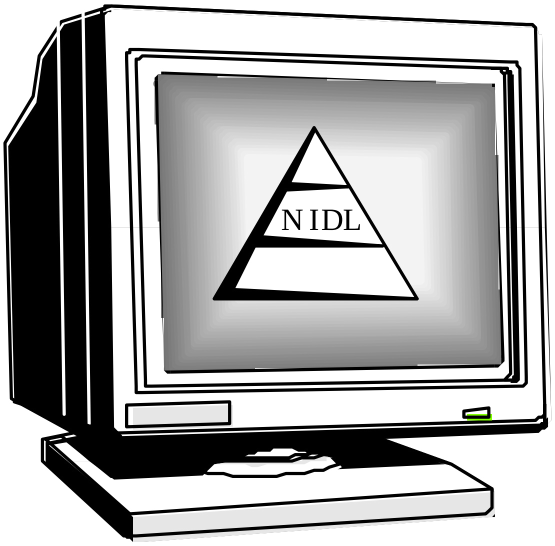

NIDL certifies the Mitsubishi 2040u color monitor as being suitable for IEC workstations. Its performance significantly exceeds the 2020u color CRT monitor it replaces. Importantly, it exceeds the IEC specification for contrast modulation by 100% in the monoscopic mode. Accordingly, NIDL rates this color monitor as “A” in the monoscopic mode. We rate it "C" in the stereoscopic mode for the Image Analyst and Cartographer applications, principally because its refresh rate of 55 Hz per eye does not meet the 60 Hz per eye IEC specification; otherwise it would have been a “B”. The Sun Creator 3D driver card in the IEC workstation is limited to about 55 Hz per eye so stereo performance may be acceptable. With the NuVision 21 inch shutter panel and passive eyewear similar to that used by the IEC workstation, we measure an extinction ratio of about 10.4 to 1. With Stereographic wireless CrystalEyes, the stereo extinction ratio at screen center measures 17.5 to 1 and exceeds the IEC specification determined with CrystalEyes of 15 to 1 for a color monitor.

Evaluation of the Mitsubishi 2040u 4 x 3 Aspect Ratio, 22-Inch Diagonal Color Monitor

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NIDL IEC Monitor Certification Report

The Mitsubishi 2040u Color CRT Monitor

FINAL GRADES
Monoscopic Mode: A
Stereoscopic Mode: C

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 certifies the Mitsubishi 2040u color monitor as being suitable for IEC workstations. Its performance significantly exceeds the 2020u color CRT monitor it replaces. Importantly, it exceeds the IEC specification for contrast modulation by 100% in the monoscopic mode. Accordingly, NIDL rates this color monitor as "A" in the monoscopic mode. We rate it "C" in the stereoscopic mode for the Image Analyst and Cartographer applications, principally because its refresh rate of 55 Hz per eye does not meet the 60 Hz per eye IEC specification; otherwise it would have been a "B". The Sun Creator 3D driver card in the IEC workstation is limited to about 55 Hz per eye so stereo performance may be acceptable. With the NuVision 21 inch shutter panel and passive eyewear similar to that used by the IEC workstation, we measure an extinction ratio of about 10.4 to 1. With Stereographic wireless CrystalEyes, the stereo extinction ratio at screen center measures 17.5 to 1 and exceeds the IEC specification determined with CrystalEyes of 15 to 1 for a color monitor.

The Mitsubishi 2040u is a versatile color monitor from the well-regarded Mitsubishi Diamond Pro series. NIMA has used successfully several of the earlier model Mitsubishi color monitors in its analyst workstations. The Diamond Pro features Mitsubishi's latest 22 inch diagonal (20 inch viewable image), 39.8% transmitting, Natural Flat Diamondtron CRT with a 0.24 mm uni-pitch aperture grill mask and new high efficiency phosphors, which develop a superior brightness. The reduced spot size from center to corner leads to enhanced corner-to-corner focus uniformity. The Natural Flat technology applies a polynomial curve to the internal phosphor screen surface to pre-distort the image and thereby optically compensate refraction of the light passing through the CRT face plate glass. The trend is to a flat external viewing surface to reduce external reflections and glare. Sony has also moved this way with their competing F500R color monitor. The Mitsubishi anti-reflection coating significantly reduces external reflections and glare. The cathode in the electron gun is a dispersed scandium oxide, sputtered tungsten coated cathode to increase brightness and life. The monitor will synchronize to a RGB analog signal in the auto scan range of 30 to 121 kHz horizontal and 50 to 160 Hz vertical. The maximum addressability is 2048 x 1536 pixels at 75 Hz non-interlaced, with a recommended addressability of 1600 x 1200 pixels at 85 Hz. The color temperature is fully adjustable from 5000 to 9950K giving the analyst or GI a choice of color warmth. The monitor is cross-platform compatible with IBM, Windows, UNIX, and Macintosh. It has a three year limited warranty, and weighs 68 pounds.

Mitsubishi was recently absorbed into the NEC fold. Its web address is now:
http://www.necmitsubishi.com/products/index.cfm

The Mitsubishi 2040u monitor has been reviewed favorably on several independent Internet sites, and was preferred to the Hitachi CM814U and the Sony F500R monitors based on quality and price. NIDL has also reviewed the performance of Sony and Hitachi competitors to the Mitsubishi 2040u monitor. In its tests, NIDL has certified the F500R 21 inch monitor and rated it B^- for monoscopic and C for stereo performance. We certified the Hitachi CM814U color monitor; our ratings are B for both monoscopic and stereoscopic performance. The estimated price for the Mitsubishi 2040u is $1050; NIDL's monitor was loaned to us for the duration of our tests, as is preferred by NIMA so we do not have a purchase price. The Sony F500R price is about $1800, and the Hitachi is $1200. Both are significantly to somewhat higher than for the Mitsubishi. NIDL also tested the Viewsonic P817 21 inch color CRT monitor and certified it with ratings of B in both the monoscopic and stereoscopic modes. The IEC Contractor has liked this monitor and incorporated it into a number of workstations. For some reason, which the manufacturer would not divulge, Viewsonic no longer carries the $1600 P817 in its catalog. A new monitor, the PF815, appears in its current highest performance lineup in addition to the older P815. NIDL plans to test the PF815, which is priced below $1000, in the near future. A comparison of a number of the IEC monitor specifications for the Viewsonic P817, preferred by the IEC Contractor but no longer available, and the Mitsubishi 2040u is given below. Here, the greater uniformity and significantly higher Cm in Zone A for the Mitsubishi push its monoscopic ranking above the Viewsonic. The stereoscopic performance with a Creator 3D card should be similar. It should be noted that the IEC specification of 15 to 1 was based on the use of the IR wireless CrystalEyes shutter glasses.

Monoscopic Mode	**IEC Requirement**	**Viewsonic P817**	**Mitsubishi 2040u**
Luminance (Lmax)	30 fL	32.8 fL	34 fL
Uniformity (Lmax)	20%	17.8%	12.4%
Halation	3.5%	4.3%	5.7%
Reflectance	Not Specified	4.6%	5.6%
Cm, Zone A, 7.6 inch	25% minimum	29%	54%
Cm, Zone B	20% minimum	40%	48%
Linearity	1.0% max	0.88%	0.42%
Warm-up time, Lmin to ± 10%	60 minutes maximum	49 minutes	53 minutes
Stereoscopic Mode			
Lmax	6 fL	6.04 fL	6.33 fL
Refresh rate	60 Hz per eye	60 Hz	55 Hz
Extinction ratio	15:1 minimum using CrystalEyes	10.0:1 Zscreen	10.4:1 Zscreen 17.6:1 CrystalEyes

As we have said in the Hitachi report, color monitors are more difficult to evaluate and their performance may not compare to monochrome monitors. But, they do give the analyst the additional dimension of color for their tasks. Color monitors have three electron guns (R, G, and B) to focus and converge. They also have a perforated steel shadow or aperture grill mask that separates the colors on the screen and this adds complexity. Color lines formed on the phosphor screen may not be as narrow as for a monochrome, single electron gun-formed spot. The color monitor's light output may not be as high. The IEC monitor specifications for color monitors reflect this difference, and are less stringent than for a monochrome monitor. Imagery analysts at a number of organizations do their analyses on color monitors.

Evaluation Datasheet
Mitsubishi 2040u 22 inch Color CRT Monitor

Mode	IEC Requirement	Measured Performance	Compliance
MONOSCOPIC			
Addressability	1024 x 1024 min.	1600 x 1200	Pass
Dynamic Range	24.7dB	24.9 dB	Pass
Luminance (Lmin)	0.1 fL min. ± 4%	0.11 fL	Pass
Luminance (Lmax)	30 fL ± 4%	34.0 fL	Pass
Uniformity (Lmax)	20% max.	12.4%	Pass
Halation	3.5% max.	5.7%	Fail
Color Temp	6500 to 9300 K	Adjustable	Pass
Reflectance	Not specified	5.6%	Pass
Bit Depth	8-bit± 5 counts	8-bit	Pass
Step Response	No visible ringing	Clean	Pass
Uniformity (Chromaticity)	0.010 delta u'v' max. ± 0.005 Δ u'v'	0.005 delta u'v'	Pass
Pixel aspect ratio	Square H = V± 6%	9.74 H x 9.75 V (mils)	Pass
Screen size, viewable diagonal	17.5 to 24 inches ± 2 mm	19.48 ins.	Pass
Cm, Zone A, 7.6"	25% min.	54%	Pass
Cm, Zone A, 9.8"	25% min.	48%	Pass
Cm, Zone B	20% min.	42%	Pass
Pixel density	72 ppi min.	103 ppi	Pass
Straightness	0.5% max ± 0.05 mm	0.20%	Pass
Linearity	1.0% max ± 0.05 mm	0.42%	Pass
Jitter	2 ± 2 mils max.	3.18 mils	Pass
Swim, Drift	5 ± 2 mils max.	3.89 mils	Pass
Warm-up time, Lmin to +/- 50%	30 mins. Max ± 0.5 minute	20 mins.	Pass
Warm-up time, Lmin to +/- 10%	60 mins. Max ± 0.5 minute	53 mins.	Pass
Refresh	72 ±1 Hz min. 60 ±1 Hz absolute minimum	Set to 75 Hz	Pass
STEREOSCOPIC			
Addressability	1024 x 1024 min.	1024 x 1024 (I)	Pass
Lmin	Not specified	0.1 fL	Pass
Lmax	6 fL min ± 4%	6.33 fL	Pass
Dynamic range	17.7 dB min	17.93 dB	Pass
Uniformity (Chromaticity)	0.02 delta u'v' max ± 0.005 Δ u'v'	0.006 delta u'v'	Pass
Refresh rate	60 Hz per eye, min	55 Hz, per eye	Fail
Extinction Ratio	15:1 min	10.4:1 (n)	Fail
		17.6 (CE)	Pass

(I) Denotes interlaced scanning
(n) Denotes 21SX NuVision LCD shutter panel and passive polarized eyewear
(CE) Denotes StereoGraphics CE-3 CrystalEyes eyewear and the ENT infrared emitter.

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 Mitsubishi 2040u color CRT high-resolution display monitor. 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.

