



NIDL evaluated a 22-inch diagonal, 0.12 mm pixel pitch IBM 3840 x 2400 pixels (9-megapixels) color digitally-addressed LCD monitor, Model T221, purchased for delivery to NIMA. IBM has recently reduced the purchase price to \$8,399. We find that images and Briggs patterns at 2X (1920 x 1200 pixels) look excellent. The monitor exceeds the NIMA IEC Working Group specifications for monoscopic mode color applications. Accordingly, NIDL gives it an "A" rating, and thereby certifies the IBM 9-megapixel monitor for color monoscopic IEC workstations. LCDs generally cannot refresh fast enough to do stereo at the 120 Hz vertical refresh rate needed for StereoGraphics ZScreen or CrystalEyes based stereo. We found that the ability to roam quickly is a function of the computer, the display graphics card, the image manipulation software, and the display itself. For the T221 using a low-end version of RemoteView, the smoothest roam of three graphics cards tested was observed using a Radeon 8500 single-DVI digital display graphics card at 1920 x 1200 pixels at 41Hz. We achieved 100 to 300 pixels per second.

Evaluation of the IBM T221 16 x 10 Aspect Ratio, 22.2-Inch Diagonal 3840 x 2400 Pixel LCD Color Monitor

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**NIDL Publication No. 750811201-130
May 8, 2002**

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Report Documentation Page

Report Date 08052002	Report Type N/A	Dates Covered (from... to) -
Title and Subtitle Evaluation of the IBM T221 16 x 10 Aspect Ratio, 22.2-Inch Diagonal 3840 x 2400 Pixel LCD Color Monitor	Contract Number	
	Grant Number	
	Program Element Number	
Author(s)	Project Number	
	Task Number	
	Work Unit Number	
Performing Organization Name(s) and Address(es) National Information Display Laboratory P. O. Box 8619 Princeton, NJ 08543-8619	Performing Organization Report Number	
	Sponsoring/Monitoring Agency Name(s) and Address(es)	
		Sponsor/Monitor's Acronym(s)
		Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited		
Supplementary Notes The original document contains color images.		
Abstract		
Subject Terms		
Report Classification unclassified	Classification of this page unclassified	
Classification of Abstract unclassified	Limitation of Abstract UU	
Number of Pages 93		

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NIDL IEC Monitor Certification Report

The IBM T221 LCD Color Monitor

FINAL GRADES

Monoscopic Mode: A

Stereoscopic Mode: F

A=Substantially exceeds IEC Requirements; B= Meets IEC Requirements; C=Nearly meets IEC Requirements; F=Fails to meet IEC Requirements in a substantial way

NIDL evaluated a 22-inch diagonal, 0.12 mm pixel pitch digital-only IBM 3840 x 2400 pixel (9-megapixel) color LCD monitor purchased for delivery to NIMA. We find that images and Briggs patterns at 1920 x 1200 pixels looks excellent, and the monitor passes the NIMA IEC Working Group specifications for monoscopic color mode applications. NIDL gives it an "A" rating, and thereby certifies the IBM 9-megapixel monitor for color monoscopic IEC workstations. We do not certify it for stereo because LCD monitors cannot refresh fast enough to do 120 Hz vertical refresh rate needed for StereoGraphics ZScreen- or CrystalEyes-based stereo image viewing.

NIDL paid \$14,500 for the T221 LCD bundled with the Matrox G200 MMS graphics card through a GSA schedule. The manufacturer has now reduced the price to \$8399.

With the high 3840 x 2400 pixel addressability, the T221 offers a number of options to the user. The 22.2-inch screen can display two 1920 x 1200 pixel pages or images side-by-side. Alternatively, the full screen can display a full 3840 x 2400 pixel image, which allows a broader viewing area for high pixel count maps or images.

Contrary to expectations, the 9-megapixel LCD monitor can be easily addressed with an inexpensive PC computer and inexpensive graphics card to produce images and test patterns. Because of the 9 megapixel, digital-only addressability (no provision for analog), NIDL could not use its traditional analog signal generators to produce test patterns on the screen for subsequent measurement. Instead, we utilized test patterns and images generated the way they will be in actual use, namely with a PC and a digital graphics card. We examined three different graphics cards with the T221 LCD monitor. The ATI Fire GL4 graphics card that refreshes the 9-megapixel LCD screen at 24 Hz, the Matrox G200 MMS quad-DVI at 41 Hz, and the Radeon 8500 single-DVI at 13 Hz. No flicker was observed with any of these graphics cards.

To confirm some details of the tonal transfer curve and the cone of luminance, NIDL performed additional measurements at the IBM Watson Laboratory in Yorktown Heights, NY. We found that the measurements made at NIDL with its Microvision system and goniometer head agreed very well with the luminance versus viewing angle measurements made at IBM using their ELDIM spatial photometer. We confirmed that the duplicate luminance level for increasing input count measured at NIDL using an ATI FireGL4 card was also missing in measurements made at IBM. IBM will bring this failure to the attention of the manufacturer of this graphics card. The Matrox G200 MMS purchased with the T221 LCD produced all 256 gray levels. Initially, we

could not produce all 256 levels with the Matrox card in our NIDL PC. This problem was finally traced to a segment of Siemens SMfitACT software residing in our NIDL PC influencing the tonal transfer curve measured using the Matrox card. After this offending segment was removed, the full 8-bit TTC using the Matrox card was observed. Thus, we have found that the computer and its software, as well as the display graphics card can influence the tonal transfer curve.

The following Evaluation Datasheet summarizes the performance of the 22 inch 3840 x 2400 pixel addressability IBM T221 LCD. We also give data on the Samsung 24 inch 1920 x 1200 pixel addressability LCD monitor to provide a comparison. The Samsung is capable of both analog and digital addressing so only the digital measurements can be compared directly. We report on the T221 at two luminance levels. The first, where Lmin is 0.1 fL with its concomitant Lmax of 38.5 fL. The second where Lmin is 0.2 fL and Lmax is 75 fL. We do this because Lmin and Lmax are not separately adjustable so increasing the brightness control increases both Lmin and Lmax. In this way, the dynamic range remains at about 375:1 as the brightness control is adjusted. NIDL has seen this single knob function on other LCD monitors also.

The table shows the angular dependence of viewability is superior for the IBM T221 compared to the Samsung 240T (nearly twice as good).

Comments were made on poor color tracking for the Samsung 24 inch 240T LCD monitor. Color tracking refers to the monitor maintaining the same correlated color temperature as the luminance is increased from Lmin to Lmax. We find that the IBM color tracking is excellent and varies from a low of 6011K to a high of 6091K over the luminance range of 0.9 to 37.9 fL. This compares favorably against the Sony GDM-F520 CRT monitor and is much better than the Samsung 240T LCD monitor.

To evaluate the human-display interface, NIDL evaluated the human response to Briggs patterns displayed at the maximum addressability using 1-pixel-on/ 1-pixel-off format (204 pixels per inch), and also at 2-pixel-on/ 2-pixel-off (102 pixels per inch) that approximates a 1920 x 1200 pixel display. We found that the observers scored the Briggs patterns significantly higher (by almost 50%) for the 2-pixel-on/ 2-pixel-off display format of the Briggs patterns compared to 1-pixel-on/ 1-pixel-off (3840 x 2400 addressability). For our evaluations of Briggs targets, optical magnification was used for both addressabilities and is permitted by the ground rules for the evaluation of Briggs targets. The increase of Briggs scores with decreasing pixel density over the range 169 to 50 ppi was reported by Leachtenauer et al (IS&T PICS p 184-189, 1999). They also reported that delta-NIIRS peaks at about 85 ppi, so the present NIDL results on the IBM 9 megapixel LCD showing a higher Briggs score at 102 ppi versus 204 ppi is not surprising. Comparing the T221 to the 240T, the data shows significantly higher Briggs scores for the IBM T221 than for the Samsung 240T.

NIDL also investigated addressabilities other than the native 3840 x 2400 (16:10) pixels. We found that the Matrox G200 MMS graphics adapter did not offer a 1920 x 1200 (16:10) addressability, or a 1600 x 1200 (4:3) addressability that NIMA uses in some of its imagery analyst workstations. We also tried a 1280 x 1024 (5:4) pixel addressability, for which the monitor displayed 1280 x 1024 but sized it at 2X so that it filled 2/3's of the screen. Also, when we examined the details of the pixel at each of these different addressabilities we found differences in the line structure using the Microvision spectrophotometer. The pixel at 3840 x 2400 pixel addressability is a single peak, but for 1280 x 1024 pixel addressability a

monochromatic green line consisted of a main peak with a 50% lower amplitude satellite peak on either side of the main peak. We anticipate that these satellite peaks could affect the Briggs patterns scores at 1280 x 1024 addressability. Thus, to achieve the highest image quality a pixelated display like an LCD must be addressed to minimize introduction of spurious extra peaks.

NIDL also evaluated the dynamic response of the IBM LCD monitor. Here we find that the rise time between the 10% and the 90% luminance levels and the fall time between the 90% and the 10% luminance levels of the T221 LCD take about 22 and 25 ms, respectively, about 30% longer than for the Samsung 240T. As stated above, the 9 megapixel LCD cannot do stereo using the IEC standard 21 inch StereoGraphics ZScreen or the active stereo glasses at 120 Hz refresh rate. Also, the T221 shows a significant (70 s) residual image at low luminance.

NIDL sought to improve upon the roam operation we observed with the IBM 9 megapixel LCD monitor and its Matrox graphics card. We consulted the staff (Mr. Steven Wright and Dr. Steve Millman) at the IBM Watson Research Center to: select the best-available graphics card; adjust the electronic EDID files within the LCD monitor to display 3840 x 2400 x 13 Hz, 1920 x 1200 x 41 Hz, and 1280 x 1024 x 60Hz modes needed for the Radeon 8500 graphics card; and program the T221 to be able to toggle between 3840 x 2400 and 1920 x 1200 pixel addressability. NIDL had found earlier that the Briggs target measurements are 50% higher for the 1920 x 1200 pixel addressability so we wanted to have the lower addressability available to demonstrate roam on a large image of the Washington, DC area. At the IBM Watson Research Center, the T221 LCD purchased by NIDL was tested with NIDL's Matrox G200 MMS quad-DVI graphics card and an economy-version PC RemoteView software. All roam tests were done for a full screen PC RemoteView window. Roaming through the Briggs test target using the Matrox card in 3840 x 2400 native mode produced severe tearing in the image. It was observed that faster roam could be achieved without image tearing by reducing the RemoteView window size (number of pixels addressed), but reducing the window size does not eliminate smearing. The reduced mode of 1920 x 1200 pixels could not be tested because it had not been pre-programmed into the Matrox driver by the manufacturer.

An ATI Fire GL4 graphics card substituted for the Matrox card allowed smooth roam in 1920 x 1200 addressability mode at up to 9 pixels per second. But in 3840 x 2400 mode, the roam motion was jerky even for the slowest roam rate of about 6 pixels per second.

A final combination tested with the T221 LCD was a Radeon 8500 single-DVI graphics card having 64 MB memory. In 3840 x 2400 x 13 Hz mode, the image was torn and motion was jerky even at the slowest roam rate. At 1920 x 1200 x 41 Hz mode, roam rates between 100 to 300 pixels per second were smooth and acceptable depending on the amount of smearing that one chooses to tolerate. Here we see that single DVI digital addressing performs remarkably well compared to the Matrox quad DVI driving the 9-megapixel LCD. The smearing may not be due to the graphics card, but rather may be caused by the response time of the LCD itself. The measured responses for rise and fall times are 22ms and 25 ms, respectively. For comparison, CRT response times are in the microseconds. We used the IBM T221 9 megapixel LCD with the Radeon graphics card for the NIMA Soft Copy Search Team visit on 3-26-02 to demonstrate roam at 3840 x 2400 and at 1920 x 1200 pixel addressability.

Evaluation Datasheet

IBM T221 MD22292A1 and Samsung 240T LCD Monitors

Mode	IEC Requirement	IBM T221		Samsung 240T	
		Measured Performance	Compliance	Measured Performance	Compliance
MONOSCOPIC					
Addressability	1024 x 1024 min.	3840 x 2400	pass	1920 x 1200	pass
Dynamic Range	24.8 dB	25.8 dB at 38.5 fL 25.7 dB at 75 fL	pass	25.9 dB, 25.5 dB ⁽¹⁾	pass
Contrast Ratio	300:1	385:1 at 38.5fL 375:1 at 75fL	pass	393:1, 355:1 ⁽¹⁾	pass
Luminance (Lmin)	0.1 fL ± 4%	0.1fL at 38.5fL Lmax 0.2fL at 75fL Lmax	pass	0.1 fL	pass
Luminance (Lmax)	30 fL ± 4%	38.5fL at 0.1fL Lmin 75fL at 0.2fL Lmin	pass	39.3 fL, 35.7 fL ⁽¹⁾ 55 fL at 5745 K	pass
Reflectance	Not specified	4.3 %	----	5.1 %	----
Uniformity (Lmin black) 240-point Sampled	Not specified	35.1 %	----	41 %	----
Uniformity (Lmax white) 9-point Sampled	20% max. 30% absolute max.	32.9 % sample #1 ⁽⁵⁾ 21.3 % sample #2 ⁽⁶⁾	pass	23.4 %	pass
240-pt. Sampled	Not specified	40.2 % sample #1 ⁽⁵⁾	----	30.3 %	----
Uniformity (Chromaticity) 9-point Sampled	0.010 ± 0.005 delta u'v' max.	0.0042 delta u'v'	pass	0.002 delta u'v'	pass
240-pt. Sampled	Not specified	Not Measured	----	0.008 delta u'v'	----
Mura	Not specified	None present	----	Some present	----
Halation	3.5% max.	0.08%	pass	0.13%	pass
Correlated Color Temperature	6500K to 9300K	6069K at 38 fL 5995K at 75 fL	pass	6107K at 39.3fL 6669K at 35.7fL ⁽¹⁾	pass
Distance from Daylight Locus	0.010 delta u'v' max.	0.005 delta u'v'	pass	0.015 delta u'v' 0.009 delta u'v' ⁽¹⁾	pass
Color Tracking	No specification	6011K to 6069K (2.9 fL to 38 fL)	----	11274K to 6111K (3.9 fL to 39 fL)	----
Color Gamut Area	No specification (Sony FW900 CRT is 27%)	22% of CIE area	----	19% of CIE area	----
Bit Depth	8-bit ± 5 counts	8-bit	pass	8-bit	pass
Step Response, Analog	No visible ringing	Does not support analog clean	----	Phantom trailing edge pixel	fail analog
Step Response, Digital	No visible ringing		pass	Clean - Digital	pass digital
Pixel aspect ratio	H = V ± 6% Square pixel	H = V + 0.0%	pass	H = V + 0.2%	pass
Pixel density	72 ppi min.	204 ppi	pass	94 ppi	pass
Phosphor-to-pixel spacing	1.0 max.	1.0 (No Moiré observed)	pass	1.0 (No Moiré observed)	pass
Screen size, viewable diag.	17.5 to 24 inches ± 2 mm	22.202 inches	pass	24.043 inches	pass

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Cm, Zone A, 7.6 inch diag.	25% min.	>81 % 1-ON/1-OFF >88% 2-ON/2-OFF	pass	77 % 1-ON/1-OFF	pass
40% circle, 10.5 in. diag.	25% min.	>81 % 1-ON/1-OFF >88% 2-ON/2-OFF	pass	77 % 1-ON/1-OFF	pass
Cm, Zone B	20% min.	>81 % 1-ON/1-OFF >88% 2-ON/2-OFF	pass	75 % 1-ON/1-OFF	pass
Straightness	0.5% max ± 0.05 mm	< 0.04%	pass	Not Measured	pass
Linearity	1.0% max ± 0.05 mm	< 0.06%	pass	Not Measured	pass
Jitter	2 ± 2 mils max.	0.276 mils	pass	0.45 mils ⁽⁴⁾	pass
Swim, Drift	5 ± 2 mils max.	0.276 / 0.306 mils	pass	0.50 / 0.42 mils	pass
Warm-up time, Lmin to +/- 50% max.	30 ± 0.5 minutes	1 min.	pass	1 min.	pass
Warm-up time, Lmin to +/- 10% max.	60 ± 0.5 minutes	5 mins.	pass	10 mins.	pass
Refresh, Analog	72 ±1 Hz min. 60 ±1 Hz absolute minimum	Does not support analog.	-----	Set to 60 Hz analog	pass ⁽²⁾ LCD exhibits no flicker
Digital	72 ±1 Hz min. 60 ±1 Hz absolute minimum	Set to 41 Hz ⁽⁷⁾ quad-DVI digital Set to 24 Hz ⁽⁸⁾ dual-DVI digital	pass ⁽²⁾ LCD exhibits no flicker	52 Hz digital single-DVI	pass ⁽²⁾ LCD exhibits no flicker
Briggs Scores 3840 x 2400, Digital	No specification	<u>1X magnification</u> (1-on/1-off = 1X) Delta-1 = 14 Delta-3 = 38 Delta-7 = 56 Delta-15 = 72 <u>2X magnification</u> (2-on/2-off = 2X) Delta-1 = 23 Delta-3 = 56 Delta-7 = 70 Delta-15 = 86	-----	Does not support 3840 x 2400	-----
1920 x 1200, Analog	No specification	Does not support analog.	-----	Delta-1 = 12 Delta-3 = 34 Delta-7 = 55 Delta-15 = 58	-----
1920 x 1200, Digital	No specification	TBD	-----	Delta-1 = 16 Delta-3 = 38 Delta-7 = 59 Delta-15 = 71	-----
1280 x 1024, Analog	No specification	Does not support analog	-----	Delta-1 = 11 Delta-3 = 33 Delta-7 = 55 Delta-15 = 71	-----
1280 x 1024, Digital	No specification	TBD	-----	Delta-1 = 16 Delta-3 = 38 Delta-7 = 59 Delta-15 = 71	-----

Viewing Angle	No specification	NIDL Measurements Vert: ± 42 degrees Horiz: ± 35 degrees IBM Measurements Vert: ± 46 degrees Horiz: ± 36 degrees	-----	NIDL Measurements Vert: ± 20 degrees Horiz: ± 20 degrees	-----
Rise Time		Does not support analog	-----	20 ms	-----
Analog	No specification		-----	13 ms	-----
Digital	No specification	22 ms	-----		-----
Fall Time		Does not support analog	-----	18 ms	-----
Analog	No specification		-----	18 ms	-----
Digital	No specification	25 ms	-----		-----
Roam Speed	No specification	TBD	Fail	TBD	Fail
Residual Image	No specification	70 s, worst case	-----	None visible	-----
STEREOSCOPIC	1024 x 1024 x 120Hz	Not Measured ⁽³⁾	fail	Not Measured ⁽³⁾	fail
AMBIENT LIGHTING					
Dynamic Range	No specification	< 3 fc at 38.5 fL < 6 fc at 75 fL	-----	<2 fc	-----
22 dB (158:1)					
Dynamic Range	No specification	< 12 fc at 38.5 fL < 25 fc at 75 fL	-----	11 fc	-----
17.8 dB (60:1)					

(1) CCT values within the IEC required range could only be obtained for slightly lower values of Lmax, i.e., 35.7 fL.

(2) No flicker is perceived at 24 Hz, 41 Hz or 60 Hz refresh rates as tested.

(3) LCD cannot achieve 120 Hz refresh rate required for stereo.

(4) 1 mil = 0.001 inch

(5) Sample #1 T221 LCD serial number 108 purchased by NIDL for delivery to NIMA.

(6) Sample #2 T221 LCD serial number 345 loaned by IBM to NIDL for evaluation.

(7) Matrox G200 MMS graphics card

(8) ATI FireGL4 graphics card

Section I INTRODUCTION

The National Information Display Laboratory (NIDL) was established in 1990 to bring together technology providers - commercial and academic leaders in advanced display hardware, softcopy information processing tools, and information collaboration and communications techniques - with government users. The Sarnoff Corporation in Princeton, New Jersey, a world research leader in high-definition digital TV, advanced displays, computing and electronics, hosts the NIDL.

The present study evaluates a production unit of the IBM Model T221, Type 9503-DG1, Serial No. 98-00108 Color LCD high-resolution display monitor purchased by NIDL for delivery to NIMA. Some measurements were also made on a second T221 monitor (Serial No. 98-00345) on loan from IBM. This report is intended for both technical users, such as system integrators, monitor designers, and monitor evaluators, and non-technical users, such as image analysts, software developers, or other users unfamiliar with detailed monitor technology.

The IEC requirements, procedures and calibrations used in the measurements are detailed in the following:

- *NIDL Publication No. 0201099-091, Request for Evaluation Monitors for the National Imagery & Mapping Agency (NIMA) Integrated Exploitation Capability (IEC), August 25, 1999.*
- *SofTrak User's Guidelines and Reference Manual Version 3.0, NIDL, Sept. 1994.*

Two companion documents that describe how the measurements are made are available from the NIDL and the Defense Technology Information Center at <http://www.dtic.mil>:

- *NIDL Publication No. 171795-036 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: CRT Color Monitor Performance Draft Version 2.0. (ADA353605)*
- *NIDL Publication No. 171795-037 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 2: Color CRT Monitor Performance Draft Version 2.0. (ADA341357)*

Other procedures are found in a recently approved standard available from the Video Electronics Standards Association (VESA) at <http://www.vesa.org>:

- *VESA Flat Panel Display Measurements Standard, Version 2.0, June 1, 2001.*

The IEC workstation provides the capability to display image and other geospatial data on either monochrome or color monitors, or a combination of both. Either of these monitors may be required to support stereoscopic viewing. Selection and configuration of these monitors will be made in accordance with mission needs for each site. NIMA users will select from monitors included on the NIMA-approved Certified Monitor List compiled by the NIDL. The color and monochrome, monoscopic and stereoscopic, monitor requirements are listed in the Evaluation Datasheet.

I.1 Manufacturer's Specifications for the IBM T221 LCD Color Monitor

Please see the IBM web site for details of its T221 monitor

<http://www-132.ibm.com/webapp/wcs/stores/servlet/ProductDisplay?catalogId=-840&langId=-1&partNumber=9503DG3&storeId=1>

Features provided by IBM

- 56.4 cm (22.2 inch) diagonal viewing area
- Color TFT LCD display
- QUXGA-Wide 3840 x 2400 pixels for total of 9.2 megapixels
- 235 candelas/square meter (69 fL)
- High contrast as 400:1
- Native 16 million colors (R, G, B 8-bit each)
- High color reproducibility
- Post spacer technology
- Wide viewing angle as 170 degrees using In Plane Switching (IPS) Dual Domain Technology

Specifications provided by IBM

- Screen diagonal 564 mm (22.2 inches)
- Active area 478.1 mm x 298.8 mm
- Pixels 3840 (horizontal) x 2400 (vertical)
- Pixel pitch 0.1245 (H) x 0.1245 (V)
- Pixel arrangement R, G, B vertical stripes
- Display mode Dual domain IPS, normally black
- Contrast ratio 400:1 typical (in a dark room)
- Optical rise time/fall time 50 msec typical
- Input voltage, frequency 100-240 AC volts, 50/60 Hz
- White luminance 235 typical cd/m²
- Power consumption 111 W maximum, 15 W standby
- Weight 11 kg with stand, w/o AC adapter
- Physical size 547 mm (W) x 399 mm (H) x 76 mm (D) w/o stand
- Video interface DVI x 4 channels with 2 cables
- Support color 16 million (R, G, B 8-bit each)
- Temperature range 0 to 35C operation, -20 to +60C storage/shipping
- Color point x=0.313, y=0.329
- Viewing angle 170 degrees typical (H/V, 10:1 CR)

I.2. Initial Monitor Set Up

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5, p 5.

For this 9-megapixel LCD, NIDL tested with a graphics card and computer since a 9-megapixel digital signal generator was not available for our measurements. Because LCDs have a continuously "ON" backlight, refresh rates can be as low as 24 Hz without visible flicker in static images. The screen should then be commanded to full addressability and Lmin set to 0.1 fL. Lmax should be measured at screen center with color temperature between D65 and D93 allowable and any operator adjustment of gain allowable. If a value >35fL is not achieved (>30 fL for color), addressability should be lowered. For a nominal 1200 by 1600 addressability, addressability should be lowered to 1280 by 1024 or to 1024 by 1024. For a nominal 2048 by 2560 addressability (or 3840 x 2400 pixels for the IBM T221 LCD), addressabilities of 1200 x 1600 and 1024 x 1024 can be evaluated if the desired Lmax is not achieved at full addressability.

I.3. Equipment

Reference: CRT Color Monitor Performance, Draft Version 2.0 Section 2.0, page 3.

The procedures described in this report should be carried out in a darkened environment such that the stray luminance diffusely reflected by the screen in the absence of electron-beam excitation is less than 0.003 cd/m² (1mfL).

Instruments used in these measurements included:

- Photo Research SpectraScan PR-650 spectroradiometer
- Photo Research SpectraScan PR-704 spectroradiometer
- Photo Research PR-1980 spot photometer with wide band output for making LC response time measurements.
- Tektronix TDS 754C 500 MHz digital oscilloscope
- Minolta LS-100 Photometer
- Graseby S370 Illuminance Meter
- Microvision Superspot 100 Display Characterization System which included OM-1 optic module (Two Dimensional photodiode linear array device, projected element size at screen set to 1.3 mils with photopic filter), OM-5 optic module (Two Dimensional CCD linear array device, projected element size at screen set to 0.2 mils with photopic filter) and Spotseeker 4-Axis Positioner.
- Microvision SS200 Display Characterization System which included SS220 optic module (collimated optics on motorized goniometer, fiber optically coupled to an Ocean Optics spectrometer) and Spotseeker 4-Axis Positioner.
- ELDIM conoscopic Fast Fourier Transform spatial photometer/colorimeter for viewing angle measurements performed at IBM.

Graphics cards and computers used in these measurements included:

- Matrox G200 MMS graphics card with quad digital outputs (1-877-MBUYNOW, Canada).
- ATI Fire GL4 graphics card with dual DVI digital outputs (on loan from IBM).
- Radeon 8500 single-DVI graphics card having 64 MB memory (on loan from IBM).
- IBM IntelliStation Pentium III PC (on loan from IBM).
- Dell 266 MHz Pentium II PC.

Stereoscopic-mode measurements were not attempted due to the limited refresh rate, less than 120 Hz, for LCD monitors.

Section II PHOTOMETRIC MEASUREMENTS

II.1. Dynamic Range and Screen Reflectance

References: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.6, p 6.
VESA FPDM, Version 2.0, Section 308-1, pages 137 – 138.

Full screen white-to-black contrast ratio measured in 3840 x 2400 format is CR = 385 (25.9 dB dynamic range) in a dark room with Lmax set to 38.5 fL and Lmin set to 0.1 fL. It decreases to under 158:1 (22 dB), the absolute threshold for IEC, in 4 fc diffuse ambient illumination incident on the screen. With Lmax set to 75 fL and Lmin set to 0.2 fL, CR = 375 (25.7 dB dynamic range) in a dark room. It decreases to under 158:1 (22 dB) in 7 fc diffuse ambient illumination incident on the screen. The IBM T221 LCD screen reflectance is 4.3%, equal to or lower than CRT color and grayscale monitors, so this LCD monitor should be good for viewing in brighter ambient environments.

Objective: Measure the photometric output (luminance vs. input command level) at Lmax and Lmin in both dark room and illuminated ambient conditions.

Equipment: Photometer, Integrating Hemisphere Light Source or equivalent

Procedure: Luminance at center of screen is measured for input counts of 0 and Max Count. Test targets are full screen (flat fields) where full screen is defined addressability. Set Lmin to 0.1 fL. For color monitors, set color temperature between D₆₅ to D₉₃. Measure Lmax.

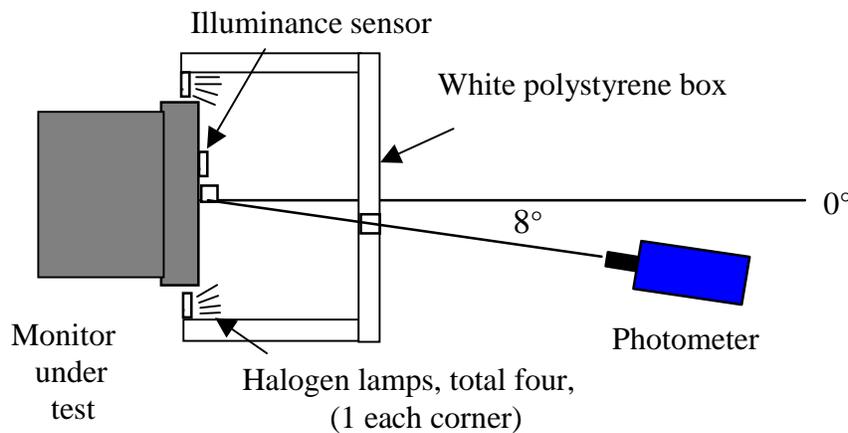
This procedure applies when intended ambient light level measured at the display is 2fc or less. For conditions of higher ambient light level, Lmin and Lmax should be measured at some nominal intended ambient light level (e.g., 18-20 fc for normal office lighting with no shielding). This requires use of a remote spot photometer following procedures outlined in VESA FPDM-2, paragraph 308-2. This will at best be only an approximation since specular reflections will not be captured. A Lmin > 0.1 fL may be required to meet grayscale visibility requirements.

According to the VESA directed hemispherical reflectance (DHR) measurement method, total combined reflections due to specular, haze and diffuse components of reflection arising from uniform diffuse illumination are simultaneously quantified as a fraction of the reflectance of a perfect white diffuse reflector using the set up depicted in figure II.1-1. Total reflectance was calculated from measured luminances reflected by the screen (display turned off) when uniformly illuminated by an integrating hemisphere simulated using a polystyrene icebox. Luminance is measured using a spot photometer with 1° measurement field and an illuminance sensor as depicted in Figure II.1-1. The measured values and calculated reflectances are given in Table II.1-1.

Data: Contrast ratio is a linear expression of Lmax to Lmin. Dynamic range expresses the contrast ratio in log units, dB, which correlates more closely with the sensitivity of the human vision system.

Define contrast ratio by: $CR = L_{max}/L_{min}$

Define dynamic range by: $DR = 10\log(L_{max}/L_{min})$



- Top View -

Figure II.1-1. Test setup according to VESA FPDM procedures for measuring total reflectance of screen.

Table II.1-1. Directed Hemispherical Reflectance of Faceplate
VESA ambient contrast illuminance source (polystyrene box)

Ambient Illuminance	20.20 fc
Reflected Luminance	0.87 fL
Faceplate Reflectance	4.3 %

Ambient dynamic ranges of full screen white-to-black given in Table II.1-2 were computed for various levels of diffuse ambient lighting using the measured value for DHR and the darkroom dynamic range measurements. With Lmin set to 0.1 fL, full screen white-to-black contrast ratio decreases from 385:1 (25.9 dB dynamic range) in a dark room to CR < 158:1 (22 dB, the absolute threshold dynamic range for IEC) in 4 fc diffuse ambient illumination. With Lmin set to 0.2 fL, full screen white-to-black contrast ratio decreases from 375:1 (25.7 dB dynamic range) in a dark room to CR < 158:1 (22 dB, the absolute threshold dynamic range for IEC) in 7 fc diffuse ambient illumination.

Table II.1-2. Dynamic Range in Dark and Illuminated Rooms

Effect of ambient lighting on dynamic range is calculated by multiplying the measured LCD screen reflectivity times the ambient illumination measured at the LCD screen in foot-candles added to the minimum screen luminance, Lmin.

Lmin = 0.1 fL, Lmax = 38.5 fL

<u>Ambient Illumination</u>	<u>Contrast Ratio</u>	<u>Dynamic Range</u>	<u>Ambient Illumination</u>	<u>Contrast Ratio</u>	<u>Dynamic Range</u>
0 fc (Dark Room)	385	25.9 dB	11 fc	68	18.3 dB
1 fc	269	24.3 dB	12 fc	63	18.0 dB
2 fc	207	23.2 dB	13 fc	59	17.7 dB
3 fc	169	22.3 dB	14 fc	56	17.5 dB
4 fc	142	21.5 dB	15 fc	52	17.2 dB
5 fc	123	20.9 dB	16 fc	50	17.0 dB
6 fc	108	20.3 dB	17 fc	47	16.7 dB
7 fc	97	19.9 dB	18 fc	45	16.5 dB
8 fc	87	19.4 dB	19 fc	43	16.3 dB
9 fc	80	19.0 dB	20 fc	41	16.1 dB
10 fc	73	18.7 dB	21 fc	39	15.9 dB

Lmin = 0.2 fL, Lmax = 75 fL

<u>Ambient Illumination</u>	<u>Contrast Ratio</u>	<u>Dynamic Range</u>	<u>Ambient Illumination</u>	<u>Contrast Ratio</u>	<u>Dynamic Range</u>
0 fc (Dark Room)	375	25.7 dB	23 fc	64	18.1 dB
1 fc	309	24.9 dB	24 fc	62	17.9 dB
2 fc	262	24.2 dB	25 fc	60	17.8 dB
3 fc	228	23.6 dB	26 fc	58	17.6 dB
4 fc	202	23.1 dB	27 fc	56	17.5 dB
5 fc	181	22.6 dB	28 fc	54	17.3 dB
6 fc	164	22.2 dB	29 fc	53	17.2 dB
7 fc	150	21.8 dB	30 fc	51	17.1 dB
8 fc	138	21.4 dB	31 fc	50	17.0 dB
9 fc	128	21.1 dB	32 fc	48	16.8 dB
10 fc	120	20.8 dB	33 fc	47	16.7 dB
11 fc	112	20.5 dB	34 fc	46	16.6 dB
12 fc	105	20.2 dB	35 fc	45	16.5 dB
13 fc	99	20.0 dB	36 fc	44	16.4 dB
14 fc	94	19.7 dB	37 fc	43	16.3 dB
15 fc	89	19.5 dB	38 fc	42	16.2 dB
16 fc	85	19.3 dB	39 fc	41	16.1 dB
17 fc	81	19.1 dB	40 fc	40	16.0 dB
18 fc	78	18.9 dB	41 fc	39	15.9 dB
19 fc	74	18.7 dB	42 fc	38	15.8 dB
20 fc	71	18.5 dB	43 fc	37	15.7 dB
21 fc	69	18.4 dB	44 fc	37	15.6 dB
22 fc	66	18.2 dB	45 fc	36	15.6 dB

II.2. Maximum White Luminance (Lmax)

References: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.2, p 6.

