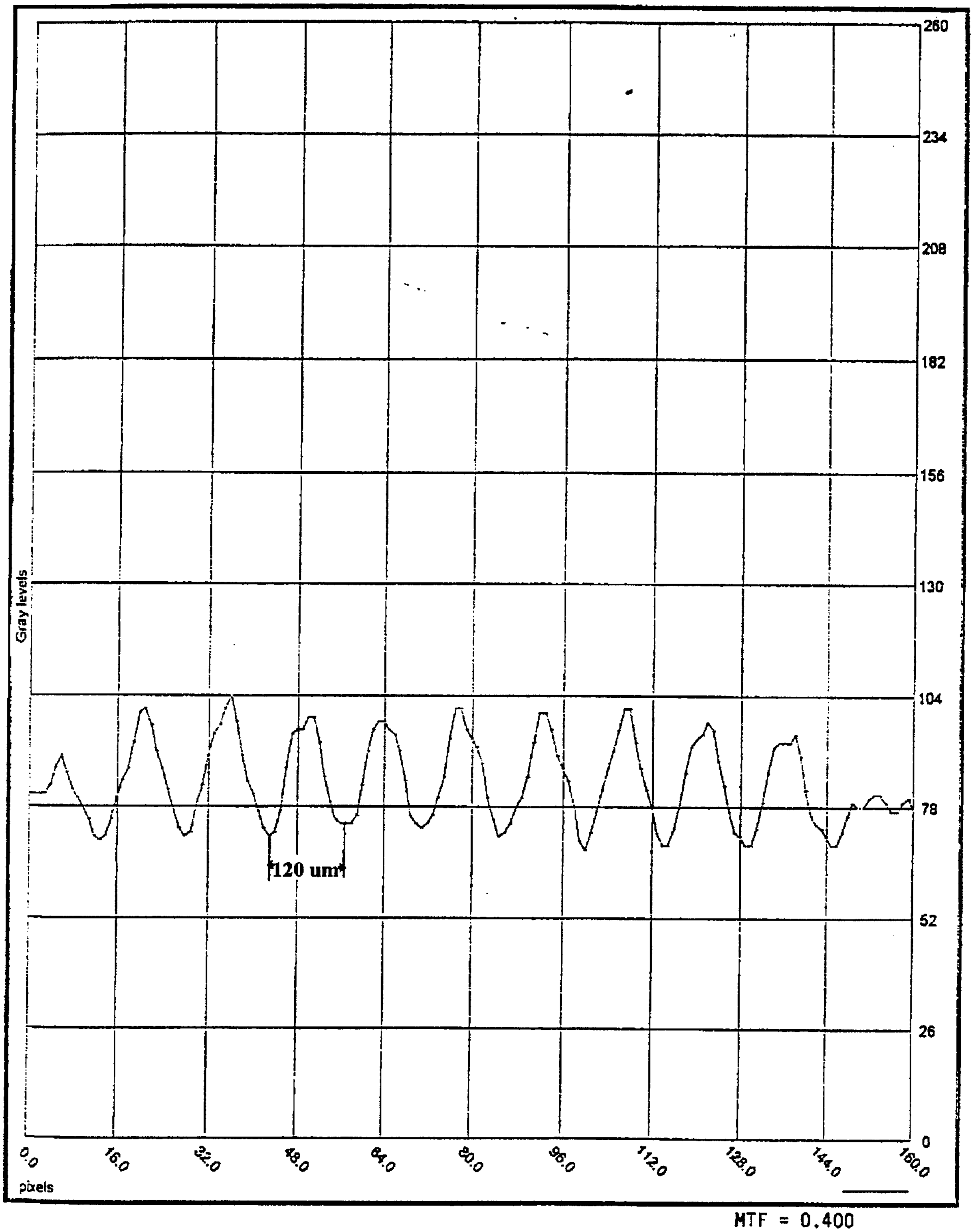
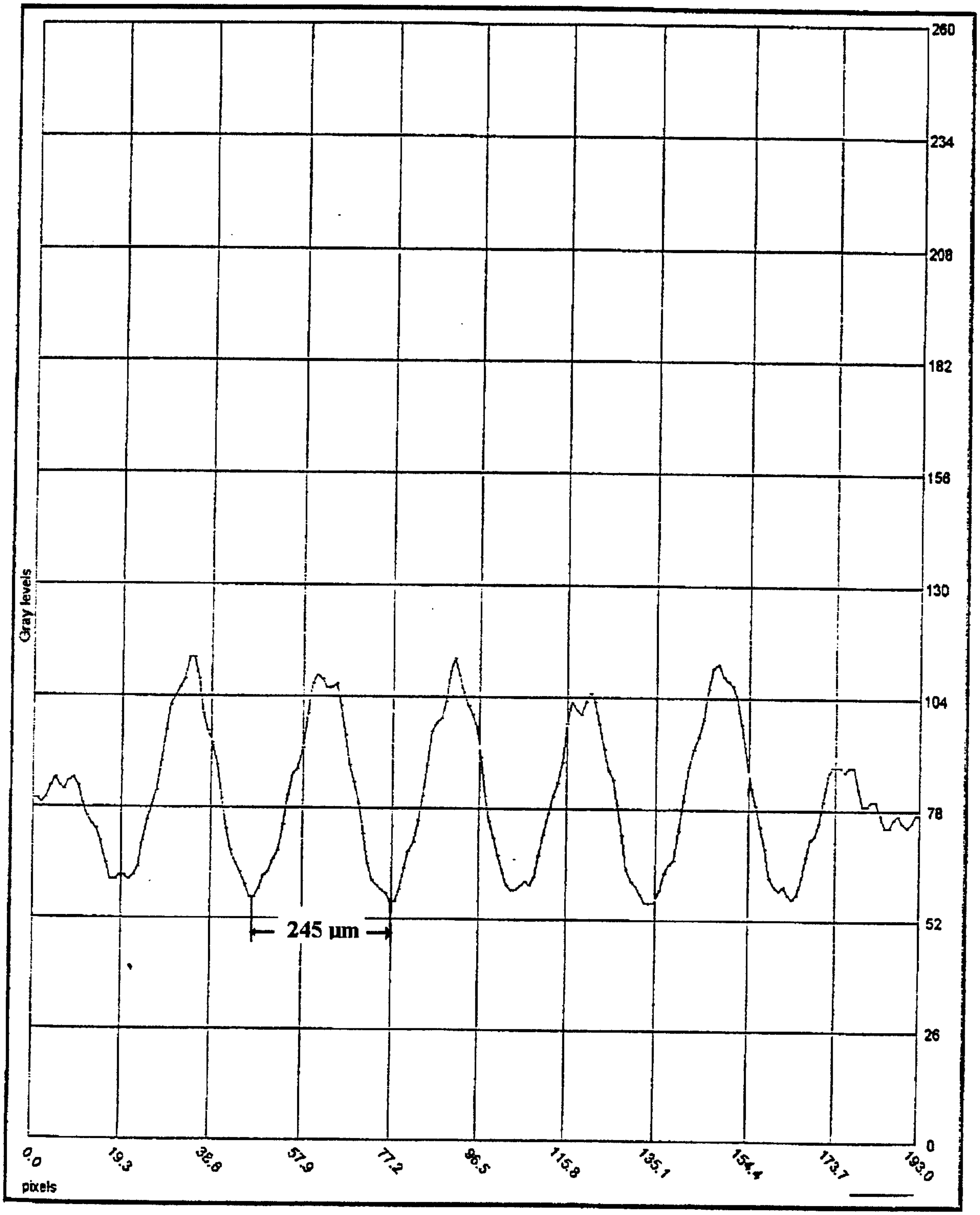
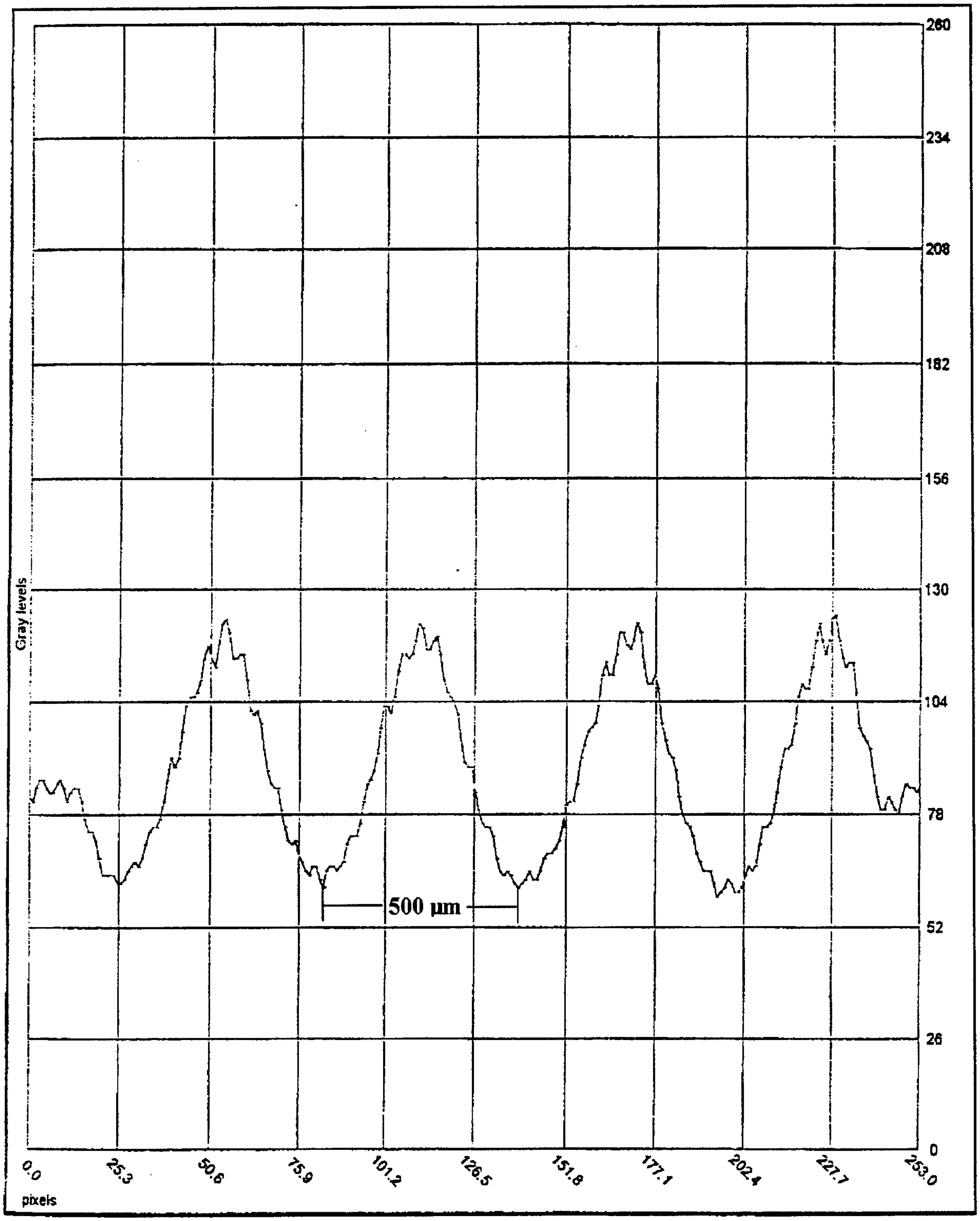