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: Monochrome CRT 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 1.0, May 15, 1998.*

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. The Mitsubishi 2040u Color CRT Monitor

Manufacturer's Specifications

According to Mitsubishi, the specifications for the Mitsubishi monitor are:

Specifications	Features
CRT Type	DIAMONDTRON NF (Natural Flat) distortion-free flat screen desktop CRT monitor which reduces external reflection and glare for easier viewing and decreased eye strain.
CRT Size	22" (20.0" diagonal viewable image)
CRT Pitch	0.24mm center to center
CRT Faceplate Glass	Optical-quality, anti-static and anti-reflective CRT coating (39.8% light transmission)
Display Area Size* (W x H)	15.5 x 11.6" (393 x 295 mm)
Maximum Addressable Resolution Format (H x V pixels)	2048 x 1536/75 Hz NI 1600 x 1200/85 Hz NI (recommended) Compatible with IBM, VGA, SVGA, XGA-2, VESA, Apple Macintosh LC, Macintosh II, and Quadra graphics standards.
Auto-Scan Range	H: 30 - 121 kHz V: 50 - 160 Hz
Scan Mode Memory With On- Screen Display	Microprocessor-based. Stores custom and pre-calibrated parameters for up to 26 different modes.
Fully Adjustable Color Balance	5000° - 9950° Continuously variable
Video Clock Frequency	240 MHz
Input Signal	Analog RGB; TTL H/V & C Sync. Separate or composite sync.
Signal Cable	1.8m length, VGA/VGA (D-Sub 9-15HD)
Cable Accessories	Macintosh adapter included. Out-of-the-box Macintosh compatibility
USB (Universal Serial Bus)	Self-powered USB hub, 3 downstream ports, 2 upstream ports
Power Requirements	100-120 or 220-240 VAC; 50/60 Hz, Auto-sensing all-world power compatibility
Power Consumption	155 W (without USB load) 170 W (with USB load)
Power Cord	1.5 m U.S. version cord with 3P plug
Compact Tilt/ Swivel Base	Integrated with monitor
Dimensions (W x H x D)	19.7 x 19.7 x 19.0" (500 x 500 x 482 mm)
Weight	68.3 lbs. (31 kg)
Packing Carton (W x H x D)	24.8 x 25.1 x 24.5" (630 x 640 x 623 mm)
Shipping Weight	81.5 lbs. (37 kg)
Regulatory Approvals	UL/cUL/DHHS/HWC/FCC-CLASS B/MPR-II/TCO-95/CE Mark/ TUV-ERGO/EPA/NUTEK
Plug And Play	VESA DDC-1 & 2B
Power Management	VESA DPMS
Warranty/ Support	Three-year parts and labor limited warranty
Corporate Partners Program	48-hour warranty exchange for qualifying accounts.
Advanced Exchange Warranty	Runs concurrently with the standard three-year warranty and provides customers with free delivery of a replacement monitor for a failed one.

I.2. Initial Monitor Set Up

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5, p5.

All measurements will be made with the display commanded through a laboratory grade programmable test pattern generator. The system will be operated in at least a 24 bit mode (as opposed to a lesser or pseudo-color mode) for color and at least 8 bits for monochrome. As a first step, refresh rate should be measured and verified to be at least 72 Hz. 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 1600 by 1200 addressability, addressability should be lowered to 1280 by 1024 or to 1024 by 1024. For a nominal 2048 by 2560 addressability, 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: Monochrome CRT 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/m^2 (1mfL).

Instruments used in these measurements included:

- Quantum Data 8701 400 MHz programmable test pattern signal generator
- Quantum Data 903 250 MHz programmable test pattern signal generator
- Photo Research SpectraScan PR-650 spectroradiometer
- Photo Research SpectraScan PR-704 spectroradiometer
- Minolta LS-100 Photometer
- Minolta CA-100 Colorimeter
- 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) and Spotseeker 4-Axis Positioner

Stereoscopic-mode measurements were made using the following commercially-available stereo products:

- 21SX NuVision LCD shutter panel with passive polarized eyewear
- StereoGraphics CE-3 CrystalEyes 3 eyewear and the ENT infrared emitter.

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 Flat Panel Display Measurements Standard, Version 1.0, May 15, 199, Section 308-1.

Full screen white-to-black dynamic range measured in 1600 x 1200 format is 24.9 dB in a dark room. It decreases to 22 dB (the absolute threshold for IEC) in 2 fc diffuse ambient illumination.

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 D_{65} to D_{93}. 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 reference 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: Define dynamic range by: DR=10log(Lmax/Lmin)

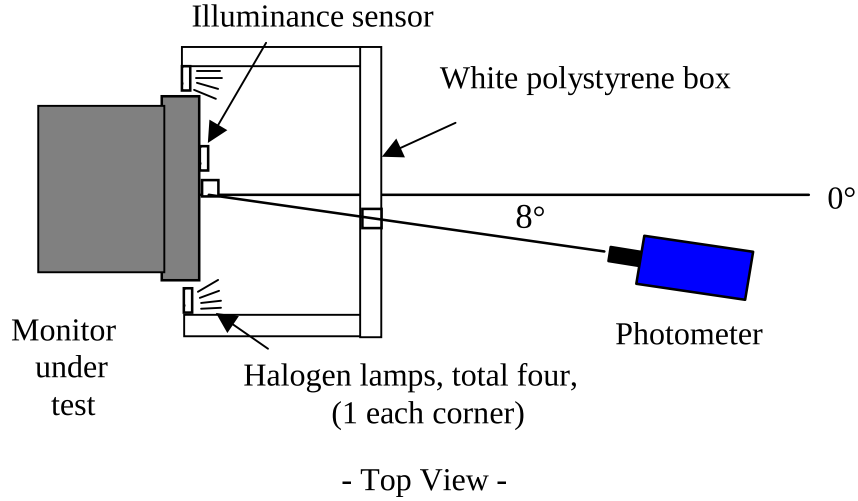


Figure II.1-1. Test setup according to VESA FPDM procedures for measuring total reflectance of screen.

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

Ambient Illuminance	21.0 fc
Reflected Luminance	1.17 fL
Faceplate Reflectance	5.6 %

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. Full screen white-to-black dynamic range decreases from 24.9 dB in a dark room to 22 dB (the absolute threshold for IEC) in 2 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 CRT faceplate reflectivity times the ambient illumination measured at the CRT in foot candles added to the minimum screen luminance, Lmin, where Lmin = 0.11 fL.

Ambient Illumination	**Displayed Addressable Format 1600 x 1200**
0 fc (Dark Room)	24.9 dB
1 fc	23.1 dB
2 fc	21.9 dB
3 fc	20.9 dB
4 fc	20.1 dB
5 fc	19.5 dB
6 fc	18.9 dB
7 fc	18.4 dB
8 fc	17.9 dB
9 fc	17.5 dB
10 fc	17.1 dB

II.2. Maximum Luminance (Lmax)

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

The highest luminance for Lmax was 34 fL measured at screen center in 1600 x 1200 format.

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 colorimeter (Minolta CA-100). The correlated color temperature (CCT) computed from the measured CIE x, y chromaticity coordinates was within range specified by IEC (6500K and 9300K).

Table II.2-1. Maximum Luminance and Color

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

Format	CCT	CIE x	CIE y	Luminance
1600 x 1200	9680K	0.280	0.294	34.0 fL

II.3. Luminance (Lmax) and Color Uniformity

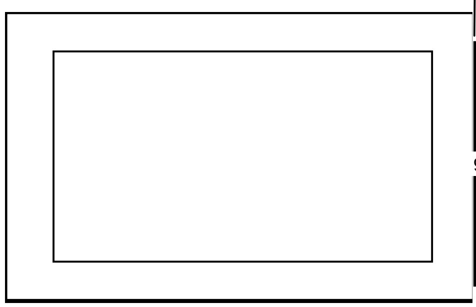
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 4.4, p. 28.

Maximum luminance (Lmax) varied by up to 12.4% across the screen. Chromaticity variations were less than 0.005 delta u'v' units.

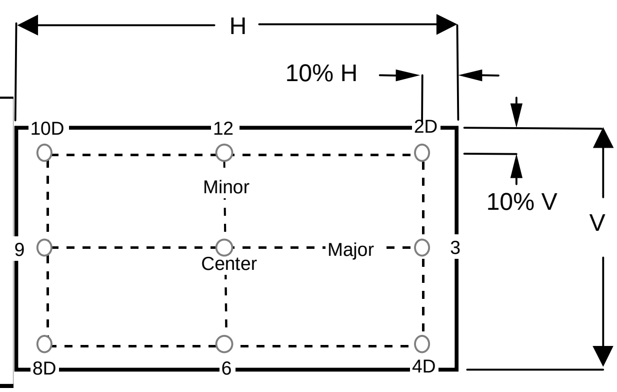
Objective: Measure the variability of luminance and chromaticity coordinates of the white point at 100% Lmax only and as a function of spatial position. Variability of luminance impacts the total number of discriminable gray steps.

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 Δ u´v´.

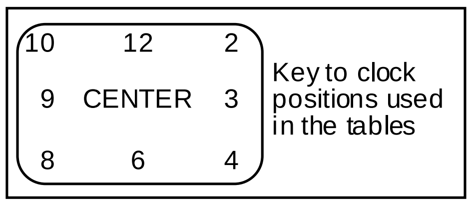
Data: Tabulate the luminance and 1931 C.I.E. chromaticity coordinates (x, y) or correlated color temperature of the white point at each of the nine locations depicted in Figure II.3-2. Additionally, note the location of any additional points that are measured along with the corresponding luminance values.

Table II.3-1. Spatial Uniformity of Luminance and Color

Color and luminance (in fL) for Full screen at 100% Lmax taken at nine screen positions.

1600 x 1200

POSITION	CCT	CIE x	CIE y	L, fL
center	9680	0.280	0.294	34.0
2	9486	0.282	0.294	29.8
3	9119	0.285	0.296	30.2
4	9294	0.284	0.294	31.6
6	9928	0.279	0.291	33.0
8	10354	0.276	0.289	30.5
9	10474	0.276	0.287	30.8
10	9531	0.282	0.293	31.1
12	9826	0.280	0.291	31.6



1600 x 1200

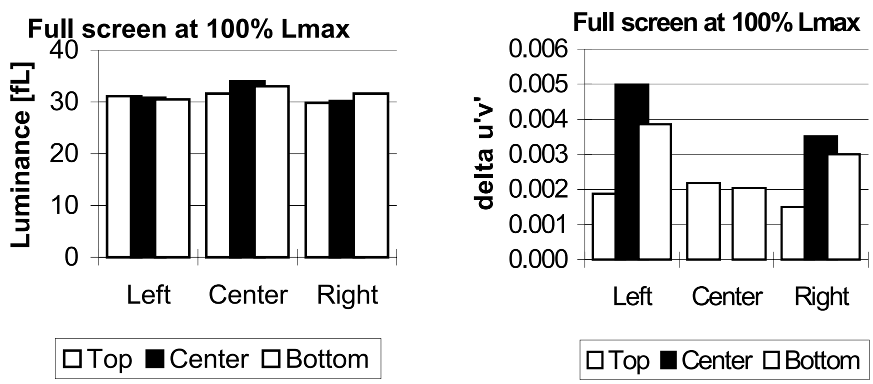


Fig.II.3-3. Spatial Uniformity of Luminance and Chromaticity. (Delta u'v' of 0.004 is just visible.)