For Lmin set to 0.1 fL, the highest luminance for Lmax was 38.5 fL measured at screen center in 3840 x 2400 x 41Hz format. There are no independently adjustable user controls for brightness and contrast. With the single user brightness control advanced to the maximum setting, Lmax was 75 fL and Lmin was 0.2 fL.

Objective: Measure the maximum output display luminance.

Equipment: Photometer

Procedure: See dynamic range. Use the value of Lmax defined for the Dynamic Range measurement.

Data: The maximum output display luminance, Lmax, and associated CIE x, y chromaticity coordinates (CIE 1976) were measured using a hand-held spectroradiometer (Photo Research PR-650). The correlated color temperature (CCT) computed from the measured CIE x, y chromaticity coordinates was slightly outside the range specified by IEC (6500K and 9300K).

Table II.2-1. Maximum Luminance

Luminance (in fL) and Color (CCT in Kelvin) for Full screen at 100% Lmax taken at screen center.

Format	CCT	Lmin	Lmax
3840 x 2400	6069 K	0.1 fL	38.5 fL
3840 x 2400	5995 K	0.2 fL	75 fL

II.3. Uniformity of Luminance (Lmax and Lmin) and Color

Reference: CRT Color Monitor Performance, Draft Version 2.0, Section 4.4, p. 28.

VESA FPDM Version 2.0, Section 306, pages 118 - 120.

Maximum white luminance (L_{max}) sampled at 9 points on the screen varied up to 32.9 % across the screen, failing to meet the IEC specification. A second sample IBM T221 varied up to 21.3 % across the screen, which passes the 30% absolute minimum value. Statistical analysis using the t test for differences in two measurements at the 95% confidence level shows that the luminance values for panel #1 are significantly different from panel #2.

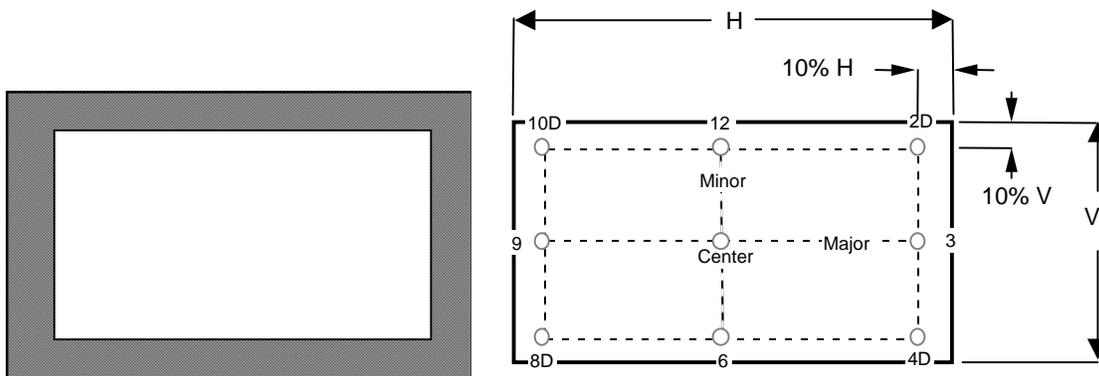
Chromaticity variations were less than 0.0042 delta $u'v'$ units, well under the 0.010 delta $u'v'$ specification for IEC. Black luminance (L_{min}) sampled at 9 points on the screen varied up to 31.3 % across the screen. IEC does not specify uniformity for L_{min} .

Because of the periodic nature of the back light, additional measurements were made at 240 points on monitor #1 to determine the variation more completely. These measurements showed greater variability in luminance and chromaticity coordinates than did the 9-point measurements. Luminance of white (L_{max}) sampled at 240 points (20 x 12 grid) varied across the screen up to 40.2%. Chromaticity coordinates measured a very low 0.0043 delta $u'v'$ units. Luminance of black (L_{min}) sampled at 240 points varied across the screen up to 35.1%.

Objective: Measure the variability of luminance and chromaticity coordinates of the white point at 100% L_{max} only and as a function of spatial position. Variability of luminance impacts the total number of discriminable gray steps.

- Equipment:
- Video generator
 - Photometer
 - Spectroradiometer or Colorimeter

Test Pattern: Full screen flat field with visible edges at L_{min} as shown in Figure II.3-1.



Full Screen Flat Field test pattern.
Figure II.3-1

Nine screen test locations.
Figure II.3-2

Procedure: Investigate the temporal variation of luminance and the white point as a function of intensity by displaying a full flat field shown in Figure II.3-1 for video input count levels corresponding L_{max} . Measure the luminance and C.I.E. color coordinates at center screen.

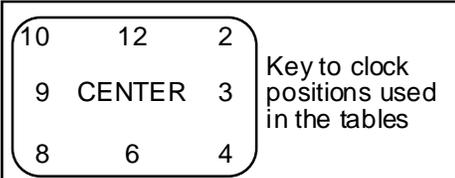
Investigate the temporal variation of luminance and the white point as a function of spatial position by repeating these measurements at each of the locations depicted in Figure II.3-2. Define color uniformity in terms of $\Delta u'v'$.

Data: Tabulate the luminance and 1931 C.I.E. chromaticity coordinates (x, y) or correlated color temperature of the white point at each of the nine locations depicted in Figure II.3-2. Additionally, note the location of any additional points that are measured along with the corresponding luminance values.

Refer to VESA FPDM-2 Section 306-1 page 118 for the definition of luminance nonuniformity:

$$\text{Nonuniformity} = 100\% (L_{\text{highest}} - L_{\text{lowest}}) / L_{\text{highest}}$$

Table II.3-1. 9-point Sampled Spatial Uniformity of Luminance and Color
Color and luminance (in fL) for full screen at 100% L_{max} and L_{min} taken at nine screen positions.

		Lmax, White Full Screen			
Screen		Sample#1			Sample #2
Position		CCT, K	CIE x	CIE y	L, fL
center		5914	0.3237	0.3336	36.92
2		5864	0.3244	0.3392	37.94
3		5953	0.3227	0.3362	34.29
4		6018	0.3214	0.3354	28.86
6		6016	0.3217	0.3312	31.76
8		6244	0.3173	0.3311	25.58
9		6143	0.3192	0.3321	29.51
10		6009	0.3216	0.3353	30.27
12		5983	0.3220	0.3365	38.12
 <p>Key to clock positions used in the tables</p>		L_{lowest}	25.58		32.5
		L_{highest}	38.12		41.3
		Range	12.54		8.8
		Average	32.58		37.01
		Sample size	9		9
		Standard Deviation	4.46		2.79

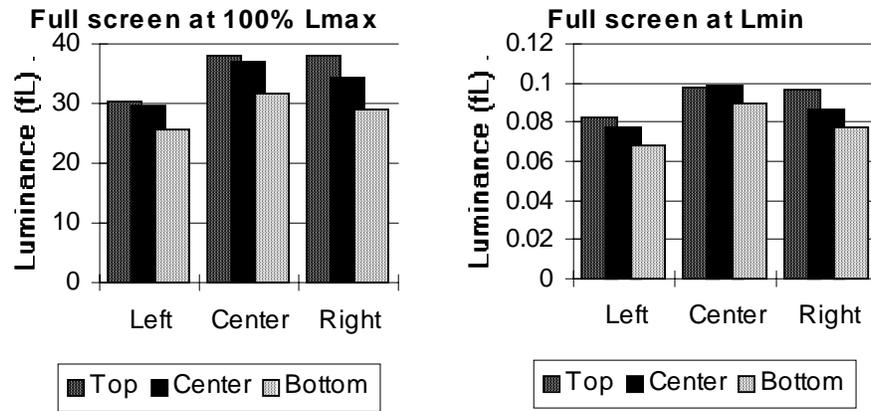


Figure II.3-3. 9-Point (3 x 3 grid) Sampled Spatial Uniformity of Luminance (Lmax and Lmin).

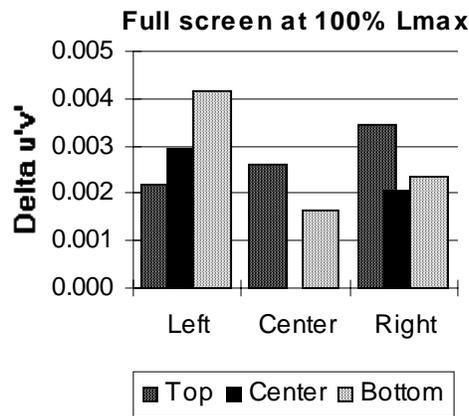


Figure II.3-4. 9-Point (3 x 3 grid) Sampled Spatial Uniformity of White (Lmax) Chromaticity. (Delta u'v' of 0.004 is just visible.)



Left Half of Screen.



Right Half of Screen

Figure.II.3-5. 240-Point (20 x 12 grid) Sampled Spatial Uniformity of Luminance of White at L_{max} for monitor #1. (Left and right halves of the screen were measured separately due to limited length of x-y translation stage.) Luminance varied across the screen by up to 40.2% on the left side and up to 36.4% on the right side. Chromaticity coordinates varied by up to 0.0043 $\Delta u'v'$.



Left Half of Screen.



Right Half of Screen

Figure.II.3-6. 240-Point (20 x 12 grid) Sampled Spatial Uniformity of Luminance of Black at L_{min} for monitor #1. (Left and right halves of the screen were measured separately due to limited length of x-y translation stage.) Luminance varied across the screen by up to 35.1% on the left side and up to 32.2% on the right side.

II.4. Halation

Reference: CRT Color Monitor Performance, Draft Version 2.0 Section 4.6, page 48.
 VESA FPDM Version 2.0, Section 304-7, page 94.

Halation was 0.08% on a small black patch surrounded by a large full white area and is over 40 times lower than the IEC specification for the maximum value of halation.

Objective: Measure the contribution of halation to contrast degradation. Halation is a phenomenon in which the luminance of a given region of the screen is increased by contributions from surrounding areas caused by light scattering within the phosphor layer and internal reflections inside the glass faceplate. The mechanisms that give rise to halation, and its detailed non-monotonic dependence on the distance along the screen between the source of illumination and the region being measured have been described in FPDM-2. The measurements specified below determine the percentage of light that is piped into the dark areas as a function of the extent of the surrounding light areas.

Equipment:

- Photometer
- Video generator

Test Pattern:

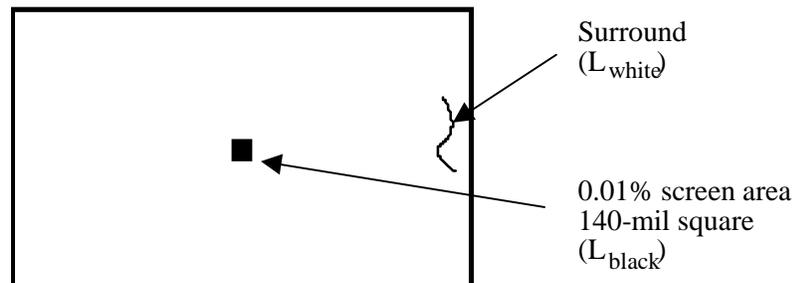


Figure II.4-1 Test pattern for measuring halation.

Procedure: Note: The halation measurements require changing the setting of the BRIGHTNESS control and will perturb the values of L_{\max} and L_{\min} that are established during the initial monitor set-up. The halation measurements should therefore be made either first, before the monitor setup, or last, after all other photometric measurements have been completed.

Determine halation by measuring the luminance of a small square displayed at L_{black} (essentially zero) and at L_{white} when surrounded by a much larger square displayed at L_{white} (approximately 75% L_{\max}).

For LCDs it may not be possible to reduce L_{\min} to cutoff. Alternatively, L_{\min} may be measured and subtracted from L_{black} and L_{white} for calculating the halation.

Next, decrease the video input level to display a measured full-screen luminance of 75% L_{\max} measured at screen center. Record this luminance (L_{white}).

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The test target used in the halation measurements is a black (L_{black}) square patch of width equal to 0.01% of the area of addressable screen, the interior square as shown in Figure II.4-1. The interior square patch is enclosed in a white (L_{white}) background encompassing the remaining area of the image. The exterior surround will be displayed at 75% L_{max} using the input count level for L_{white} as determined above. The interior square will be displayed at input digital count level zero.

Care must be taken during the luminance measurement to ensure that the photometer's measurement field is less than one-half the size of the interior square and is accurately positioned not to extend beyond the boundary of the interior square. The photometer should be checked for light scattering or lens flare effects that allow light from the surround to enter the photosensor. A black card with aperture equal to the measurement field (one-half the size of the interior black square) may be used to shield the photometer from the white exterior square while making measurements in the interior black square.

Analysis: Compute the percent halation for each test target configuration. Percent halation is defined as:

$$\% \text{ Halation} = L_{\text{black}} / (L_{\text{white}} - L_{\text{black}}) \times 100$$

Where, L_{black} = measured luminance of interior square displayed at L_{black} using input count level zero,
 L_{white} = measured luminance of interior square displayed at L_{white} using input count level determined to produce a full screen luminance of 75% L_{max} .

Data: Table II.4-1 contains measured values of L_{black} , L_{white} and percentage halation.

Table II.4-1 Halation for 3840 x 2400 Addressability LCD.
 L_{min} is subtracted from L_{black} and L_{white} for calculating the halation.

L_{min}	0.086 fL
$L_{\text{black}} + L_{\text{min}}$	0.1134 fL
$L_{\text{black}} - L_{\text{min}}$	0.0274 fL
L_{white}	35.8 fL
$L_{\text{white}} - L_{\text{min}}$	35.77 fL
Halation	0.08%

II.5. Color Temperature and Color Tracking

Reference: CRT Color Monitor Performance, Draft Version 2.0 Section 5.4, page 22.

VESA FPDM Version 2.0, Section A201, page 249.

Correlated color temperature (CCT) values are very constant (6091K to 6011 K) and are less than 0.007 delta u'v' units (0.010 is the IEC limit) from the CIE Daylight Locus over the luminance range from 100% L_{max} (37.85 fL) to less than 3% L_{max} (0.9 fL). This result is indicative of good color tracking. The IEC specification does not include color tracking.

Objective: Insure measured screen white of a color monitor has a correlated color temperature (CCT) between 6500K and 9300K within a tolerance of 0.010 $\Delta u'v'$ units of the Daylight Locus. Absolute minimum and maximum values of CCT are 5700K and 11250K, respectively.

Equipment: Spectroradiometer (preferred) or colorimeter

Procedure: Command screen to L_{max} . Measure $u'v'$ chromaticity coordinates (CIE 1976).

Data: Coordinates of screen white should be within 0.01 $\Delta u'v'$ of the corresponding CIE daylight, which is defined as follows: If the measured screen white has a CCT between 6500 and 9300 K, the corresponding daylight has the same CCT as the screen white. The following equations were used to compute $\Delta u'v'$ values listed in table II.5.1:

1. Compute the correlated color temperature (CCT) associated with (x,y) by the VESA/McCamy formula: $CCT = 437 n^3 + 3601 n^2 + 6831 n + 5517$, where $n = (x-0.3320)/(0.1858 - y)$. [This is on p. 227 of the FPDM standard]
2. If $CCT < 6500$, replace CCT by 6500. If $CCT > 9300$, replace CCT by 9300.
3. Use formulas 5(3.3.4) and 6(3.3.4) in Wyszecki and Stiles (pp.145-146 second edition) to compute the point (xd,yd) associated with CCT.
 - First, define $u = 1000/CCT$.

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- If CCT < 7000, then $x_d = -4.6070 u^3 + 2.9678 u^2 + 0.09911 u + 0.244063$.
 - If CCT > 7000, then $x_d = -2.0064 u^3 + 1.9018 u^2 + 0.24748 u + 0.237040$.
 - In either case, $y_d = -3.000 x_d^2 + 2.870 x_d - 0.275$.
4. Convert (x,y) and (x_d,y_d) to u'v' coordinates:
- $(u',v') = (4x,9y)/(3 + 12y - 2x)$
 - $(u'_d,v'_d) = (4x_d,9y_d)/(3 + 12y_d - 2x_d)$
5. Evaluate $\Delta u'v'$ between (u,v) and (u_d,v_d):
- $\Delta u'v' = \sqrt{(u' - u'_d)^2 + (v' - v'_d)^2}$.
6. If $\Delta u'v'$ is greater than 0.01, display fails the test. Otherwise it passes the test.

Correlated Color Temperature and Daylight Locus

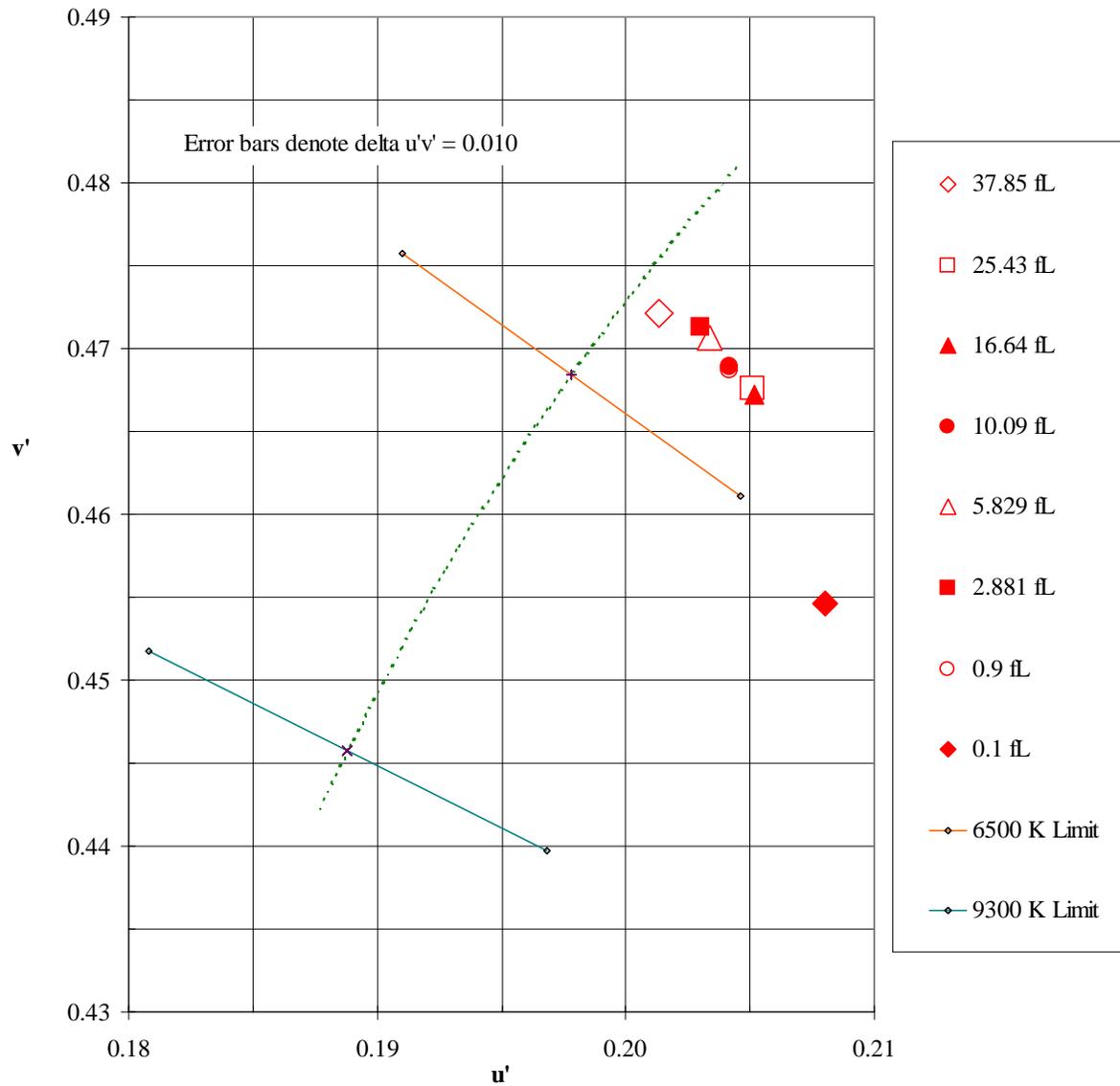


Figure II.5-1. CCT of measured white points for 8 gray levels of luminance values ranging from 37.85 fL (Lmax) to 0.1 fL (Lmin) of the IBM T221 LCD monitor compared with the Daylight Locus shown by the dotted curve. The range of acceptable chromaticity coordinates is shown by the dashed line 0.010 $\Delta u'v'$ units from the Daylight Locus. This includes extreme CCT values as low as 5700 K and as high as 11250 K.

Table II.5-1 $\Delta u'v'$ Distances between measured white point and CIE coordinate values for the IBM T221 LCD monitor sample #1

	37.85 fL	25.43 fL	16.64 fL	10.09 fL	5.829 fL	2.881 fL	0.9 fL	0.1 fL
CIE x	0.321	0.321	0.321	0.321	0.322	0.322	0.321	0.313
CIE y	0.334	0.325	0.325	0.328	0.331	0.332	0.327	0.304
CIE u'	0.201	0.205	0.205	0.204	0.203	0.203	0.204	0.208
CIE v'	0.472	0.468	0.467	0.469	0.471	0.471	0.469	0.455
CCT	6069	6073	6091	6063	6020	6011	6075	6679
$\Delta u'v'$ from Daylight Locus	0.005	0.007	0.007	0.006	0.006	0.006	0.006	0.016

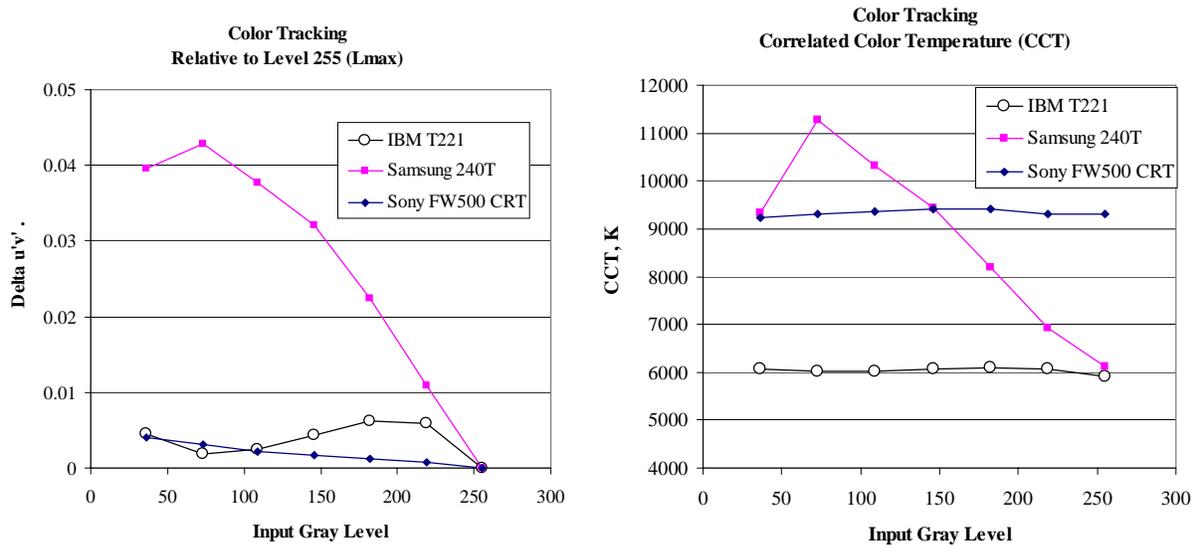


Figure II.5-2. Chromaticity and color temperature shift of measured white points for gray levels shown relative to Lmax (Level 255) for the IBM T221 LCD monitor compared to the Samsung 240T LCD and Sony FW900 CRT monitors. The T221 has excellent color tracking.

II.6. Bit Depth

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.6, p 6.

The T221 gray level luminance response was found to depend somewhat on the particular graphics card. Monotonic increases in luminance were measured for each of the 256 input levels for 8 bits of addressable gray scale when digitally addressed through a Matrox G200 MMS quad DVI-digital graphics card installed in an IBM IntelliStation Pentium III PC. Neither black level clipping nor white level saturation was observed. Monotonic increases in luminance were also measured for each of the 256 input levels for 8 bits of addressable gray scale when digitally addressed through a Radeon 8500 single DVI-digital graphics. The ATI FireGL4 DVI-digital graphics card lost a single luminance step between input count level 128 and 129. According to IBM, not all ATI FireGL4 cards tested at IBM exhibited a lost step. IBM informed ATI of the problem.

Objective: Measure the number of bits of data that can be displayed as a function of the DAC and display software.

Equipment: Photometer

Test targets: Targets are four-inch patches with command levels of all commandable levels; e.g., 256 for 8 bit display. Background is commanded to $0.5 * ((0.7 * P) + 0.3 * n)$ where P = patch command level, n = number of command levels.

Procedure: Measure patch center for all patches with Lmin and Lmax as defined previously. Count number of monotonically increasing luminance levels. Use the NEMA/DICOM model to define discriminable luminance differences. For color displays, measure white values.

Data: Define bit depth by \log_2 (number of discrete luminance levels)

The number of bits of data that can be displayed as a function of the input signal voltage level were verified through measurements of the luminance of a set gray level test patterns. The test patterns were displayed using Microsoft Office 97 PowerPoint Slideshow and an IBM Pentium III PC. The luminance was measured using a Minolta LS-100 spot photometer. Gray level test patterns were displayed using the PC Matrox G200 MMS quad-DVI 60-pin digital graphics card and the Radeon 8500 single-DVI digital graphics card. Targets are n four-inch patches with command levels of all commandable levels; e.g., 256 for 8 bit display. Background is commanded to $0.5 * ((0.7 * P) + 0.3 * n)$ where P = patch command level, n = number of command levels. The NEMA/DICOM was used to define discriminable luminance differences in JNDs.

Figure II.6-1 shows the System Tonal Transfer curve at center screen as a function of input counts. Figure II.6-2 shows the perceptible differences between gray levels according to the NEMA/DICOM JND metric. The data for each of the 256 levels are listed in Tables II.6-1 and II.6-2. As a result of input from a member of the American Association of Physicists in Medicine Task Group 18 (AAPM

TG#18), differences between adjacent gray levels are reported in tenths of JND units rather than whole JNDs.

Matrox G200 MMS DVI-60-pin digital graphics card

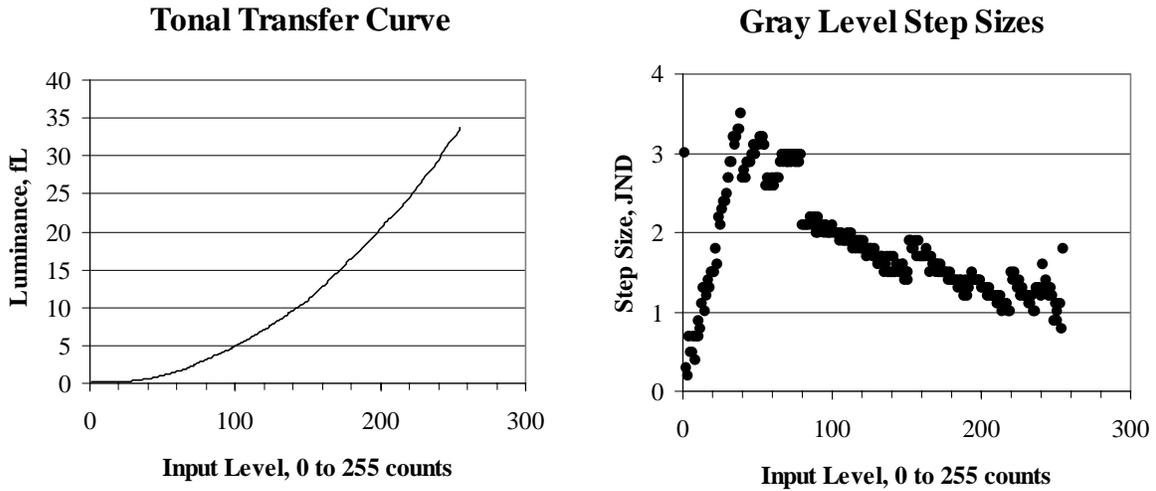


Figure II.6-1. System tonal transfer curve at center screen as a function of input counts for digital addressing in 3840 x 2400 pixels at 41 Hz refresh for Lmin values of 0.1 fL and 0.2 fL. Gray level test patterns are displayed on the PC Matrox G200 MMS DVI-60-pin digital graphics card using Microsoft Office 97 PowerPoint Slideshow and an IBM Pentium III PC. The tonal transfer curve is monotonically increasing with input level.

Radeon Single DVI digital graphics card

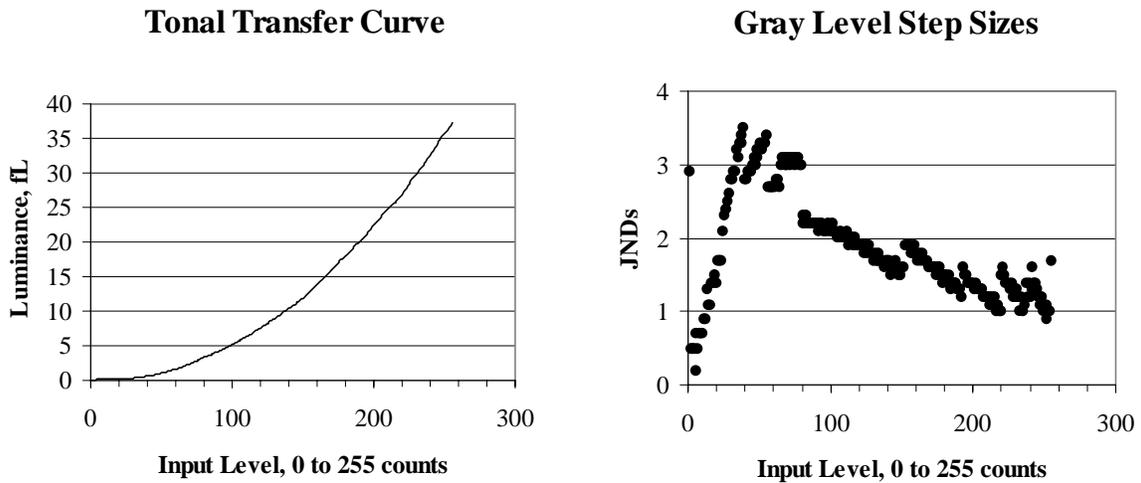


Figure II.6-2. System tonal transfer curve at center screen as a function of input counts for digital addressing in 3840 x 2400 pixels at 13 Hz refresh for Lmin values of 0.1 fL. Gray level test patterns are displayed on the PC Radeon 8500 single DVI digital graphics card using Microsoft Office 97 PowerPoint Slideshow and an IBM Pentium III PC. The tonal transfer curve is monotonically increasing with input level.

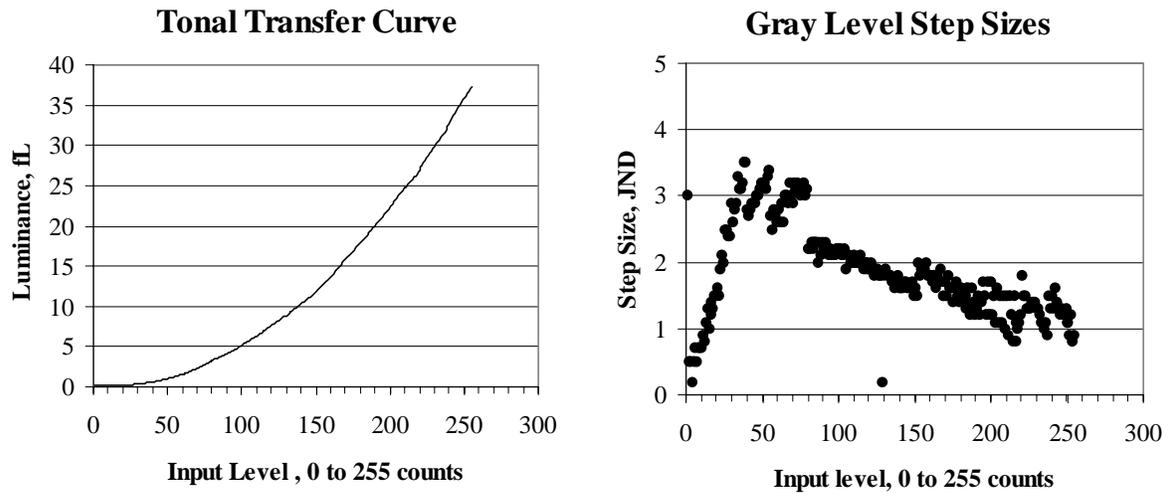
ATI FireGL4 DVI digital graphics card

Figure II.6-3. System tonal transfer curve at center screen as a function of input counts for digital addressing in 3840 x 2400 pixels at 24 Hz refresh for Lmin value of 0.1 fL is plotted on the left. Gray level test patterns are displayed on the IBM PC with ATI FireGL4 graphics card using Microsoft Office 97 PowerPoint Slideshow gray level images. Perceptibility of gray level steps at center screen as a function of input counts are plotted on the right. The data set indicates a redundancy in screen luminance for input signal levels 128 and 129. Otherwise, the tonal transfer curve is monotonically increasing with input level.

Table II.6-1a. System Tonal Transfer using Matrox G200 MMS graphics, counts 000 to 127, Lmin = 0.1 fL.