FIGURE 8. MTF FOR LCD WITH DEPIXELIZER, 2.0 MHz



MTF = 0.662

FIGURE 9. MTF FOR LCD WITH DEPIXELIZER, 1.5 MHz



MTF = 0.683

FIGURE 10. MTF FOR LCD WITH DEPIXELIZER, 0.5 MHz

Figures 11 through 13 show MTF measurements for the FED without a depixelizer and Figures 14 through 16 are the same measurements for FED with a depixelizer for 2.0, 1.5, and 0.5 multiburst frequency, respectively. These figures were taken from the most uniform region of the display.

Figure 17 shows the MTF for all four display device scenarios. The literal spatial frequencies on the display were 0, 2, 4, 6, and 8 lp/mm. A line showing the approximate average MTF has been sketched.

Color Testing

Figure 18 (the Commission International de l'Eclairage (CIE) Uniform Chromaticity Scale (UCS) chromaticity diagram) has several areas marked and labeled to indicate colors required by existing standards. For example, illuminant D65 is the color of normal daylight and has a correlated color temperature of 6500 K. MIL-I-85762 defines night vision goggles (NVG) colors and the three standard color areas.

The LCD and FED tests are presented in Table 1. Both 1931 (x,y) and 1976 UCS (u',v') coordinates were measured. Based on measurement data, u' and v' numbers from Table 1 can be placed on the 1976 CIE UCS diagram (Figure 18) to determine their deviations from the standard RED, GREEN and BLUE limits. Figure 18 shows the data points for the non-depixelized LCD and FED.

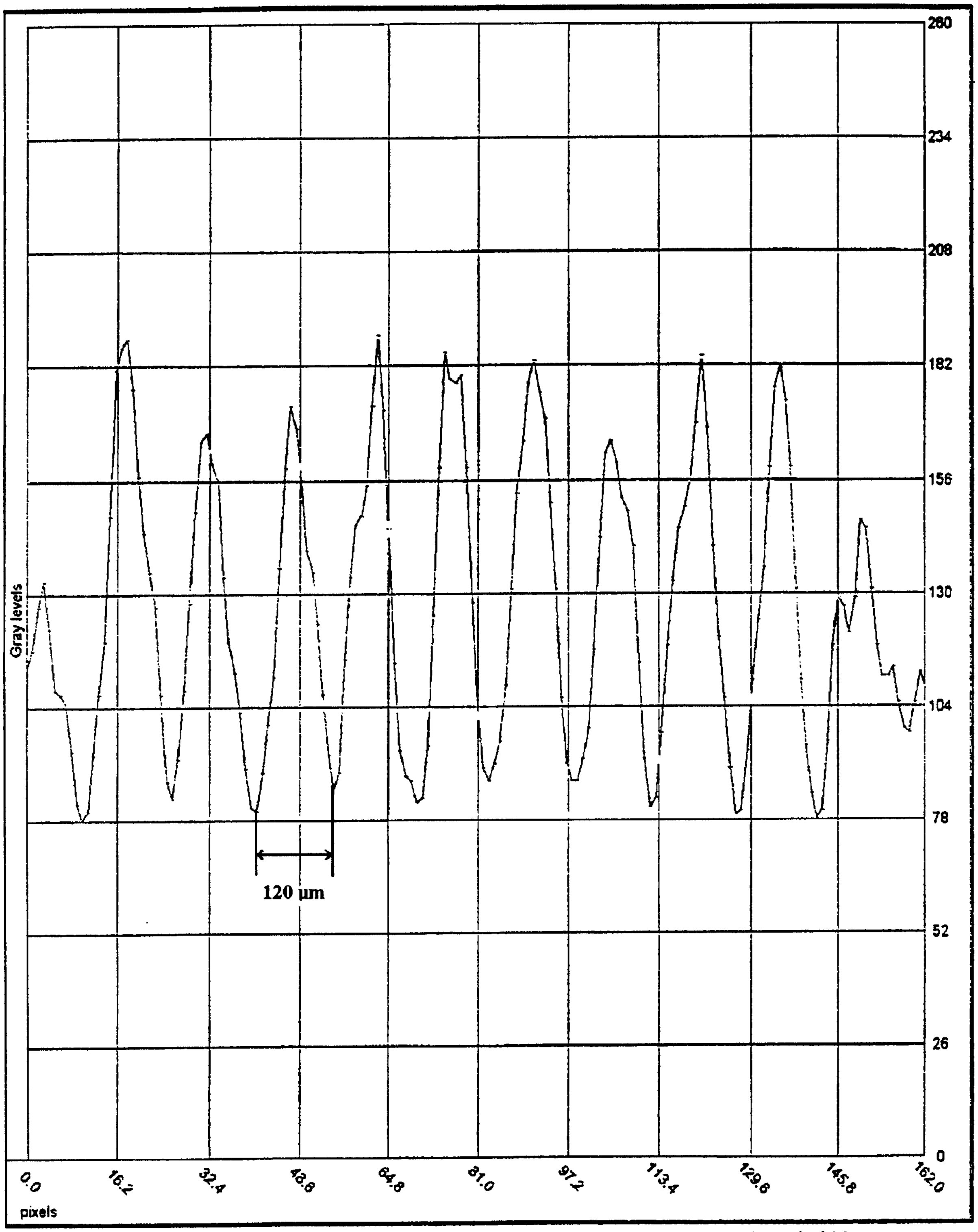
Brightness

The brightness of each color measurement is also shown in Table 1. The units are foot Lamberts (fL) because this is the standard measurement unit on the colorimeter. There are a number of photometric units, and all photometric units are derived by multiplying the eye response curve by the radiometer data. The eye response curve (normalized sensitivity versus wavelength, denoted as Vlambda) is Gaussian in shape and is based on measured human factors data and documented by the CIE.

Contrast

L_t, or total luminance, refers to the luminance emitted from a source but also includes any reflected or stray light. This is a subtle but important point when specifying/testing in a stated ambient such as sunshine or office lighting. L_b is the background luminance, which also includes stray light and reflected ambient. The contrast is different depending on ambient conditions, so a contrast number is incomplete without the associated ambient.