II.4. Halation

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 4.6, page 48.

Halation was 5.7 % on a small black patch surrounded by a large full white area.

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 by E. B. Gindele and S.L. Shaffer. 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:

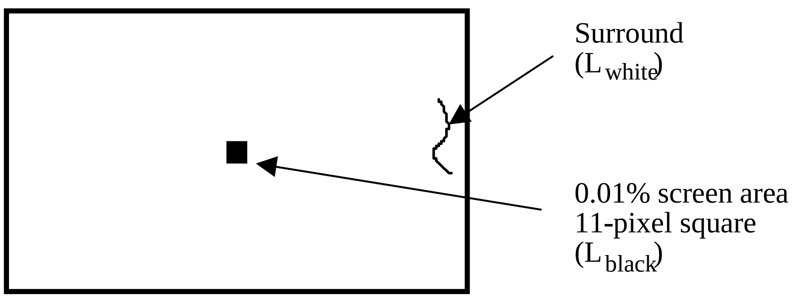


Figure II.4-1. *Test pattern for measuring halation.*

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}).

Establish L_{black} by setting the display to cutoff. To set the display to cut-off, display a flat field using video input count level zero, and use a photometer to monitor the luminance at center screen. Vary the BRIGHTNESS control until the CRT beam is visually cut off, and confirm that the corresponding luminance (L_{stray}) is essentially equal to zero. Fine tune the BRIGHTNESS control such that

CRT beam is just on the verge of being cut off. These measurements should be made with a photometer which is sensitive at low light levels (below L_{min} of the display). Make no further adjustments or changes to the BRIGHTNESS control or the photometer measurement field.

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}).

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 which 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:

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

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 1600 x 1200 Addressability

	Reported Values	Range for 4% uncertainty
Lblack	1.138	1.092 fL to 1.184 fL
Lwhite	19.98 fL	19.180 fL to 20.779 fL
Halation	5.7%	5.26% to 6.17%

II.5. Color Temperature

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

The CCT of the measured white point lies within the boundaries accepted by IEC.

Objective: Insure measured screen white of a color monitor has a correlated color temperature (CCT) between 6500K and 9300K.

Equipment: Colorimeter

Procedure: Command screen to Lmax. Measure u'v' chromaticity coordinates (CIE 1976).

Data: Coordinates of screen white should be within 0.01 Δu'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. If the measured CCT is greater than 9300 K, the corresponding daylight is D93. If the measured CCT is less than 6500 K, the corresponding daylight is D65. The following equations were used to compute Δu'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.

4. 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.
   - If CCT < 7000, then xd = -4.6070 u^3 + 2.9678 u^2 + 0.09911 u +
   - 0.244063.
   - If CCT > 7000, then xd = -2.0064 u^3 + 1.9018 u^2 + 0.24748 u +
   - 0.237040.
   - In either case, yd = -3.000 xd^2 + 2.870 xd -0.275.

5. Convert (x,y) and (xd,yd) to u'v' coordinates:
   - (u',v') = (4x,9y)/(3 + 12y - 2x)
   - (u'd,v'd) = (4xd,9yd)/(3 + 12yd - 2xd)

6. Evaluate delta-u'v' between (u,v) and (ud,vd):
   - delta-u'v' = sqrt[(u' - u'd)^2 + (v' - v'd)^2].

7. If delta-u'v' is greater than 0.01, display fails the test. Otherwise it passes the test.

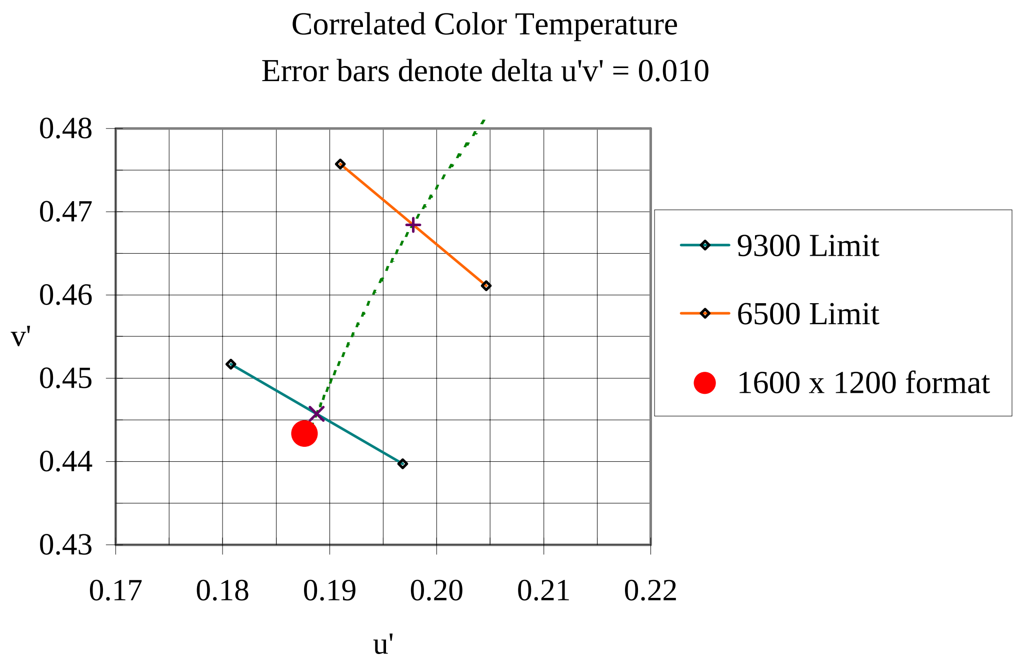


Figure II.5-1. *CCTs of measured whitepoints are within the boundaries required by IEC.*

Table II.5-1. Δu'v' Distances between measured whitepoints and CIE coordinate values from D_{65} to D_{93}.

	1600 x 1200
CIE x	0.280
CIE y	0.294
CIE u'	0.188
CIE v'	0.443
CCT	9680
delta u'v'	0.003

II.6. Bit Depth

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

Positive increases in luminance were measured for each of the 256 input levels for 8 bits of gray scale. Neither black level clipping nor white level saturation was observed.

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 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.

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 white test targets displayed using a Quantum Data 8701 test pattern generator and a Minolta CA-100 colorimeter. 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 model was used to define discriminable luminance differences in JNDs.

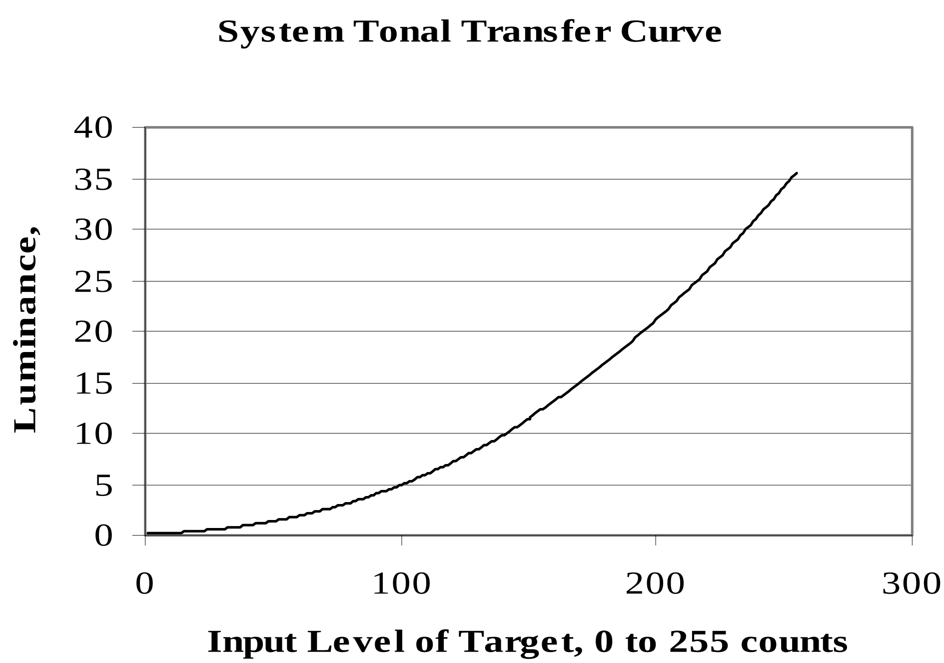


Figure II.6-1 shows the System Tonal Transfer curve at center screen as a function of input counts. The data for each of the 256 levels are listed in Tables II.6-1 and II.6-2.

Figure II.6-1. System Tonal Transfer at center screen as a function of input counts.

Table II.6-1. System Tonal Transfer at center screen as a function of input counts. Target levels 000 to 127.

Back Ground	Target	L, fL	Diff, fL	Diff, JND	Back Ground	Target	L, fL	Diff, fL	Diff, JND
38	0	0.106	0	0	61	64	2.142	0.049	2
39	1	0.115	0.01	3	61	65	2.202	0.052	2
39	2	0.125	0.01	2	62	66	2.263	0.045	2
39	3	0.135	0.011	2	62	67	2.325	0.048	2
40	4	0.146	0.01	2	62	68	2.387	0.059	2
40	5	0.156	0.012	2	63	69	2.453	0.062	2
41	6	0.167	0.011	3	63	70	2.512	0.061	2
41	7	0.179	0.013	2	63	71	2.582	0.058	3
41	8	0.192	0.012	2	64	72	2.646	0.051	1
42	9	0.206	0.013	2	64	73	2.709	0.062	3
42	10	0.221	0.015	3	64	74	2.776	0.068	2
42	11	0.236	0.013	2	65	75	2.852	0.056	2
43	12	0.251	0.015	2	65	76	2.922	0.064	2
43	13	0.267	0.015	2	65	77	2.994	0.061	2
43	14	0.283	0.016	2	66	78	3.065	0.067	2
44	15	0.301	0.016	2	66	79	3.141	0.067	2
44	16	0.322	0.019	3	66	80	3.225	0.061	2
44	17	0.341	0.018	2	67	81	3.304	0.068	2
45	18	0.361	0.019	3	67	82	3.383	0.08	2
45	19	0.382	0.018	2	67	83	3.459	0.067	2
45	20	0.403	0.018	2	68	84	3.537	0.07	2
46	21	0.424	0.02	2	68	85	3.616	0.07	2
46	22	0.446	0.02	2	69	86	3.704	0.061	2
46	23	0.468	0.021	2	69	87	3.788	0.088	2
47	24	0.493	0.022	3	69	88	3.867	0.07	2
47	25	0.518	0.021	2	70	89	3.955	0.079	2
48	26	0.543	0.024	2	70	90	4.042	0.061	2
48	27	0.568	0.021	2	70	91	4.133	0.093	2
48	28	0.594	0.024	2	71	92	4.217	0.065	2
49	29	0.622	0.025	3	71	93	4.308	0.09	2
49	30	0.651	0.026	2	71	94	4.399	0.079	2
49	31	0.68	0.027	2	72	95	4.489	0.084	2
50	32	0.711	0.026	2	72	96	4.594	0.076	2
50	33	0.742	0.026	2	72	97	4.687	0.09	2
50	34	0.774	0.028	3	73	98	4.784	0.089	2
51	35	0.806	0.029	2	73	99	4.883	0.096	2
51	36	0.839	0.028	2	73	100	4.979	0.079	2
51	37	0.873	0.031	2	74	101	5.078	0.096	2
52	38	0.908	0.031	3	74	102	5.181	0.09	2
52	39	0.944	0.031	2	74	103	5.283	0.076	2
52	40	0.979	0.031	2	75	104	5.384	0.097	2
53	41	1.017	0.033	2	75	105	5.487	0.087	2
53	42	1.056	0.036	2	76	106	5.589	0.099	2
53	43	1.095	0.029	2	76	107	5.691	0.089	1
54	44	1.136	0.038	3	76	108	5.799	0.081	2
54	45	1.176	0.036	2	77	109	5.904	0.111	2
55	46	1.218	0.038	2	77	110	6.024	0.11	2
55	47	1.261	0.04	2	77	111	6.136	0.103	2
55	48	1.313	0.033	2	78	112	6.255	0.09	2
56	49	1.358	0.046	3	78	113	6.374	0.085	1
56	50	1.403	0.042	2	78	114	6.488	0.116	3
56	51	1.449	0.041	2	79	115	6.605	0.126	2
57	52	1.496	0.038	2	79	116	6.719	0.082	1
57	53	1.544	0.042	2	79	117	6.838	0.113	2
57	54	1.593	0.041	3	80	118	6.955	0.114	2
58	55	1.644	0.048	2	80	119	7.078	0.111	2
58	56	1.697	0.039	2	80	120	7.197	0.105	2
58	57	1.747	0.044	2	81	121	7.315	0.105	2
59	58	1.8	0.053	2	81	122	7.445	0.112	1
59	59	1.855	0.049	3	81	123	7.571	0.122	2
59	60	1.907	0.046	2	82	124	7.685	0.117	2
60	61	1.964	0.047	2	82	125	7.819	0.125	2
60	62	2.021	0.053	2	83	126	7.953	0.117	2
60	63	2.08	0.049	2	83	127	8.085	0.108	2