Background	Target	L, fL	Diff, fL	Diff, JND	Background	Target	L, fL	Diff, fL	Diff, JND
38	0	0.104			61	64	1.821	0.063	2.7
39	1	0.116	0.012	3.0	61	65	1.891	0.07	2.9
39	2	0.117	0.001	0.3	62	66	1.963	0.072	3.0
39	3	0.118	0.001	0.2	62	67	2.037	0.074	2.9
40	4	0.121	0.003	0.7	62	68	2.114	0.077	3.0
40	5	0.123	0.002	0.5	63	69	2.192	0.078	2.9
41	6	0.125	0.002	0.5	63	70	2.273	0.081	3.0
41	7	0.128	0.003	0.7	63	71	2.355	0.082	2.9
41	8	0.13	0.002	0.4	64	72	2.44	0.085	3.0
42	9	0.133	0.003	0.7	64	73	2.527	0.087	2.9
42	10	0.136	0.003	0.7	64	74	2.616	0.089	3.0
42	11	0.14	0.004	0.9	65	75	2.709	0.093	3.0
43	12	0.144	0.004	0.8	65	76	2.802	0.093	2.9
43	13	0.149	0.005	1.1	65	77	2.899	0.097	3.0
43	14	0.155	0.006	1.3	66	78	2.997	0.098	2.9
44	15	0.16	0.005	1.0	66	79	3.097	0.1	3.0
44	16	0.166	0.006	1.2	66	80	3.173	0.076	2.1
44	17	0.173	0.007	1.4	67	81	3.246	0.073	2.1
45	18	0.18	0.007	1.3	67	82	3.321	0.075	2.1
45	19	0.188	0.008	1.5	67	83	3.4	0.079	2.1
45	20	0.196	0.008	1.5	68	84	3.479	0.079	2.1
46	21	0.205	0.009	1.5	68	85	3.561	0.082	2.2
46	22	0.215	0.01	1.8	69	86	3.642	0.081	2.1
46	23	0.225	0.01	1.6	69	87	3.727	0.085	2.1
47	24	0.238	0.013	2.2	69	88	3.812	0.085	2.2
47	25	0.252	0.014	2.1	70	89	3.896	0.084	2.0
48	26	0.267	0.015	2.3	70	90	3.984	0.088	2.2
48	27	0.283	0.016	2.4	70	91	4.071	0.087	2.0
48	28	0.3	0.017	2.4	71	92	4.162	0.091	2.1
49	29	0.319	0.019	2.5	71	93	4.25	0.088	2.1
49	30	0.339	0.02	2.7	71	94	4.343	0.093	2.1
49	31	0.361	0.022	2.7	72	95	4.433	0.09	2.0
50	32	0.385	0.024	2.9	72	96	4.53	0.097	2.1
50	33	0.41	0.025	2.9	72	97	4.623	0.093	2.0
50	34	0.438	0.028	3.2	73	98	4.719	0.096	2.0
51	35	0.467	0.029	3.1	73	99	4.816	0.097	2.0
51	36	0.498	0.031	3.2	73	100	4.915	0.099	2.1
51	37	0.532	0.034	3.3	74	101	5.014	0.099	2.0
52	38	0.567	0.035	3.3	74	102	5.116	0.102	2.0
52	39	0.605	0.038	3.5	74	103	5.216	0.1	2.0
52	40	0.636	0.031	2.7	75	104	5.321	0.105	2.0
53	41	0.669	0.033	2.8	75	105	5.423	0.102	1.9
53	42	0.702	0.033	2.7	76	106	5.528	0.105	2.0
53	43	0.738	0.036	2.9	76	107	5.633	0.105	1.9
54	44	0.776	0.038	2.9	76	108	5.735	0.102	1.9
54	45	0.815	0.039	2.9	77	109	5.843	0.108	1.9
55	46	0.856	0.041	3.0	77	110	5.954	0.111	2.0
55	47	0.9	0.044	3.1	77	111	6.065	0.111	1.9
55	48	0.945	0.045	3.0	78	112	6.173	0.108	1.9
56	49	0.992	0.047	3.1	78	113	6.29	0.117	2.0
56	50	1.041	0.049	3.1	78	114	6.401	0.111	1.8
56	51	1.092	0.051	3.1	79	115	6.514	0.113	1.9
57	52	1.146	0.054	3.2	79	116	6.628	0.114	1.8
57	53	1.202	0.056	3.2	79	117	6.745	0.117	1.9
57	54	1.258	0.056	3.2	80	118	6.862	0.117	1.8
58	55	1.317	0.059	3.1	80	119	6.981	0.119	1.9
58	56	1.366	0.049	2.6	80	120	7.101	0.12	1.8
58	57	1.418	0.052	2.7	81	121	7.221	0.12	1.9
59	58	1.47	0.052	2.6	81	122	7.343	0.122	1.8
59	59	1.524	0.054	2.6	81	123	7.46	0.117	1.7
59	60	1.58	0.056	2.7	82	124	7.586	0.126	1.8
60	61	1.638	0.058	2.6	82	125	7.708	0.122	1.8
60	62	1.697	0.059	2.7	83	126	7.837	0.129	1.8
60	63	1.758	0.061	2.7	83	127	7.959	0.122	1.7

Use or disclosure of data on this sheet is subject to the restrictions on the cover and title of this report.

Table II.6-1b. System Tonal Transfer using Matrox G200 MMS graphics, counts 128 to 255, Lmin = 0.1 fL.

Background	Target	L, fL	Diff, fL	Diff, JND	Background	Target	L, fL	Diff, fL	Diff, JND
83	128	8.085	0.126	1.8	106	192	18.7	0.18	1.3
84	129	8.21	0.125	1.7	106	193	18.91	0.21	1.4
84	130	8.336	0.126	1.7	106	194	19.13	0.22	1.5
84	131	8.461	0.125	1.6	107	195	19.35	0.22	1.4
85	132	8.59	0.129	1.7	107	196	19.56	0.21	1.4
85	133	8.715	0.125	1.7	107	197	19.77	0.21	1.4
85	134	8.847	0.132	1.7	108	198	19.99	0.22	1.4
86	135	8.969	0.122	1.5	108	199	20.21	0.22	1.4
86	136	9.098	0.129	1.6	108	200	20.42	0.21	1.3
86	137	9.229	0.131	1.7	109	201	20.63	0.21	1.3
87	138	9.357	0.128	1.5	109	202	20.84	0.21	1.3
87	139	9.491	0.134	1.7	109	203	21.04	0.2	1.3
87	140	9.623	0.132	1.5	110	204	21.25	0.21	1.2
88	141	9.76	0.137	1.7	110	205	21.45	0.2	1.3
88	142	9.894	0.134	1.5	111	206	21.66	0.21	1.2
88	143	10.03	0.136	1.6	111	207	21.86	0.2	1.2
89	144	10.17	0.14	1.6	111	208	22.06	0.2	1.2
89	145	10.3	0.13	1.5	112	209	22.27	0.21	1.2
90	146	10.44	0.14	1.5	112	210	22.46	0.19	1.1
90	147	10.58	0.14	1.6	112	211	22.66	0.2	1.2
90	148	10.71	0.13	1.4	113	212	22.86	0.2	1.1
91	149	10.85	0.14	1.5	113	213	23.06	0.2	1.2
91	150	10.99	0.14	1.5	113	214	23.24	0.18	1.0
91	151	11.12	0.13	1.4	114	215	23.45	0.21	1.1
92	152	11.3	0.18	1.9	114	216	23.64	0.19	1.1
92	153	11.48	0.18	1.9	114	217	23.83	0.19	1.1
92	154	11.66	0.18	1.8	115	218	24.02	0.19	1.0
93	155	11.84	0.18	1.8	115	219	24.21	0.19	1.0
93	156	12.03	0.19	1.9	115	220	24.48	0.27	1.5
93	157	12.2	0.17	1.7	116	221	24.75	0.27	1.4
94	158	12.39	0.19	1.9	116	222	25.02	0.27	1.5
94	159	12.57	0.18	1.7	116	223	25.3	0.28	1.4
94	160	12.75	0.18	1.7	117	224	25.55	0.25	1.3
95	161	12.93	0.18	1.7	117	225	25.81	0.26	1.4
95	162	13.12	0.19	1.7	118	226	26.06	0.25	1.2
95	163	13.31	0.19	1.8	118	227	26.31	0.25	1.3
96	164	13.5	0.19	1.7	118	228	26.55	0.24	1.2
96	165	13.67	0.17	1.5	119	229	26.79	0.24	1.2
97	166	13.86	0.19	1.7	119	230	27.04	0.25	1.2
97	167	14.05	0.19	1.6	119	231	27.27	0.23	1.2
97	168	14.23	0.18	1.6	120	232	27.51	0.24	1.1
98	169	14.41	0.18	1.5	120	233	27.74	0.23	1.1
98	170	14.6	0.19	1.6	120	234	27.98	0.24	1.2
98	171	14.79	0.19	1.6	121	235	28.2	0.22	1.0
99	172	14.97	0.18	1.5	121	236	28.41	0.21	1.0
99	173	15.16	0.19	1.6	121	237	28.69	0.28	1.3
99	174	15.35	0.19	1.5	122	238	28.97	0.28	1.3
100	175	15.54	0.19	1.5	122	239	29.25	0.28	1.3
100	176	15.72	0.18	1.5	122	240	29.51	0.26	1.2
100	177	15.91	0.19	1.5	123	241	29.86	0.35	1.6
101	178	16.1	0.19	1.4	123	242	30.15	0.29	1.3
101	179	16.29	0.19	1.5	123	243	30.47	0.32	1.4
101	180	16.47	0.18	1.4	124	244	30.76	0.29	1.3
102	181	16.66	0.19	1.4	124	245	31.05	0.29	1.2
102	182	16.85	0.19	1.4	125	246	31.35	0.3	1.3
102	183	17.03	0.18	1.4	125	247	31.61	0.26	1.2
103	184	17.22	0.19	1.3	125	248	31.84	0.23	0.9
103	185	17.41	0.19	1.4	126	249	32.1	0.26	1.1
104	186	17.6	0.19	1.4	126	250	32.34	0.24	1.0
104	187	17.78	0.18	1.3	126	251	32.54	0.2	0.9
104	188	17.96	0.18	1.2	127	252	32.81	0.27	1.1
105	189	18.15	0.19	1.4	127	253	33.07	0.26	1.1
105	190	18.34	0.19	1.3	127	254	33.27	0.2	0.8
105	191	18.52	0.18	1.2	128	255	33.71	0.44	1.8

Table II.6-2a. System Tonal Transfer using FireGL4 graphics, counts 000 to 127, Lmin = 0.1 fL.

Background	Target	L, fL	Diff, fL	Diff, JND	Background	Target	L, fL	Diff, fL	Diff, JND
38	0	0.102			61	64	1.843	0.062	2.6
39	1	0.114	0.012	3.0	61	65	1.915	0.072	3.0
39	2	0.116	0.002	0.5	62	66	1.989	0.074	3.0
39	3	0.118	0.002	0.5	62	67	2.064	0.075	2.9
40	4	0.119	0.001	0.2	62	68	2.146	0.082	3.2
40	5	0.121	0.002	0.5	63	69	2.227	0.081	3.0
41	6	0.124	0.003	0.7	63	70	2.307	0.08	2.9
41	7	0.126	0.002	0.5	63	71	2.397	0.09	3.2
41	8	0.129	0.003	0.7	64	72	2.488	0.091	3.1
42	9	0.132	0.003	0.7	64	73	2.582	0.094	3.2
42	10	0.135	0.003	0.7	64	74	2.678	0.096	3.1
42	11	0.139	0.004	0.9	65	75	2.772	0.094	3.0
43	12	0.143	0.004	0.8	65	76	2.872	0.1	3.1
43	13	0.148	0.005	1.1	65	77	2.98	0.108	3.2
43	14	0.154	0.006	1.3	66	78	3.082	0.102	3.0
44	15	0.159	0.005	1.0	66	79	3.19	0.108	3.1
44	16	0.165	0.006	1.2	66	80	3.266	0.076	2.2
44	17	0.172	0.007	1.4	67	81	3.348	0.082	2.2
45	18	0.179	0.007	1.3	67	82	3.432	0.084	2.3
45	19	0.187	0.008	1.5	67	83	3.52	0.088	2.3
45	20	0.195	0.008	1.5	68	84	3.605	0.085	2.2
46	21	0.204	0.009	1.6	68	85	3.695	0.09	2.3
46	22	0.213	0.009	1.5	69	86	3.785	0.09	2.3
46	23	0.224	0.011	1.9	69	87	3.867	0.082	2.0
47	24	0.237	0.013	2.1	69	88	3.961	0.094	2.3
47	25	0.25	0.013	2.0	70	89	4.051	0.09	2.1
48	26	0.266	0.016	2.5	70	90	4.147	0.096	2.3
48	27	0.283	0.017	2.5	70	91	4.244	0.097	2.2
48	28	0.3	0.017	2.4	71	92	4.343	0.099	2.3
49	29	0.318	0.018	2.4	71	93	4.442	0.099	2.2
49	30	0.34	0.022	2.9	71	94	4.541	0.099	2.1
49	31	0.361	0.021	2.6	72	95	4.641	0.1	2.2
50	32	0.384	0.023	2.8	72	96	4.74	0.099	2.1
50	33	0.409	0.025	2.9	72	97	4.842	0.102	2.1
50	34	0.438	0.029	3.3	73	98	4.947	0.105	2.1
51	35	0.467	0.029	3.1	73	99	5.055	0.108	2.2
51	36	0.497	0.03	3.1	73	100	5.166	0.111	2.2
51	37	0.53	0.033	3.2	74	101	5.28	0.114	2.2
52	38	0.566	0.036	3.5	74	102	5.391	0.111	2.1
52	39	0.605	0.039	3.5	74	103	5.502	0.111	2.1
52	40	0.637	0.032	2.8	75	104	5.618	0.116	2.2
53	41	0.669	0.032	2.7	75	105	5.726	0.108	1.9
53	42	0.703	0.034	2.8	76	106	5.84	0.114	2.1
53	43	0.739	0.036	2.9	76	107	5.96	0.12	2.1
54	44	0.777	0.038	2.9	76	108	6.077	0.117	2.0
54	45	0.816	0.039	2.9	77	109	6.193	0.116	2.0
55	46	0.858	0.042	3.0	77	110	6.316	0.123	2.1
55	47	0.901	0.043	3.0	77	111	6.436	0.12	2.0
55	48	0.947	0.046	3.1	78	112	6.561	0.125	2.0
56	49	0.995	0.048	3.2	78	113	6.684	0.123	2.0
56	50	1.045	0.05	3.1	78	114	6.812	0.128	2.1
56	51	1.097	0.052	3.2	79	115	6.94	0.128	2.0
57	52	1.15	0.053	3.2	79	116	7.066	0.126	1.9
57	53	1.205	0.055	3.1	79	117	7.197	0.131	2.0
57	54	1.264	0.059	3.3	80	118	7.326	0.129	1.9
58	55	1.328	0.064	3.4	80	119	7.457	0.131	2.0
58	56	1.38	0.052	2.7	80	120	7.59	0.133	1.9
58	57	1.429	0.049	2.5	81	121	7.723	0.133	1.9
59	58	1.485	0.056	2.8	81	122	7.86	0.137	2.0
59	59	1.54	0.055	2.7	81	123	7.997	0.137	1.9
59	60	1.595	0.055	2.6	82	124	8.131	0.134	1.8
60	61	1.658	0.063	2.8	82	125	8.271	0.14	1.9
60	62	1.715	0.057	2.6	83	126	8.409	0.138	1.9
60	63	1.781	0.066	2.9	83	127	8.549	0.14	1.8

Use or disclosure of data on this sheet is subject to the restrictions on the cover and title of this report.

Table II.6-2b. System Tonal Transfer using FireGL4 graphics, counts 128 to 255, Lmin = 0.1 fL.

Background	Target	L, fL	Diff, fL	Diff, JND	Background	Target	L, fL	Diff, fL	Diff, JND
83	128	8.686	0.137	1.8	106	192	20.43	0.23	1.5
84	129	8.701	0.015	0.2	106	193	20.63	0.2	1.2
84	130	8.843	0.142	1.8	106	194	20.85	0.22	1.4
84	131	8.989	0.146	1.9	107	195	21.13	0.28	1.7
85	132	9.135	0.146	1.8	107	196	21.38	0.25	1.5
85	133	9.28	0.145	1.8	107	197	21.57	0.19	1.2
85	134	9.427	0.147	1.8	108	198	21.86	0.29	1.7
86	135	9.57	0.143	1.7	108	199	22.06	0.2	1.2
86	136	9.71	0.14	1.7	108	200	22.35	0.29	1.7
86	137	9.853	0.143	1.6	109	201	22.56	0.21	1.2
87	138	9.999	0.146	1.7	109	202	22.83	0.27	1.5
87	139	10.15	0.151	1.8	109	203	23.02	0.19	1.1
87	140	10.29	0.14	1.6	110	204	23.3	0.28	1.6
88	141	10.44	0.15	1.6	110	205	23.5	0.2	1.1
88	142	10.58	0.14	1.6	111	206	23.77	0.27	1.5
88	143	10.74	0.16	1.7	111	207	23.96	0.19	1.1
89	144	10.89	0.15	1.7	111	208	24.24	0.28	1.5
89	145	11.04	0.15	1.6	112	209	24.42	0.18	1.0
90	146	11.19	0.15	1.6	112	210	24.7	0.28	1.5
90	147	11.35	0.16	1.6	112	211	24.87	0.17	0.9
90	148	11.51	0.16	1.7	113	212	25.16	0.29	1.5
91	149	11.66	0.15	1.5	113	213	25.39	0.23	1.2
91	150	11.81	0.15	1.5	113	214	25.55	0.16	0.8
91	151	11.97	0.16	1.6	114	215	25.84	0.29	1.5
92	152	12.12	0.15	1.5	114	216	26.06	0.22	1.1
92	153	12.32	0.2	2.0	114	217	26.22	0.16	0.8
92	154	12.51	0.19	1.8	115	218	26.42	0.2	1.0
93	155	12.71	0.2	1.9	115	219	26.64	0.22	1.1
93	156	12.91	0.2	1.9	115	220	26.88	0.24	1.2
93	157	13.12	0.21	1.9	116	221	27.23	0.35	1.8
94	158	13.33	0.21	2.0	116	222	27.55	0.32	1.5
94	159	13.54	0.21	1.8	116	223	27.85	0.3	1.5
94	160	13.74	0.2	1.8	117	224	28.14	0.29	1.3
95	161	13.94	0.2	1.8	117	225	28.41	0.27	1.3
95	162	14.14	0.2	1.7	118	226	28.68	0.27	1.3
95	163	14.35	0.21	1.8	118	227	28.98	0.3	1.4
96	164	14.54	0.19	1.6	118	228	29.3	0.32	1.4
96	165	14.75	0.21	1.8	119	229	29.6	0.3	1.4
97	166	14.96	0.21	1.7	119	230	29.89	0.29	1.3
97	167	15.19	0.23	1.9	119	231	30.18	0.29	1.3
97	168	15.4	0.21	1.7	120	232	30.44	0.26	1.2
98	169	15.59	0.19	1.5	120	233	30.7	0.26	1.1
98	170	15.8	0.21	1.7	120	234	30.94	0.24	1.1
98	171	15.99	0.19	1.5	121	235	31.17	0.23	1.0
99	172	16.23	0.24	1.8	121	236	31.43	0.26	1.1
99	173	16.44	0.21	1.6	121	237	31.64	0.21	0.9
99	174	16.65	0.21	1.6	122	238	31.99	0.35	1.5
100	175	16.84	0.19	1.4	122	239	32.31	0.32	1.3
100	176	17.05	0.21	1.6	122	240	32.66	0.35	1.5
100	177	17.28	0.23	1.7	123	241	32.98	0.32	1.3
101	178	17.49	0.21	1.5	123	242	33.36	0.38	1.6
101	179	17.68	0.19	1.4	123	243	33.71	0.35	1.4
101	180	17.91	0.23	1.6	124	244	34.03	0.32	1.3
102	181	18.13	0.22	1.5	124	245	34.35	0.32	1.2
102	182	18.32	0.19	1.4	125	246	34.67	0.32	1.3
102	183	18.52	0.2	1.3	125	247	34.97	0.3	1.2
103	184	18.74	0.22	1.5	125	248	35.29	0.32	1.2
103	185	18.97	0.23	1.6	126	249	35.61	0.32	1.3
104	186	19.17	0.2	1.3	126	250	35.9	0.29	1.1
104	187	19.35	0.18	1.2	126	251	36.19	0.29	1.1
104	188	19.59	0.24	1.6	127	252	36.45	0.26	0.9
105	189	19.81	0.22	1.4	127	253	36.75	0.3	1.2
105	190	20	0.19	1.2	127	254	36.98	0.23	0.8
105	191	20.2	0.2	1.3	128	255	37.21	0.23	0.9

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Table II.6-3a. System Tonal Transfer using Radeon 8500 graphics, counts 000 to 127, Lmin = 0.1 fL.

Background	Target	L, fL	Diff, fL	Diff, JND	Background	Target	L, fL	Diff, fL	Diff, JND
38	0	0.098	0	0.0	61	64	1.87	0.065	2.7
39	1	0.109	0.011	2.9	61	65	1.943	0.073	3.0
39	2	0.111	0.002	0.5	62	66	2.02	0.077	3.1
39	3	0.113	0.002	0.5	62	67	2.098	0.078	3.1
40	4	0.115	0.002	0.5	62	68	2.178	0.08	3.0
40	5	0.116	0.001	0.2	63	69	2.261	0.083	3.0
41	6	0.119	0.003	0.7	63	70	2.346	0.085	3.1
41	7	0.121	0.002	0.5	63	71	2.434	0.088	3.1
41	8	0.124	0.003	0.7	64	72	2.523	0.089	3.0
42	9	0.127	0.003	0.7	64	73	2.617	0.094	3.1
42	10	0.13	0.003	0.7	64	74	2.713	0.096	3.1
42	11	0.134	0.004	0.9	65	75	2.809	0.096	3.0
43	12	0.138	0.004	0.9	65	76	2.908	0.099	3.1
43	13	0.144	0.006	1.3	65	77	3.012	0.104	3.1
43	14	0.149	0.005	1.1	66	78	3.117	0.105	3.0
44	15	0.154	0.005	1.1	66	79	3.222	0.105	3.0
44	16	0.161	0.007	1.4	66	80	3.301	0.079	2.2
44	17	0.168	0.007	1.4	67	81	3.386	0.085	2.3
45	18	0.175	0.007	1.4	67	82	3.467	0.081	2.2
45	19	0.183	0.008	1.5	67	83	3.552	0.085	2.3
45	20	0.191	0.008	1.4	68	84	3.637	0.085	2.2
46	21	0.2	0.009	1.7	68	85	3.724	0.087	2.2
46	22	0.21	0.01	1.7	69	86	3.812	0.088	2.2
46	23	0.22	0.01	1.7	69	87	3.902	0.09	2.2
47	24	0.233	0.013	2.1	69	88	3.996	0.094	2.2
47	25	0.247	0.014	2.3	70	89	4.086	0.09	2.2
48	26	0.263	0.016	2.4	70	90	4.182	0.096	2.2
48	27	0.279	0.016	2.4	70	91	4.276	0.094	2.2
48	28	0.297	0.018	2.5	71	92	4.372	0.096	2.1
49	29	0.316	0.019	2.6	71	93	4.47	0.098	2.2
49	30	0.337	0.021	2.8	71	94	4.57	0.1	2.2
49	31	0.359	0.022	2.8	72	95	4.67	0.1	2.1
50	32	0.383	0.024	2.9	72	96	4.772	0.102	2.1
50	33	0.408	0.025	2.9	72	97	4.874	0.102	2.1
50	34	0.436	0.028	3.2	73	98	4.98	0.106	2.2
51	35	0.465	0.029	3.1	73	99	5.087	0.107	2.1
51	36	0.497	0.032	3.3	73	100	5.193	0.106	2.1
51	37	0.531	0.034	3.3	74	101	5.303	0.11	2.2
52	38	0.566	0.035	3.4	74	102	5.414	0.111	2.1
52	39	0.605	0.039	3.5	74	103	5.525	0.111	2.1
52	40	0.637	0.032	2.8	75	104	5.639	0.114	2.1
53	41	0.67	0.033	2.8	75	105	5.75	0.111	2.0
53	42	0.705	0.035	2.9	76	106	5.864	0.114	2.0
53	43	0.742	0.037	2.9	76	107	5.98	0.116	2.1
54	44	0.78	0.038	2.9	76	108	6.1	0.12	2.0
54	45	0.82	0.04	3.0	77	109	6.217	0.117	2.0
55	46	0.863	0.043	3.1	77	110	6.336	0.119	2.0
55	47	0.907	0.044	3.0	77	111	6.459	0.123	2.1
55	48	0.953	0.046	3.1	78	112	6.58	0.121	2.0
56	49	1.002	0.049	3.2	78	113	6.704	0.124	1.9
56	50	1.053	0.051	3.2	78	114	6.827	0.123	2.0
56	51	1.106	0.053	3.3	79	115	6.952	0.125	2.0
57	52	1.161	0.055	3.2	79	116	7.078	0.126	1.9
57	53	1.219	0.058	3.3	79	117	7.209	0.131	2.0
57	54	1.279	0.06	3.3	80	118	7.337	0.128	1.9
58	55	1.342	0.063	3.4	80	119	7.466	0.129	1.9
58	56	1.394	0.052	2.7	80	120	7.597	0.131	1.9
58	57	1.448	0.054	2.7	81	121	7.729	0.132	1.9
59	58	1.503	0.055	2.7	81	122	7.863	0.134	1.9
59	59	1.559	0.056	2.7	81	123	7.997	0.134	1.9
59	60	1.618	0.059	2.7	82	124	8.131	0.134	1.8
60	61	1.678	0.06	2.7	82	125	8.27	0.139	1.9
60	62	1.74	0.062	2.8	83	126	8.406	0.136	1.8
60	63	1.805	0.065	2.8	83	127	8.546	0.14	1.9

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Table II.6-3b. System Tonal Transfer using Radeon 8500 graphics, counts 128 to 255, Lmin = 0.1 fL.

Background	Target	L, fL	Diff, fL	Diff, JND	Background	Target	L, fL	Diff, fL	Diff, JND
83	128	8.686	0.14	1.8	106	192	20.49	0.2	1.2
84	129	8.826	0.14	1.8	106	193	20.74	0.25	1.6
84	130	8.96	0.134	1.7	106	194	20.98	0.24	1.5
84	131	9.106	0.146	1.8	107	195	21.22	0.24	1.5
85	132	9.241	0.135	1.7	107	196	21.45	0.23	1.4
85	133	9.384	0.143	1.8	107	197	21.69	0.24	1.4
85	134	9.526	0.142	1.7	108	198	21.93	0.24	1.4
86	135	9.67	0.144	1.7	108	199	22.17	0.24	1.4
86	136	9.813	0.143	1.7	108	200	22.4	0.23	1.4
86	137	9.959	0.146	1.7	109	201	22.63	0.23	1.3
87	138	10.1	0.141	1.6	109	202	22.87	0.24	1.4
87	139	10.25	0.15	1.7	109	203	23.1	0.23	1.3
87	140	10.4	0.15	1.7	110	204	23.33	0.23	1.3
88	141	10.55	0.15	1.7	110	205	23.57	0.24	1.3
88	142	10.69	0.14	1.5	111	206	23.8	0.23	1.3
88	143	10.84	0.15	1.6	111	207	24.02	0.22	1.2
89	144	10.99	0.15	1.6	111	208	24.25	0.23	1.2
89	145	11.14	0.15	1.6	112	209	24.47	0.22	1.2
90	146	11.3	0.16	1.7	112	210	24.69	0.22	1.2
90	147	11.45	0.15	1.6	112	211	24.91	0.22	1.2
90	148	11.6	0.15	1.5	113	212	25.13	0.22	1.1
91	149	11.75	0.15	1.5	113	213	25.35	0.22	1.2
91	150	11.91	0.16	1.6	113	214	25.57	0.22	1.1
91	151	12.07	0.16	1.6	114	215	25.79	0.22	1.2
92	152	12.26	0.19	1.9	114	216	26	0.21	1.0
92	153	12.46	0.2	1.9	114	217	26.21	0.21	1.1
92	154	12.66	0.2	1.9	115	218	26.42	0.21	1.0
93	155	12.86	0.2	1.9	115	219	26.62	0.2	1.0
93	156	13.06	0.2	1.9	115	220	26.92	0.3	1.5
93	157	13.26	0.2	1.8	116	221	27.24	0.32	1.6
94	158	13.46	0.2	1.8	116	222	27.55	0.31	1.5
94	159	13.67	0.21	1.9	116	223	27.84	0.29	1.4
94	160	13.87	0.2	1.8	117	224	28.13	0.29	1.4
95	161	14.07	0.2	1.7	117	225	28.43	0.3	1.4
95	162	14.28	0.21	1.8	118	226	28.71	0.28	1.3
95	163	14.48	0.2	1.7	118	227	29	0.29	1.4
96	164	14.69	0.21	1.8	118	228	29.27	0.27	1.2
96	165	14.89	0.2	1.7	119	229	29.54	0.27	1.2
97	166	15.1	0.21	1.7	119	230	29.83	0.29	1.3
97	167	15.31	0.21	1.7	119	231	30.09	0.26	1.2
97	168	15.52	0.21	1.7	120	232	30.35	0.26	1.2
98	169	15.72	0.2	1.6	120	233	30.59	0.24	1.0
98	170	15.93	0.21	1.6	120	234	30.85	0.26	1.2
98	171	16.13	0.2	1.6	121	235	31.08	0.23	1.0
99	172	16.34	0.21	1.6	121	236	31.35	0.27	1.1
99	173	16.55	0.21	1.6	121	237	31.67	0.32	1.4
99	174	16.76	0.21	1.5	122	238	31.96	0.29	1.2
100	175	16.97	0.21	1.6	122	239	32.28	0.32	1.4
100	176	17.18	0.21	1.6	122	240	32.57	0.29	1.2
100	177	17.39	0.21	1.5	123	241	32.95	0.38	1.6
101	178	17.6	0.21	1.5	123	242	33.27	0.32	1.3
101	179	17.8	0.2	1.4	123	243	33.62	0.35	1.4
101	180	18.01	0.21	1.5	124	244	33.97	0.35	1.4
102	181	18.22	0.21	1.5	124	245	34.29	0.32	1.3
102	182	18.43	0.21	1.4	125	246	34.59	0.3	1.2
102	183	18.64	0.21	1.5	125	247	34.88	0.29	1.1
103	184	18.84	0.2	1.3	125	248	35.17	0.29	1.2
103	185	19.05	0.21	1.4	126	249	35.43	0.26	1.0
104	186	19.26	0.21	1.4	126	250	35.7	0.27	1.0
104	187	19.47	0.21	1.4	126	251	35.93	0.23	0.9
104	188	19.68	0.21	1.4	127	252	36.22	0.29	1.1
105	189	19.88	0.2	1.3	127	253	36.48	0.26	1.0
105	190	20.08	0.2	1.3	127	254	36.75	0.27	1.0
105	191	20.29	0.21	1.3	128	255	37.21	0.46	1.7

II.7. Moiré

The IBM T221 LCD monitor is a pixelated flat panel display and does not use a phosphor screen as does a CRT. Therefore, the IEC specification of phosphor-to-pixel spacing is not applicable to the LCD. Pixelated flat panel displays are inherently free of Moiré patterns when digitally addressed at the native resolution, in this case, 3840 x 2400 pixels.

II.8. Luminance Step Response

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.8, p 7.

No video artifacts were observed when the IBM T221 LCD monitor was driven in 3840 x 2400 format using digital input signals.

Objective: Determine the presence of artifacts caused by undershoot or overshoot.

Equipment: Test targets, SMPTE Test Pattern RP-133-1991, 2-D CCD array

Procedure: Display a center box 15% of screen size at input count levels corresponding to 25%, 50%, 75%, and 100% of Lmax with a surround of count level 0. Repeat using SMPTE Test pattern

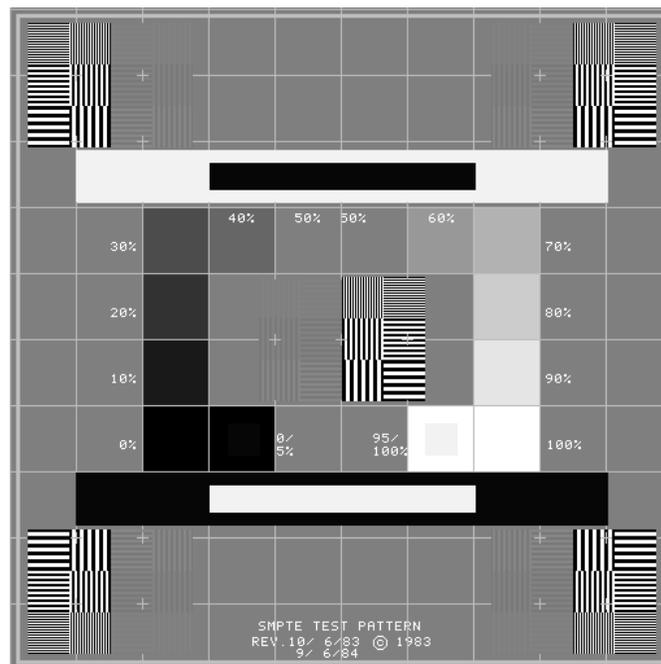


Figure II.8-1. SMPTE Test Pattern.

Data: Define pass by absence of noticeable ringing, undershoot, overshoot, or streaking.

The test pattern shown in Figure II.8-1 was used in the visual evaluation of the monitor. This test pattern is defined in SMPTE Recommended Practice RP-133-1986 published by the Society of Motion Picture and Television Engineers (SMPTE) for medical imaging applications. Referring to the large white-in-black
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and black-in-white horizontal bars contained in the test pattern, RP133-1986, paragraph 2.7 states “ These areas of maximum contrast facilitate detection of mid-band streaking (poor low-frequency response), video amplifier ringing or overshoot, deflection interference, and halo.”

II.9. Addressability

Reference: CRT Color Monitor Performance, Draft Version 2.0, Section 6.1, page 67.

This monitor properly displayed all addressed pixels for the 3840 H x 2400 V x 41 Hz format using the Matrox G200 digital graphics card.

Objective: Define the number of addressable pixels in the horizontal and vertical dimension; confirm that stated number of pixels is displayed.

Equipment: Matrox G200 MMS graphics card with quad digital outputs.
Dell 266 MHz Pentium II PC.
Test pattern with pixels lit on first and last addressable rows and columns and on two diagonal lines beginning at upper left and lower right; H & V grill patterns 1-on/1-off.

Procedure: The numbers of addressed pixels were programmed into the Windows NT display settings for 41 Hz refresh rate for monoscopic mode. Stereoscopic mode was not tested. All perimeter lines of a crosshatch test pattern image were confirmed to be visible, with no irregular jaggies on diagonals and no strongly visible moiré on grilles.