The test was conducted in an optical measurement laboratory at OPTICS 1, Incorporated. All samples were tested with the lights turned off. The last column in Table 1 shows the contrast data.



MTF = 0.446

FIGURE 11. MTF FOR FED WITHOUT DEPIXELIZER, 2.0 MHz

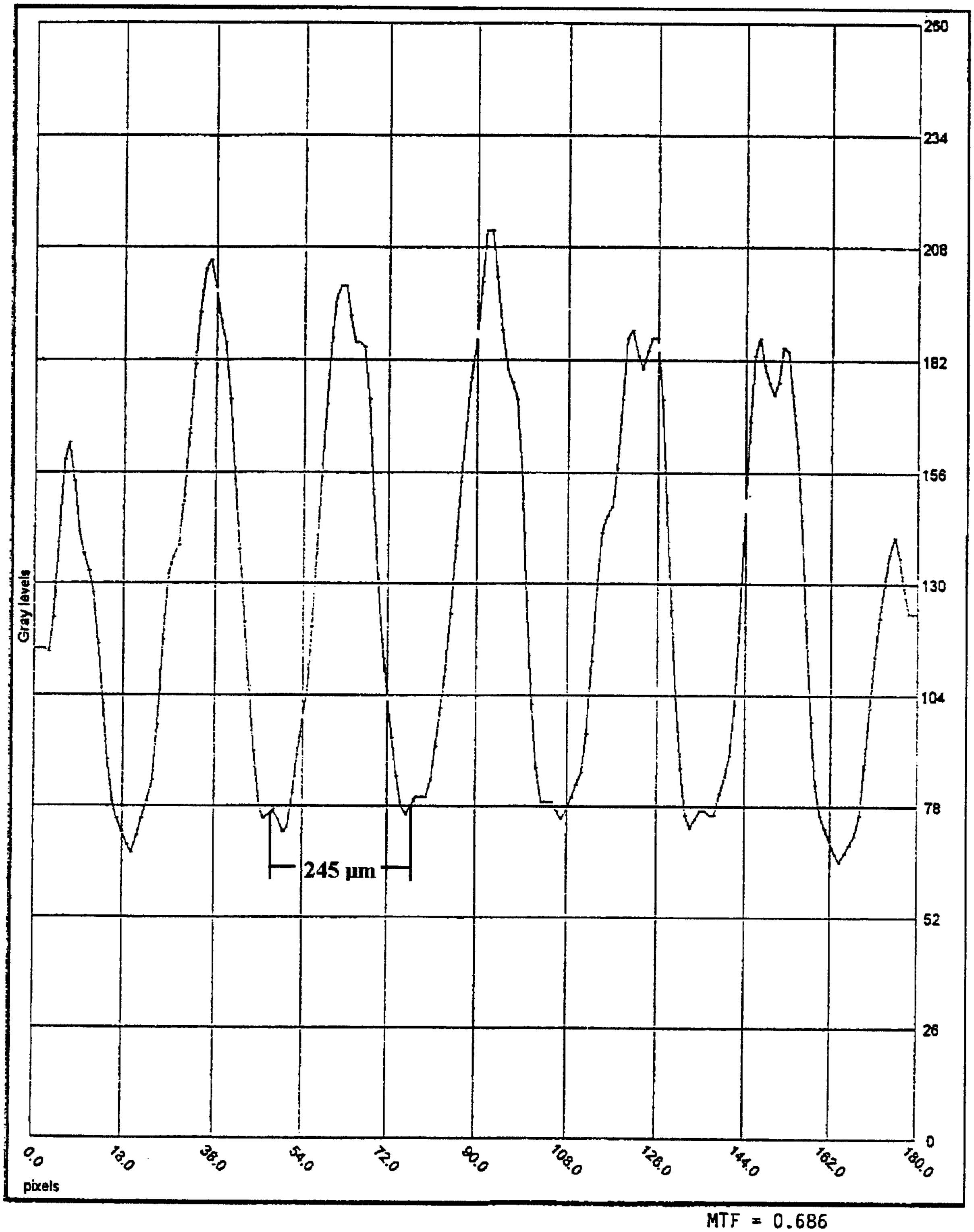


FIGURE 12. MTF FOR FED WITHOUT DEPIXELIZER, 1.5 MHz

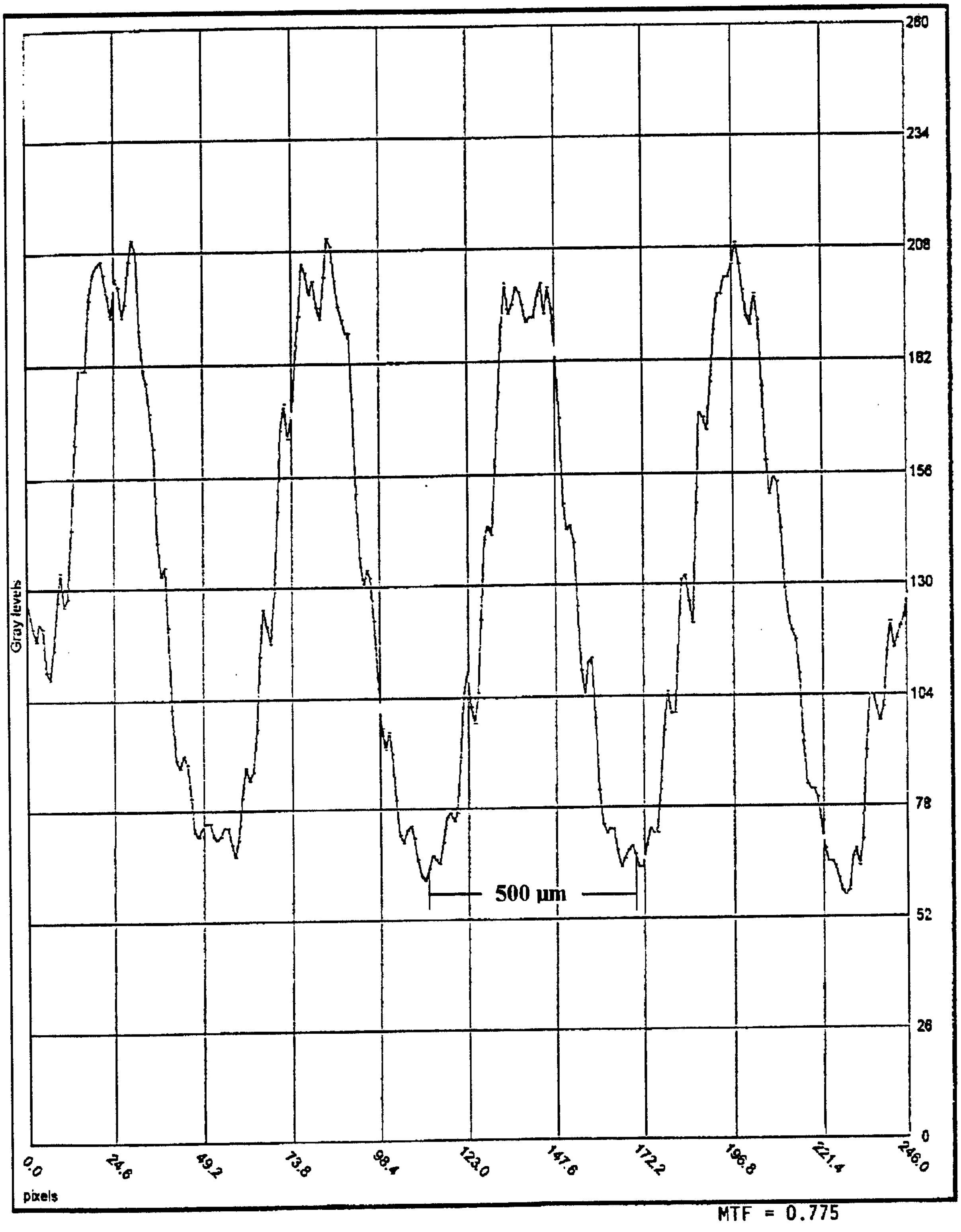


FIGURE 13. MTF FOR FED WITHOUT DEPIXELIZER, 0.5 MHz

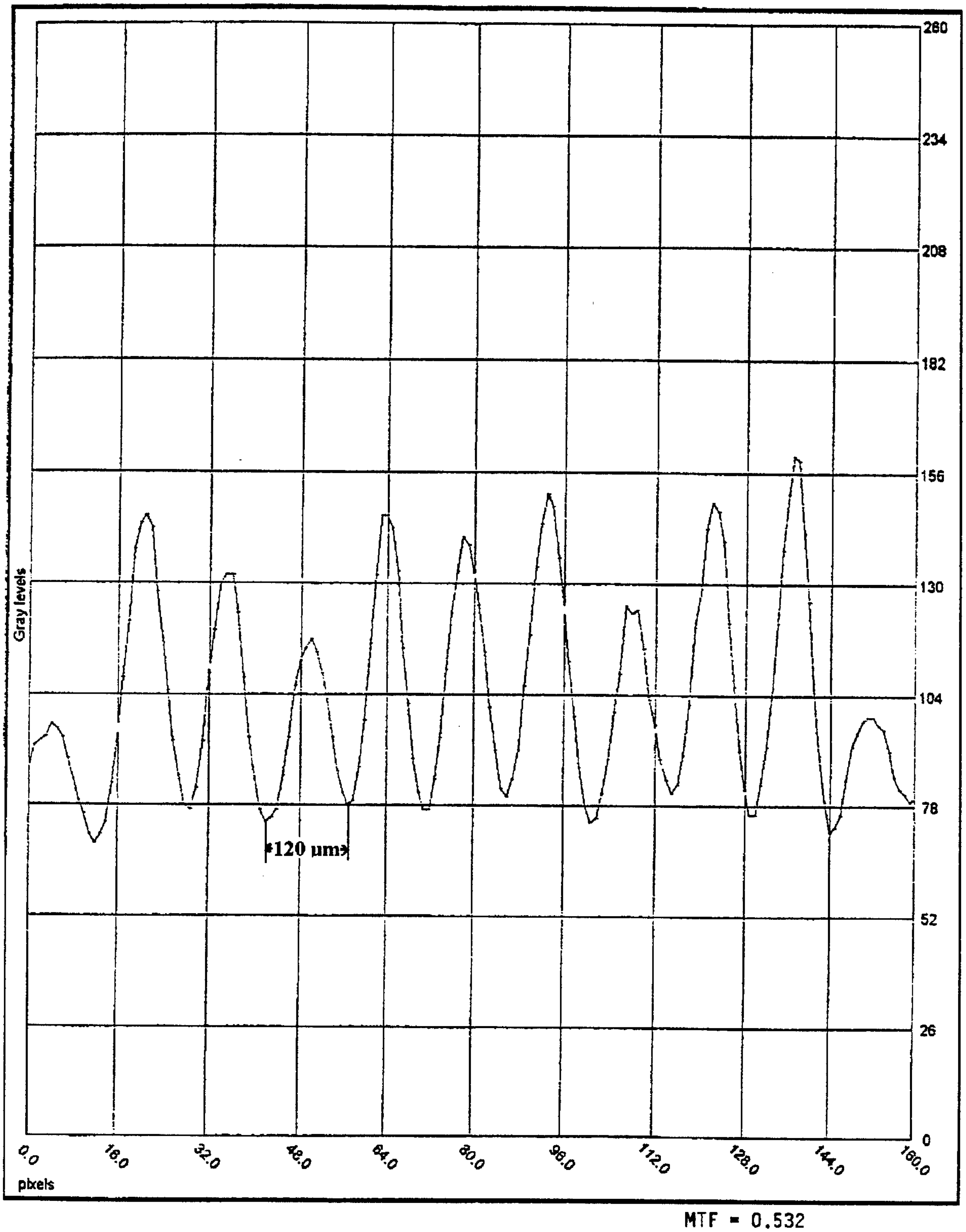


FIGURE 14. MTF FOR FED WITH DEPIXELIZER, 2.0 MHz

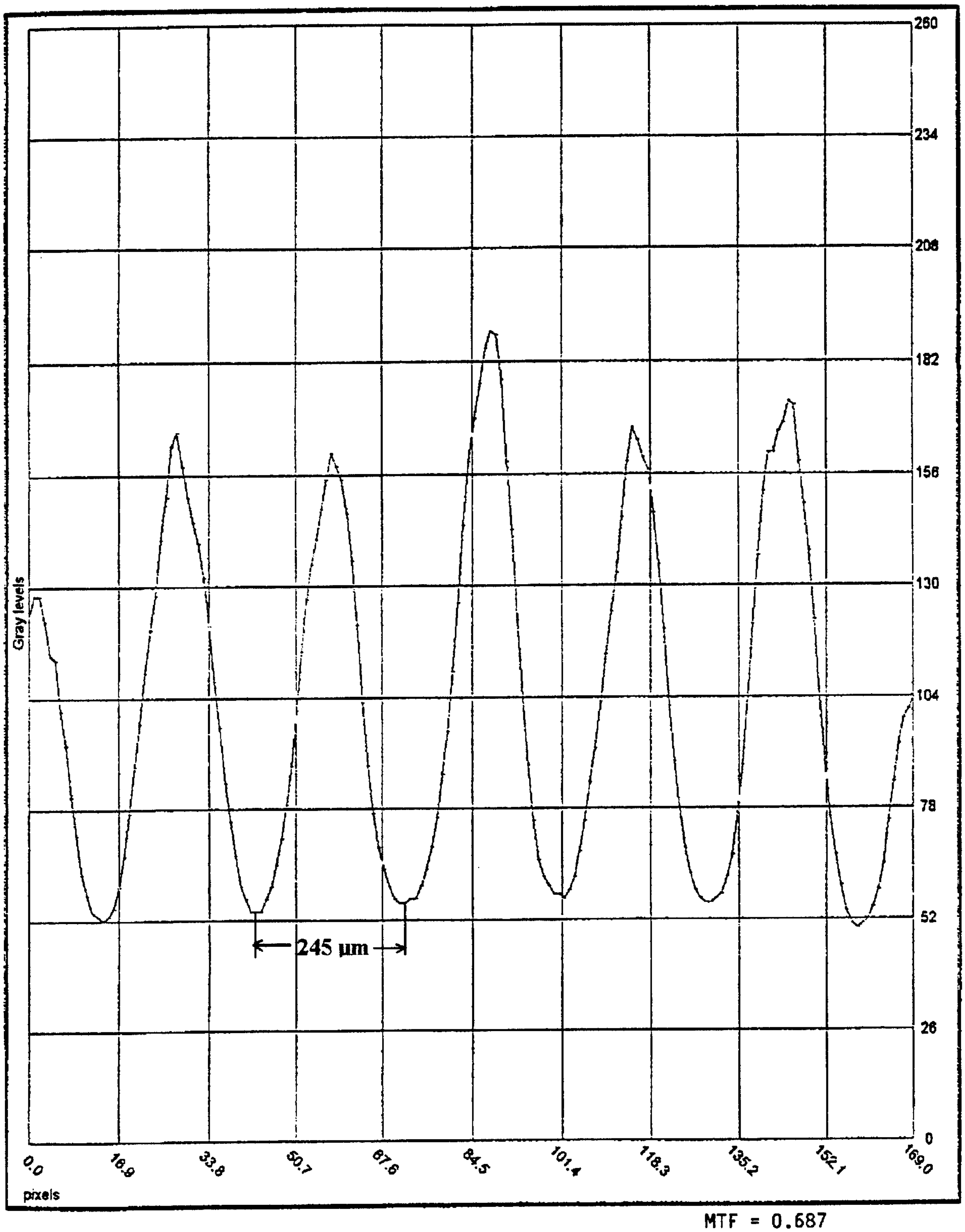


FIGURE 15. MTF FOR FED WITH DEPIXELIZER, 1.5 MHz

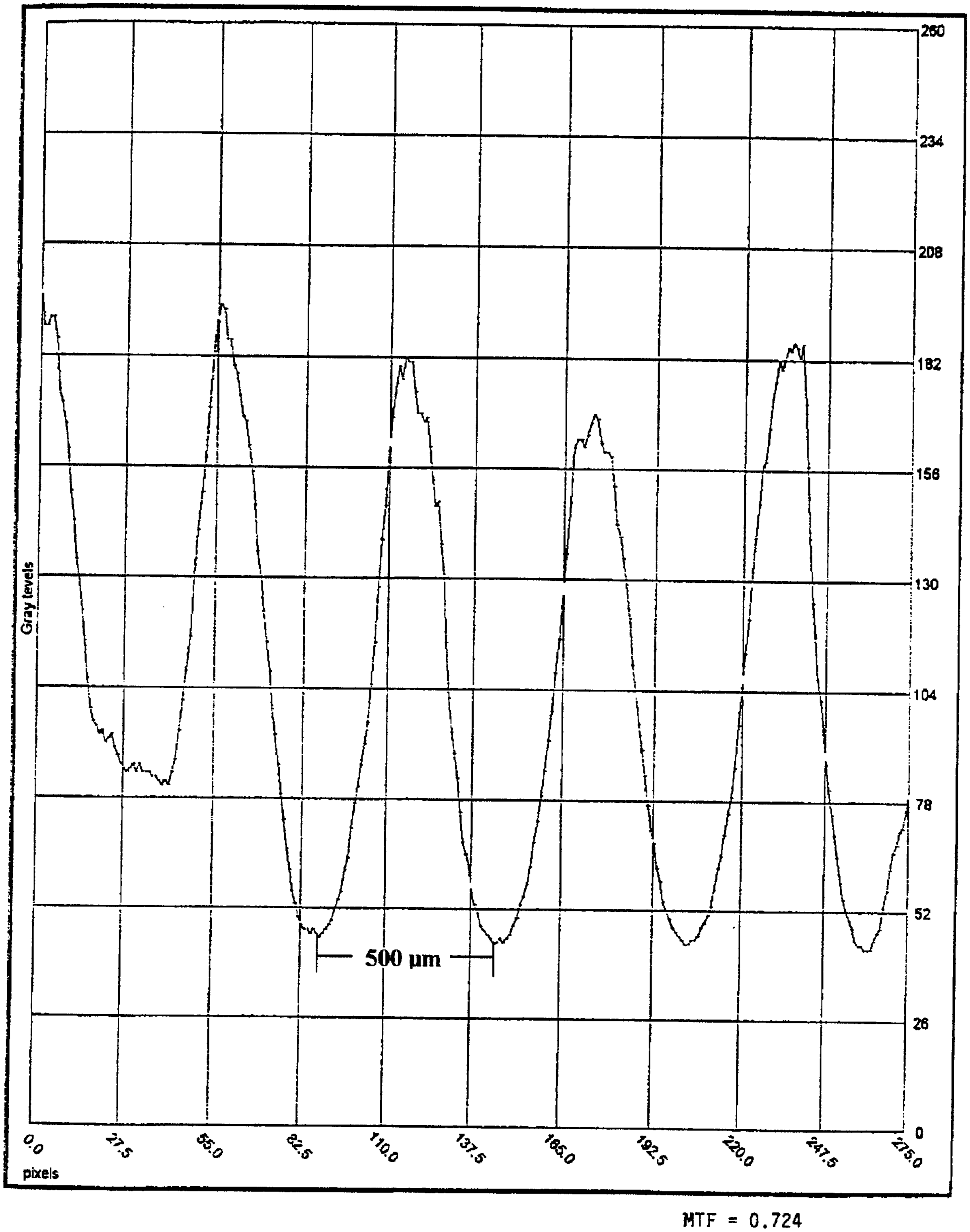


FIGURE 16. MTF FOR FED WITH DEPIXELIZER, 0.5 MHz

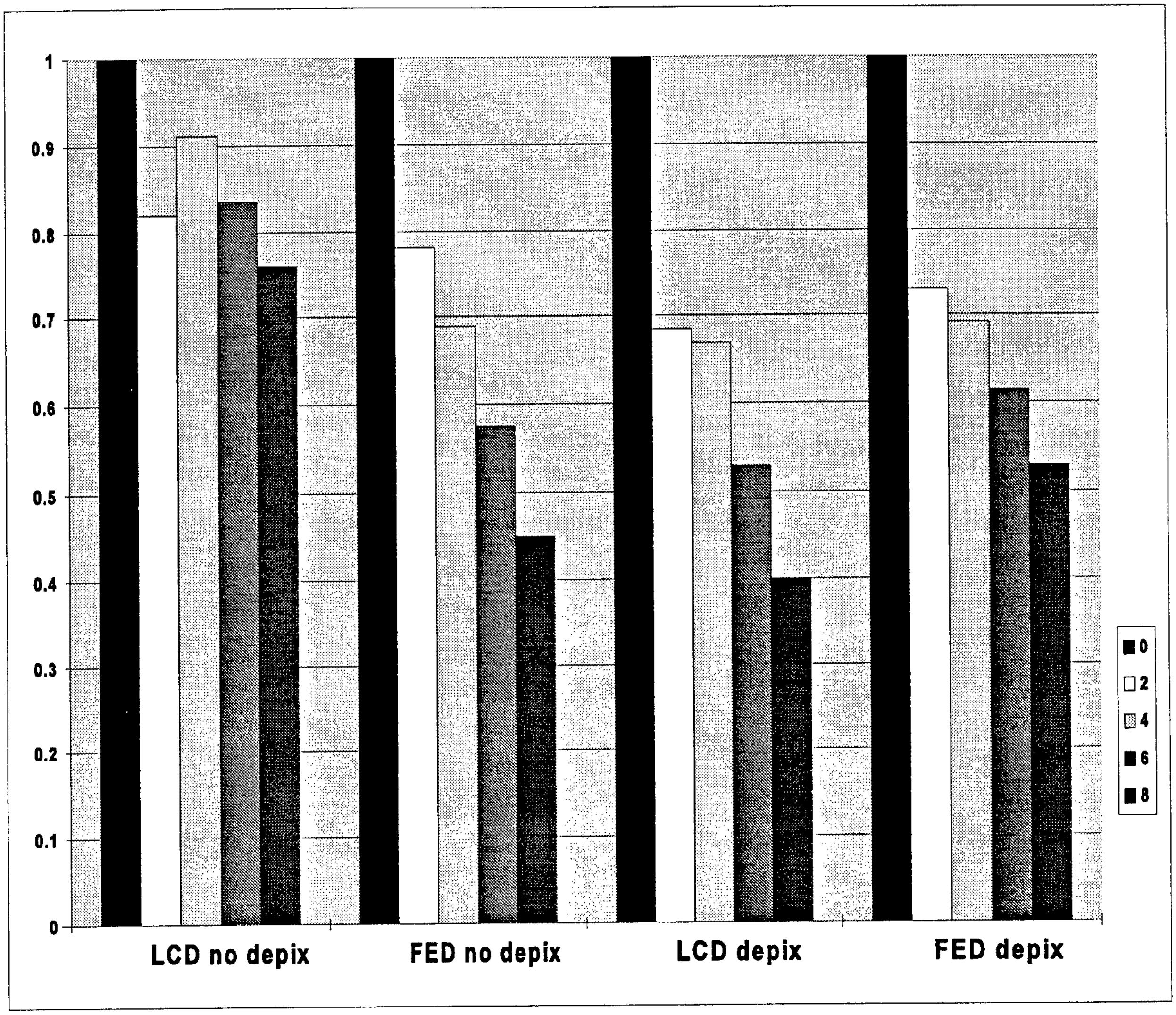