Table II.6-2. System Tonal Transfer at center screen as a function of input counts Target levels 128 to 255.

Back ground	Target	L, fL	Diff, fL	Diff, JND
83	128	8.216	0.083	1
84	129	8.348	0.127	2
84	130	8.476	0.131	2
84	131	8.616	0.126	1
85	132	8.747	0.14	2
85	133	8.893	0.119	2
85	134	9.027	0.135	2
86	135	9.168	0.131	2
86	136	9.308	0.087	1
86	137	9.453	0.164	2
87	138	9.592	0.129	2
87	139	9.742	0.137	2
87	140	9.883	0.116	1
88	141	10.03	0.126	2
88	142	10.18	0.143	1
88	143	10.32	0.155	2
89	144	10.53	0.16	2
89	145	10.67	0.143	2
90	146	10.83	0.137	2
90	147	10.98	0.132	1
90	148	11.14	0.16	2
91	149	11.29	0.124	1
91	150	11.46	0.1	2
91	151	11.62	0.19	2
92	152	11.77	0.15	1
92	153	11.93	0.14	2
92	154	12.09	0.16	2
93	155	12.26	0.15	1
93	156	12.43	0.15	2
93	157	12.59	0.16	2
94	158	12.75	0.14	1
94	159	12.93	0.16	2
94	160	13.11	0.17	1
95	161	13.28	0.15	2
95	162	13.45	0.16	1
95	163	13.62	0.16	2
96	164	13.79	0.18	2
96	165	13.97	0.18	2
97	166	14.16	0.16	1
97	167	14.34	0.14	1
97	168	14.51	0.16	2
98	169	14.7	0.2	2
98	170	14.88	0.16	1
98	171	15.07	0.19	2
99	172	15.26	0.13	1
99	173	15.45	0.16	1
99	174	15.63	0.16	2
100	175	15.82	0.2	1
100	176	16.05	0.18	2
100	177	16.25	0.23	2
101	178	16.45	0.17	1
101	179	16.65	0.18	2
101	180	16.84	0.19	1
102	181	17.04	0.19	2
102	182	17.24	0.2	2
102	183	17.44	0.16	1
103	184	17.64	0.16	1
103	185	17.85	0.23	2
104	186	18.04	0.18	1
104	187	18.25	0.21	2
104	188	18.46	0.21	1
105	189	18.67	0.16	2
105	190	18.88	0.21	1
105	191	19.1	0.22	2

Back ground	Target	L, fL	Diff, fL	Diff, JND
106	192	19.33	0.21	1
106	193	19.55	0.2	2
106	194	19.77	0.35	2
107	195	19.99	0.22	2
107	196	20.21	0.24	1
107	197	20.43	0.18	2
108	198	20.66	0.21	1
108	199	20.88	0.07	0
108	200	21.1	0.16	1
109	201	21.34	0.18	2
109	202	21.57	0.14	1
109	203	21.8	0.26	1
110	204	22.01	0.16	1
110	205	22.25	0.32	2
111	206	22.49	0.12	1
111	207	22.73	0.18	1
111	208	22.99	0.33	2
112	209	23.24	0.29	2
112	210	23.48	0.11	1
112	211	23.72	0.29	1
113	212	23.95	0.14	1
113	213	24.19	0.29	2
113	214	24.45	0.27	2
114	215	24.71	0.18	1
114	216	24.95	0.29	1
114	217	25.19	0.14	1
115	218	25.45	0.32	2
115	219	25.7	0.26	1
115	220	25.94	0.17	1
116	221	26.18	0.18	1
116	222	26.44	0.36	2
116	223	26.7	0.22	2
117	224	26.98	0.18	0
117	225	27.25	0.26	2
118	226	27.52	0.34	2
118	227	27.79	0.14	0
118	228	28.04	0.12	1
119	229	28.3	0.34	2
119	230	28.56	0.39	2
119	231	28.83	0.13	0
120	232	29.08	0.24	2
120	233	29.36	0.26	1
120	234	29.63	0.26	1
121	235	29.91	0.32	2
121	236	30.18	0.26	1
121	237	30.44	0.18	1
122	238	30.72	0.27	1
122	239	31	0.28	1
122	240	31.29	0.27	2
123	241	31.58	0.16	0
123	242	31.87	0.35	2
123	243	32.16	0.3	1
124	244	32.43	0.21	1
124	245	32.72	0.23	1
125	246	32.99	0.31	2
125	247	33.27	0.4	2
125	248	33.54	0.2	1
126	249	33.86	0.4	1
126	250	34.15	0.15	1
126	251	34.44	0.2	1
127	252	34.72	0.25	1
127	253	35.01	0.35	1
127	254	35.29	0.25	1
128	255	35.58	0.3	2

II.8. Luminance Step Response

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

No video artifacts were observed.

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

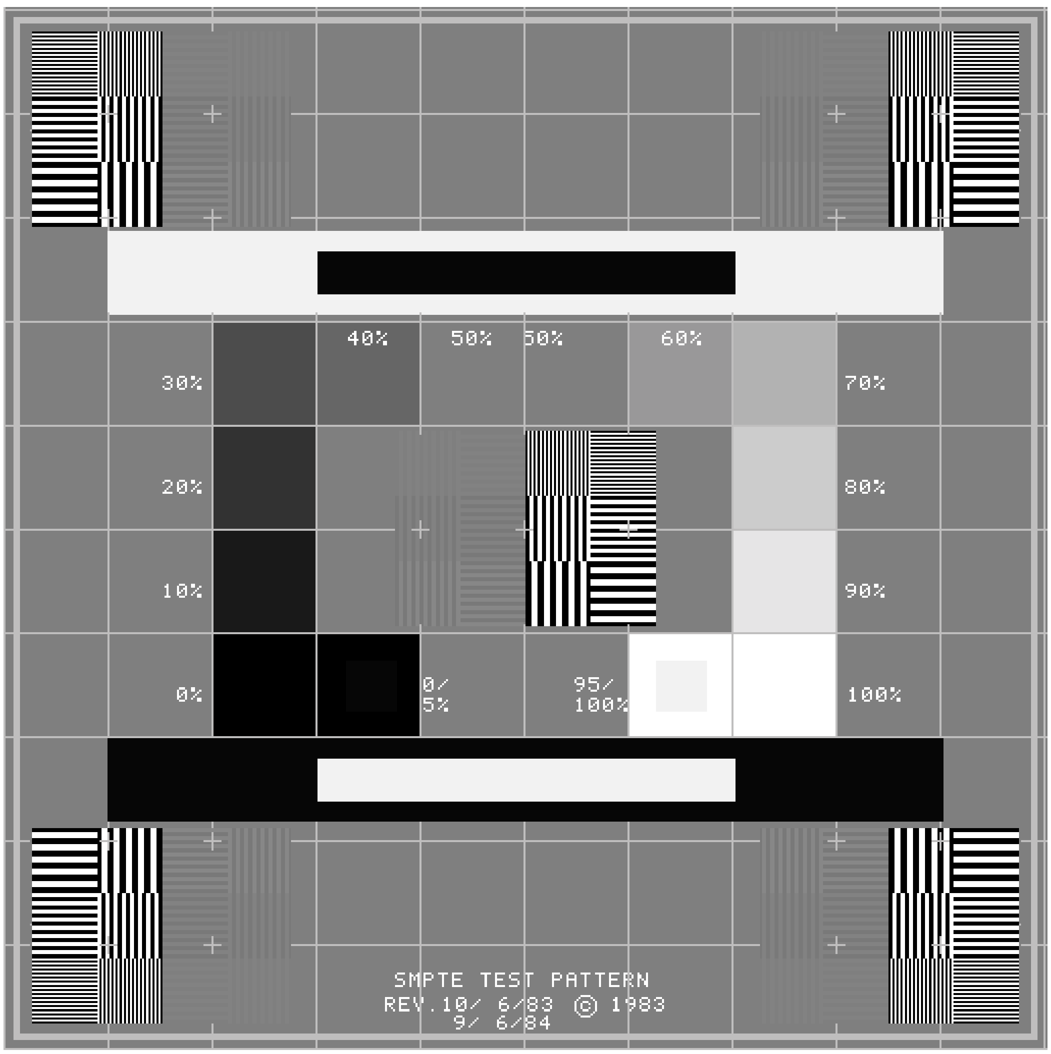


Figure II.8-1. SMPTE Test Pattern.

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 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.” None of these artifacts was observed in the MITSUBISHI 2040u monitor, signifying good electrical performance of the video circuits.

II.9. Addressability

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

This monitor properly displayed all addressed pixels for the following tested formats (HxV): 1600 x 1200 x 75 Hz, and 1024 x 1024 x 110 Hz.

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

Equipment: Programmable video signal generator.
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 and V grille patterns 1-pixel-on/1-pixel-off.

Procedure: The number of addressed pixels were programmed into the Quantum Data 8701 test pattern generator for 75 Hz for monoscopic mode and 110 Hz maximum addressable for stereoscopic mode, where possible. All perimeter lines were confirmed to be visible, with no irregular jaggies on diagonals and, for monochrome monitors, 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	Stereo Mode
1600 x 1200	1024 x 1024

II.10. Pixel Aspect Ratio

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

Pixel aspect ratio is square to within 0.1%.