Data: If tests passed, number of pixels in horizontal and vertical dimension. If test fails, addressability unknown.

Table II.9-1 Addressabilities Tested

Monoscopic Mode
3840 x 2400 x 41 Hz

II.10. Pixel Aspect Ratio

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.10, p 8.

Pixel aspect ratio is 1:1 for an addressability of 3840 x 2400 pixels and passes the IEC specification.

Objective: Characterize aspect ratio of pixels.

Equipment: Test target, measuring tape with at least 1/16th inch increments

Procedure: Display box of 400 x 400 pixels at input count corresponding to 50% Lmax and background of 0. Measure horizontal and vertical dimension.

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Alternatively, divide number of addressable pixels by the total image size to obtain nominal pixel spacings in horizontal and vertical directions.

Data: Define pass if $H = V \pm 6\%$ for pixel density < 100 ppi and $\pm 10\%$ for pixel density > 100 ppi.

Table II.11-1. Pixel Aspect Ratio
Monoscopic Mode

	<u>3840 x 2400 Full Screen</u>
H x V Image Size (inches)	18.828 x 11.766
H x V Pixel Spacing (mils)	4.90 x 4.90
H x V Pixel Aspect Ratio	$H = V + 0.0\%$

II.11. Screen Size (Viewable Active Image)

Reference: VESA FPDm, Version 2.0, Section 501-1, pages 167 – 170.

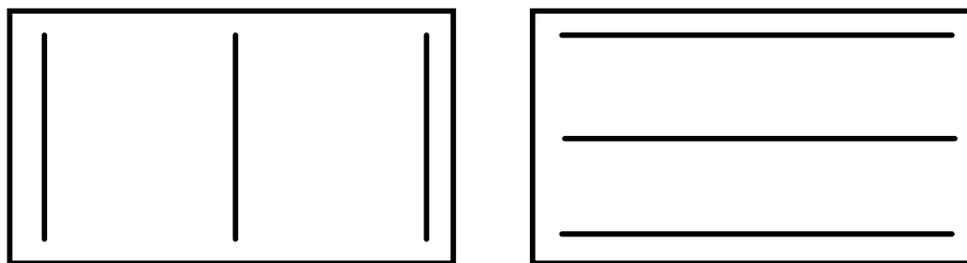
Image size as tested in monoscopic mode (3840 x 2400) was 22.202 inches in diagonal.

Objective: Measure pixel position on the LCD display to quantify width and height of active image size visible by the user (excludes any overscanned portion of an image).

Equipment:

- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.11-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern are displayed at 100% L_{max} must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



1-pixel-wide lines displayed at 100% L_{max}
Figure II.11-1 Three-line grille test patterns.

Procedure: Use diode optic module to locate center of line profiles in conjunction with calibrated X-Y translation to measure screen x, y coordinates of lines at the ends of the major and minor axes.

Data: Compute the image width defined as the average length of the horizontal lines along the top, bottom and major axis of the screen. Similarly, compute the image

height defined as the average length of the vertical lines along the left side, right side, and minor axis of the screen. Compute the diagonal screen size as the square root of the sum of the squares of the width and height.

Table II.11-1. Image Size

	Monoscopic Mode
Addressability (H x V)	3840 x 2400
H x V Image Size (inches)	18.828 x 11.766
Diagonal Image Size (inches)	22.202

II.12. Contrast Modulation

Reference: CRT Color Monitor Performance, Draft Version 2.0, Section 5.2, page 57.

VESA FPDM Version 2, Section 303-2, pages 62-63.

Contrast modulation (C_m) for 1-on/1-off grille patterns displayed at 50% L_{max} exceeded $C_m = 81%$ in Zone A and in Zone B. Contrast modulation (C_m) for 2-on/2-off grille patterns displayed at 50% L_{max} exceeded $C_m = 88%$ in Zone A and in Zone B. These values significantly exceed the IEC specification for contrast modulation in Zones A and B.

Objective: Quantify contrast modulation as a function of screen position.

Equipment:

- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Photometer with linearized response

Procedure: The maximum video modulation frequency for the 3840 x 2400 format was examined using horizontal and vertical grille test patterns consisting of alternating lines with 1 pixel on, 1 pixel off. A second set of contrast modulation measurements was made for alternating lines with 2 pixels on, 2 pixels off. Contrast modulation was measured in both horizontal and vertical directions at screen center and at eight peripheral screen positions. The measurements should be along the horizontal and vertical axes and along the diagonal from these axes. Use edge measurements no more than 10% of screen size in from border of active screen. The input signal level was set so that 1-line-on/1-line-off horizontal grille patterns produced a screen area-luminance of 25% of maximum level, L_{max} .

Zone A is defined as a 24 degree subtended circle from a viewing distance of 18 inches (7.6 inch circle). Zone B is the remainder of the display. Use edge measurements no more than 10% of screen size in from border of active screen area to define C_m for Zone B (remaining area outside center circle). Determine C_m at eight points on circumference of circle by interpolating between center and display edge measurements to define C_m for Zone A. If measurements exceed the threshold, do not make any more measurements. If one or more measurements fail the threshold, make eight additional measurements at the edge (but wholly within) the defined circle.

Data: Values of vertical and horizontal C_m for Zone A and Zone B are given in Tables II.12-1 and II.12-2. The contrast modulation, C_m , is reported (the defining equation is given below) for the 1-on/1-off grille patterns. The modulation greatly exceeds the IEC specification for equal to or greater than 25% in Zone A, and equal to or greater than 20% in Zone B.

$$C_m = \frac{L_{\text{peak}} - L_{\text{valley}}}{L_{\text{peak}} + L_{\text{valley}}}$$

Table II.12-1. Contrast Modulation for 1-Pixel-ON/1-Pixel-OFF Grilles
Corrected for lens flare and Zone Interpolation

Zone A = 7.6-inch diameter circle for 24-degree subtended angle at 18-inch viewing distance

	Left		Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	83%	89%	83% 90%		83% 89%		84%	88%
Major	81%	89%	82%	89%	83%	90%	83%	88%
			81%	89%	82%	89%	83%	88%
Bottom	81%	90%	82%	90%	86%	87%	82%	88%
			88% 86%		82% 86%			

Zone A = 10.5-inch diameter circle for 40% area

	Left		Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	83%	89%	83% 90%		83% 89%		84%	88%
Major	81%	89%	83%	89%	83%	90%	83%	88%
			81%	89%	82%	89%	83%	88%
Bottom	81%	90%	81%	90%	87%	86%	82%	88%
			88% 86%		82% 86%			

Table II.12-2. Contrast Modulation for 2-Pixel-ON/2-Pixel-OFF Grilles
Corrected for lens flare and Zone Interpolation

Zone A = 7.6-inch diameter circle for 24-degree subtended angle at 18-inch viewing distance

	Left		Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	91%	93%	91% 93%				90% 95%	
Major	89%	93%	90%	93%	91%	93%	90%	93%
			89%	93%	89%	93%	90%	93%
Bottom	89%	95%	88% 91%				90% 93%	

Zone A = 10.5-inch diameter circle for 40% area

	Left		Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	91%	93%	91% 93%				90% 95%	
Major	89%	93%	90%	93%	91%	93%	90%	94%
			89%	93%	89%	93%	91%	93%
Bottom	89%	95%	88% 91%				90% 93%	

II.13. Pixel Density

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.13, p 9.

Pixel density was 204 H x 204 V pixels per inch (ppi) as tested for the 3840 x 2400-line format.

Objective: Characterize density of image pixels

Equipment: Measuring tape with at least 1/16 inch increments

Procedure: Measure H&V dimension of active image window and divide by vertical and horizontal addressability

Data: Define horizontal and vertical pixel density in terms of pixels per inch

Table II.13-1. Pixel-Density

	Monoscopic Mode
H x V Addressability, Pixels	3840 x 2400
H x V Image Size, Inches	18.828 x 11.766
H x V Pixel Density, ppi	204 x 204

II.14. Residual Image

Reference: VESA FPDM Version 2, Section 305-2, pages 105 – 106.

A residual image persisted on a gray (0.85 fL) flat field for up to 70 seconds after removing a static checkerboard pattern.

We viewed 8 full screen gray levels alternately with a 5 x 5 black and white checkerboard test pattern to determine whether a residual image of the checkerboard pattern could be seen on any gray level. The checkerboard was displayed continuously for 30 seconds immediately prior to displaying each gray level.

Objective: Characterize the response of the display to long-term static images

Equipment: • Video generator or PC graphics card
• Photometer

Procedure: Compare measured display luminance before and after a high contrast checkerboard image is continuously displayed for a predetermined period on time.

Data: Tabulate observed time periods for any noticeable residual images.

Table II.14-1. Residual image observations for alternating checkerboard/gray levels

Gray Level	Luminance (fL)	Visible Residual Checkerboard after 30 second "burn-in"
7	35.3	None
6	23.9	None
5	15.7	None
4	9.52	None
3	5.5	1 second to decay
2	2.72	5 seconds to decay
1	0.85	70 seconds to decay, worst case tested
0	0.093	15 seconds to decay, less than for level 1

II.15. Straightness

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.1 Waviness, page 67.

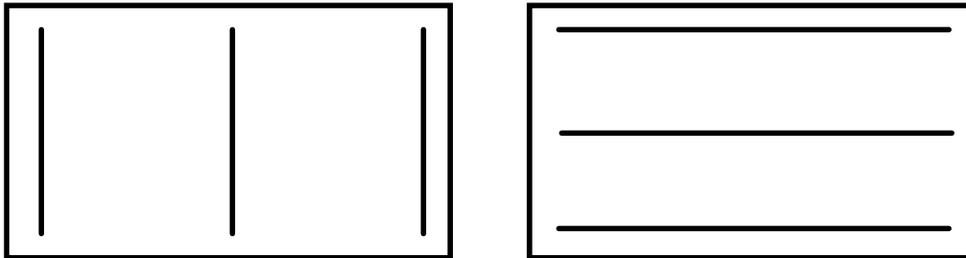
For the native 3840 x 2400 mode, waviness, a measure of straightness, did not exceed 0.04% of the image width or height. The IBM T221 LCD monitor is a pixelated flat panel display, which is inherently straight and free of geometric distortions such as pincushion and nonlinearity normally associated with other display technologies such as raster-scanned CRT monitors and projectors.

Objective: Measure pixel position on the LCD display to quantify effects of waviness, which causes nonlinearities within small areas of the display distorting nominally straight features in images, characters, and symbols.

Equipment:

- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.28-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern are displayed at 100% L_{\max} must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



1-pixel-wide lines displayed at 100% L_{\max}

Figure II.15-1 Three-line grille test patterns.

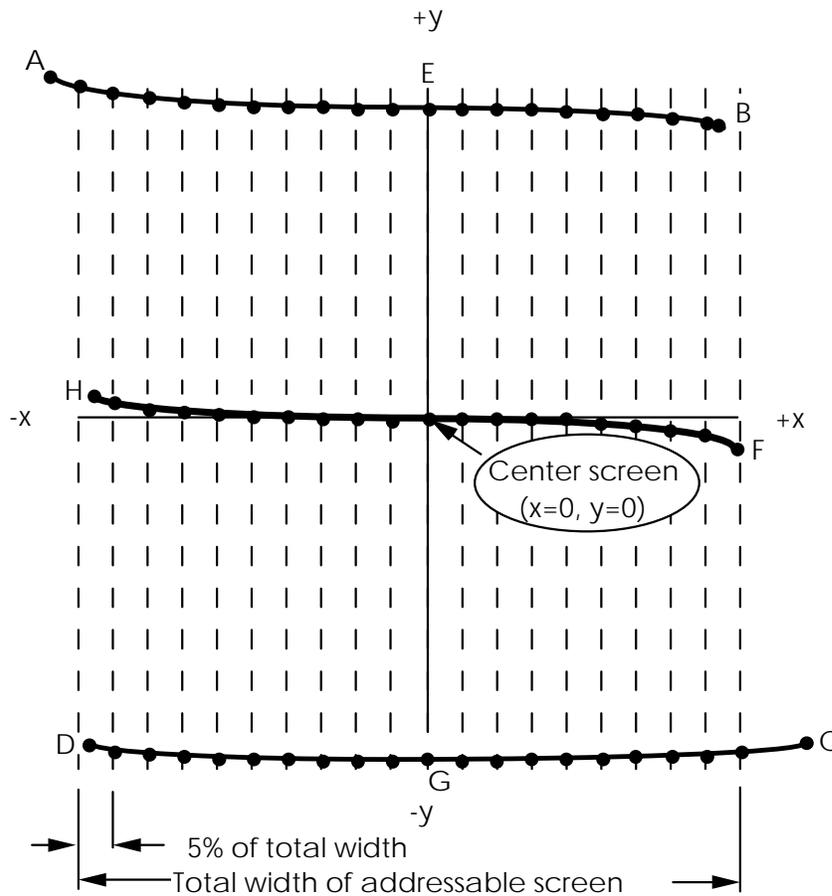


Figure II.15-2 Measurement locations for waviness along horizontal lines. Points A, B, C, D are extreme corner points of addressable screen. Points E, F, G, H are the endpoints of the axes.

Procedure: Use diode optic module to locate center of line profiles in conjunction with calibrated X-Y translation to measure screen x, y coordinates along the length of a nominally straight line. Measure x, y coordinates at 5% addressable screen intervals along the line. Position vertical lines in video to land at each of three (3) horizontal screen locations for determining waviness in the horizontal direction. Similarly, position horizontal lines in video to land at each of three (3) vertical screen locations for determining waviness in the vertical direction.

Data: Tabulate x, y positions at 5% addressable screen increments along nominally straight lines at top and bottom, major and minor axes, and left and right sides of the screen as shown in Table II.15-1. Figure II.15-3 shows the results in graphical form.

Table II.15-1. Straightness

Tabulated x, y positions at 5% addressable screen increments along nominally straight lines.

Top		Bottom		Major		Minor		Left Side		Right Side	
x	y	x	y	x	y	x	y	x	y	x	y
-9396	5877	-9407	-5865	-9404	6	2	5865	-9395	5876	9424	5865
-8469	5876	-8469	-5866	-8469	6	2	5292	-9397	5292	9423	5292
-7528	5876	-7528	-5868	-7528	4	2	4704	-9397	4704	9423	4704
-6587	5875	-6587	-5869	-6587	3	3	4116	-9397	4116	9424	4116
-5646	5874	-5646	-5870	-5646	3	3	3528	-9398	3528	9424	3528
-4705	5874	-4705	-5870	-4705	2	3	2940	-9398	2940	9424	2940
-3764	5873	-3764	-5871	-3764	2	3	2352	-9398	2352	9423	2352
-2823	5873	-2823	-5872	-2823	1	3	1764	-9399	1764	9422	1764
-1882	5872	-1882	-5872	-1882	1	2	1176	-9400	1176	9421	1176
-941	5872	-941	-5872	-941	0	1	588	-9401	588	9420	588
0	5871	0	-5872	0	0	0	0	-9403	0	9420	0
941	5871	941	-5872	941	0	0	-588	-9402	-588	9419	-588
1882	5871	1882	-5872	1882	0	1	-1176	-9402	-1176	9419	-1176
2823	5871	2823	-5872	2823	0	2	-1764	-9401	-1764	9420	-1764
3764	5871	3764	-5872	3764	0	3	-2352	-9401	-2352	9421	-2352
4705	5871	4705	-5873	4705	-1	4	-2940	-9400	-2940	9422	-2940
5646	5870	5646	-5873	5646	-2	4	-3528	-9400	-3528	9422	-3528
6587	5870	6587	-5874	6587	-2	4	-4116	-9401	-4116	9421	-4116
7528	5869	7528	-5874	7528	-2	4	-4704	-9402	-4704	9420	-4704
8469	5869	8469	-5875	8469	-2	3	-5292	-9403	-5292	9419	-5292
9425	5868	9414	-5876	9416	-3	2	-5871	-9404	-5863	9418	-5875

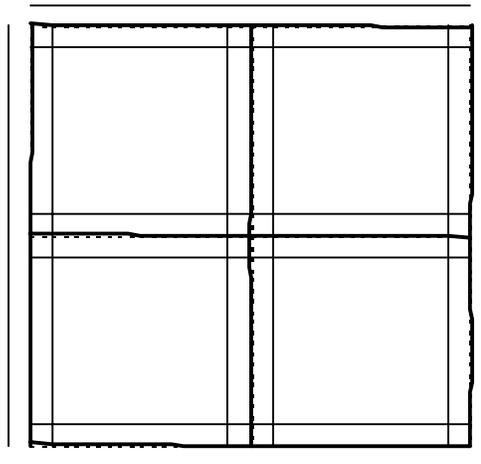


Figure II.15-3 Waviness of IBM T221 LCD Monitor in 3840 x 2400 mode. Departures from straight lines are exaggerated on a 10X scale. Error bars are +/- 0.5% of total screen size. Waviness does not exceed 0.04%.

II.16. Refresh Rate

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.16, p 9.

Vertical refresh rate for the 3840 x 2400 monoscopic format was set to 41 Hz by the Matrox G200 graphics card. The refresh using the ATO Fire GL4 graphics card was set to 24 Hz. No flicker is observed for either the 41 Hz or 24 Hz refresh rates in this LCD monitor. Vertical refresh rate for the Radeon 8500 graphics card was set to 13 Hz.

Objective: Define vertical and horizontal refresh rates.

Equipment: Programmable video signal generator.

Procedure: The refresh rates were determined by the graphics cards supplied by the monitor manufacturer.

Data: Report refresh rates in Hz.

Table II.16-1 Refresh Rates as Tested

Addressability	Monoscopic Mode, 3840 x 2400 pixels		
Graphics card	Matrox G200 MMS	ATI FireGL4	Radeon 8500
DVI channels	Quad	Dual	Single
Refresh	41 Hz	24 Hz	13 Hz

II.17. Extinction Ratio

Extinction ratio measurement is not applicable because the IBM T221 LCD monitor cannot be run in stereoscopic mode using the StereoGraphics ZScreen or active shutter glasses.

II.18. Linearity

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.2, page 73.

The maximum nonlinearity of scan for the 3840 x 2400 native resolution was 0.06% of full screen and far exceeded the IEC requirement of 1.0% or less. The IBM T221 LCD is a pixelated flat panel display, which is inherently straight and free of geometric distortions such as pincushion, and nonlinearity normally associated raster-scanned CRT monitors and projectors.

Objective: Measure the relation between the actual position of a pixel on the screen and the commanded position to quantify effects of raster nonlinearity. Nonlinearity of scan degrades the preservation of scale in images across the display.

Equipment: • Video generator or PC and graphics card

Use or disclosure of data on this sheet is subject to the restrictions on the cover and title of this report.

- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use grille patterns of single-pixel horizontal lines and single-pixel vertical lines displayed at 100% L_{max} . Lines are equally spaced in addressable pixels. Spacing must be constant and equal to approximately 5% screen width and height to the nearest addressable pixel as shown in Figure II.18-1.

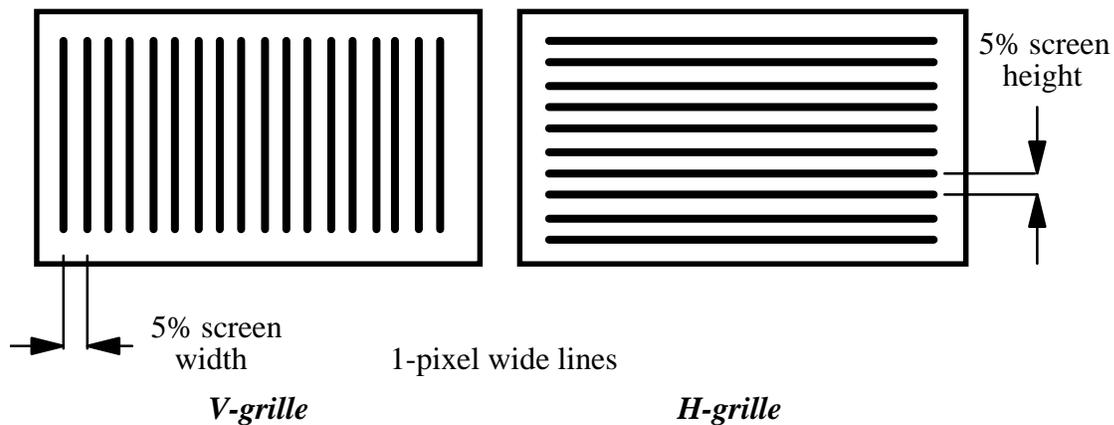


Figure II.18-1. Grille patterns for measuring linearity

Procedure: The linearity of the raster scan is determined by measuring the positions of lines on the screen. Vertical lines are measured for the horizontal scan, and horizontal lines for the vertical scan. Lines are commanded to 100% L_{max} and are equally spaced in the time domain by pixel indexing on the video test pattern. Use optic module to locate center of line profiles in conjunction with x, y-translation stage to measure screen x, y coordinates of points where video pattern vertical lines intersect horizontal centerline of screen and where horizontal lines intersect vertical centerline of the CRT screen as shown in Figure II.18-2.

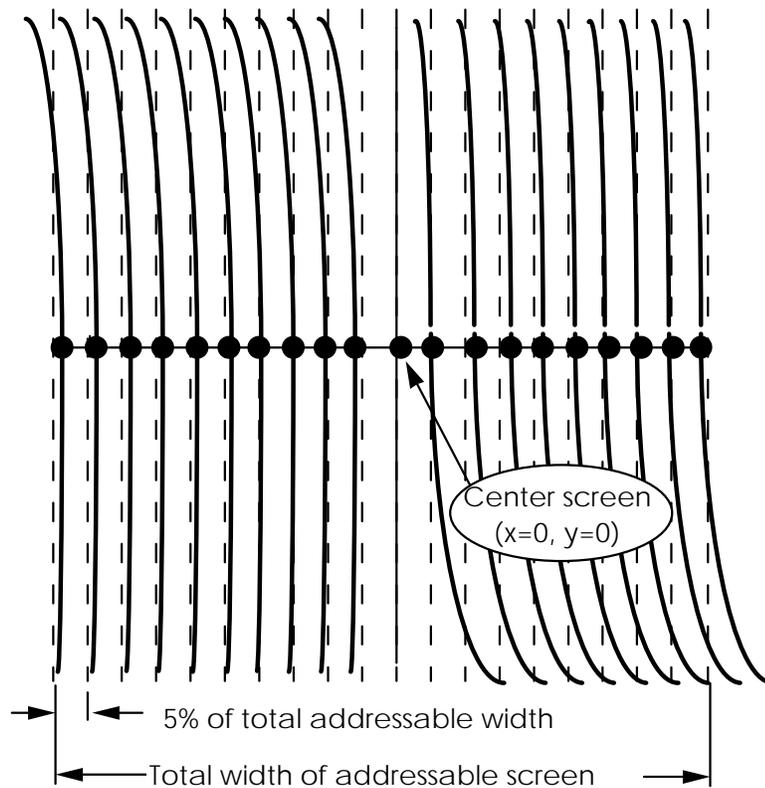


Figure II.18-2. Measurement locations for horizontal linearity along the major axis of the display. Equal pixel spacings between vertical lines in the grille pattern are indicated by the dotted lines. The number of pixels per space is nominally equivalent to 5% of the addressable screen size.

Data: Tabulate x, y positions of equally spaced lines (nominally 5% addressable screen apart) along major (horizontal centerline) and minor (vertical centerline) axes of the raster. If both scans were truly linear, the differences in the positions of adjacent lines would be a constant. The departure of these differences from constancy impacts the absolute position of each pixel on the screen and is, then, the nonlinearity. The degree of nonlinearity may be different between left and right and between top and bottom. The maximum horizontal and vertical nonlinearities (referred to full screen size) are listed in table II.18-1. The complete measured data are listed in table II.18-2 and shown graphically in Figure II.18-3.

Table II.18-1. Maximum Horizontal and Vertical Nonlinearities

<u>Set Up Condition</u>	<u>Format</u>	<u>Left Side</u>	<u>Right Side</u>	<u>Top</u>	<u>Bottom</u>
Native Resolution	3840 x 2400	0.03%	0.06%	-0.03%	-0.03%

Table II.18-2. Horizontal and Vertical Nonlinearity Data

Vertical Lines x-Position (mils)		Horizontal lines y-Position (mils)	
<u>Left Side</u>	<u>Right Side</u>	<u>Top</u>	<u>Bottom</u>
-9403	9417	---	---
-8227	8244	---	---
-7053	7065	5867	-5870
-5877	5884	4890	-4896
-4704	4706	3914	-3917
-3528	3529	2938	-2937
-2353	2353	1959	-1957
-1176	1176	979	-978
0	0	0	0

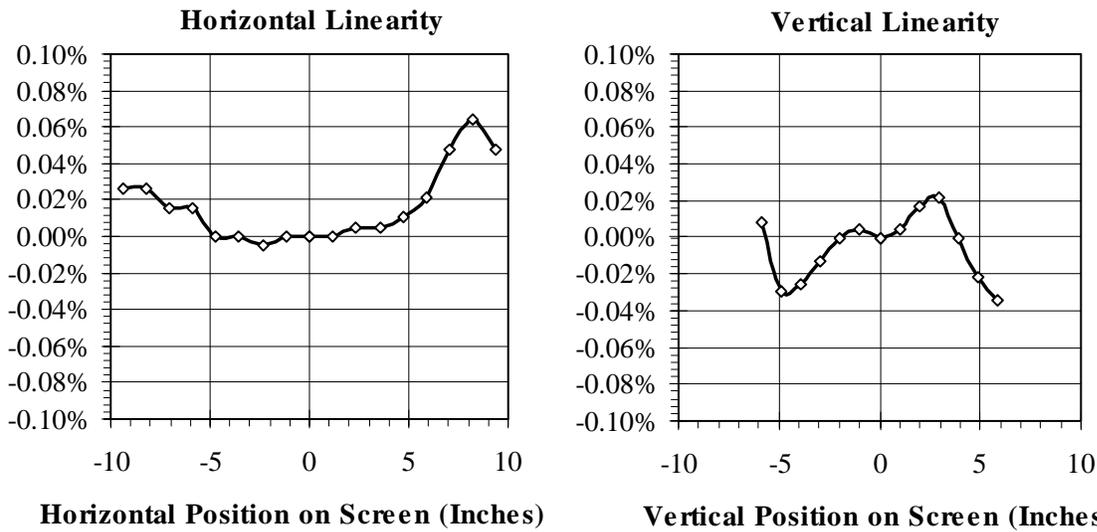


Fig. II.18-3. Horizontal and vertical linearity characteristics. The values are well below the 1% maximum needed to pass the IEC requirements.

II.19. Jitter/Swim/Drift

Reference: *CRT Color Monitor Performance, Draft Version 2.0 Section 6.4, p 80.*
VESA FPDM Version 2.0, Section 305-6, page 113.

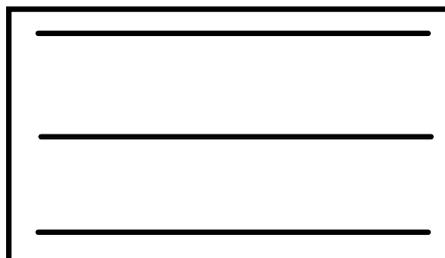
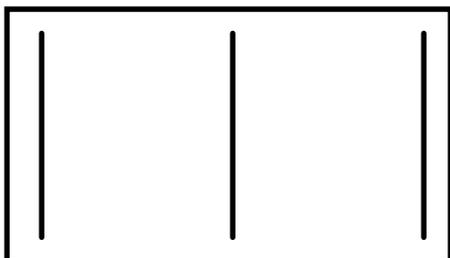
Maximum jitter, swim, and drift were less than 0.276 mils, 0.276 mils and 0.306 mils, respectively, smaller by factors of 7 or more than required by the IEC specification.

Objective: Quantify the effects of perceptible time varying raster distortions: jitter, swim, and drift. The perceptibility of changes in the position of an image depends upon the amplitude and frequency of the motions, which can be caused by imprecise control electronics or external magnetic fields.

Equipment:

- Video generator or PC graphics card
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.19-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



V-grille for measuring horizontal motion

H-grille for measuring vertical motion

1-pixel wide lines

Three-line grille test patterns.

Figure II.19-1

Procedure: With the monitor set up for intended scanning rates, measure vertical and horizontal line jitter (0.01 to 2 seconds), swim (2 to 60 seconds) and drift (over 60 seconds) over a 2.5 minute duration as displayed using grille video test patterns. Generate a histogram of raster variance with time. The measurement interval must be equal to a single field period.

Optionally, for multi-sync monitors measure jitter over the specified range of scanning rates. Some monitors running vertical scan rates other than AC line frequency may exhibit increased jitter.

Measure and report instrumentation motion by viewing Ronchi ruling or illuminated razor edge mounted to the top of the display. Mount both the optics and the monitor on a vibration-damped surface to reduce vibrations.

Data: Tabulate motion as a function of time in x-direction at top-left corner screen location. Repeat for variance in y-direction. Tabulate maximum motions (in mils) with display input count level corresponding to L_{\max} for jitter (0.01 to 2 seconds), swim (2 to 60 seconds) and drift (over 60 seconds) over a 2.5 minute duration. The data are presented in Table II.19-1. Both the monitor and the Microvision equipment sit on a vibration-damped aluminum-slab measurement bench.

Table II.19-1. Jitter/Swim/Drift

Maximum motions in mils.

Time scales: Jitter 2 sec., Swim 10 sec., and Drift 60 sec.

Signal Source: Matrox G200 MMS Graphics Card

<u>Screen Position</u>		<u>H-lines</u>	<u>V-lines</u>
10D corner	Jitter	0.276	0.153
	Swim	0.276	0.181
	Drift	0.306	0.212
Center Screen	Jitter	0.194	0.128
	Swim	0.208	0.153
	Drift	0.208	0.173

II.20 Warm-up Period

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.20, p. 10.

A 5-minute warm-up was necessary for luminance stability of $L_{min} = 0.1 \text{ fL} \pm 10\%$. This is much shorter than required by the IEC specification.

Objective: Define warm-up period

Equipment: Photometer, test target (full screen 0 count)

Procedure: Turn monitor off for three-hour period. Turn monitor on and measure center of screen luminance (L_{min} as defined in Dynamic range measurement) at 1-minute intervals for first five minutes and five-minute intervals thereafter. Discontinue when three successive measurements are $\pm 10\%$ of L_{min} .

Data: Pass if L_{min} within $\pm 50\%$ in 30 minutes and $\pm 10\%$ in 60 minutes.

The luminance of the screen (commanded to the minimum input level, 0 for L_{min}) was monitored for 120 minutes after a cold start. Measurements were taken every minute. Figure II.20-1 shows the data in graphical form. The black luminance remains very stable after 30 minutes.

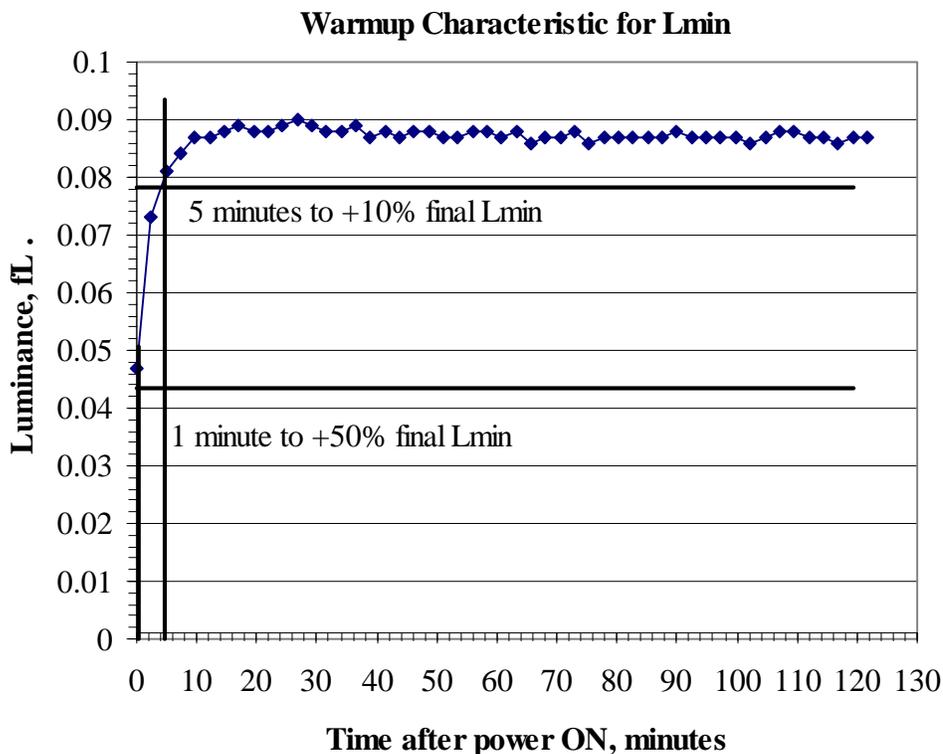


Figure II.20.1. Luminance (fL) as a function of time (in minutes) from a cold start with an input count of 0.

II.21 Briggs Scores

Reference: SofTrak User's Guidelines and Reference Manual Version 3.0, NIDL, Sept. 1994, page 3.

Briggs BTP #4 test patterns were displayed at both 1X (3840 x 2400 pixels) and 2X (1920 x 1200 pixels) magnifications on the IBM T221 LCD monitor operating in 3840 x 2400 digital format. The IBM T221 LCD Briggs scores for 1X magnification averaged 14, 38, 56, and 72 for the Delta-1, Delta-3, Delta-7 and Delta-15 contrast ratio targets sets, respectively. The IBM T221 LCD Briggs scores for 2X magnification averaged 23, 56, 70, and 86 for the Delta-1, Delta-3, Delta-7 and Delta-15 contrast ratio targets sets, respectively. These IBM 2X scores were significantly better than obtained for the Samsung 240T monitor operating at 1920 x 1200 digital format: 16, 38, 59, and 71 for Delta-1, Delta-3, Delta-7 and Delta-15, respectively. The Delta-1, Delta-3, Delta-7 and Delta-15 were virtually identical for the Matrox G200 MMS and ATI FireGL4 at 1920 x 1200. Also, the Briggs scores were the same for the FireGL4 at Lmax values of 38 fL and 75 fL.