FIGURE 17. MTFs FOR FOUR DISPLAY DEVICE SCENARIOS

CSS RESULTS

Mechanical and Electrical Testing

Physical Size of Displays. The physical dimensions of the LCD and FED are shown in Figure 19. The driver boards were the same size for both displays, 1.4 by 1.665 by .3 in.

TABLE 1. LCD AND FED TEST COLOR BRIGHTNESS

	x	y	u'	v'	Brightness (fL)	Darkness (fL)	Contrast
RED							
LCD without depixelizer	0.566	0.361	0.35	0.2	5.62	1.1	0.804
LCD with depixelizer	0.557	0.36	0.359	0.522	3.42	0.41	0.88
FED sample 1, P74-6	0.579	0.369	0.369	0.53	10.6	0.25	0.976
FED sample 2, P69-49	0.526	0.396	0.314	0.532	7.46	<0.1	>0.999
GREEN							
	x	y	u'	v'	Brightness (fL)	Darkness (fL)	Contrast
LCD without depixelizer	0.301	0.532	0.137	0.545	14.4	1.1	0.924
LCD with depixelizer	0.295	0.564	0.129	0.553	8.72	0.41	0.953
FED sample 1, P74-6	0.349	0.543	0.158	0.554	14.3	0.25	0.983
FED sample 2, P69-49	0.276	0.613	0.113	0.563	11.4	<.01	>0.991
BLUE							
	x	y	u'	v'	Brightness (fL)	Darkness (fL)	Contrast
LCD without depixelizer	0.163	0.156	0.143	0.309	4.82	1.1	0.772
LCD with depixelizer	0.165	0.142	0.151	0.292	2.74	0.41	0.85
FED sample 1, P74-6	0.245	0.263	0.173	0.418	2.9	0.25	0.914
FED sample 2, P69-49	0.207	0.193	0.169	0.354	4	<.01	>0.975
WHITE							
	x	y	u'	v'	Brightness (fL)	Darkness (fL)	Contrast
LCD without depixelizer	0.317	0.355	0.192	0.482	22.5	1.1	0.951
LCD with depixelizer	0.295	0.326	0.187	0.464	12.9	0.41	0.968
FED sample 1, P74-6	0.419	0.419	0.233	0.526	20.4	0.25	0.988
FED sample 2, P69-49	0.339	0.431	0.181	0.517	21.6	<0.1	>0.995