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.

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± 6% for pixel density <100 ppi and ± 10% for pixel density > 100 ppi.

	Monoscopic Mode
Addressability (H x V)	**1600 x 1200**
H x V Image Size (inches)	15.579 x 11.696
H x V Pixel Spacing (mils)	9.74 x 9.75 mils
H x V Pixel Aspect Ratio	H = V - 0.1%

II.11. Screen Size (Viewable Active Image)

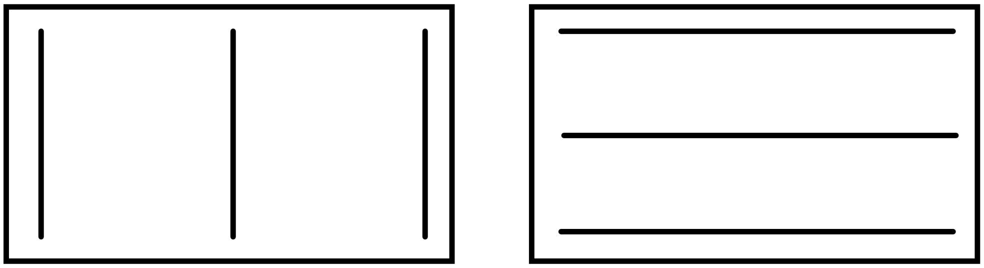
Reference: VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 1998, Section 501-1.

Image size for 1600 x 1200 format was 19.481 inches in diagonal.

Objective: Measure beam position on the CRT 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 Modes
Addressability (H x V)	1600 x 1200
H x V Image Size (inches) Diagonal Image Size (inches)	15.579 x 11.696 19.481

II.12. Contrast Modulation

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

Contrast modulation (Cm) for 1-on/1-off grille patterns displayed at 50% Lmax exceeded Cm = 54% in Zone A of diameter 7.6 inches, and exceeded Cm = 42% in Zone B. Cm exceeded 48% for Zone A diameter of 9.79 inches (40% of image area)and exceeded 42% for zone 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 each format (1024 x 1024, 1600 x 1200) was examined using horizontal and vertical grille test patterns consisting of alternating lines with 1 pixel on, 1 pixel 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, Lmax.

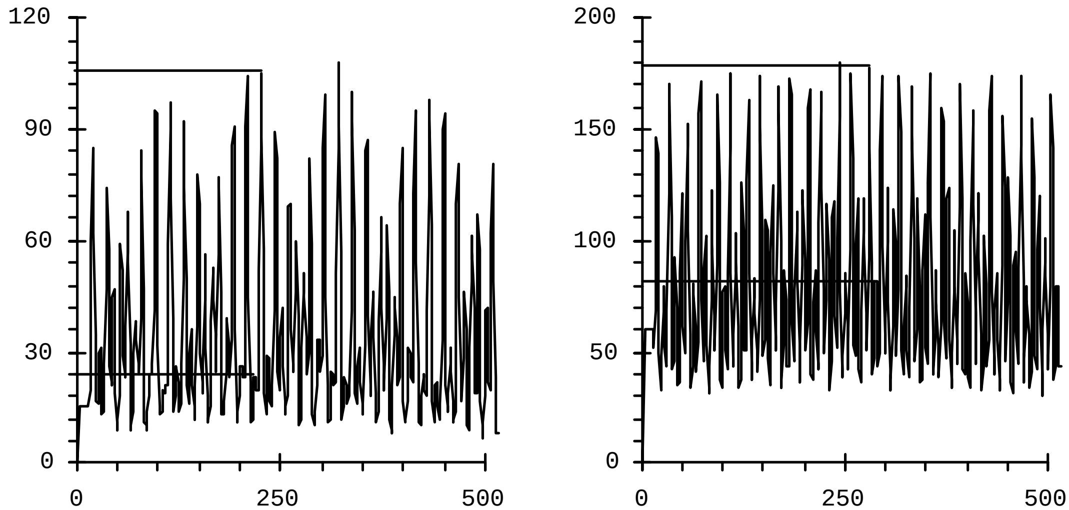
Zone A is defined as a 24 degree subtended circle from a viewing distance of 18 inches (7.6 inch circle). Zone B is the remainder of the display. Use edge measurements no more than 10% of screen size in from border of active screen area to define Cm for Zone B (remaining area outside center circle). Determine Cm at eight points on circumference of circle by interpolating between center and display edge measurements to define Cm 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 Cm for Zone A and Zone B are given in Table II.12-1. The contrast modulation, Cm, is reported (the defining equation is given below) for the 1-on/1-off grille patterns. The modulation is equal to or greater than 54% in Zone A, and is equal to or greater than 42% in Zone B.

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

The Mitsubishi 2040u shows very little moiré. For other shadow mask monitors, noise can affect the contrast modulation as shown below.

The sample contrast modulations shown in Figure II.12-1 for two different color CRTs are not fully realized because of the presence of moiré caused by aliasing between the image and the shadowmask. Because contrast modulation values are calculated for the maximum peak and minimum valley luminance levels as indicated in the sample data shown, they do not include the degrading effects of aliasing.



Monitor A Monitor B

$$Cm = \frac{105 - 24}{105 + 24} = 63\%$$

$$Cm = \frac{179 - 821}{179 + 821} = 37\%$$

Figure II.12-1. *Contrast modulation for sample luminance profiles (1 pixel at input level corresponding to 50% Lmax, 1 pixel at level 0 = Lmin) for monitors exhibiting moiré due to aliasing.*

Table II.12-1. Contrast Modulation

Corrected for lens flare and Zone Interpolation

Moiré Cancellation OFF

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

	Left				Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	66%	55%			42%	74%			50%	42%
			72%	59%	54%	69%	65%	54%		
Major	55%	80%	65%	70%	75%	61%	78%	62%	80%	64%
			70%	55%	66%	64%	73%	55%		
Bottom	63%	45%			61%	66%			70%	46%

Zone A = 9.79-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	H-grille	V-grille
Top	66%	55%			42%	74%			50%	42%
			71%	58%	48%	72%	63%	52%		
Major	55%	80%	63%	73%	75%	61%	78%	63%	80%	64%
			69%	53%	63%	65%	72%	53%		
Bottom	63%	45%			61%	66%			70%	46%

Line Width, 1600 x 1200 Monoscopic Mode

Table II.12-2. Measured Linewidth

Lmax,fL	V Line 50%	V Line 10%	V Line 5%	H Line 50%	H Line 10%	H Line 5%
33.8	13.7	25	28.5	12.5	22.8	26
30	13.9	25.4	29	11.9	21.8	24.9
25	13.6	24.9	28.4	10	18.3	20.9
20	12	22	25.1	9.01	16.4	18.7
15	11.4	20.9	23.8	8.39	15.3	17.4
10	11.3	20.6	23.5	8.15	14.8	16.9
5	10.4	19	21.7	8.05	14.6	16.7
0						

Avg.H,V Line 50%	Avg.H,V Line 10%	Avg.H,V Line 5%	V Line RAR	H Line RAR	Avg H,V RAR
13.1	23.9	27.3	1.41	1.28	1.34
12.9	23.6	27.0	1.43	1.22	1.32
11.8	21.6	24.7	1.40	1.03	1.21
10.5	19.2	21.9	1.23	0.92	1.08
9.9	18.1	20.6	1.17	0.86	1.02
9.7	17.7	20.2	1.16	0.84	1.00
9.2	16.8	19.2	1.07	0.83	0.95
			0.00	0.00	0.00

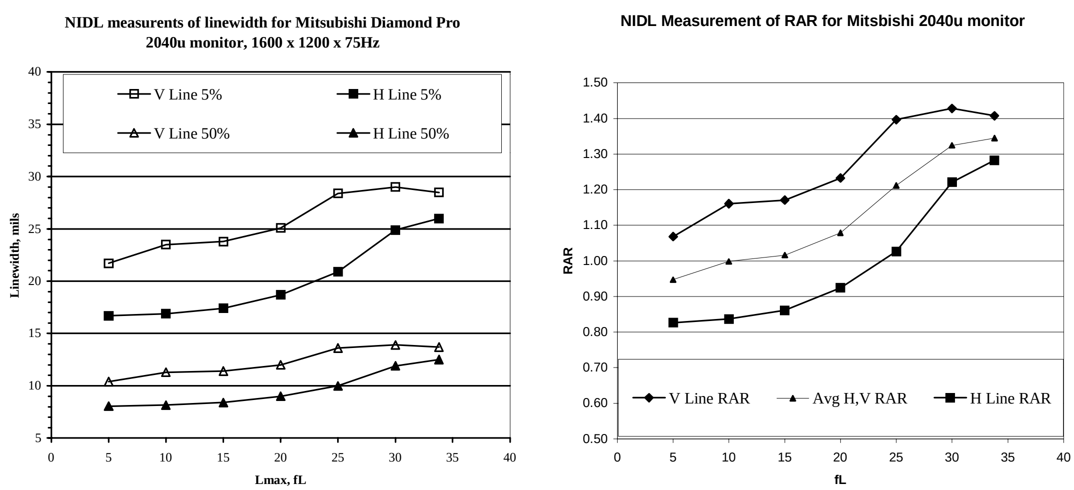


Figure II.12-2. *Linewidth and RAR as a function of Luminance*

* RAR = Resolution addressability ratio = linewidth / pixel size
Full width at half maximum of the signal line. (50% values)

II.13. Pixel Density

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

Pixel density was 103 ppi as tested for the 1600 x 1200-line addressable 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	1600 x 1200
H x V Image Size, Inches H x V Pixel Density, ppi	15.579 x 11.696 103 x 103 ppi

II.14. Moiré

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.14, p 9.

Phosphor-to-pixel spacing ratios are less than 1.0 at screen center for the 1600 x 1200 format. The Mitsubishi 2040u monitor shows very little moiré. The monitor has compensation circuitry which can effectively reduce the visibility of any evident moiré patterns but which can also reduce the contrast modulation.

Objective: Determine lack of moiré.

Equipment Loupe with scale graduated in 0.001 inch or equivalent

Procedure Measure phosphor pitch in vertical and horizontal dimension at screen center. For aperture grille screens, vertical pitch will be 0. Define pixel size by 1/pixel density.

Data: Define value of phosphor: pixel spacing. Value <1 passes, but <0.6 preferred.

Table II.14-1. Phosphor-to-Pixel-Spacing Ratios

	Monoscopic Mode
Addressability	1600 x 1200
Phosphor Pitch, aperture grille	0.24mm per manufacturer
Pixel Spacing	9.75 mils (0.248mm) horizontal
Phosphor-to-Pixel-Spacing	0.97

Discussion: Moiré occurs when the phosphor pitch is too large in comparison to the pixel size. Studies have shown that a phosphor pitch of about 0.6 pixels or less is required for adequate visibility of image information without interference from the phosphor structure.