- Objective:** The Briggs series of test targets were developed to visually evaluate the image quality of grayscale monitors.
- Equipment:** Signal generator or computer graphics workstation and display graphics card
Briggs BTP#4 test target
- Procedure:** Three NIDL observers selected the maximum scores for each target set displayed on both the IBM T221 and Samsung 240T color LCD monitors. The operating and environmental conditions were identical (a very low light level room) to ensure a level-playing-field comparison between the LCD monitors. In accordance with Briggs procedures, magnifying devices were used when deemed by the observer to be advantageous in achieving higher scores.
- The IBM T221 LCD was run at 3840 x 2400 pixel addressability at 41 Hz refresh rate using a Matrox G200 MMS quad-DVI graphics card, and at 24 Hz refresh rate using an ATI FireGL4 dual-DVI graphics card. The Briggs target was displayed both at 1X magnification in the native 3840 x 2400 resolution of the T221 LCD, and at 2X magnification for an effective addressability of 1920 x 1200 pixels. The Samsung 240T LCD was run at its native resolution of 1920 x 1200 pixels at a 52 Hz refresh rate using a PC with Elsa Synergy III single-DVI graphics card. No flicker was observed at the 24 Hz, 41 Hz or 52 Hz refresh rates.
- Data:** Briggs score results are summarized below in Table II.21-1. The IBM T221 Briggs scores are significantly better than for the Samsung 240T LCD monitor. Detailed results are presented in Tables II.21-2 through II.21-5 and shown graphically in Figures II.21-3 through II.21-6.

Table II.21-1. Summary of Average Briggs Scores for Digital Addressing of LCDs

LCD Monitor	Samsung 240T	IBM T221, 3840 x 2400 native			
Effective Resolution	1920 x 1200 94 ppi	3840 x 2400 204 ppi	1920 x 1200 102 ppi	1920 x 1200 102 ppi	1920 x 1200 102 ppi
	1X	1X	2X	2X	2X
Lmax	39 fL	38 fL	39 fL	38 fL	75 fL
Graphics Card	Elsa Synergy III	Matrox G200	Matrox G200	ATI FireGL4	ATI FireGL4
Briggs Target					
Delta-1	16	14	23	23	23
Delta-3	38	38	59	53	52
Delta-7	59	56	72	69	73
Delta-15	71	72	86	85	86

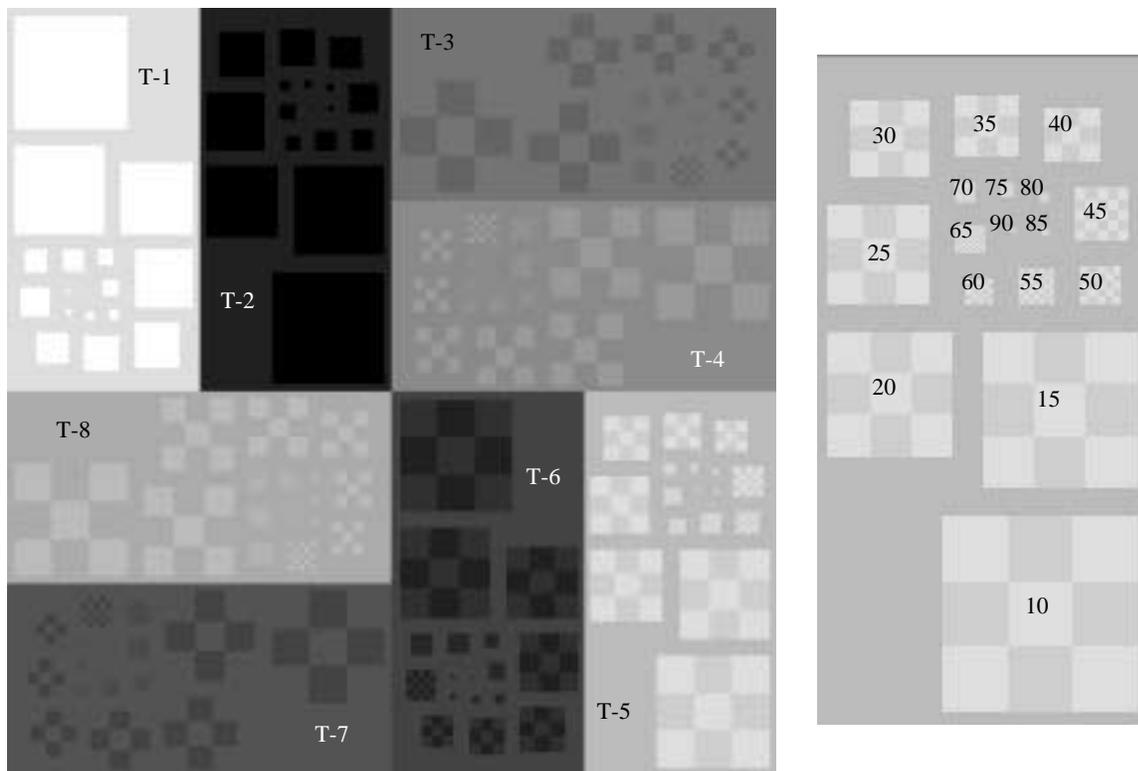


Figure II.21.1. Briggs BPT#4 Test Patterns comprised of 8 targets labeled T-1 through T-8. A series of 17 checkerboards is contained within each of the 8 targets. Each checkerboard is assigned a score value ranging from 10 to 90. Higher scores are assigned to smaller checkerboards.

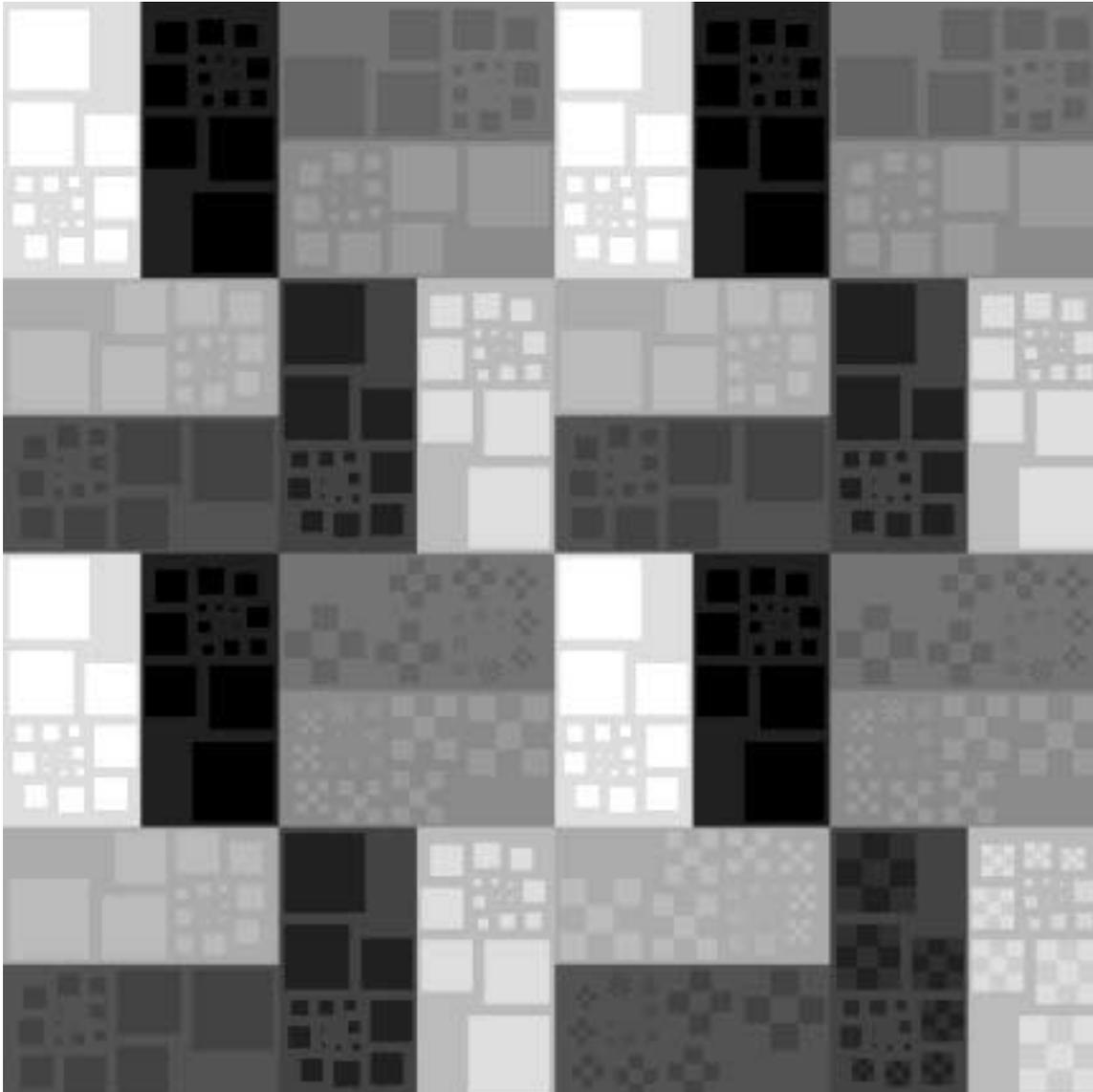


Figure II.21-2. 1024 x 1024 mosaic comprised of four 512 x 512 Briggs BPT#4 Test Patterns. The upper left quadrant contains the set of 8 Briggs targets with command contrast of delta 1. The upper right quadrant contains command contrast of delta 3. Delta 7 targets are in the lower left quadrant and delta 15 targets are in the lower right.

Table II.21-2. Briggs Scores for IBM T221 (3840 x 2400 pixels) and ATI FireGL4 Graphics Card at 2X Magnification Compared to Samsung 240T (1920 x 1200 pixels) at 1X Magnification

IBM T221 3840 x 2400, Lmin = 0.1fL, Lmax = 40 fL ATI FireGL4 PC Graphics Card Image at 2X Magnification					Samsung 240T, Digital Mode 1920 x 1200 x 52 Hz, Lmin = 0.1fL, Lmax = 39 fL Elsa Synergy III PC Graphics Card Image at 1X Magnification				
Target	Observer 1	Observer 2	Observer 3	Average	Observer 1	Observer 2	Observer 3	Average	
Delta-1	40fL IBM T221/FireGL4, average score = 23					39fL, Samsung 240T/Elsa Synergy III, average score = 16			
T-2 Dark	4	60	50	38	4	4	4	4	
T-6	30	60	60	50	30	40	60	43	
T-7	40	55	50	48	30	50	60	47	
T-3	4	45	4	18	30	20	4	18	
T-4	4	40	4	16	4	4	4	4	
T-8	4	4	4	4	4	4	4	4	
T-5	4	4	4	4	4	4	4	4	
T-1 Bright	4	4	4	4	4	4	4	4	
			Average	22.8			Average	16.0	
Delta-3	40fL IBM T221/FireGL4, average score = 53					39fL, Samsung 240T/Elsa Synergy III, average score = 38			
T-2 Dark	20	60	50	43	4	4	30	13	
T-6	60	85	60	68	50	60	55	55	
T-7	50	90	70	70	50	60	60	57	
T-3	50	80	60	63	60	60	60	60	
T-4	40	60	60	53	50	60	60	57	
T-8	40	60	60	53	35	50	60	48	
T-5	30	50	60	47	10	4	15	10	
T-1 Bright	4	50	25	26	4	4	4	4	
			Average	53.1			Average	37.9	
Delta-7	40fL IBM T221/FireGL4, average score = 69					39fL, Samsung 240T/Elsa Synergy III, average score = 59			
T-2 Dark	40	80	60	60	45	45	60	50	
T-6	60	90	80	77	60	60	80	67	
T-7	60	90	80	77	60	60	90	70	
T-3	60	90	80	77	60	60	90	70	
T-4	60	90	75	75	60	60	60	60	
T-8	60	90	70	73	50	60	60	57	
T-5	50	60	60	57	50	50	60	53	
T-1 Bright	45	60	60	55	40	50	55	48	
			Average	68.8			Average	59.4	
Delta-15	40fL IBM T221/FireGL4, average score = 85					39fL, Samsung 240T/Elsa Synergy III, average score = 71			
T-2 Dark	60	90	60	70	60	60	60	60	
T-6	90	90	85	88	90	90	80	87	
T-7	90	90	90	90	60	90	90	80	
T-3	90	90	90	90	60	90	90	80	
T-4	90	90	90	90	60	60	90	70	
T-8	90	90	85	88	60	60	90	70	
T-5	60	90	85	78	60	60	60	60	
T-1 Bright	75	85	85	82	60	60	60	60	
			Average	84.6			Average	70.8	

Briggs Scores for IBM T221 (3840 x 2400 pixels) and ATI FireGL4 Graphics Card at 2X Magnification Compared to Samsung 240T (1920 x 1200 pixels) at 1X Magnification

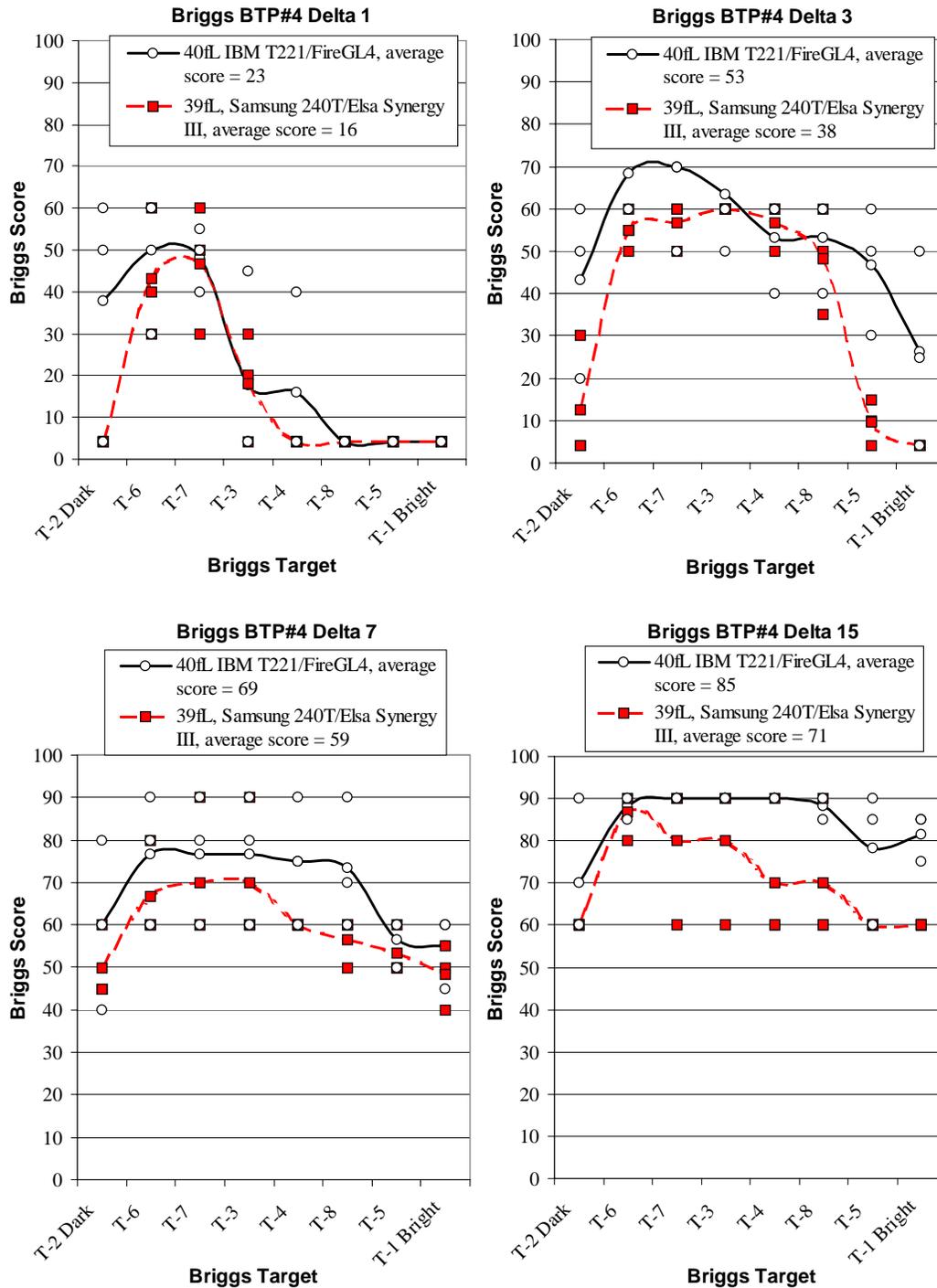


Figure II.21-3. Briggs scores for delta-1, delta-3, delta-7, and delta-15 contrast ratios on BPT#4 test pattern for the IBM T221 color LCD compared to Samsung 240T color LCD monitor. Each of these data points represents an individual score by each of three NIDL observers. The solid line shows the average score for each target, T-1 through T-8.

Table II.21-3. Briggs Scores for IBM T221 (3840 x 2400 pixels) and ATI FireGL4 Graphics Card at 2X Magnification and Lmax Set to 40 fL and 75 fL

IBM T221 3840 x 2400, Lmin = 0.1fL, Lmax = 40 fL ATI FireGL4 PC Graphics Card Image at 2X Magnification					IBM T221 3840 x 2400, Lmin = 0.2fL, Lmax = 75 fL ATI FireGL4 PC Graphics Card Image at 2X Magnification					
Target	Observer 1	Observer 2	Observer 3	Average	Observer 1	Observer 2	Observer 3	Average		
Delta-1 40fL IBM T221/FireGL4, average score = 23					75fL IBM T221/FireGL4, average score = 23					
T-2 Dark	4	60	50	38	4	60	50	38		
T-6	30	60	60	50	40	60	55	52		
T-7	40	55	50	48	30	50	55	45		
T-3	4	45	4	18	4	50	50	35		
T-4	4	40	4	16	4	4	4	4		
T-8	4	4	4	4	4	4	4	4		
T-5	4	4	4	4	4	4	4	4		
T-1 Bright	4	4	4	4	4	4	4	4		
				Average						
				22.8					Average	23.2
Delta-3 40fL IBM T221/FireGL4, average score = 53					75fL IBM T221/FireGL4, average score = 52					
T-2 Dark	20	60	50	43	35	60	50	48		
T-6	60	85	60	68	55	80	60	65		
T-7	50	90	70	70	60	85	60	68		
T-3	50	80	60	63	60	60	60	60		
T-4	40	60	60	53	50	60	60	57		
T-8	40	60	60	53	50	60	60	57		
T-5	30	50	60	47	4	50	60	38		
T-1 Bright	4	50	25	26	4	30	25	20		
				Average						
				53.1					Average	51.6
Delta-7 40fL IBM T221/FireGL4, average score = 69					75fL IBM T221/FireGL4, average score = 73					
T-2 Dark	40	80	60	60	45	85	60	63		
T-6	60	90	80	77	60	90	85	78		
T-7	60	90	80	77	60	90	85	78		
T-3	60	90	80	77	90	90	80	87		
T-4	60	90	75	75	60	90	85	78		
T-8	60	90	70	73	60	85	85	77		
T-5	50	60	60	57	60	65	60	62		
T-1 Bright	45	60	60	55	50	60	60	57		
				Average						
				68.8					Average	72.5
Delta-15 40fL IBM T221/FireGL4, average score = 85					75fL IBM T221/FireGL4, average score = 86					
T-2 Dark	60	90	60	70	45	90	60	65		
T-6	90	90	85	88	90	90	85	88		
T-7	90	90	90	90	90	90	90	90		
T-3	90	90	90	90	90	90	90	90		
T-4	90	90	90	90	90	90	90	90		
T-8	90	90	85	88	90	90	90	90		
T-5	60	90	85	78	90	90	85	88		
T-1 Bright	75	85	85	82	75	90	85	83		
				Average						
				84.6					Average	85.6

Briggs Scores for IBM T221 (3840 x 2400 pixels) and ATI FireGL4 Graphics Card at 2X Magnification and Lmax Set to 40 fL and 75 fL

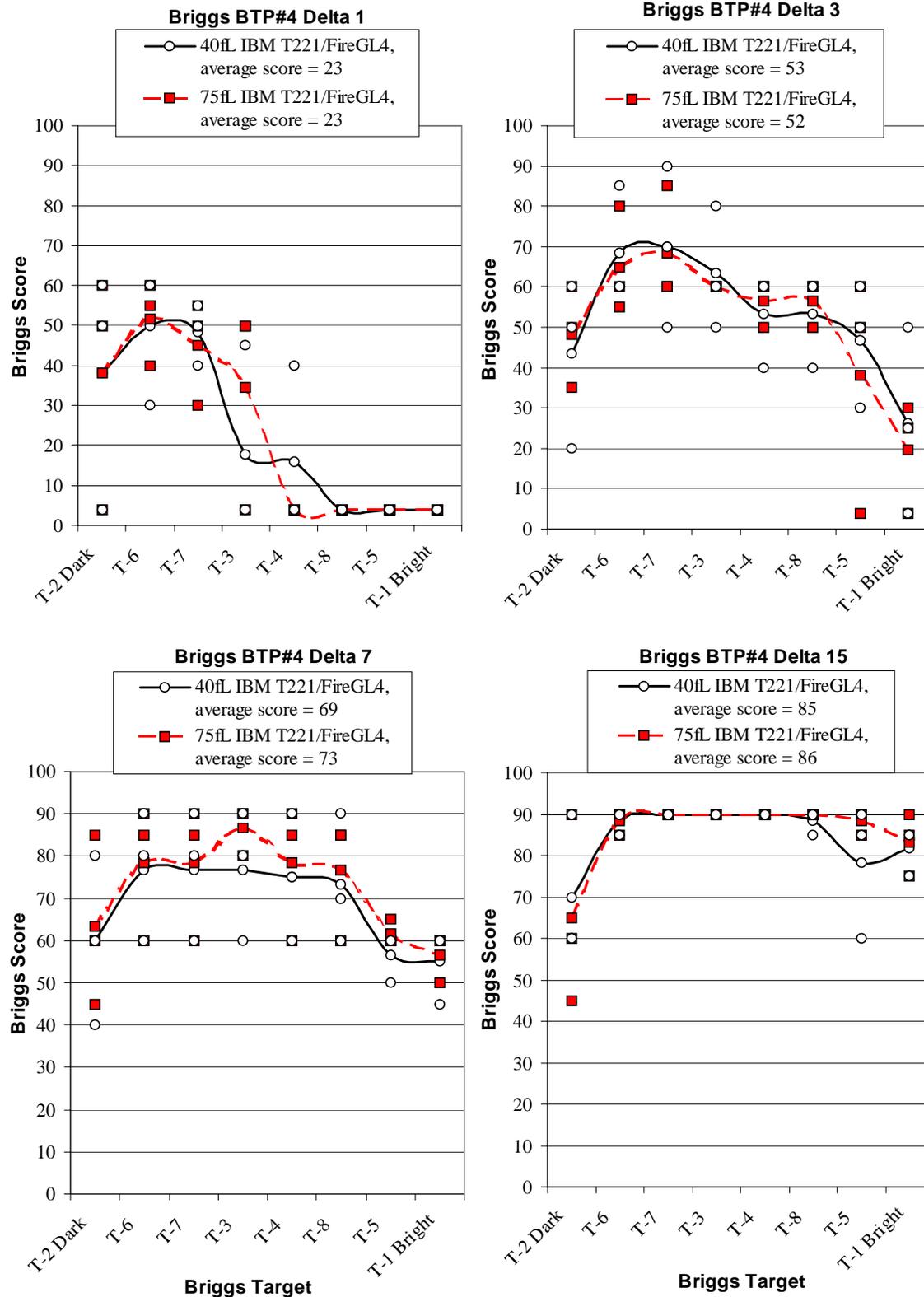


Figure II.21-4. Briggs scores for delta-1, delta-3, delta-7, and delta-15 contrast ratios on BPT#4 test pattern for the IBM T221 color LCD with Lmax set to 40 fL and to 75 fL. Each of these data points represents an individual score by each of three NIDL observers. The solid line shows the average score for each target, T-1 through T-8.

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Table II.21-4. Briggs Scores for IBM T221 (3840 x 2400 pixels) and ATI FireGL4 graphics card compared to the Matrox G200 MMS Graphics Card at 2X Magnification with Lmin set to 0.1 fL. Lmax was 39 fL.

IBM T221 LCD with IBM IntelliStation PC 3840 x 2400, Lmin = 0.1fL, Lmax = 40 fL ATI FireGL4 PC Graphics Card Image at 2X Magnification					IBM T221 LCD with IBM IntelliStation PC 3840 x 2400, Lmin = 0.1fL, Lmax = 40 fL Matrox G200 MMS PC Graphics Card Image at 2X Magnification				
Target	Observer 1	Observer 2	Observer 3	Average	Observer 1	Observer 2	Observer 3	Average	
Delta-1 40fL IBM T221/FireGL4 graphics at 2X, average score = 23					39fL IBM T221/Matrox G200 MMS at 2X, average score = 23				
T-2 Dark	4	60	50	38	4	50	45	33	
T-6	30	60	60	50	40	55	50	48	
T-7	40	55	50	48	35	40	50	42	
T-3	4	45	4	18	40	40	45	42	
T-4	4	40	4	16	4	4	4	4	
T-8	4	4	4	4	4	4	4	4	
T-5	4	4	4	4	4	4	4	4	
T-1 Bright	4	4	4	4	4	4	4	4	
	Average			22.8	Average			22.6	
Delta-3 40fL IBM T221/FireGL4 graphics at 2X, average score = 53					39fL IBM T221/Matrox G200 MMS at 2X, average score = 59				
T-2 Dark	20	60	50	43	30	60	50	47	
T-6	60	85	60	68	60	85	60	68	
T-7	50	90	70	70	60	80	80	73	
T-3	50	80	60	63	60	80	85	75	
T-4	40	60	60	53	50	60	60	57	
T-8	40	60	60	53	40	55	60	52	
T-5	30	50	60	47	40	50	55	48	
T-1 Bright	4	50	25	26	40	50	60	50	
	Average			53.1	Average			58.8	
Delta-7 40fL IBM T221/FireGL4 graphics at 2X, average score = 69					39fL IBM T221/Matrox G200 MMS at 2X, average score = 72				
T-2 Dark	40	80	60	60	40	75	60	58	
T-6	60	90	80	77	60	90	80	77	
T-7	60	90	80	77	90	90	85	88	
T-3	60	90	80	77	60	90	90	80	
T-4	60	90	75	75	60	90	60	70	
T-8	60	90	70	73	60	90	85	78	
T-5	50	60	60	57	60	60	75	65	
T-1 Bright	45	60	60	55	40	60	75	58	
	Average			68.8	Average			71.9	
Delta-15 40fL IBM T221/FireGL4 graphics at 2X, average score = 85					39fL IBM T221/Matrox G200 MMS at 2X, average score = 86				
T-2 Dark	60	90	60	70	60	85	65	70	
T-6	90	90	85	88	90	90	80	87	
T-7	90	90	90	90	90	90	90	90	
T-3	90	90	90	90	90	90	90	90	
T-4	90	90	90	90	90	90	90	90	
T-8	90	90	85	88	90	90	85	88	
T-5	60	90	85	78	90	85	85	87	
T-1 Bright	75	85	85	82	85	85	90	87	
	Average			84.6	Average			86.0	

Briggs Scores for IBM T221 (3840 x 2400 pixels) and ATI FireGL4 graphics card compared to the Matrox G200 MMS Graphics Card at 2X Magnification with Lmin set to 0.1 fL. Lmax was 39 fL.

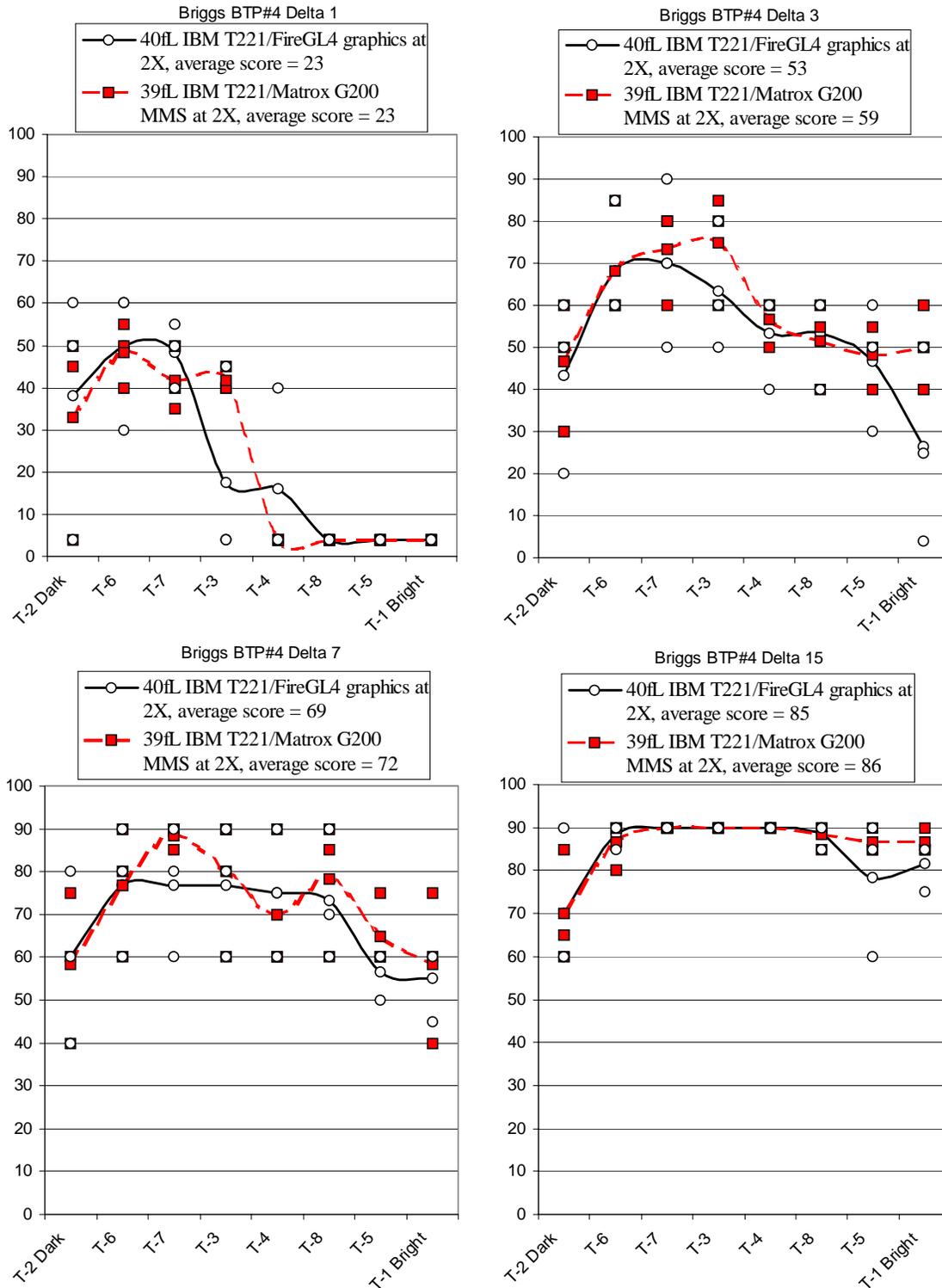


Figure II.21-5. Briggs scores for delta-1, delta-3, delta-7, and delta-15 contrast ratios on BPT#4 test pattern for the IBM T221 color LCD with Lmin set to 0.1fL. Lmax was 39 fL. Each of these data points represents an individual score by each of three NIDL observers. The solid line shows the average score for each target, T-1 through T-8.

Table II.21-5. Briggs Scores for IBM T221 (3840 x 2400 pixels) and Matrox G200 MMS Graphics Card at 1X and at 2X Magnification with Lmin set to 0.1 fL. Lmax was 39 fL.

IBM T221 LCD with IBM IntelliStation PC 3840 x 2400, Lmin = 0.1fL, Lmax = 40 fL Matrox G200 MMS PC Graphics Card Image at 2X Magnification					IBM T221 LCD with IBM IntelliStation PC 3840 x 2400, Lmin = 0.1fL, Lmax = 39 fL Matrox G200 MMS PC Graphics Card Image at 1X Magnification				
Target	Observer 1	Observer 2	Observer 3	Average	Observer 1	Observer 2	Observer 3	Average	
Delta-1	39fL IBM T221/Matrox G200 MMS at 2X, average score = 23				39fL IBM T221/Matrox G200 MMS at 1X, average score = 14				
T-2 Dark	4	50	45	33	4	50	30	28	
T-6	40	55	50	48	15	50	25	30	
T-7	35	40	50	42	20	45	15	27	
T-3	40	40	45	42	10	25	4	13	
T-4	4	4	4	4	4	4	4	4	
T-8	4	4	4	4	4	4	4	4	
T-5	4	4	4	4	4	4	4	4	
T-1 Bright	4	4	4	4	4	4	4	4	
	Average			22.6	Average			14.2	
Delta-3	39fL IBM T221/Matrox G200 MMS at 2X, average score = 59				39fL IBM T221/Matrox G200 MMS at 1X, average score = 38				
T-2 Dark	30	60	50	47	20	50	40	37	
T-6	60	85	60	68	40	60	55	52	
T-7	60	80	80	73	50	60	50	53	
T-3	60	80	85	75	40	50	50	47	
T-4	50	60	60	57	40	50	25	38	
T-8	40	55	60	52	50	45	4	33	
T-5	40	50	55	48	30	35	4	23	
T-1 Bright	40	50	60	50	30	35	4	23	
	Average			58.8	Average			38.2	
Delta-7	39fL IBM T221/Matrox G200 MMS at 2X, average score = 72				39fL IBM T221/Matrox G200 MMS at 1X, average score = 56				
T-2 Dark	40	75	60	58	35	60	50	48	
T-6	60	90	80	77	60	60	60	60	
T-7	90	90	85	88	60	80	75	72	
T-3	60	90	90	80	50	80	60	63	
T-4	60	90	60	70	45	60	60	55	
T-8	60	90	85	78	40	60	60	53	
T-5	60	60	75	65	50	50	60	53	
T-1 Bright	40	60	75	58	30	50	60	47	
	Average			71.9	Average			56.5	
Delta-15	39fL IBM T221/Matrox G200 MMS at 2X, average score = 86				39fL IBM T221/Matrox G200 MMS at 1X, average score = 72				
T-2 Dark	60	85	65	70	40	60	50	50	
T-6	90	90	80	87	60	90	90	80	
T-7	90	90	90	90	60	90	90	80	
T-3	90	90	90	90	50	90	80	73	
T-4	90	90	90	90	60	85	85	77	
T-8	90	90	85	88	60	90	85	78	
T-5	90	85	85	87	60	60	90	70	
T-1 Bright	85	85	90	87	60	60	90	70	
	Average			86.0	Average			72.3	

Briggs Scores for IBM T221 (3840 x 2400 pixels) and Matrox G200 MMS Graphics Card at 1X and at 2X Magnification with Lmin set to 0.1 fL. Lmax was 39 fL.