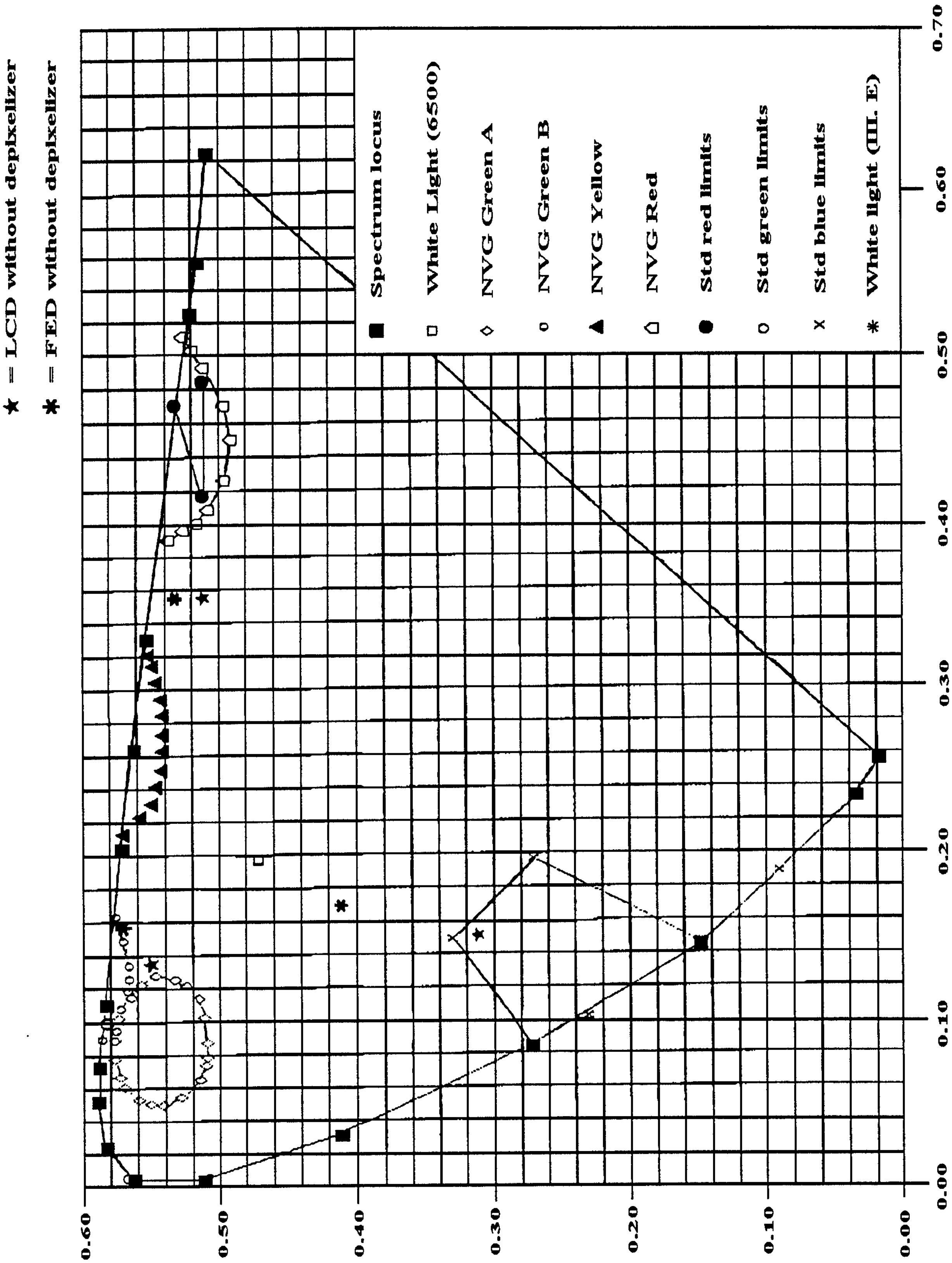


FIGURE 18. 1976 CIE UCS CHROMATICITY DIAGRAM

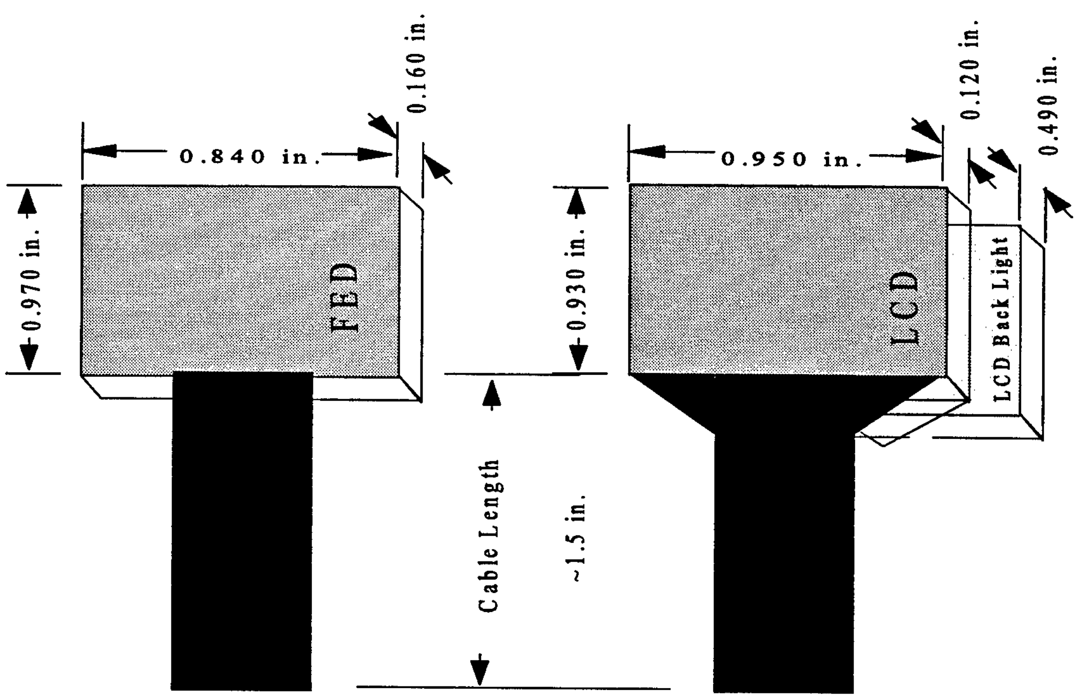


FIGURE 19. LDC AND FED PHYSICAL DIMENSIONS

Power Consumption (Board and Display)

	FED	LCD
Voltage (2 signif fig)	5.0 V	5.0 V
Current (2 signif fig)	170 mA	190 mA
(Calculated)	850 mW	950 mW

Magnetic Testing. The results of the magnetic testing are shown in Table 2.

Temperature Extremes. No problems were noted with either display during any of the extreme temperature testing.

User Testing

The results of the resolution testing are recorded on the data sheets from Appendix A. Overall image quality results are shown in Table 3. A graph of the scoring in the resolution testing is shown in Figure 20.

TABLE 2. MAGNETIC TESTING RESULTS

COMPONENT	GAMMA 5 in.	GAMMA 5 in.
Components Unique to the FED		
Low mu FED	0	0
Standard FED	65	720
48614 Flyback Xformer	80	1060
Flyback Controller 7610-317	0	1
Sony 133-F Xformer	1.55	21.5
Driver Board (Complete)	90	1070
Components Unique to the LCD		
LCD	0	2
LCD Florescent Backlight	8	75
LCD Driver Board	30	377.5
Components Common to Both		
Stripped Driver Board	5	47
Surf Mount Potentiometer	0.5	5.25
Xtal Osc RO35Y855	7.25	76
ETM3030 Timing Chip	5	68
IR3Y05 Chroma Chip	6.25	75
LM393D	0	1.5
LT320	0	0.25
SMT Inductor 330	0	4
SMT Inductor 330 w/Line	0	1.75
SMT Inductor 820J	0	1

TABLE 3. OVERALL IMAGE QUALITY RESULTS

				6 POINT CORRECT		11 POINT CORRECT		16 POINT CORRECT		UNDERWATER			6 POINT CORRECT		11 POINT CORRECT		16 POINT CORRECT	
LCD	FED	Dif.	User	FED	LCD	FED	LCD	FED	LCD	User	FED	LCD	FED	LCD	FED	LCD	FED	LCD
7	5	2	Rich	0	27	21	27	6	6	Lori	6	7.5	22	22	28	28	6	6
6.5	5	1.5	John D.	19	22	28	28	6	6	Bill O.	2.5	4.5	19	27	28	28	6	6
7	5.5	1.5	Pete	21	27	28	28	6	6	Paul	5	8	22	22	28	28	6	6
4	2.5	1.5	Bill O.	15	27	27	28	6	6	Ken	5	4.5	22	26	28	28	6	6
10	7	3	Dale	0	18	15	28	6	6	John M.	5.5	7.5	0	28	28	28	6	6
9	7	2	Lori	23	24	28	28	6	6	Rich	4	8	7	25	23	26	6	6
7.5	6	1.5	Billy C.	23	25	27	28	6	6	John D.	5	8	18	26	28	28	6	6
5	4	1	John K.	25	24	27	28	6	6	Frank	4.5	6	18	26	28	28	6	6
8	6.5	1.5	Paul	23	26	28	28	6	6	Wes	5	7	23	23	28	27	6	6
5.5	6	-0.5	Wes	25	27	28	27	6	6		4.72	6.78	17.4	25.22	27.33	27.56	6	6
6.5	4.5	2	John M.	14	25	28	28	6	6									
7	6	1	Ray	23	25	28	28	6	6									
9	7	2	Jim A.	22	6	28	28	6	6									
6	5	1	Kirk	22	27	28	28	6	6									
4.5	6.5	-2	Ken	21	24	26	27	6	6									
7	5	2	Carl	0	4	23	25	6	6									
6	4	2	Frank H.	24	23	28	28	6	6									
6.5	3.5	3	Bill G.	20	25	28	28	6	6									
10	9	1	Diane B.	25	25	28	28	6	6									
6	9	-3	Terry S.	22	0	28	23	6	6									
Average				18.35	21.55	26.5	27.45	6	6									
6.9	5.7	1.2																
Standard Deviation																		
1.66	1.67	1.48																