II.15. Straightness

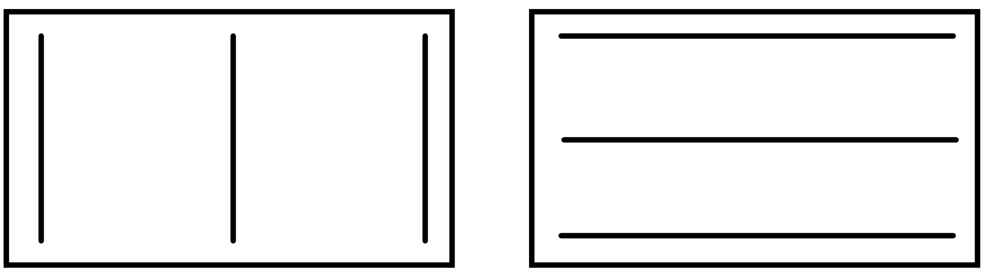
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.1 Waviness, page 67.

Waviness, a measure of straightness, did not exceed 0.20% of the image width or height.

Objective: Measure beam position on the CRT 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.15-1 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.

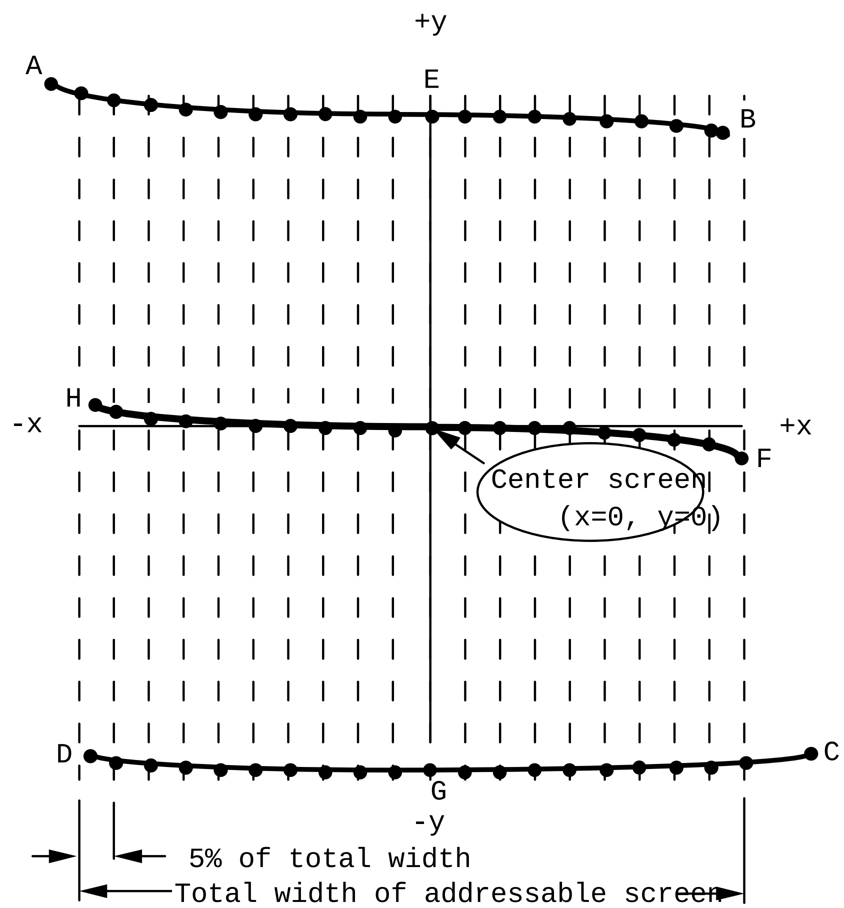


Figure II.15-2. Measurement locations for waviness along horizontal lines. Points A, B, C, D are extreme corner points of addressable screen. Points E, F, G, H are the endpoints of the axes.

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-I. 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
-7779	5883	-7777	-5836	-7775	6	4	5855	-7779	5883	7806	5881
-7200	5880	-7200	-5835	-7200	6	3	5400	-7778	5400	7805	5400
-6400	5878	-6400	-5831	-6400	6	4	4800	-7775	4800	7808	4800
-5600	5872	-5600	-5826	-5600	6	4	4200	-7773	4200	7810	4200
-4800	5866	-4800	-5821	-4800	6	3	3600	-7773	3600	7811	3600
-4000	5862	-4000	-5818	-4000	6	2	3000	-7772	3000	7812	3000
-3200	5858	-3200	-5818	-3200	4	1	2400	-7772	2400	7811	2400
-2400	5856	-2400	-5816	-2400	3	1	1800	-7771	1800	7811	1800
-1600	5854	-1600	-5819	-1600	1	1	1200	-7771	1200	7811	1200
-800	5854	-800	-5820	-800	1	0	600	-7771	600	7809	600
0	5854	0	-5821	0	0	0	0	-7772	0	7808	0
800	5855	800	-5821	800	0	1	-600	-7771	-600	7806	-600
1600	5857	1600	-5820	1600	1	1	-1200	-7770	-1200	7801	-1200
2400	5859	2400	-5819	2400	2	0	-1800	-7770	-1800	7799	-1800
3200	5862	3200	-5818	3200	3	-1	-2400	-7770	-2400	7798	-2400
4000	5865	4000	-5817	4000	3	0	-3000	-7772	-3000	7798	-3000
4800	5870	4800	-5817	4800	3	2	-3600	-7773	-3600	7801	-3600
5600	5876	5600	-5818	5600	3	5	-4200	-7775	-4200	7801	-4200
6400	5881	6400	-5818	6400	3	8	-4800	-7775	-4800	7802	-4800
7200	5884	7200	-5815	7200	3	12	-5400	-7775	-5400	7801	-5400
7806	5881	7801	-5813	7799	3	15	-5821	-7777	-5836	7801	-5813

1600 x 1200

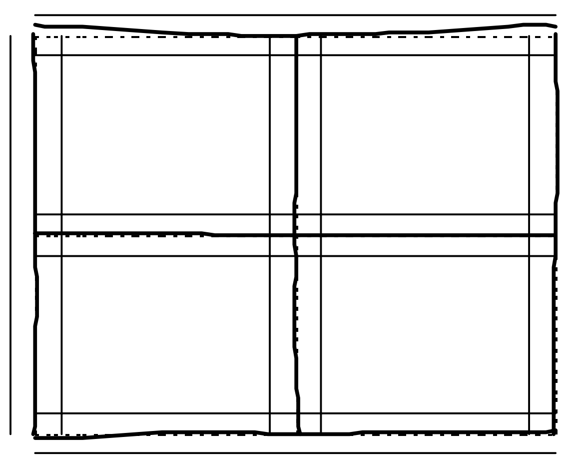


Figure II.15-3 Waviness of Mitsubishi 2040u color monitor in 1600 x 1200 mode. Departures from straight lines are exaggerated on a 10X scale. Error bars are +/- 0.5% of total screen size.

II.16. Refresh Rate

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

Vertical refresh rate for 1600 x 1200 format was set to 75 Hz. Vertical refresh rate for the 1024 x 1024 stereo format was 110 Hz, limited by the monitor.

Objective: Define vertical and horizontal refresh rates.

Equipment: Programmable video signal generator.

Procedure: The refresh rates were programmed into the Quantum Data 8701 test pattern generator for 72 Hz minimum for monoscopic mode and 120 Hz minimum for stereoscopic mode, where achievable.

Data: Report refresh rates in Hz.

Table II.16-1. Refresh Rates as Tested

	Monoscopic Mode	**Stereo Mode**
Addressability	1600 x 1200	1024 x 1024
Vertical Scan	75.0 Hz	110 Hz
Horizontal Scan	93.750 kHz	119.955 kHz*

* Manufacturer states 121 kHz maximum scan rate, thus, 120 Hz vertical scan rate is not achievable in stereo mode.

II.17. Extinction Ratio (NuVision Panel)

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.17, p10.

Stereo extinction ratio averaged 10.4 to 1 (11.3 right, 9.5 left) at screen center. Luminance of white varied by up to 12.7% across the screen. Chromaticity variations of white were less than 0.006 delta u'v' units.

Objective: Measure stereo extinction ratio

Equipment: Two “stereo” pairs with full addressability. One pair has left center at command level of 255 (or Cmax) and right center at 0. The other pair has right center at command level of 255 (or Cmax) and left center at 0.

Stereoscopic-mode measurements were made using a commercially-available Nuvision 19-inch LCD shutter with passive polarized eyeglasses.

Procedure: Calibrate monitor to 0.1 fL Lmin and 35 fL Lmax (no ambient) if possible. Measure ratio of Lmax to Lmin on both left and right side images through the stereo system.

Data: Extinction ratio (left) = L (left,on, white/black)/left,off, black/white)

L(left,on, white/black) ~ trans(left,on)*trans(stereo)*L(max)*Duty(left)
+ trans(left,off)*trans (stereo)*L(min)*Duty (right)
Use left,off/right,on to perform this measurement

Extinction ratio (right) = L (right,on,white/black)/right,off, black/white)

L(right,on, white/black) ~
trans(right,on)*trans(stereo)*L(max)*Duty(right)
+ trans(right,off)*trans (stereo)*L(min)*Duty (left)
Use left,on/right,off to perform this measurement

Stereo extinction ratio is average of left and right ratios defined above.

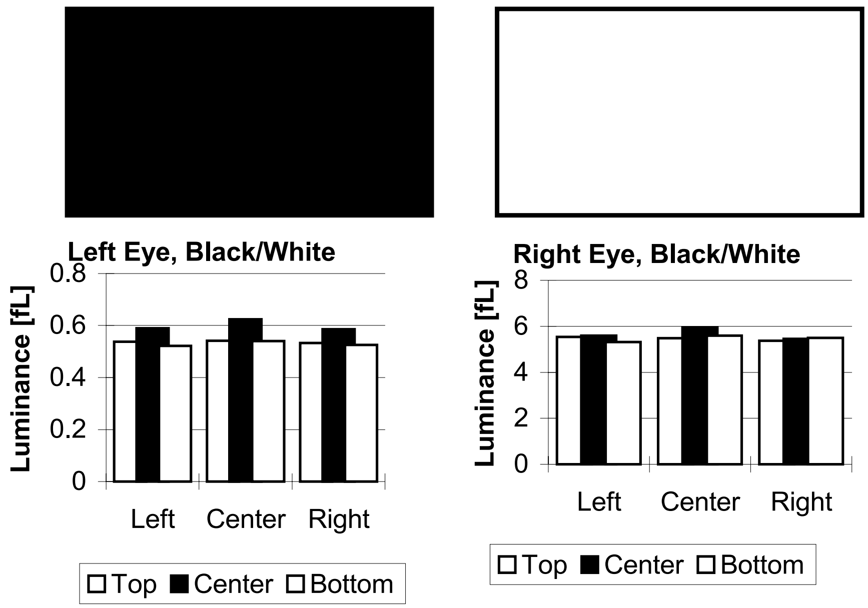


Fig.II.17-1. Spatial Uniformity of luminance in stereo mode when displaying black to the left eye while displaying white to the right eye.