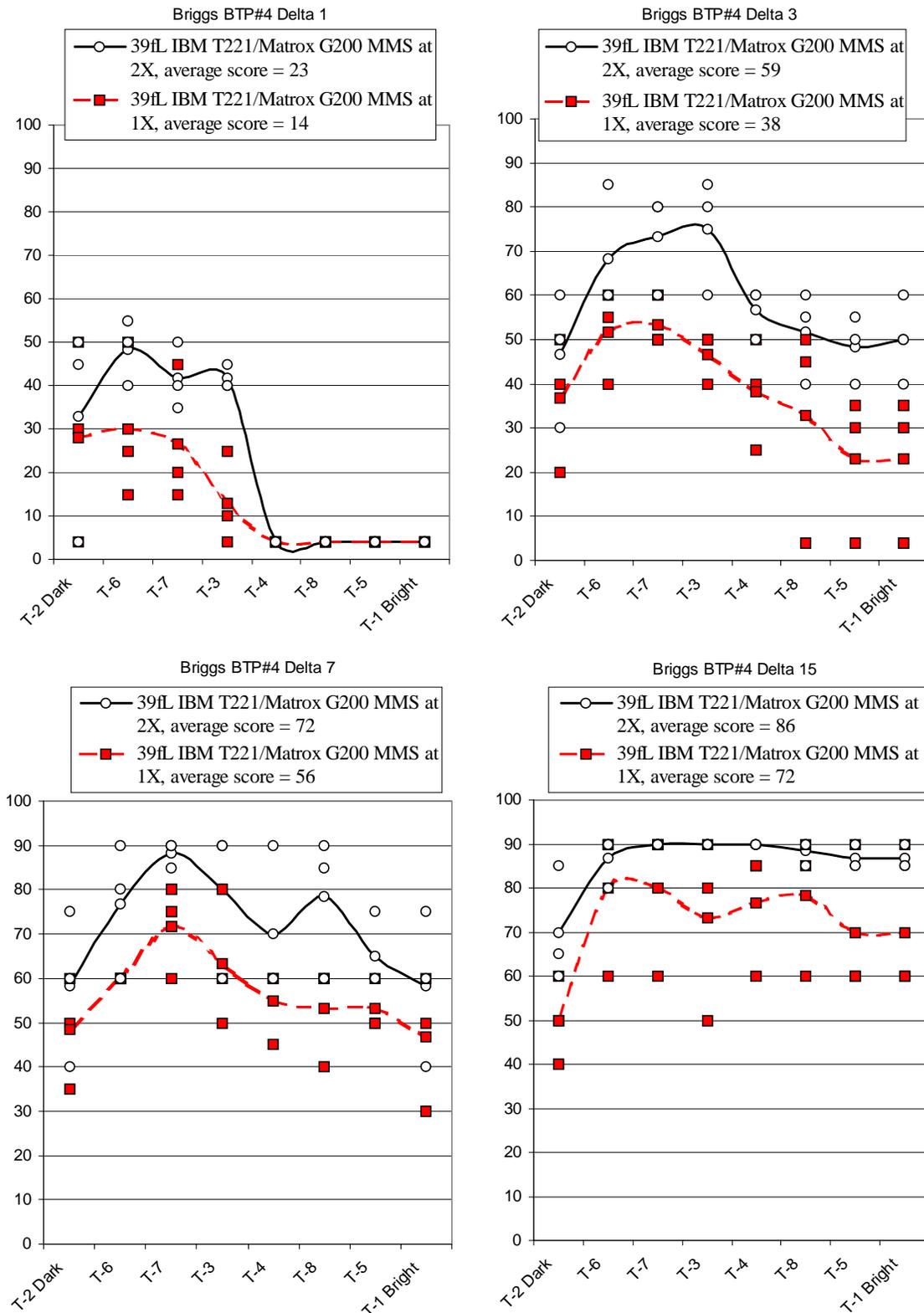


Figure II.21-6. Briggs scores for delta-1, delta-3, delta-7, and delta-15 contrast ratios on BPT#4 test pattern for the IBM T221 color LCD with Lmin set to 0.1fL. Lmax was 39 fL. Each of these data points represents an individual score by each of three NIDL observers. The solid line shows the average score for each target, T-1 through T-8.

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II.22. Pixel Defects

Reference: VESA FPDM Version 2.0, Section 303-6, p70.

We observed very few (only 5) defective pixels. One in 1.8 million color pixels were stuck on.

The IBM T221 LCD monitor had very few defective pixels. While viewing a full black (Lmin) screen, 5 pixels were observed to be "stuck ON": 2 white, 1 red, 1 green, and 1 blue. Locations of these defects are illustrated in Figure II.22-1. While viewing a full white (Lmax) screen, no defects were observed.

Objective: Quantify the number of malfunctioning pixels in the display.

Equipment: Signal generator or computer graphics workstation
Full-screen test patterns for Lmax, Lmin, and gray levels

Procedure: NIDL observers inspected flat-field full-screen test patterns for the presence of pixels or groups of pixels that are either stuck on or stuck off compared to the rest of the display screen.

Data: The type of each pixel defect is recorded along with the position on the screen. Results are shown in Figure II.22-1.

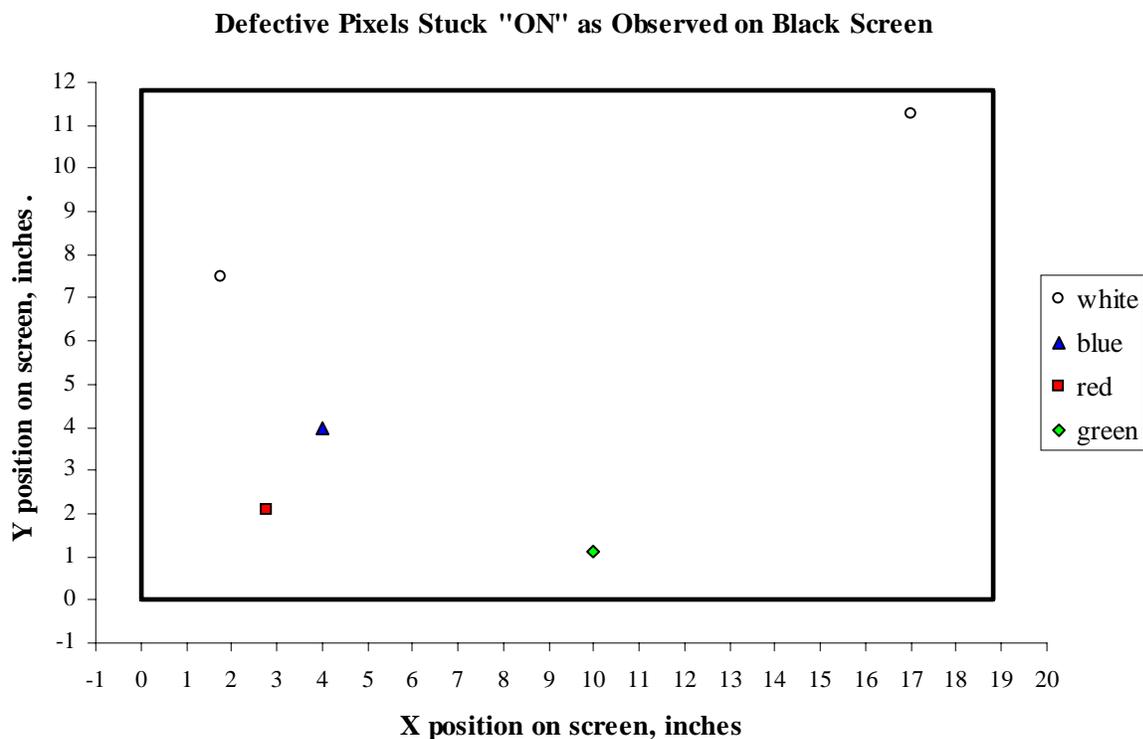


Figure II.22-1. Locations of pixel defects observed on the IBM T221 LCD monitor.

II.23. Crosstalk

References: VESA FPDM Version 2, Section 303-4, pages 66 - 67.

No luminance nonuniformities or shadowing due to crosstalk effects were visible on the IBM T221 LCD monitor.

Objective: Quantify effects on the luminance in one part of the screen caused by the luminance state in a different location on the screen.

Equipment: Signal generator or PC with graphics card
Photometer

Procedure: Inspect various combinations of gray level boxes displayed on different gray level backgrounds for the presence of shadowing caused by electrical crosstalk among rows and/or columns of pixels. VESA test patterns may be used. Select the combination of box and background gray levels that exhibit the worst-case shadowing. Switch the box On and OFF and measure the change in background luminance.

Data: Measure and report the luminance of the background with and without the box displayed. Compute and report the change in background luminance.

II.24. Viewing Angle

Reference: VESA FPDM, Version 2.0, Section 307, pages 125 - 134.

NIDL used an accepted method to measure the viewing angle as that angle where the contrast ratio has decreased to half the value measured perpendicular to the screen. The effective viewing cone angle for the IBM T221 LCD monitor whereby the maximum contrast ratio of 385:1 (25.9dB) does not vary by more than a factor of 2 (3dB) based on luminance viewing cone measurements of L_{max} (level 255) and L_{min} (level 000) is approximately ± 42 degrees from the perpendicular to the LCD screen in the vertical direction, and ± 35 degrees in the horizontal direction. This LCD monitor did not exhibit grayscale inversion with viewing angle. We observed excellent agreement between measurements taken with the Microvision goniometer and the ELDIM spatial photometer.

Objective: Characterize the displayed luminance and color for off-axis viewing positions.

Equipment: Signal generator or PC with graphics card
Full-screen gray-level test patterns
Microvision SS220 spectrometer with goniometric head
ELDIM spatial photometer (Used at IBM Watson Research Laboratory for comparison measurements.)

Procedure: Luminance and chromaticity of full screen gray levels was measured at screen center as a function of viewing angle.

Data: The data are plotted in Figures II.24-2 through II.24-13. From this data, horizontal viewing angle with vertical angle set perpendicular to the screen, and as a function of vertical viewing angle with horizontal angle set perpendicular to the screen were determined. H and V threshold viewing cone angles where contrast ratio (CR = Lmax/Lmin) decreases by a factor of two from 385:1 to 192:1 were determined using linear interpolation.

Viewing angle for LCD monitors using the criterion of only a factor of 2 reduction in contrast ratio is approximately ± 42 degrees from the perpendicular to the LCD screen in the vertical direction, and ± 35 degrees in the horizontal direction. This is much smaller than the ± 85 degree viewing angle claimed in the manufacturer's description of their monitor. Thus the IA and GI should maintain their head position within ± 35 degrees of the perpendicular to the LCD screen. An exception may be to use the change in contrast with viewing angle to make a subtle feature more prominent. Care must be taken when a second viewer is looking over the analyst's shoulder so that the point of interest is not obscured. It will be noted that a CRT monitor shows less variation in contrast ratio with viewing angle than does the LCD monitor.

The IBM T221 LCD monitor did not exhibit grayscale inversion with viewing angle. Grayscale inversion can occur on many other LCDs as shown in Figure II.24-1 taken from VESA FPDM.

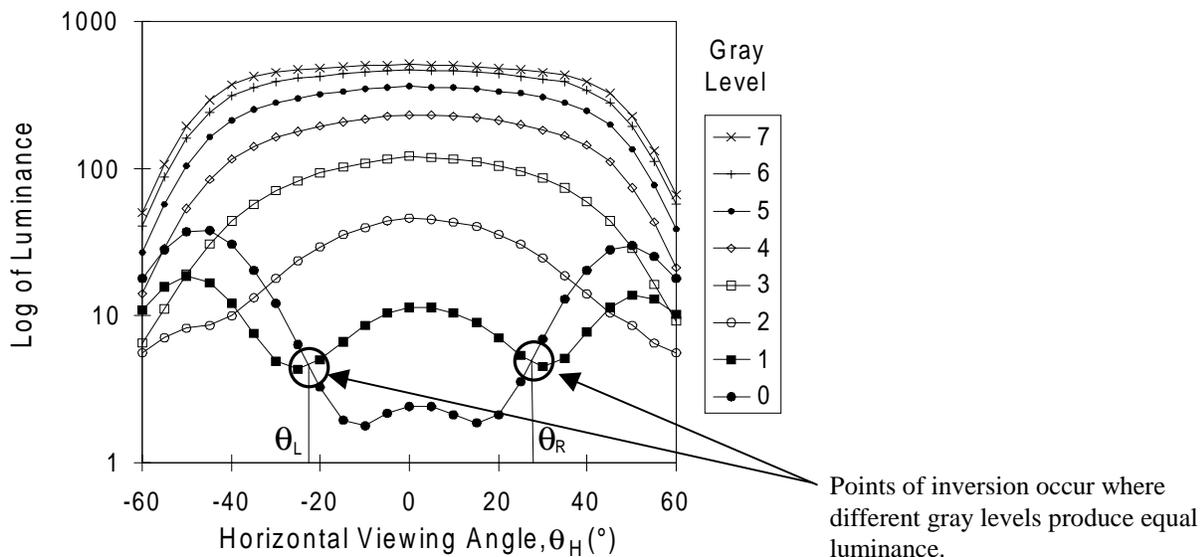


Figure II.24-1. Example of Gray Scale Inversion. Points of inversion occur where different gray levels produce equal luminance as indicated in the plot.

Table II.24-1. Summary Comparison Between NIDL/SS220 and IBM/ELDIM Viewing Angle Measurements of T221 LCDs

Measurement	NIDL/SS220	IBM/Eldim	IBM/Eldim	IBM/Eldim	IBM/Eldim
LCD Serial No.	108	108	108	345	345
Lmax	38.5	39.9	71.9	38.6	71.5
Lmin	0.1 fL	0.1 fL	0.2 fL	0.1 fL	0.2 fL
CR	385	318	321	315	320
Interpolation of viewing angles for 50%reduction in contrast ratio					
Horizontal Angle	Deg CR				
	40 172	40 145	40 148	40 136	40 138
Interpolated angle ->	36.6 192.5	37.3 159	37.7 160.5	35.6 157.5	35.8 160
	30 233	30 197	30 203	30 185	30 190
	-30 217	-30 187	-30 189	-30 164	-30 166
Interpolated angle ->	-34.0 192.5	-35.2 159	-35.2 160.5	-31.3 157.5	-31.2 160
	-40 156	-40 133	-40 134	-40 114	-40 115
Average angle	35.3	36.2	36.5	33.5	33.5
Vertical Angle	Deg CR				
	50 148	50 134	50 138	50 134	50 132
Interpolated angle ->	41.4 192.5	44.4 159	44.8 160.5	44.5 157.5	43.8 160
	40 200	40 179	40 181	40 177	40 177
	-40 209	-40 190	-40 192	-40 192	-40 191
Interpolated angle ->	-43.0 192.5	-46.5 159	-46.7 160.5	-47.2 157.5	-46.3 160
	-50 154	-50 142	-50 145	-50 144	-50 142
Average angle	42.2	45.5	45.7	45.9	45.1
Interpolation of viewing angles for 50% reduction in Lmax					
Horizontal Angle	Deg Lmax				
	50 13.35	50 15.5	50 28.8	50 15.8	50 28.95
Interpolated angle ->	40.1 19.25	42.4 19.95	43.1 35.95	43.9 19.3	43.8 35.75
	40 19.32	40 21.34	40 39.14	40 21.56	40 39.87
	-40 20.74	-40 24.46	-40 43.78	-40 22.7	-40 42.08
Interpolated angle ->	-42.3 19.25	-46.8 19.95	-46.8 35.95	-45.5 19.3	-45.4 35.75
	-50 14.36	-50 17.85	-50 32.3	-50 16.5	-50 30.3
Average angle	41.2	44.6	45.0	44.7	44.6
Vertical Angle	Deg Lmax				
	50 15.61	50 17.09	50 31.64	50 16.29	50 30.16
Interpolated angle ->	43.9 19.25	45.6 19.95	46.3 35.95	45.3 19.3	45.2 35.75
	40 21.54	40 23.63	40 43.2	40 22.63	40 41.86
	-40 23.1	-40 24.86	-40 45.18	-40 24.34	-40 44.64
Interpolated angle ->	-46.3 19.25	-47.6 19.95	-47.9 35.95	-47.7 19.3	-47.5 35.75
	-50 16.99	-50 18.39	-50 33.53	-50 17.83	-50 32.72
Average angle	45.1	46.6	47.1	46.5	46.3
Chromaticity Shift with Viewing Angle					
White level 255	Delta u'v'				
Viewed 45 degrees from left	0.011	0.011	0.011	0.012	0.012
Viewed 45 degrees from right	0.012	0.012	0.012	0.01	0.01
Viewed 45 degrees from above	0.006	0.003	0.003	0.003	0.003
Viewed 45 degrees from below	0.004	0.004	0.005	0.006	0.006
Black level 0	Delta u'v'				
Viewed 45 degrees from left	0.018	0.025	0.026	0.027	0.027
Viewed 45 degrees from right	0.018	0.025	0.027	0.024	0.024
Viewed 45 degrees from above	0.006	0.012	0.012	0.013	0.013
Viewed 45 degrees from below	0.008	0.012	0.012	0.012	0.012

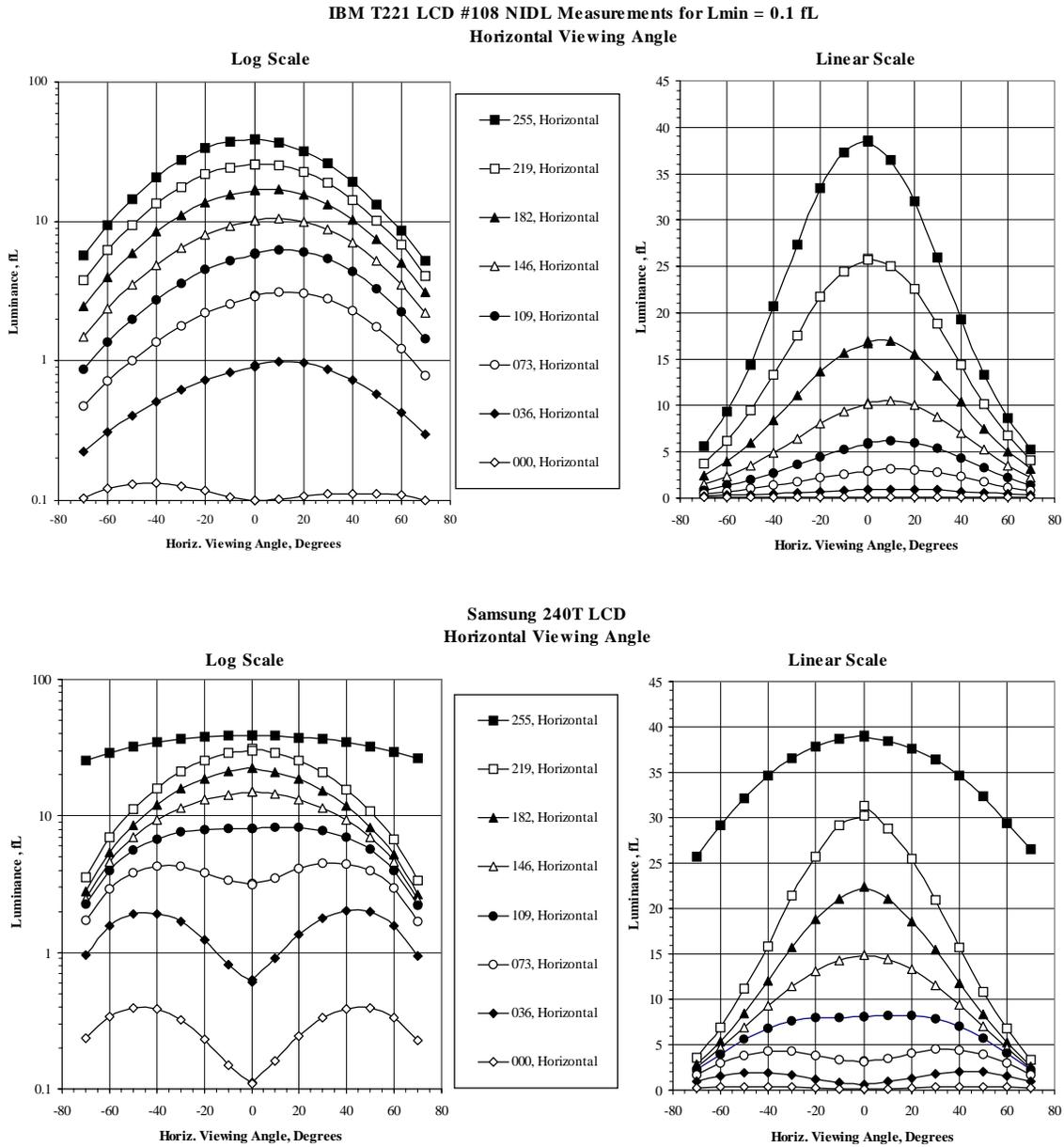


Figure II.24-2a. Horizontal Viewing Angle for 8 gray levels measured by NIDL using a Microvision goniometric spectrometer for the IBM T221 #108 LCD compared to the Samsung 240T LCD monitor for Lmin set to 0.1 fL. For both the IBM T221 and Samsung 240T LCDs, the data shows a 50% drop in luminance when viewed 45 degrees from the perpendicular. The 50% drop in luminance occurs at level 255 for the IBM LCD, and occurs for level 219 for the Samsung 240T LCD.

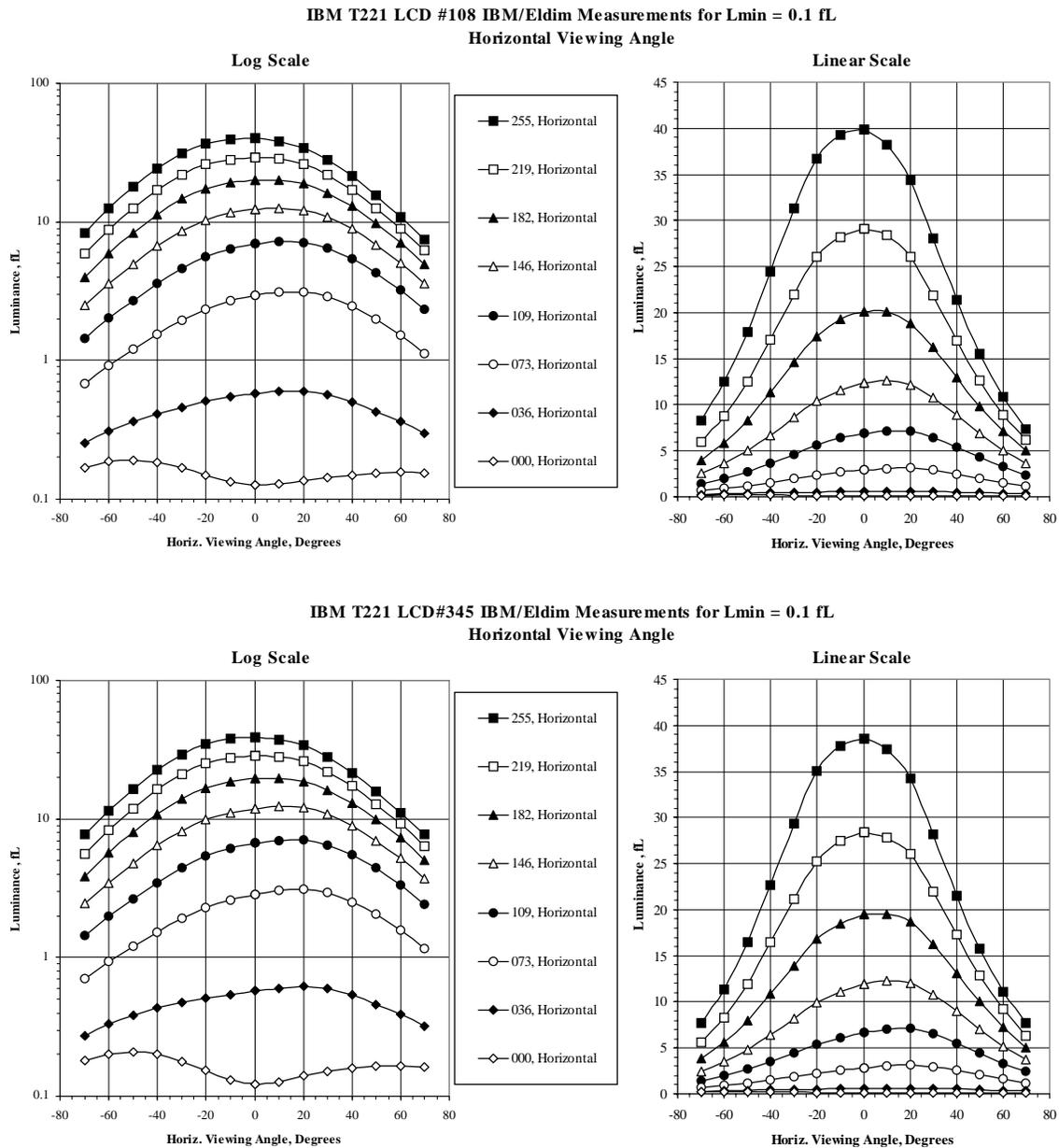


Figure II.24-2b. Horizontal Viewing Angle for 8 gray levels measured by IBM using an ELDIM conoscopic spectrometer for the IBM T221 #108 LCD compared to the IBM T221 #345 LCD monitor for Lmin set to 0.1 fL. For both the IBM T221 LCDs, the data shows a 50% drop in luminance when viewed 45 degrees from the perpendicular. The 50% drop in luminance occurs at level 255.

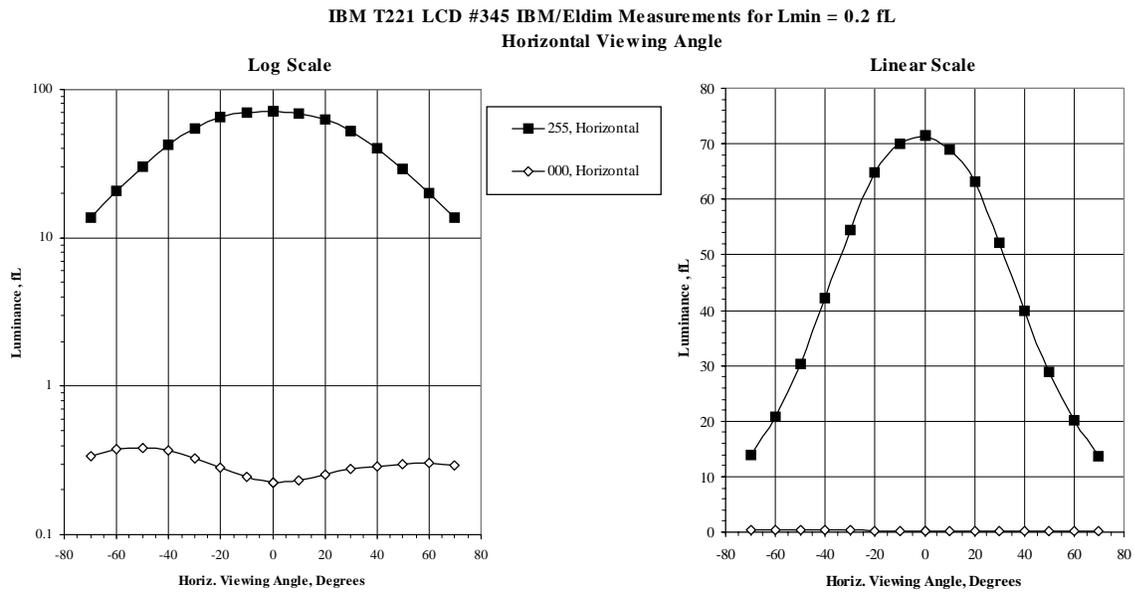
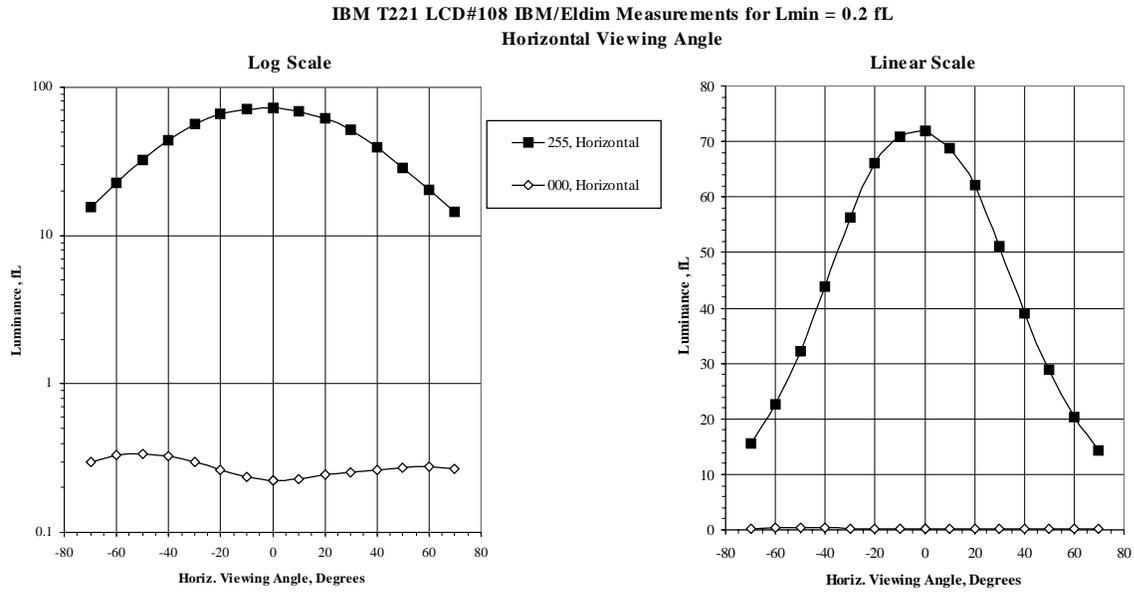


Figure II.24-2c. Horizontal Viewing Angle for Lmax (level 255) and Lmin (level 0) measured by IBM using an ELDIM conoscopic spectrometer for the IBM T221 #108 LCD compared to the IBM T221 #345 LCD monitor for Lmin set to 0.2 fL. For both the IBM T221 LCDs, the data shows a 50% drop in luminance when viewed 45 degrees from the perpendicular. The 50% drop in luminance occurs at level 255.

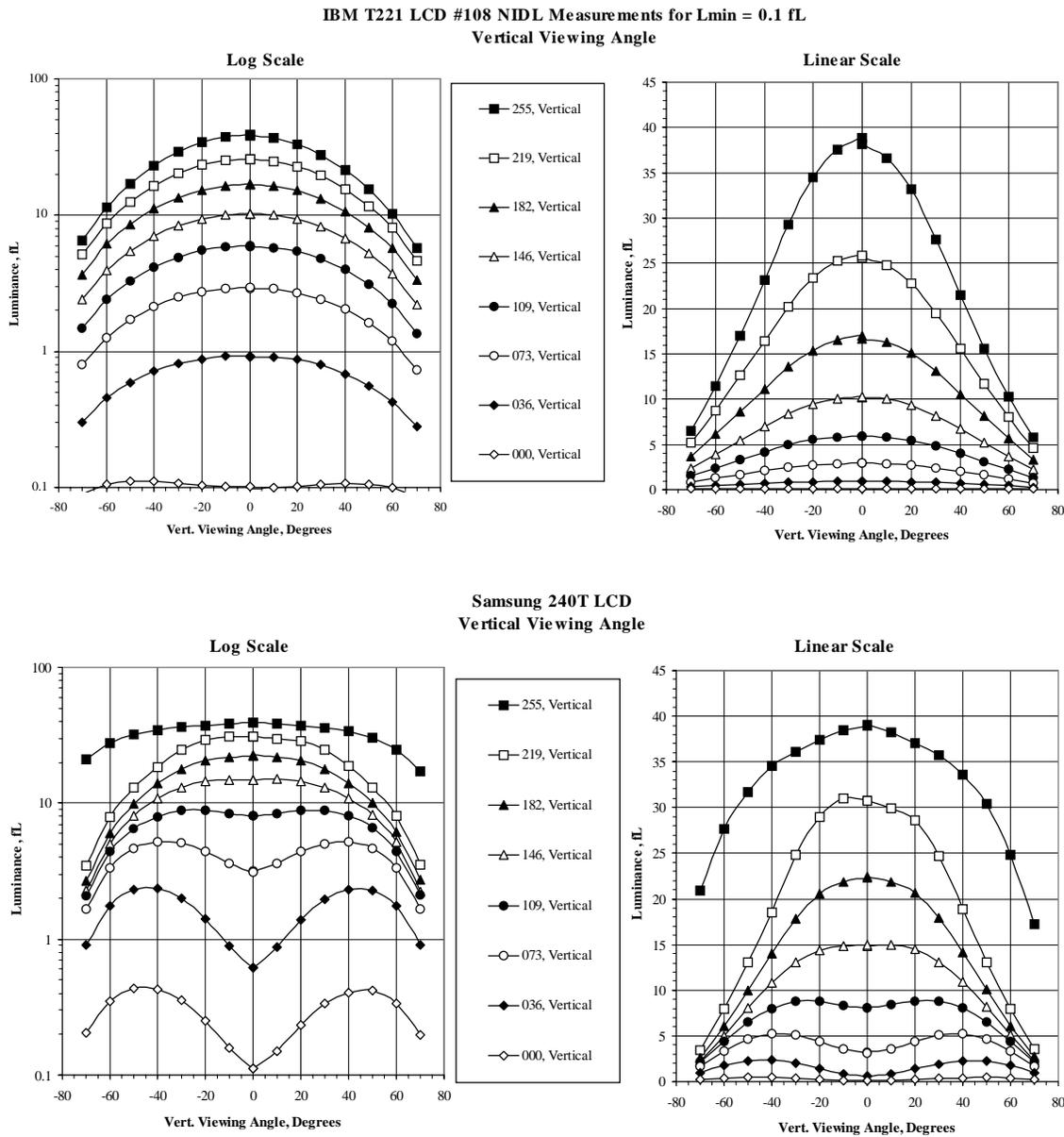


Figure II.24-3a. Vertical Viewing Angle for 8 gray levels measured by NIDL using a Microvision goniometric spectrometer for the IBM T221 #108 LCD compared to the Samsung 240T LCD monitor for Lmin set to 0.1 fL. For both the IBM T221 and Samsung 240T LCDs, the data shows a 50% drop in luminance when viewed 45 degrees from the perpendicular. The 50% drop in luminance occurs at level 255 for the IBM LCD, and occurs for level 219 for the Samsung 240T LCD.