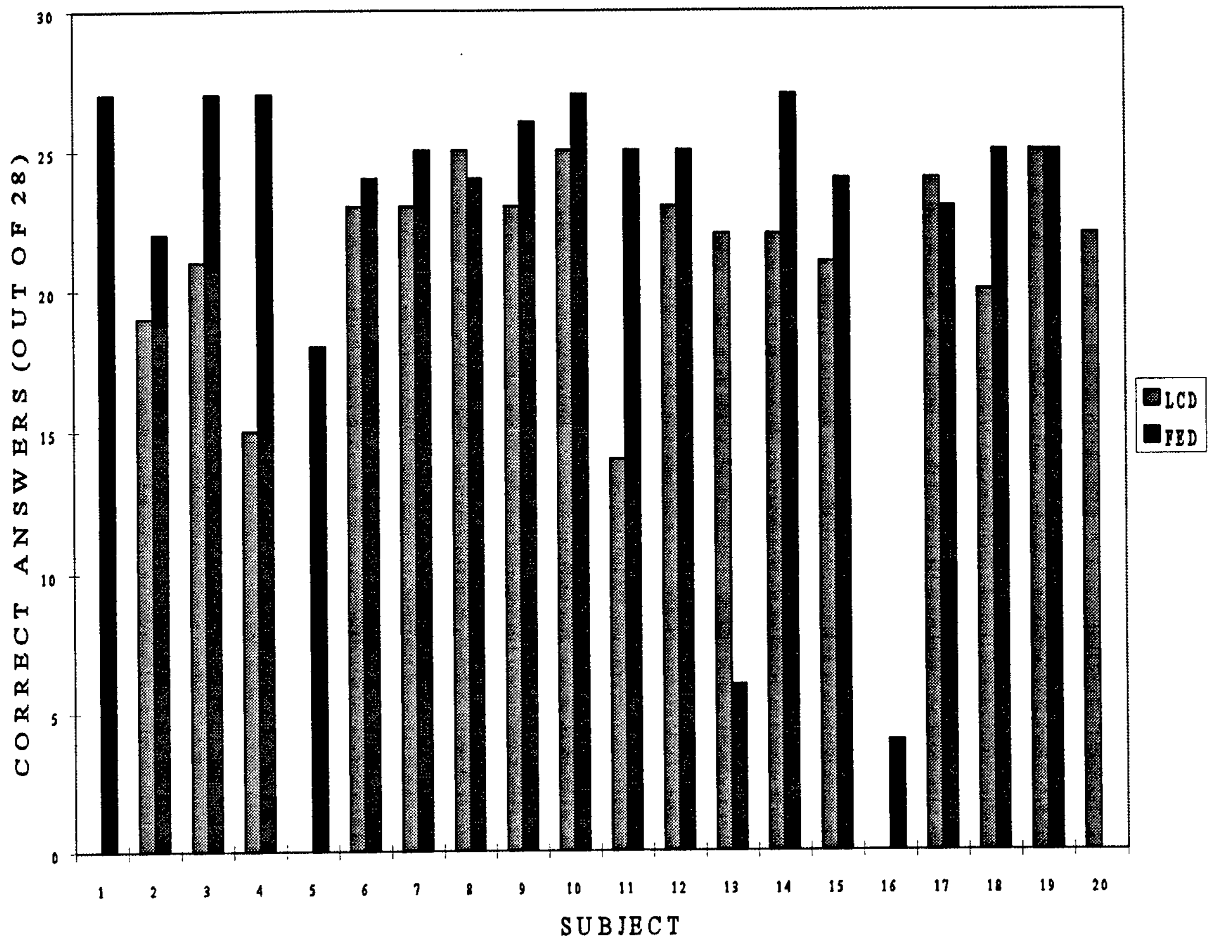


FIGURE 20. RESOLUTION SCORING (CORRECT ANSWERS ON SIZE 6 LETTERING)

DISCUSSION

Resolution is a description of the fine detail that can be presented clearly on a display. Television resolution is commonly defined as the ability of the system to produce an alternate black and white line structure. Each line, black or white, is counted (as opposed to the common *line-pair* terminology in optics or photography). Traditionally, television resolution is stated in lines per picture height.

Displays having a fixed array of pixels are typically described using the number of pixels in the horizontal direction, times the number of pixels in the vertical direction. The FED and LCD are similar in number of pixels; the FED is a 420 by 240 display and the LCD is a 420 by 230 display. While this is an important parameter, it does not take into account the user's visual system, crosstalk, or other degradating effects in the drive electronics or other components (such as a depixelizer). The number of pixels refers only to how the electronic signal was generated and may or may not be close to the actual resolution of the display. For example, a standard video graphics adapter card provides 640 by 480 pixels, but if the signal is displayed on a screen with poor resolution, these pixels cannot be seen. Because a large number of pixels does not assure a high resolution, this test also attempted to measure the modulation associated with sinusoidally varying bar patterns of different spatial frequencies.

Test results show some noticeable differences in resolution between the LCD and FED. On a truly digital display (such as LCD), adjacent pixels are independently controllable and do not abut. They are typically separated by small non-illuminated areas. Therefore, especially in close-up viewing, the display will appear as a collection of illuminated squares. Image integrity is dependent upon two factors: (1) the proportion of inactive area to active area and (2) the typical viewing distance from which the inactive areas are not visually distracting. The LCD produced a uniform pixel pattern on the OPTIMA video screen.

Unlike the LCD, the FED-generated pixel patterns are not uniform. Some pixels are brighter than others; hence they appear bigger while some pixels are darker than others. From Figures 11 through 16, it can be seen that substantially non-uniform gray levels cross the bar pattern. The depixelizer is not necessarily well matched to the FED, so these results should be taken at face value only. With a more properly matched depixelizer to the FED pixel structure and display device geometry, better results are likely.

The modulation for a sinusoidally varying intensity pattern is defined as (Imax - Imin) / (Imax + Imin). At any given frequency, the MTF is the ratio of the modulation of the sinusoidally varying bar patterns divided by the modulation of the very large bars (modulation in the image divided by the modulation in the object). The MTF is plotted as a function of the spatial frequency in line-pairs per millimeter. If sinusoidally varying bar patterns are extremely large or wide, the blacks should be as black as those of the wide bar patterns and the lights should be a light as those of the wide bar patterns, and the resulting MTF would be unity (0 lp/mm).

The MTF can be used to characterize a display's performance at various spatial frequencies, therefore indicating the display's resolution at more than one frequency of interest. MTF analysis can accurately characterize the loss in image quality due to each part of an imaging system, and therefore is an aid in predicting the loss in resolving power.

Color is a multidimensional phenomenon and is based on the relative proportions of energy detected by three distinct types of photoreceptors in the eye. Since the human eye can only provide a subjective measure of color performance, a color standard was needed to enable manufacturers of paints, dyes, inks, electronics, etc., to specify and communicate the colors of their products. In 1931, the CIE; a Vatican Council of color science, developed a (x,y) chromaticity diagram. In 1976, the CIE revised its 1931 diagram. The 1976 UCS diagram is now the internationally recognized industry standard. The 1976 CIE UCS was used to determine deviations from the standard RED, GREEN, and BLUE limits.

The data indicate that LCD colors do not vary significantly with or without the depixelizer, and the colors are in the vicinity of the standard RED, GREEN, and BLUE limit. Two FED samples were measured, and the variance in the color coordinates was greater between the two displays. For the FEDs, GREEN is the closest color to the standard, with RED in the vicinity of its standard, and

BLUE well removed from the standard color limit. This can also be seen from the video window; when FED BLUE was turned on, GREEN pixels were not totally turned off and hence shifted BLUE to GREENISH BLUE.