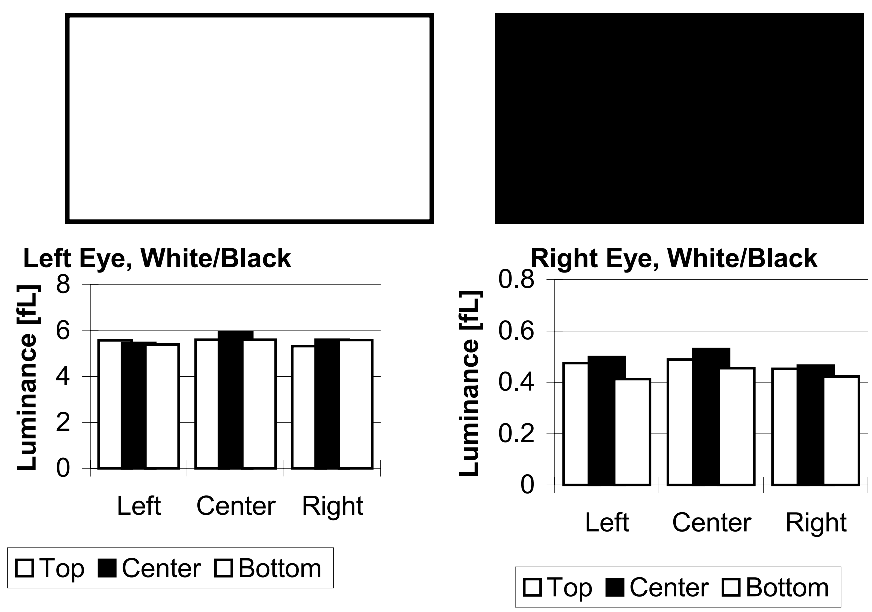


Fig.II.17-2. Spatial Uniformity of luminance in stereo mode when displaying white to the left eye while displaying black to the right eye.

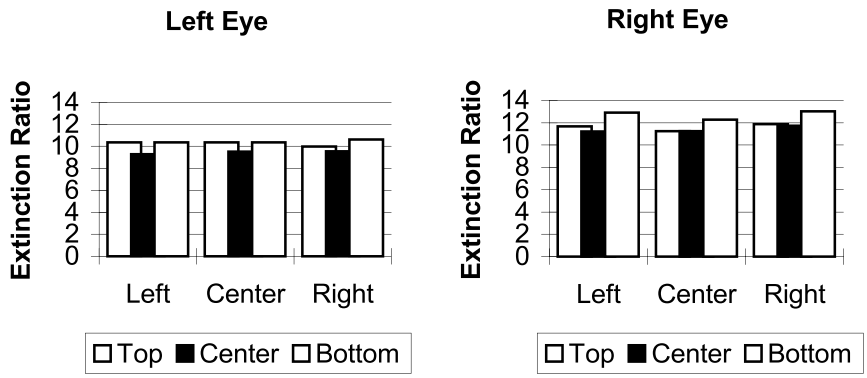


Fig.II.17-3. Spatial Uniformity of extinction ratio in stereo mode.

Fig.II.17-4. Spatial uniformity of chromaticity of white in stereo mode.

Extinction Ratio (StereoGraphics IR Glassware)

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.17, p10.

Stereo extinction ratio averaged 17.6 to 1 (17.6 right, 17.5 left) at screen center. Luminance of white in stereo mode varied by up to 54% across the screen.

Objective: Measure stereo extinction ratio

Equipment: Two "stereo" pairs with full addressability. One pair has left center at command level of 255 (or Cmax) and right center at 0. The other pair has right center at command level of 255 (or Cmax) and left center at 0.

Stereoscopic-mode measurements were made using a commercially available StereoGraphics CE-3 CrystalEyes

Procedure: Calibrate monitor to 0.1 fL Lmin and 35 fL Lmax (no ambient) if possible. Measure ratio of Lmax to Lmin on both left and right side images through the stereo system.

Data: Extinction ratio (left) = L (left,on, white/black)/left,off, black/white)

L (left,on, white/black) ~ trans(left,on)*trans(stereo)*L(max)*Duty(left)
+ trans(left,off)*trans (stereo)*L(min)*Duty (right)
Use left,off/right,on to perform this measurement

Extinction ratio (right) = L (right,on,white/black)/right,off, black/white)

L(right,on, white/black) ~
trans(right,on)*trans(stereo)*L(max)*Duty(right)
+ trans(right,off)*trans (stereo)*L(min)*Duty (left)
Use left,on/right,off to perform this measurement

Stereo extinction ratio is average of left and right ratios defined above.

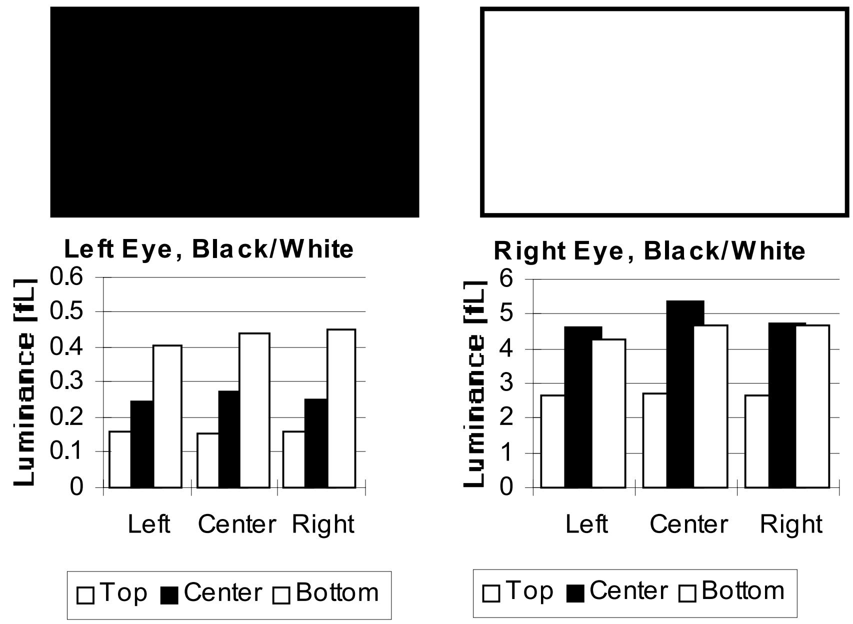


Fig.II.17-5. Spatial Uniformity of luminance in stereo mode when displaying black to the left eye while displaying white to the right eye.

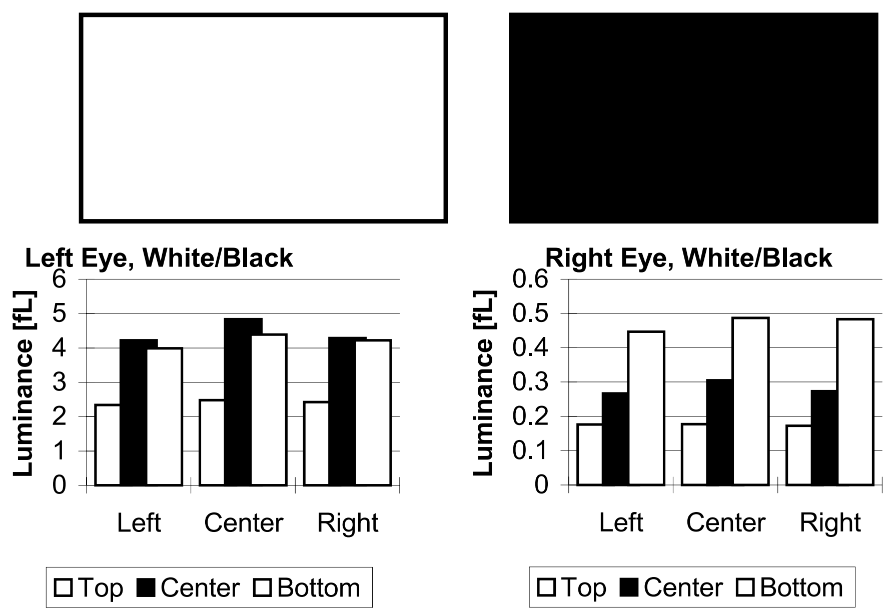


Fig.II.17-6. Spatial Uniformity of luminance in stereo mode when displaying white to the left eye while displaying black to the right eye.

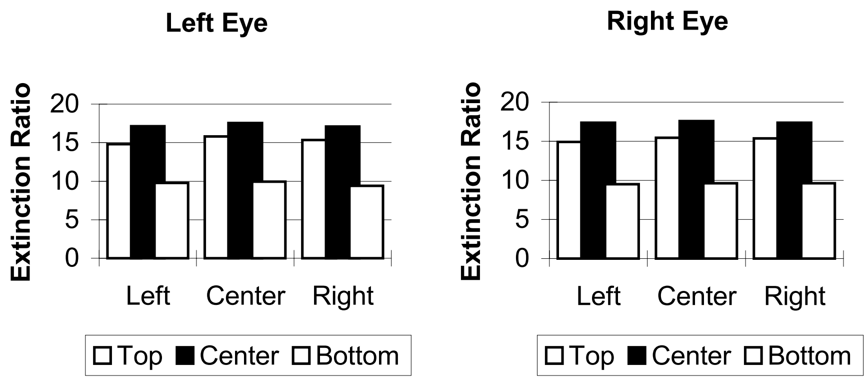


Fig.II.17-7. Spatial Uniformity of extinction ratio in stereo mode.

II.18. Linearity

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

The maximum nonlinearity of the scan was 0.42% of full screen.

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
- 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.

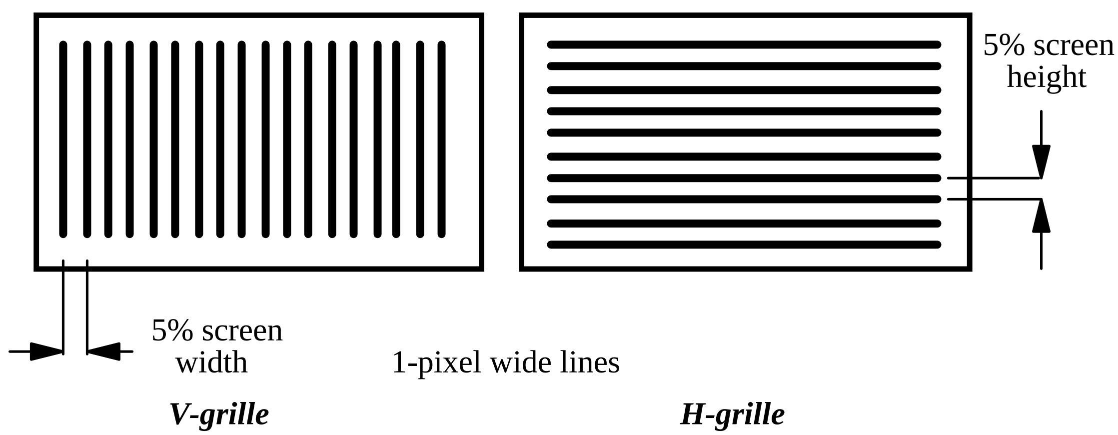


Figure II.18-1. *Grille patterns for measuring linearity*

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% Lmax 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.