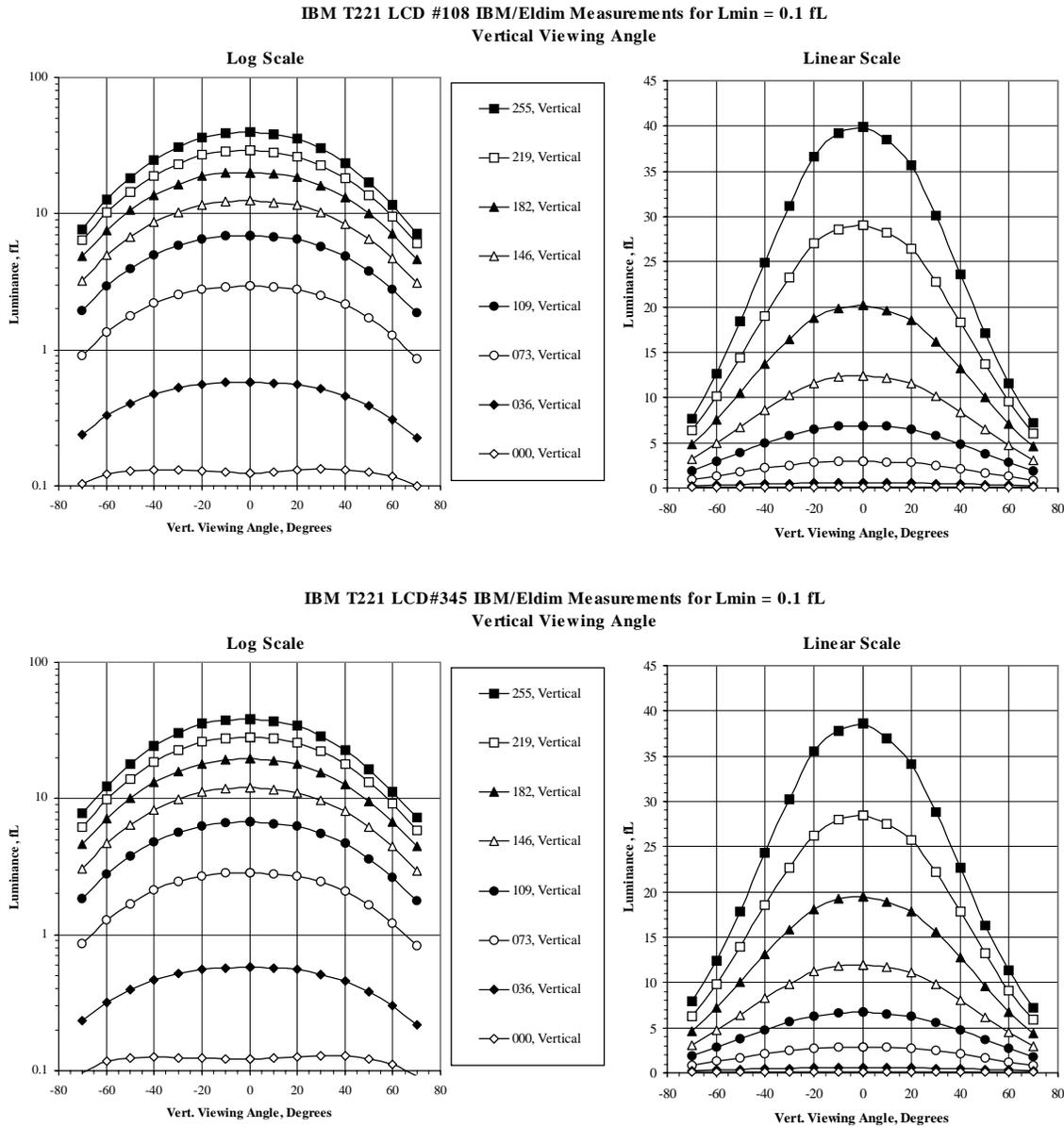


Figure II.24-3b. Vertical Viewing Angle for 8 gray levels measured by IBM using an ELDIM conoscopic spectrometer for the IBM T221 #108 LCD compared to the IBM T221 #345 LCD monitor for Lmin set to 0.1 fL. For both the IBM T221 LCDs, the data shows a 50% drop in luminance when viewed 45 degrees from the perpendicular. The 50% drop in luminance occurs at level 255.

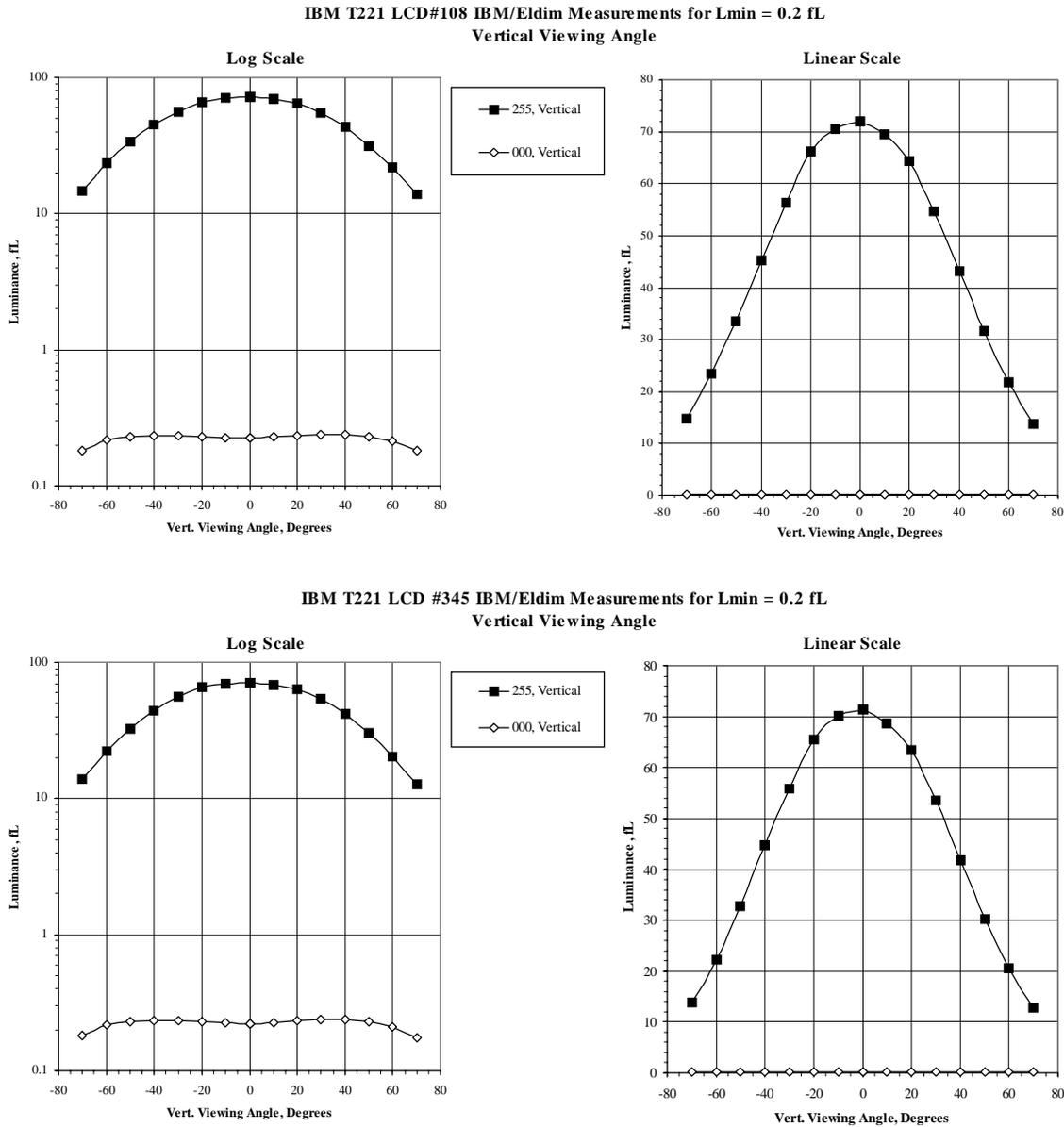


Figure II.24-3c. Vertical Viewing Angle for Lmax (level 255) and Lmin (level 0) measured by IBM using an ELDIM conoscopic spectrometer for the IBM T221 #108 LCD compared to the IBM T221 #345 LCD monitor for Lmin set to 0.2 fL. For both the IBM T221 LCDs, the data shows a 50% drop in luminance when viewed 45 degrees from the perpendicular. The 50% drop in luminance occurs at level 255.

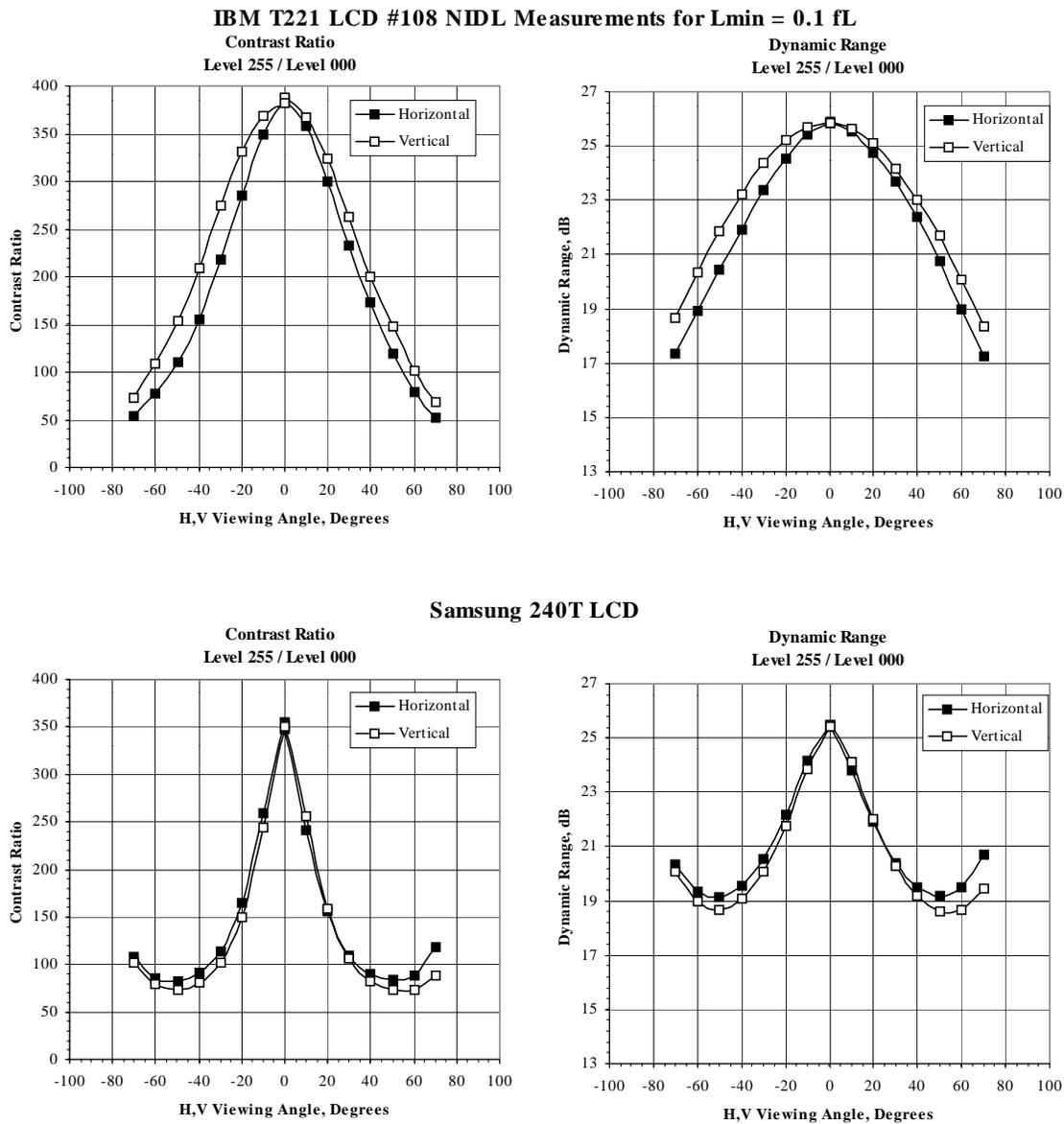


Figure II.24-4a. Vertical and Horizontal Viewing Angle for Contrast Ratio and Dynamic Range measured by NIDL using a Microvision goniometric spectrometer for the IBM T221 #108 LCD compared to the Samsung 240T LCD monitor for Lmin set to 0.1 fL. Contrast ratio is Lmax/Lmin, and dynamic range is 10 log (Lmax/Lmin), where Lmax is white level 255 and Lmin is black level 0. For the IBM T221 LCD, the data shows a 50% drop in contrast ratio when viewed 45 degrees horizontally from the perpendicular, and when viewed 35 degrees vertically from the perpendicular. The Samsung 240T LCD exhibits a reduced viewing angle range compared to the IBM T221. The Samsung 240T data shows a 50% drop in contrast ratio when viewed 20 degrees horizontally or vertically from the perpendicular.

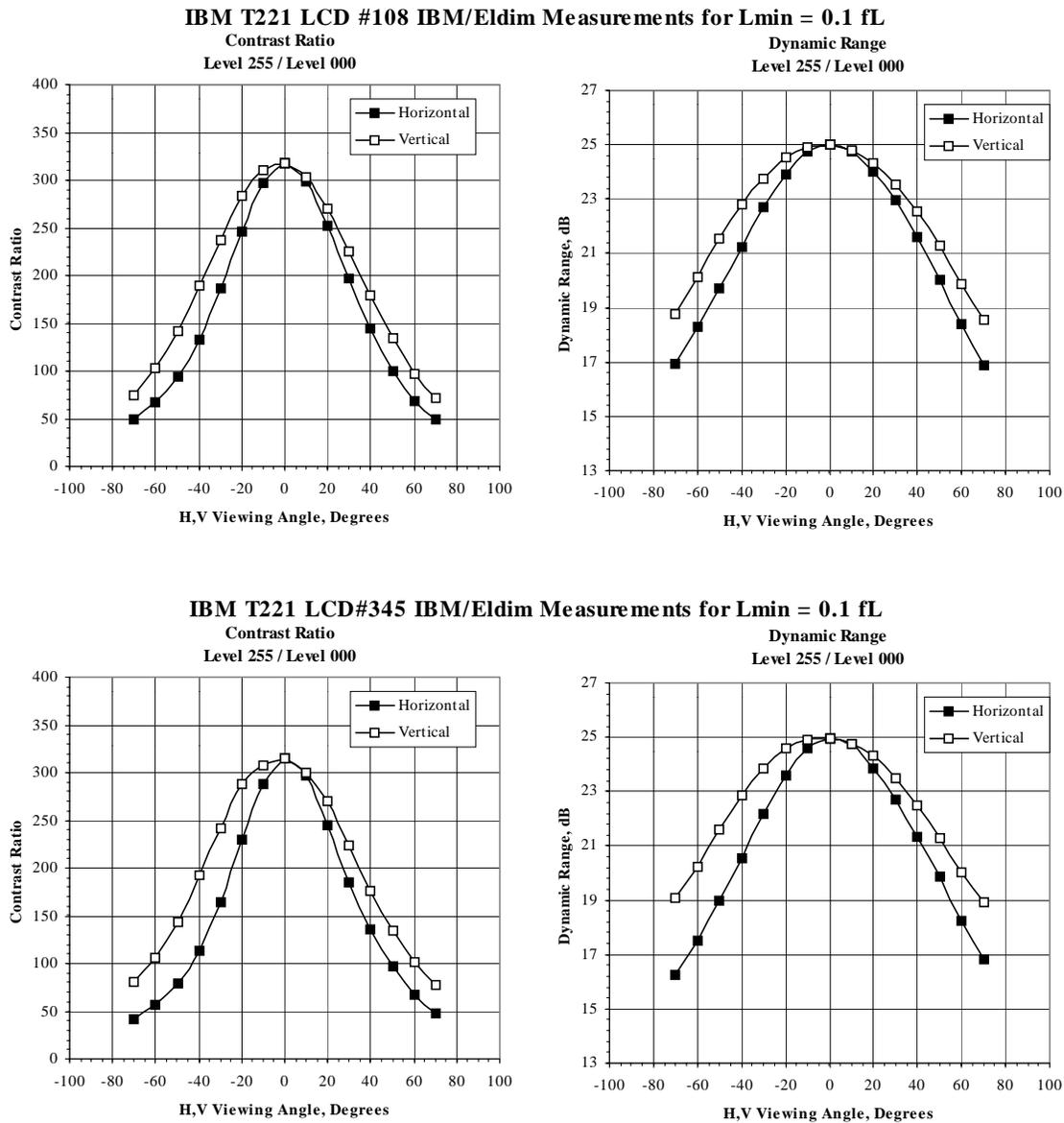


Figure II.24-4b. Vertical and Horizontal Viewing Angle for Contrast Ratio and Dynamic Range measured by IBM using an ELDIM conoscopic spectrometer for the IBM T221 #108 LCD compared to the IBM T221 #345 LCD monitor for Lmin set to 0.1 fL. Contrast ratio is Lmax/Lmin, and dynamic range is 10 log (Lmax/Lmin), where Lmax is white level 255 and Lmin is black level 0. For both the IBM T221 LCDs, the data shows a 50% drop in contrast ratio when viewed 45 degrees horizontally from the perpendicular, and when viewed 35 degrees vertically from the perpendicular.

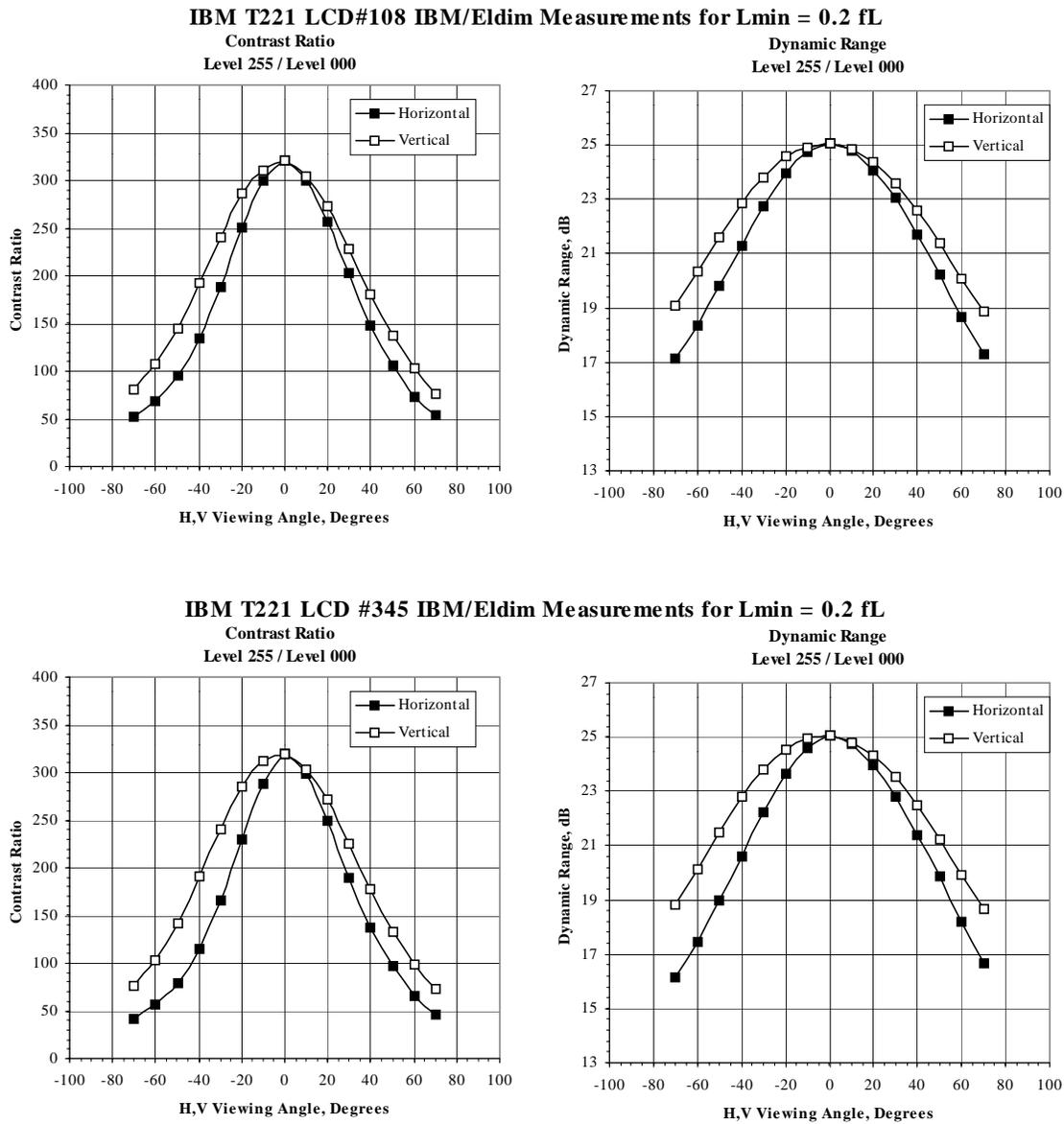


Figure II.24-4c. Vertical and Horizontal Viewing Angle for Contrast Ratio and Dynamic Range measured by IBM using an ELDIM conoscopic spectrometer for the IBM T221 #108 LCD compared to the IBM T221 #345 LCD monitor for Lmin set to 0.2 fL. Contrast ratio is Lmax/Lmin, and dynamic range is 10 log (Lmax/Lmin), where Lmax is white level 255 and Lmin is black level 0. For both the IBM T221 LCDs, the data shows a 50% drop in contrast ratio when viewed 45 degrees horizontally from the perpendicular, and when viewed 35 degrees vertically from the perpendicular.

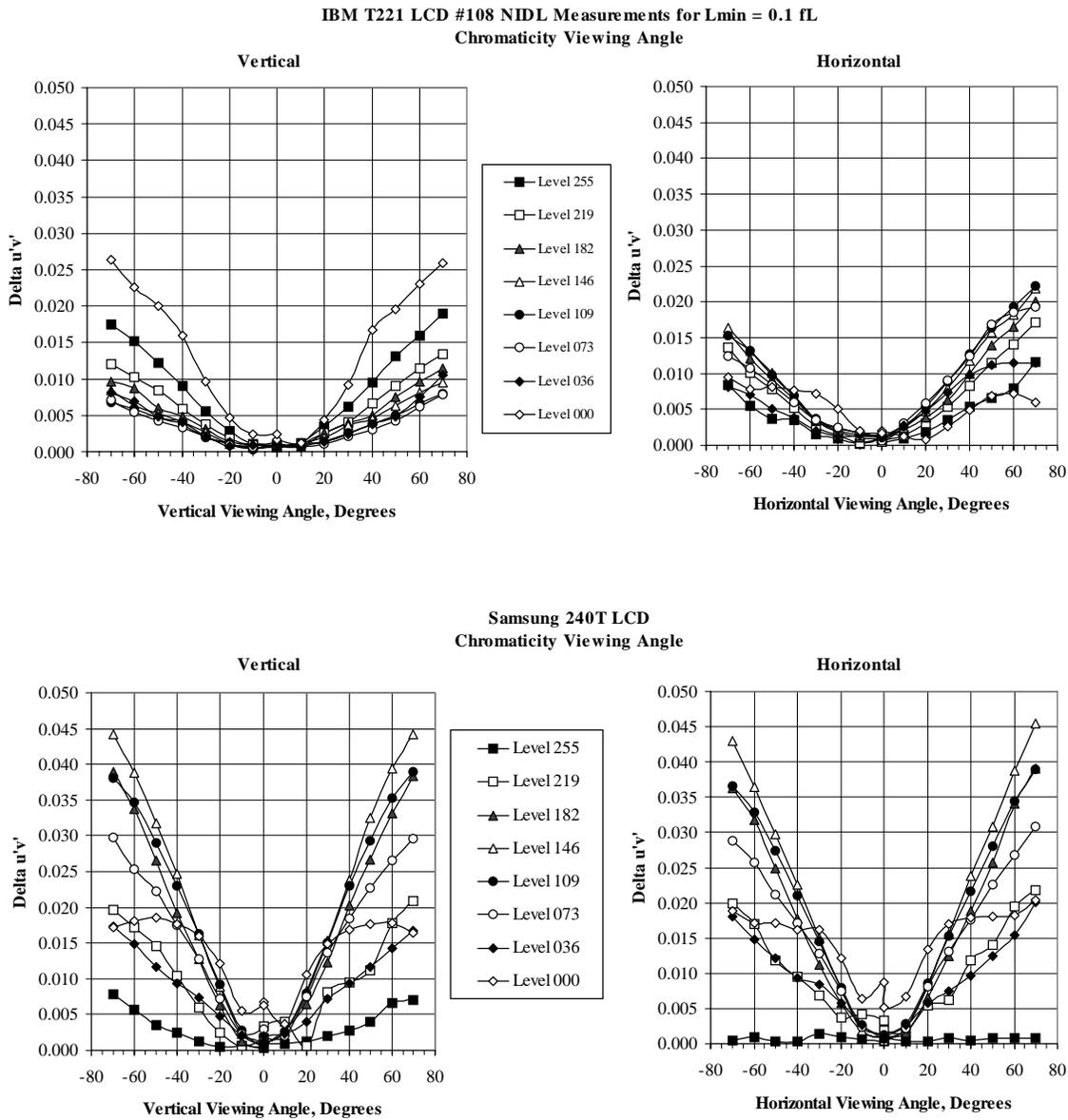


Figure II.24-5a Vertical and Horizontal Viewing Angle for Chromaticity of 8 gray levels measured by NIDL using a Microvision goniometric spectrometer for the IBM T221 #108 LCD compared to the Samsung 240T LCD monitor for Lmin set to 0.1 fL.

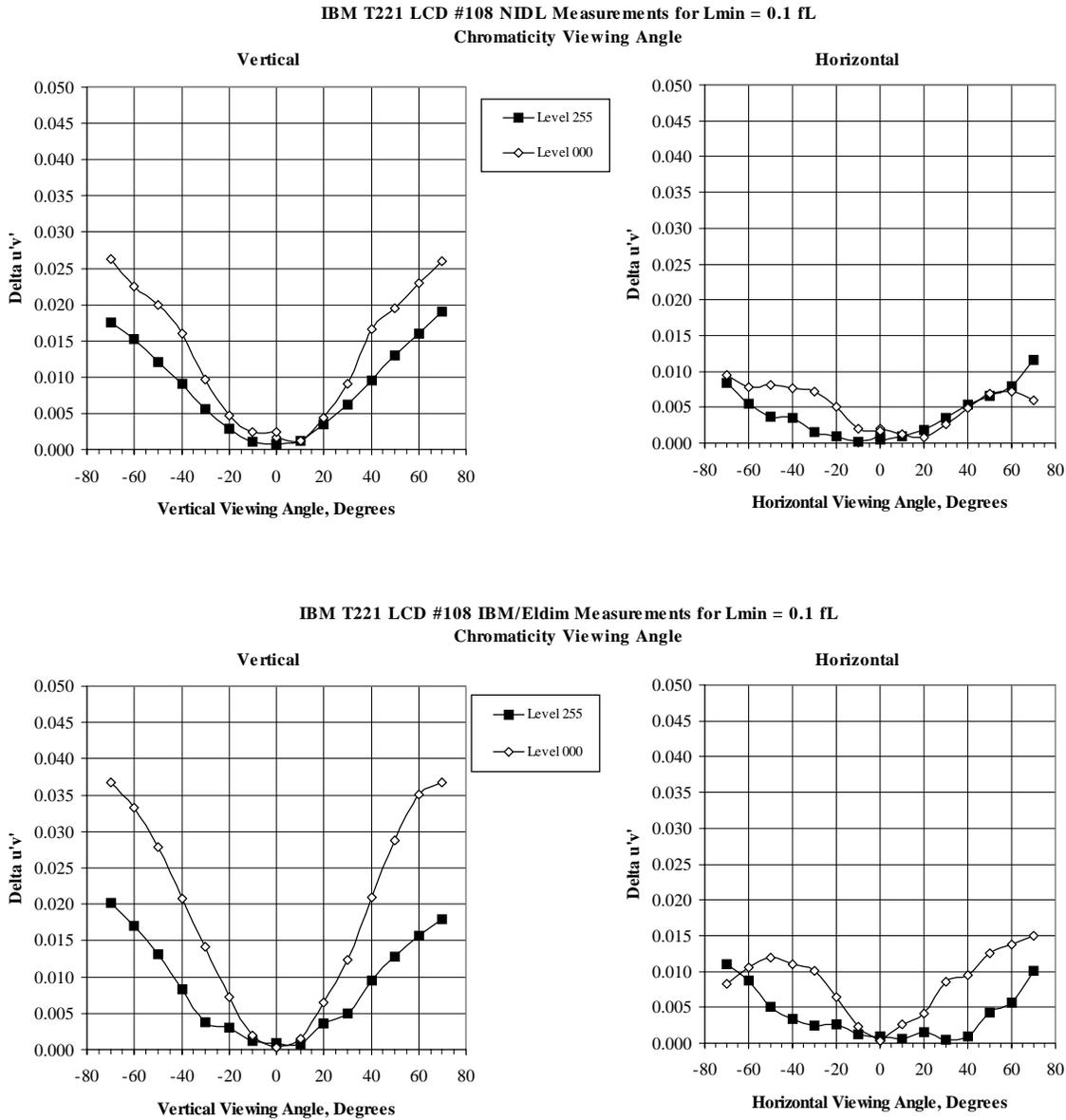


Figure II.24-5b Vertical and Horizontal Viewing Angle for Chromaticity of Lmax (white level 255) and Lmin (black level 0) measured by NIDL using a Microvision goniometric spectrometer, and measured by IBM using an ELDIM conoscopic spectrometer for the IBM T221 #108 LCD monitor for Lmin set to 0.1 fL.

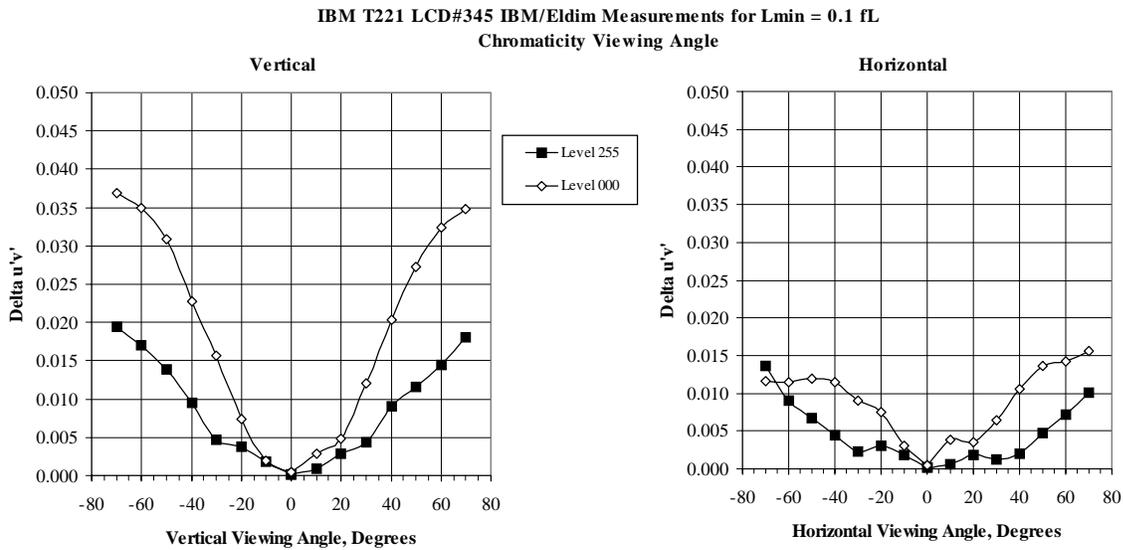


Figure II.24-5c Vertical and Horizontal Viewing Angle for Chromaticity of Lmax (white level 255) and Lmin (black level 0) measured by IBM using an ELDIM conoscopic spectrometer for the IBM T221 #345 LCD monitor for Lmin set to 0.1 fL.