For brightness testing of the LCD, Table 1 documents that the depixelizer blocks about 40 percent light. The FEDs were significantly brighter in RED than the LCD sample, but comparable in other colors to the LCD. The LCDs had uniform brightness across the surfaces, while the FEDs (as discussed earlier) showed variance in brightness across the display (see Figures 11-13). Clearly, the FEDs have excellent contrast, which exceeds the contrast values for LCDs.

Image quality is a complex subject that involves several parameters. The key indicator of image quality relates to the color accuracy and the MTF of the display, which describes how much contrast is available or displayed as a function of spatial frequency. Two parameters related to the MTF are gray-shades (contrast) and resolution (maximum spatial frequency that can be seen or *resolved*). As discussed in prior sections, for the basic display device itself, the resolution of a display is often stated as simply the number of pixels in the horizontal and vertical directions. This, however, can be misleading because the overall resolution can be affected by a loss in contrast due to the electronics (*bleeding* between rows and columns), depixelization components, and other effects.

Although benchtop testing indicated some measurable differences in color, brightness, and resolution, the users' opinions were not nearly so clear cut. There were some obvious trends in user testing, but no clear consensus. In some cases, there were conflicting opinions.

In 17 of 20 users, the LCD was rated higher in overall image quality than the FED. The average score on a scale of 1 to 10 was 5.7 for the FED and 6.9 for the LCD. This was determined to be statistically significant with a T-Test ($t=3.25$, $P<.01$). In addition, 15 of 20 users were more successful at reading the small lettering with the LCD than the FED. Several users indicated that the FED was fuzzy or that the focus was not as good as the LCD.

The impression of the correctness of color was affected by the object on the screen and the intensity of the colors. Generally, the opinion was that the FED's colors were not intense enough and the LCD was too intense. Responses indicated the FED was washed out, the grass was too green on the LCD, and some colors bloomed on the LCD. Although several responses indicated that the FED was too green or yellowish green, other responses indicate that on white or light colors, red dots or splotches could be seen. A couple of responses indicated that the LCD was slightly too red. Most subjects however agreed that the color was better on the LCD. Possibly the most significant color question concerned the background color of the sonar display. A blue background was used. User response to the question of the background was purple for the FED, but blue for the LCD. Although the benchtop test had indicated some lack of consistency in micro (or pixel) level on brightness and colors, the users responded that color was consistent across the screen.

Several other general comments were made including that the LCD was dark around the edges, the FED was much grainier than the LCD, and the FED had high contrast such that the whites were too white and the darks were too dark.

Neither of the displays was considered adequately bright when looking into a bright sunny sky with both eyes open. Both displays were considered marginal in bright light but facing away from the sun. Both displays were considered acceptable in brightness inside, in darker conditions, and in the water.

CONCLUSIONS

Table 1 summarizes the color (u', v') coordinates of each LCD and FED. The location of the coordinates in Figure 18, the standard CIE UCS Chromaticity Diagram, shows where the color is located on the diagram. Both pixelized LCD and FED color locations are shown on Figure 18. The color on the LCD tends to be more accurate than on the FED, especially in the blue.

The final test for a display device is the visual perception of the viewer, which will vary from person to person. The visual parameter corresponding to image quality (resolution and contrast) is visual acuity. Normal visual acuity for the human eye for highly luminous objects is approximately 1 min of arc, depending on the contrast and shape of the object. Test results show the FEDs have higher contrast, while LCDs have better MTF.

Resolution and color accuracy testing on the benchtop and with the users were in agreement and indicate that the LCD has better resolution and color accuracy than the FED. The differences were not as striking with the users. For instance, in benchtop testing, it was noted that there was a great deal of non-uniformity in individual pixel brightness for the FED. The users indicated that the color was consistent across the display. Although the differences in user scores were statistically significant, the overall opinion was that the LCD was only slightly better than the FED and both displays were acceptable.

It should be noted that this evaluation was accomplished with a FED prototype for which improvements are still being made. A production LCD however was used during all tests. It should be realized that the LCD was not state-of-the-art and higher resolution LCDs are now readily available.

Some darkening of the edges of the LCD was noted. This would appear to be the result of the optics design's causing too great a viewing angle with the LCD. Since the liquid crystals act as polarizing filters, relatively small viewing angles reduce the amount of light viewed. This is not a problem with the FED.

The brightness of both displays was acceptable inside, but unacceptable in bright sunlight. Neither display seemed to have a significant advantage. Both would require shading in bright sunlight.

In underwater testing, a slightly higher score was given to the LCD than in topside testing and a slightly lower score was given to the FED than in topside testing. This may be indicative of a more stressful environment. Further testing is needed to determine the significance of this observation.

One interesting anomaly occurred in the user testing. Two users are nearsighted and were unable to wear their glasses in the testing because of interference with the mask. Both were able to read the small lettering better with the FED. This contradicted all test results on other users. A possible explanation of this was generated by Dr. Kerry Hunt from the Opthomology Department at the Pensacola Naval Hospital.[6] He indicated that since the individuals were nearsighted, their focal distance without glasses was close to their eyes as compared to people with normal vision who focus at infinity. The eye is able to modify its focal distance to accommodate shorter distance, but is unable to refocus at longer distances. This would mean that people with focal distances shorter than the display focal distance could not focus on the display. Dr. Hunt theorized that the focal distances for the two displays were slightly different with the LCD being slightly further from the eye. The subjects could focus on the FED but not the LCD.

The other characteristics of the two displays, such as their power consumption, magnetic signatures, size, and operation in temperature extremes, demonstrated little difference. One FED passed the magnetic specification, but the driving circuitry did not. Since many of the components of the driving circuitry are similar, redesigning the circuit board for low magnetic signature should require the same level of effort. The LCD has a slight disadvantage in that its backlight would also require redesign for low magnetic signature.

In certain application, the differences in the FED and LCD would have little effect on operational efforts. Small lettering and exact colors are not necessary and human factors indicate that the graphics should be designed to be easily readable. Some applications however indicate that the highest resolution and best colors are important. For instance, identifying a piece of ordnance with a camera or sonar requires high resolution. For these applications, the LCD is the appropriate choice.

This project was meant as a quick comparison test between two technologies. More extensive testing would be required to give a complete evaluation. Environmental and field testing were minimal and should be expanded before introduction of these displays into products for the Fleet.

REFERENCES

1. Gallagher, D. and Dorch, R., *Diver's Head Mounted Display*, Coastal Systems Station, Panama City, FL, 1994.

2. Dorch, R.; Gallagher, D.; and Downs, F., *Diver's Head Mounted Display Final Report*, EOD/LIC Task 60, Coastal Systems Station, Panama City, FL, 1994.

3. F. Sears; M. Zemansky; and H. Young, Lenses and Optical Instruments, Chapter 41, 5th Ed., University Physics, Addison-Wesley Publishing, 1979, pp. 696-697.

4. *Edmund Scientific Reference Catalog for Optics, Scientific Lens Primer*, Edmund Scientific Company, Barrington, NJ, 1992, pp. 19, 34, 40.

5. MIL-M-19595C, *Magnetic Effect for Non-magnetic Equipment Used in the Proximity of Magnetic Influence Ordnance*, 2 Aug 78.

6. Telephone conversation with Dr. Kerry Hunt from the Opthamology Department of Pensacola Naval Hospital, Pensacola, FL, 10 Apr 96.

APPENDIX A

DATA SHEETS

DATA SHEET 1

Name:____________________
Date:____________________

Do you wear glasses or contacts (circle): Yes No

If so, what eye condition is it to modify (Nearsighted, Farsighted, Astigmatism, etc.)

____

Do you have glaucoma (circle): Yes No

Are you taking any medications? _____________________

If so, what type ____________________________________

When was your last eye exam? _________________________

Eyesight at last eye exam ____________________________

Are you color blind (circle): Yes No

If so, what type of color blindness __________________

Eye Chart Results:

Smallest Correct Line (Number) _____

Smallest Line Attempted (Number) _____

Smallest Line Attempted (Letters) ______________________________

DATA SHEET 2

Name ____________________ Date ____________________

Color Test:
Do the facial colors look correct (circle): Yes No

If not, do they look (circle):

Too red? Too Blue? Too Green?

Other Comments ____
____
____

Resolution Test:
Read back the characters

____________________ ____________________
____________________ ____________________
____________________ ____________________
____________________ ____________________
____________________ ____________________
____________________ ____________________

Operational:

Direction of compass arrow ______________

Background color ______________

Color of lowest bar ______________

Do you have any problems reading the information displayed (circle): Yes No

Other comments ____
____
____

Overall:
Image Quality (1 lowest, 10 highest) ______

Was the image quality consistent across the image (circle): Yes No
(describe differences if any occurred)

Inside Brightness (circle): Acceptable Marginal Unacceptable

Outside Brightness (circle): Acceptable Marginal Unacceptable

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