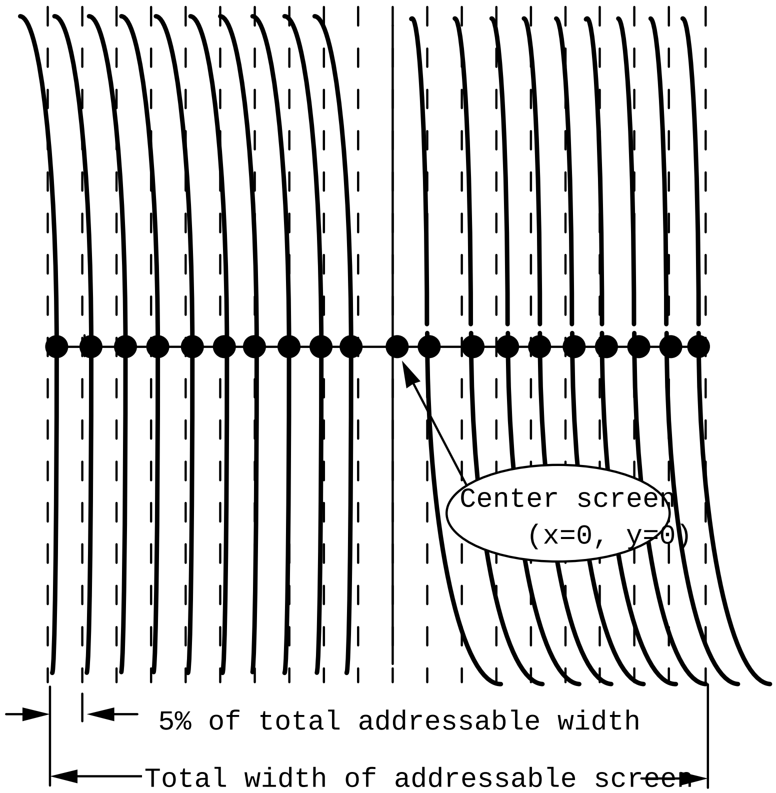


Figure II.18-2. *Measurement locations for horizontal linearity along the major axis of the display. Equal pixel spacings between vertical lines in the grille pattern are indicated by the dotted lines. The number of pixels per space is nominally equivalent to 5% of the addressable screen size.*

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 departures of these differences from constancy impact the absolute position of each pixel on the screen and are, 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 Figures II.18-3 and II.18-4.

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

Format	Left Side	Right Side	Top	Bottom
1600 x 1200	0.42%	0.23%	0.40%	0.30%

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

Vertical Lines x-Position (mils)		Horizontal lines y-Position (mils)	
Left Side	Right Side	Top	Bottom
-7669	7711	5842	-5828
-6866	6931	5257	-5250
-6081	6152	4667	-4668
-5307	5369	4076	-4082
-4544	4595	3487	-3496
-3790	3827	2900	-2910
-3038	3063	2318	-2327
-2286	2300	1738	-1744
-1529	1536	1159	-1162
-766	769	579	-580
0	0	0	0

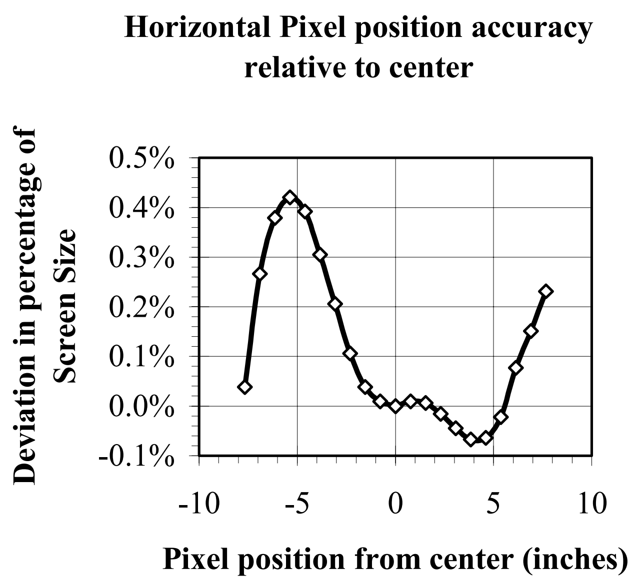


Fig. II.18-3. Horizontal linearity characteristic.

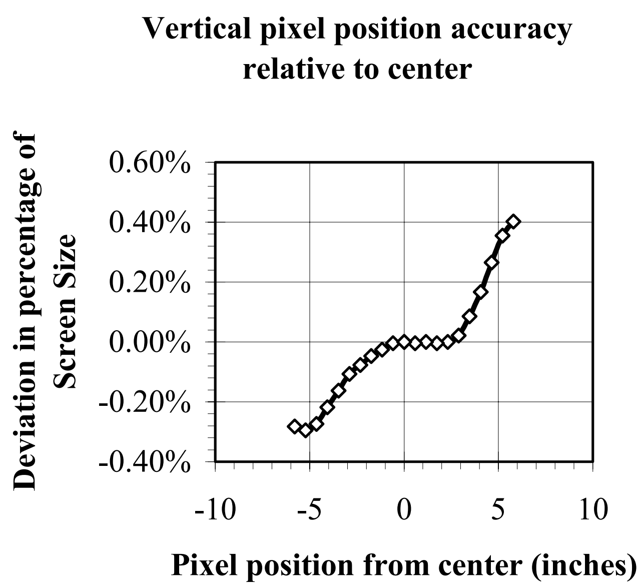


Fig. II.18-4. Vertical linearity characteristic

II.19. Jitter/Swim/Drift

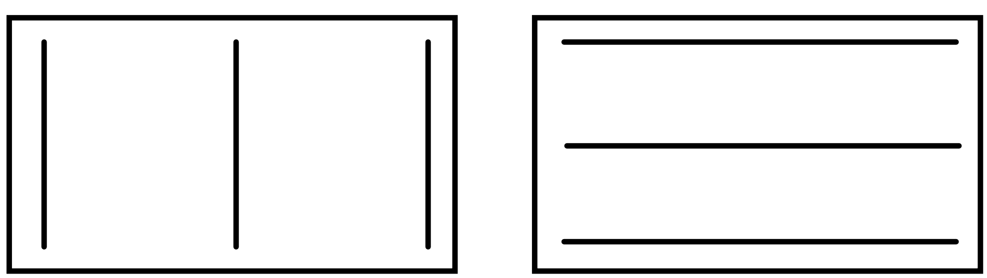
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 6.4, p80.

Maximum jitter and swim/drift was 3.18 mils and 3.89 mils, respectively.

Objective: Measure amplitude and frequency of variations in beam spot position of the CRT display. 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
- 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. It may be necessary to 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. The motion of the test bench was a factor of 10 times smaller than the CRT raster motion.

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

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

1600 x 1200 x 75hz

		H-lines	V-lines	
10D corner	Max Motions			
	Jitter	3.31	3.03	
	Swim	3.82	3.61	
	Drift	4.07	3.65	
Black Tape	Max Motions			
	Jitter	0.129	0.155	
	Swim	0.181	0.178	
	Drift	0.182	0.199	
Less Tape Motion				maximums
	Jitter	3.18	2.88	3.18
	Swim	3.64	3.43	3.64
	Drift	3.89	3.45	3.89

II.20. Warm-up Period

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

A 53 minute warm-up was necessary for luminance to be stable within 10% of Lmin = 0.11 fL

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 (Lmin 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 ± 10% of Lmin.

Data: Pass if Lmin within ± 50% in 30 minutes and ±10% in 60 minutes.

The luminance of the screen (commanded to the minimum input level, 0 for Lmin) was monitored for 120 minutes after a cold start. Measurements were taken every minute. Figure II.20-1 shows the data for 1600 x 1200 format in graphical form. The luminance remains very stable after 53 minutes.

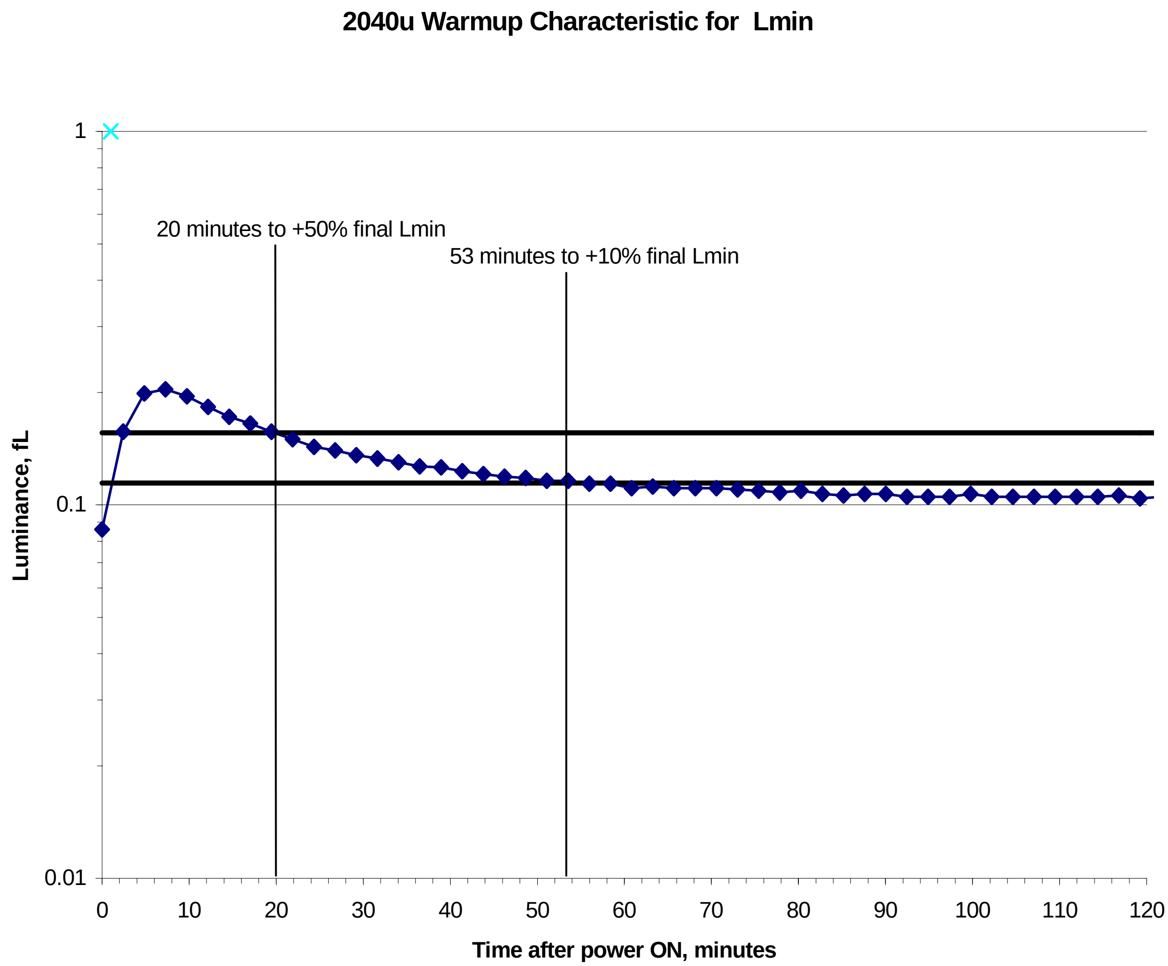


Figure II.20.1. Luminance (fL) as a function of time (in minutes) from a cold start with an input count of 0. (Note suppressed zero on luminance scale).