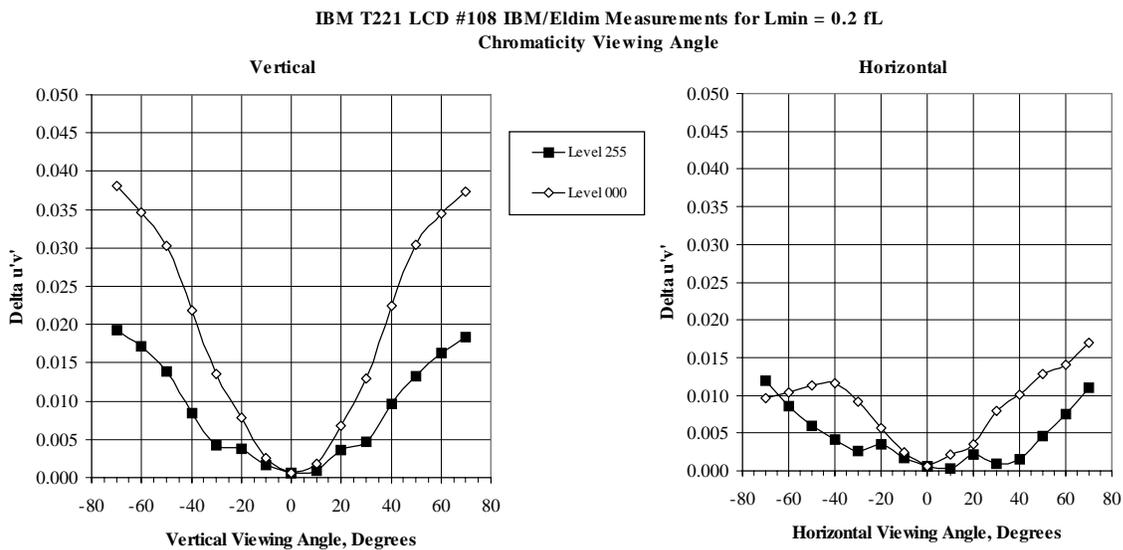


Figure II.24-5d Vertical and Horizontal Viewing Angle for Chromaticity of Lmax (white level 255) and Lmin (black level 0) measured by IBM using an ELDIM conoscopic spectrometer for the IBM T221 #108 LCD monitor for Lmin set to 0.2 fL.

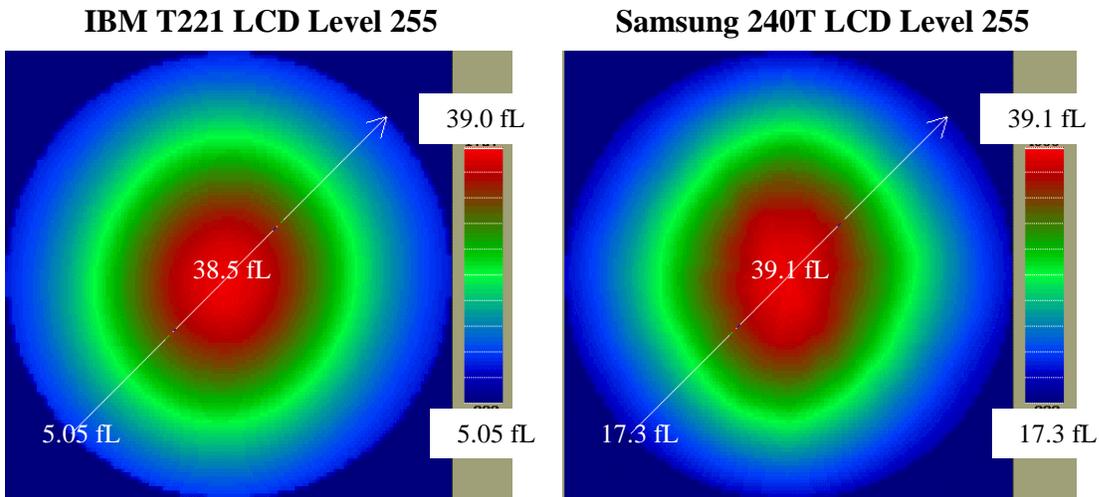


Figure II.24-6. Viewing Cone Luminance of Lmax (level 255). The center of the plot is perpendicular to the screen. The edge of the circle is 70 degrees off perpendicular.

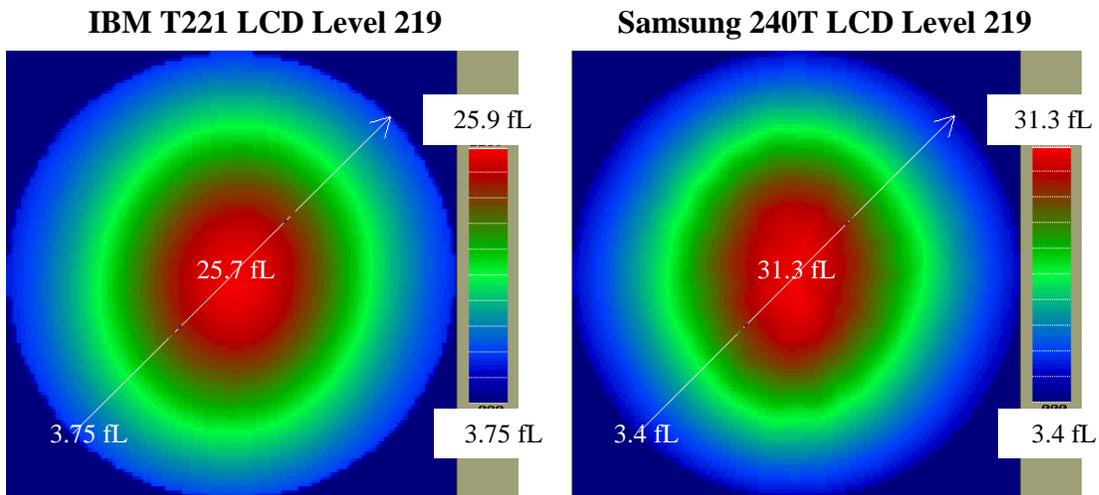


Figure II.24-7. Viewing Cone Luminance of gray level 219. The center of the plot is perpendicular to the screen. The edge of the circle is 70 degrees off perpendicular.

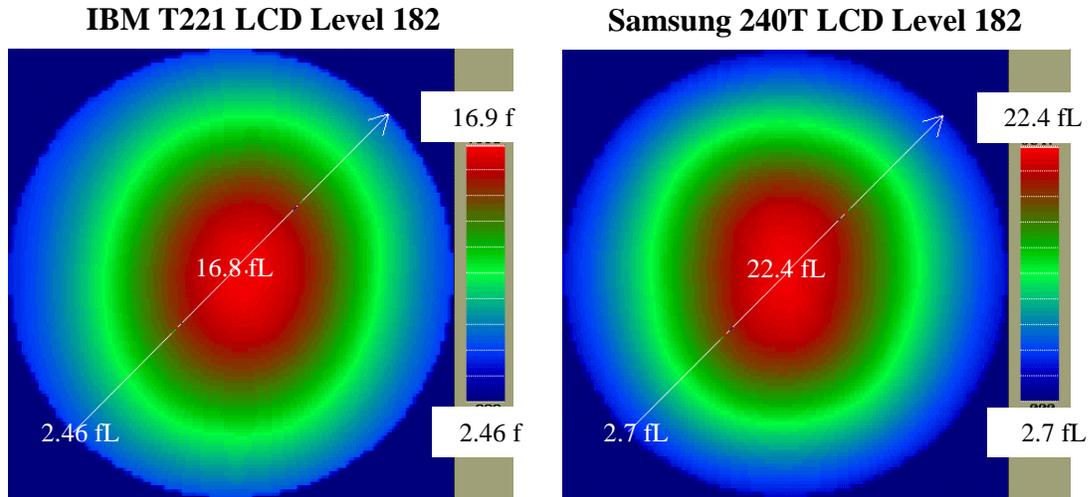


Figure II.24-8. Viewing Cone Luminance of gray level 182. The center of the plot is perpendicular to the screen. The edge of the circle is 70 degrees off perpendicular.

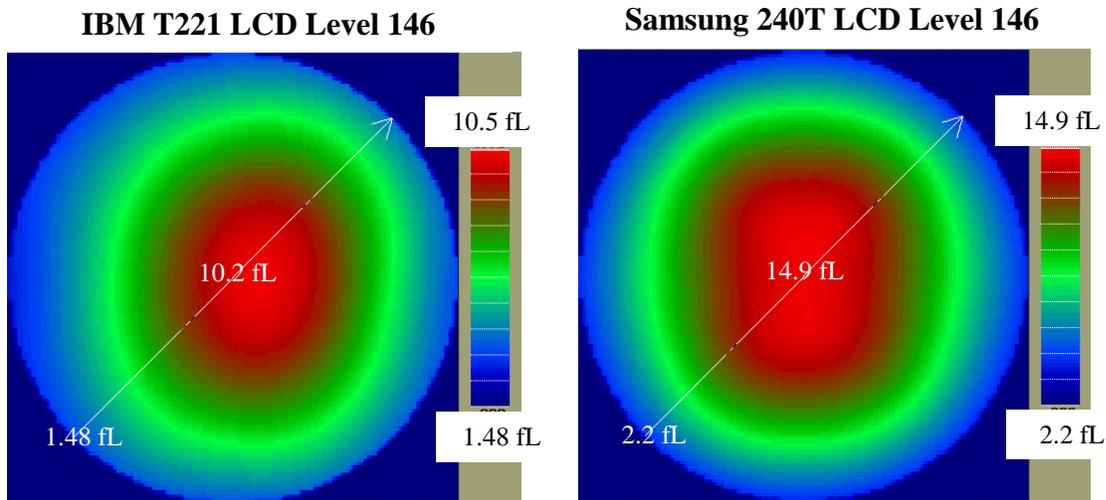


Figure II.24-9. Viewing Cone Luminance of gray level 146. The center of the plot is perpendicular to the screen. The edge of the circle is 70 degrees off perpendicular.

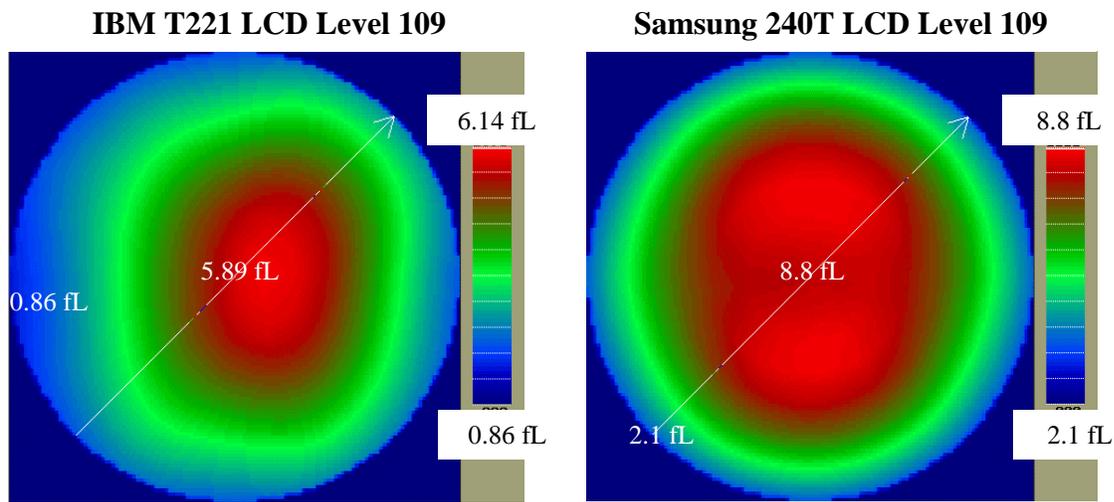


Figure II.24-10. Viewing Cone Luminance of gray level 109. The center of the plot is perpendicular to the screen. The edge of the circle is 70 degrees off perpendicular.

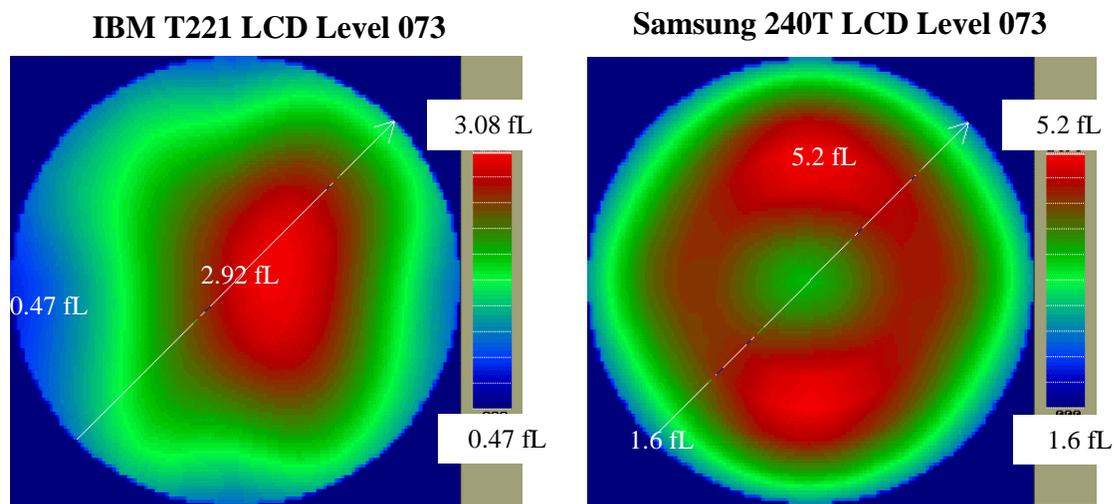


Figure II.24-11. Viewing Cone Luminance of gray level 073. The center of the plot is perpendicular to the screen. The edge of the circle is 70 degrees off perpendicular.

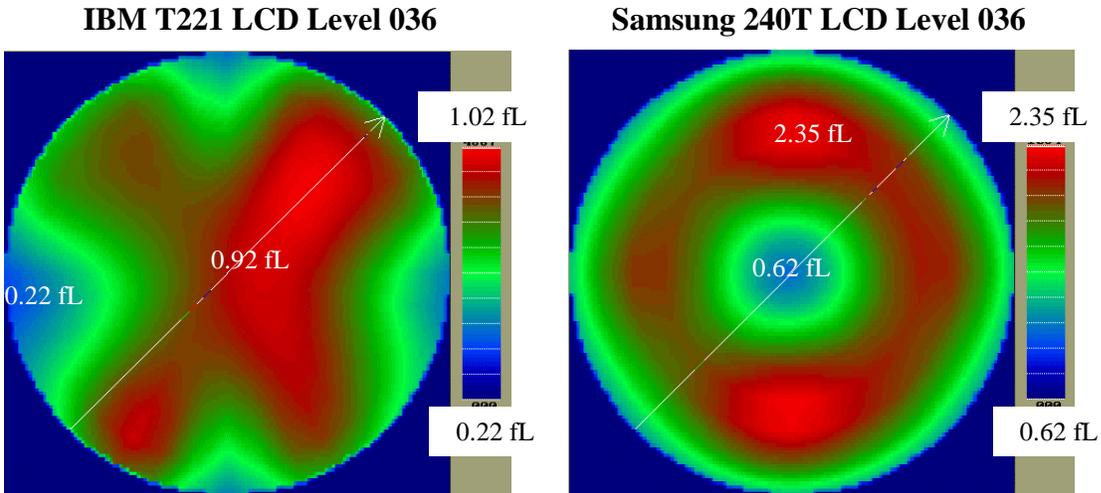


Figure II.24-12. Viewing Cone Luminance of gray level 036. The center of the plot is perpendicular to the screen. The edge of the circle is 70 degrees off perpendicular.

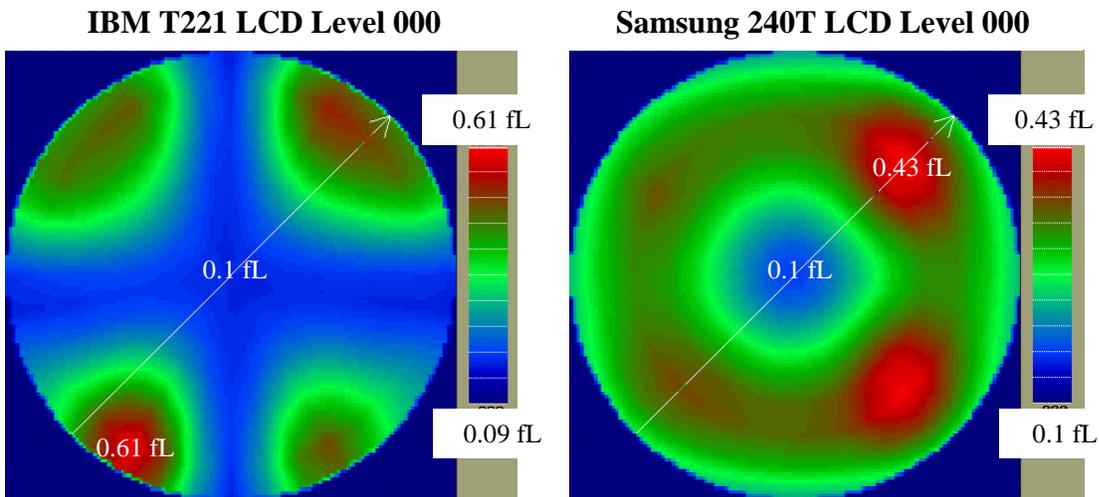


Figure II.24-13. Viewing Cone Luminance of Lmin (level 000). The center of the plot is perpendicular to the screen. The edge of the circle is 70 degrees off perpendicular.

IBM /ELDIM Measurement of contrast ratio for IBM T221 #108 LCD Monitor

Lmax == 40fL, Lmin = 0.1 fL

Lmax == 75 fL, Lmin = 0.2 fL

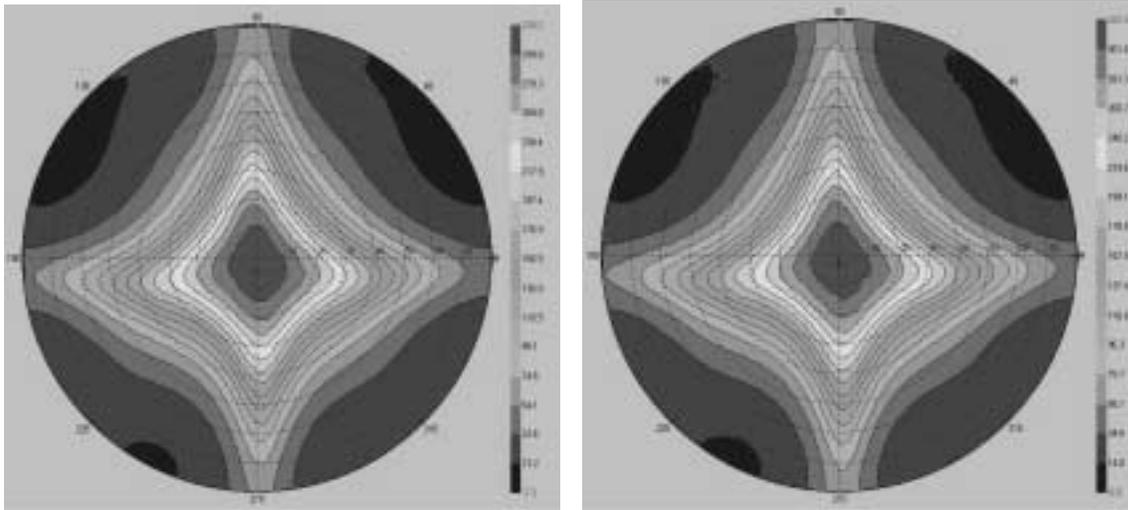


Figure II.24-14c. Viewing Cone Luminance of contrast ratio measured by IBM using an ELDIM conoscopic spectrometer. The center of the plot is perpendicular to the screen. The edge of the circle is 80 degrees off perpendicular.

IBM /ELDIM Measurement of contrast ratio for IBM T221 #345 LCD Monitor

Lmax == 40fL, Lmin = 0.1 fL

Lmax == 75 fL, Lmin = 0.2 fL

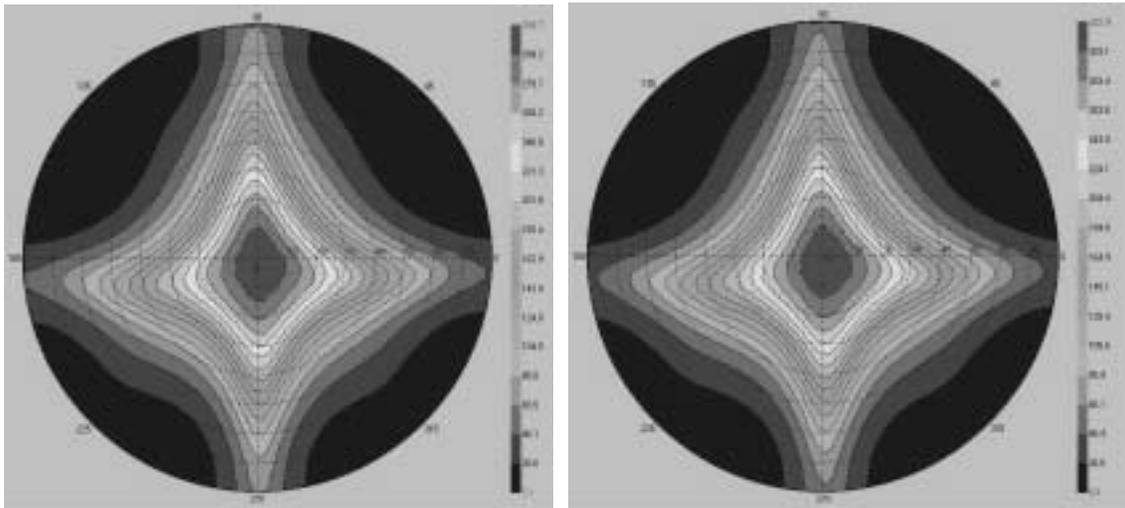


Figure II.24-14d. Viewing Cone Luminance of contrast ratio measured by IBM using an ELDIM conoscopic spectrometer. The center of the plot is perpendicular to the screen. The edge of the circle is 80 degrees off perpendicular.

II.25. Color Gamut

Reference: VESA FPDM Version 2.0, Section 302-4A, p. 47.

The area bounded by CIE 1976 u'v' color coordinates of R, G, and B primaries of the IBM T221 LCD monitor is 22% and, for the Samsung 240T, is 19% of the total area bounded by the spectrum locus from 380 nm to 700 nm. These values compare to 27% for a CRT monitor.

The area bounded by CIE 1976 u'v' color coordinates of R, G, and B primaries is measured and compared to the total area accessible to the display. The total area accessible to the display is define to be equal to a value of 0.1952 and is equal to the area inside the spectrum locus from 380 nm to 700 nm evaluated at 1 nm intervals. After multiplying by 100%, the gamut area of the display is computed as:

$$\text{Gamut Area} = 256.1 [(u'_r - u'_b)(v'_g - v'_b) - (u'_g - u'_b)(v'_r - v'_b)]$$

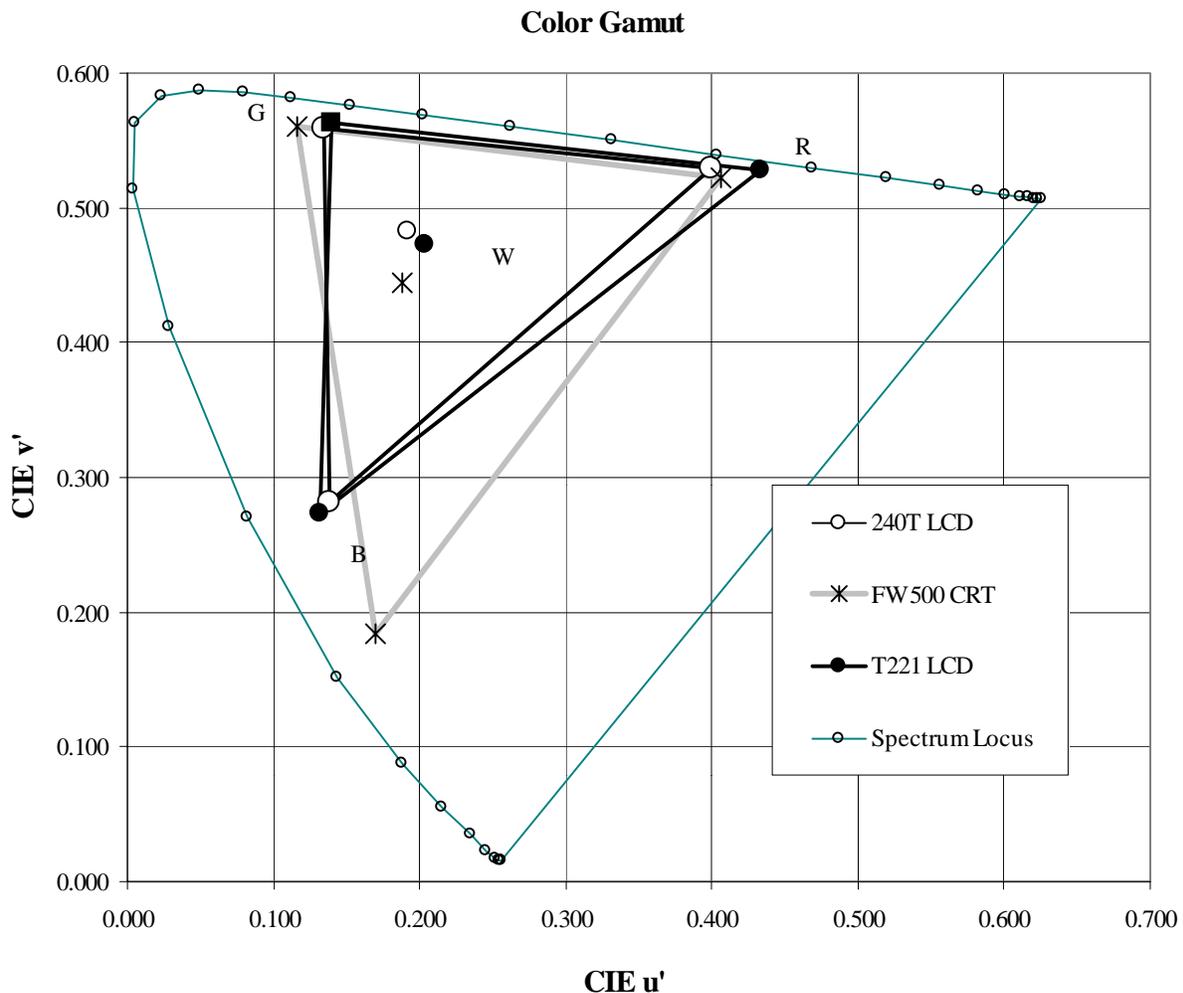


Figure II.25.1. CIE chromaticity coordinates and color gamut of the IBM T221 LCD monitor compared to the Samsung 240T LCD monitor and the Sony FW500 color CRT monitor.

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Table II.25.1. CIE chromaticity coordinates and color gamut area of the IBM T221 LCD monitor compared to the Samsung 240T LCD monitor and to a CRT monitor.

IBM T221 LCD monitor						
	x	y	u'	v'	fL	CCT
White	0.3234	0.3334	0.204	0.472	36.34	5929
Red	0.6328	0.342	0.434	0.527	8.648	
Green	0.3276	0.5874	0.139	0.563	23.61	
Blue	0.1407	0.13	0.132	0.273	4.215	
Gamut Area	22% of total area from 380 nm to 700 nm.					
Samsung 240T LCD monitor						
	x	y	u'	v'	fL	CCT
White	0.318	0.355	0.192	0.482	39.4	6090
Red	0.607	0.358	0.399	0.530	9.17	
Green	0.314	0.579	0.135	0.559	24.2	
Blue	0.15	0.135	0.139	0.281	5.9	
Gamut Area	19% of total area from 380 nm to 700 nm.					
Sony FW900 CRT monitor						
	x	y	u'	v'	fL	CCT
White	0.31	0.348	0.189	0.478	31.4	9652
Red	0.602	0.344	0.406	0.523	7.77	
Green	0.28	0.599	0.116	0.560	22.3	
Blue	0.152	0.073	0.170	0.184	3.87	
Gamut Area	27% of total area from 380 nm to 700 nm.					

II.26. LCD Dynamic Response Time

Reference: VESA FPDm Version 2.0, Section 305-1, June 2001, pp 102-104.

Based on measurements, the IBM T221 LCD monitor luminance rise times average 22 ms and fall times average 25 ms, somewhat slower than the Samsung 240T LCD monitor when switching between white and black states. These response times prohibit the LCD for use in sequential stereoscopic mode as used with the 21-inch StereoGraphics ZScreen at 120 Hz (60 Hz per eye).

Objective: Measure the time required for the display to switch between luminance levels. The response time determines whether a display may be suitable for roaming in monoscopic mode or stereoscopic mode operation.

- Equipment:**
- Video signal generator or PC with graphics card
 - Storage oscilloscope
 - Photometer with fast response

Procedure: Blinking white targets on black backgrounds were measured. Targets and backgrounds of other gray levels may optionally be measured. Blink rate was approximately 2 seconds ON, 2 seconds OFF. Targets included a small square box (4 mm x 4 mm), a horizontal line segment (4 mm in length), and a vertical line segment (4 mm in length).

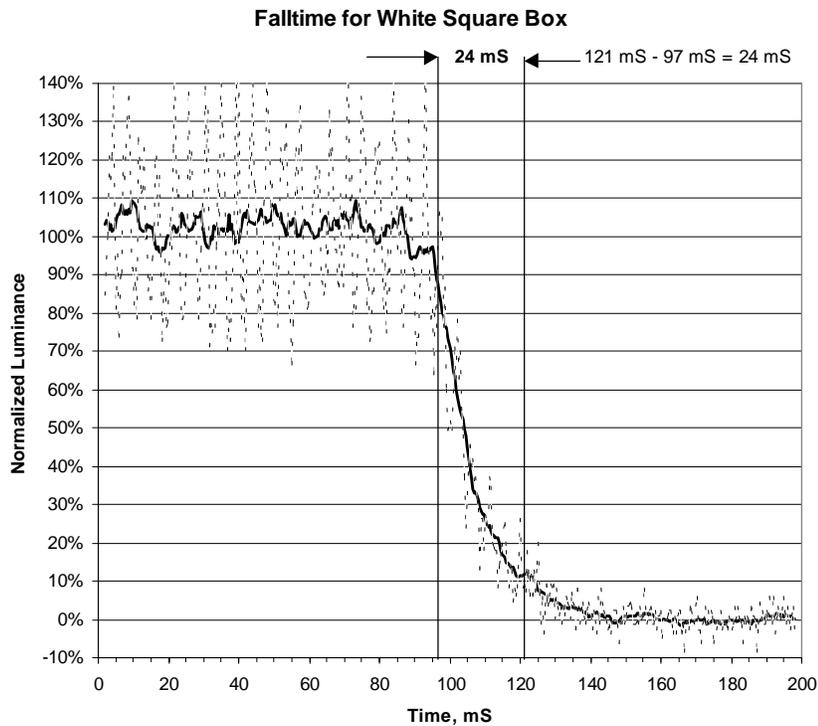
Data: The results are summarized in Table II.26-1. Luminance response characteristics are plotted in Figures II.26-1 and II.26-2.

Table II.26-1. Results of the measured 10% to 90% rise and fall times of blinking cursor boxes and lines (White on black)

Test Pattern	IBM T221 LCD Digital Addressing		Samsung 240T LCD			
	Rise Time (ms)	Fall Time (ms)	Analog Addressing		Digital Addressing	
			Rise Time (ms)	Fall Time (ms)	Rise Time (ms)	Fall Time (ms)
White Square	23	24	14	17	13	19
White Horizontal Line	21	25	15	18	13	17
White Vertical Line	22	25	32	18	12	18
Average	22	25	20	18	13	18



Figures II.26-1 Luminance rise time response characteristic for a black (Lmin) to white (Lmax) transition.



Figures II.26-2. Luminance fall time response characteristic for a white (Lmax) to black (Lmin) transition.

II.27. Image Roam

Reference: None.

The smoothest roam appeared to be with the T221 LCD and a Radeon 8500 single-DVI graphics card having 64 MB memory. In 3840 x 2400 x 13 Hz mode, the image was torn and motion was jerky even at the slowest roam rate. At 1920 x 1200 x 41 Hz mode, roam rates between 100 to 300 pixels per second were smooth and acceptable depending on the amount of smearing that one chooses to tolerate. Here we see that single DVI digital addressing performs remarkably well even compared to quad DVI driving of the 9-megapixel LCD.

NIDL sought to improve upon the roam operation we observed with the IBM 9 megapixel LCD monitor and its Matrox graphics card. We consulted the staff (Mr. Steven Wright and Dr. Steve Millman) at the IBM Watson Research Center to: select the best-available graphics card; adjust the electronic EDID files within the LCD monitor to display 3840 x 2400 x 13 Hz, 1920 x 1200 x 41 Hz, and 1280 x 1024 x 60Hz modes needed for the Radeon 8500 graphics card; and program the T221 to be able to toggle between 3840 x 2400 and 1920 x 1200 pixel addressability. NIDL had found earlier that the Briggs target measurements are 50% higher for the 1920 x 1200 pixel addressability so we wanted to have the lower addressability available to demonstrate roam on a large image of the Washington, DC area. At the IBM Watson Research Center, the T221 LCD purchased by NIDL was tested with NIDL's Matrox G200 MMS quad-DVI graphics card and an economy-version PC RemoteView software. All roam tests were done for a full screen PC RemoteView window. Roaming through the Briggs test target using the Matrox card in 3840 x 2400 native mode produced severe tearing in the image. It was observed that faster roam could be achieved without image tearing by reducing the RemoteView window size (number of pixels addressed), but reducing the window size does not eliminate smearing. The reduced mode of 1920 x 1200 pixels could not be tested because it had not been pre-programmed into the Matrox driver by the manufacturer.

An ATI Fire GL4 graphics card substituted for the Matrox card allowed smooth roam in 1920 x 1200 addressability mode at up to 9 pixels per second. But in 3840 x 2400 mode, the roam motion was jerky even for the slowest roam rate of about 6 pixels per second.

A final combination tested with the T221 LCD was a Radeon 8500 single-DVI graphics card having 64 MB memory. In 3840 x 2400 x 13 Hz mode, the image was torn and motion was jerky even at the slowest roam rate. At 1920 x 1200 x 41 Hz mode, roam rates between 100 to 300 pixels per second were smooth and acceptable depending on the amount of smearing that one chooses to tolerate. Here we see that single DVI digital addressing performs remarkably well compared to the Matrox quad DVI driving the 9-megapixel LCD. The smearing may not be due to the graphics card, but rather may be caused by the response time of the LCD itself. The measured responses for rise and fall times are 22ms and 25 ms, respectively. For comparison, CRT response times are in the microseconds. We used the IBM T221 9 megapixel LCD with the Radeon graphics card for the NIMA Soft Copy Search Team visit on 3-26-02 to demonstrate roam at 3840 x 2400 and at 1920 x 1200 pixel addressability.

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