This evaluation of the AmPro 7400 CRT Light Valve projection system is intended to quantify the performance of the projector as it is used in combination with a Stewart Studiotek 130 projection screen for demonstrating progressively scanned images of 1280 pixels x 1024 lines and 2000 pixels x 1340 lines.

EVALUATION of the AmPro 7400 CRT Light Valve Projector

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at the
Sarnoff Corporation
CN 5300, Princeton, NJ 08543-5300

NIDL Publication No. 021198-059

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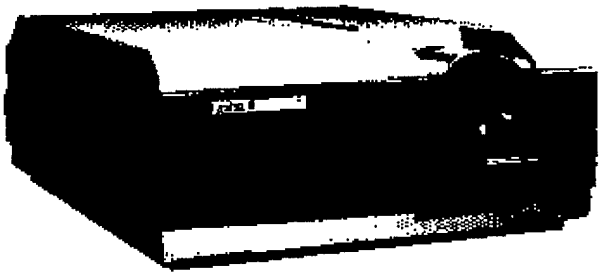

CONTENTS

FOREWORD

On behalf of the government user community, the *National Information Display Laboratory* (NIDL) has prepared this report, which discusses the performance of the following projection display:

AmPro 7400 Projector and Stewart Studiotek 130 Screen

as one in a series of evaluations of projection displays. Such objective evaluations are essential to enable government users to obtain, at reasonable cost, projection displays with the required performance. The following summary pages give the reader an overview of the results.

A document that describes how the ANSI measurements are made, is available from the American National Standards Institute:

- NAPM IT7227-1996 Draft 5, Revision and Redesignation of ANSI Standard No. IT7.215-1992, *For Audiovisual Systems - Data Projection Equipment and Large Screen Data Displays - Test Methods and Performance Characteristics.* American National Standards Institute, 11 West 42nd Street, New York, New York 10036.

Two companion documents that describe other measurement procedures are available directly from the NIDL and may also be accessed on the world wide web at http://www.nta.org/SoftcopyQualityControl/MonitorReports:

- 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, July 12, 1995.*

- 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, July 12, 1995.*

The NIDL procedures were developed in collaboration with the display industry and have been distributed for comments to EIA, ANSI, ASTM, ISO, and VESA Committees and have been exercised by the National Institute of Standards and Technology.

Other procedures are found in a draft standard being developed at the Video Electronics Standards Association:

- VESA FPDM136 Draft #7 Flat Panel Display measurements Standard (Proposal) Version 1.0P, Revision 0.0, November 10, 1997.

Comments, suggestions and questions about this report or the procedures used are welcome and encouraged. Depending on the user's specific application and budget, NIDL would be glad to make a display system recommendation. The NIDL can be reached at:

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COMPLETE SAMPLE SPECIFICATION

According to NAPM IT7227-1996 Draft 5
Revision and Redesignation of ANSI IT7.215-1992

AmPro 7400

Brand		AmPro	
Model		7400 Light Valve	
Specification based on measurements of		July 1997	
		Measured	Advertised
Light output (illuminance)			
	Lens		1.5 : 1
	ANSI Lumens	1861 (average of 9 points)	4000
Aspect ratio		3H:2V (2000 x 1340 format)	
Light output uniformity, Brightest zone		7.4% greater than average	<15%
	Dimmest zone	7.6% less than average	
Contrast ratio (4 x 4 Chessboard)		165 to 1	150 to 1
Blanking time	Horizontal	2.54 µS	
	Vertical	452 µS	
Resolution at light output			
Projector only	Center (measured)	810 horizontal at 82.917 kHz by 560 vertical at 72 Hz	
Frequency response at CRT cathode		Not measured	120 MHz
Response time (10% - 90%)		Not measured	
Input signal compatibility			RGB analog, BNC 75 ohms termination Composite video RS-232 for computer control VGA 15 pin HD
Correlated color temperature		7010 K	
Color chromaticity	White	u' = 0.188 v' = 0.469	
at Screen center	Red	u' = 0.446 v' = 0.529	
	Green	u' = 0.132 v' = 0.573	
	Blue	u' = 0.153 v' = 0.167	
Color uniformity	White	?u' = 0.005 ?v' = 0.005	
relative to average screen		?u'v' = 0.006	
Audio	Power	Not measured	Not specified
	Total harmonic distortion	Not measured	Not specified
Light source		Not measured	1500 Watt Xenon
Power (Input)		Not measured	2760 Watts at 220 VAC
	Input voltage tolerance	Not measured	

NIDL EVALUATION DATASHEET

AmPro 7400 Projector
and
Stewart Studiotek 130 Screen

I. MANUFACTURER'S DATA

Projector Manufacturer and Model	AmPro 7400 Light Valve	
Price	$80,000	
Monochrome or Color	Color	
Screen Manufacturer and Model	Stewart Studiotek 130	
Screen Gain	1.3	
Addressable Pixel Number	1280 x 1024	2000 x 1340
Screen Diagonal (viewable)	78.4 inches	88.0 inches
Horizontal Scan Rate	65 KHz	82.9 KHz
Vertical Scan Rate	60 Hz, progressive	60 Hz, progressive
Viewing position, distance and angle	156 inches, ±9° Vert., ±11° Horiz.	156 inches, ±9° Vert., ±13° Horiz.
Image Size (H x V) viewable	61.25 x 49 inches	73.13 x 49 inches
Pixel Size	47.9 x 47.9 mils	36.6 x 36.6 mils

II. MEASURED PERFORMANCES

A. Performance Related to Illuminance of the Projector Only

Light Output (9-point average)	1642 lumens	1857 lumens
Illuminance Nonuniformity	13% (790 to 904 Lux)	14% (751 to 873 Lux)

B. Performance Related to Luminance of the Image on the Screen

Warmup Time	Not measured	Not measured
Full-Screen Center Minimum Luminance	0.462 fL	0.462 fL
Full-Screen Center Maximum Luminance	92.8 fL	97.57 fL
Full-Screen Center Contrast Ratio	201 : 1	211 : 1
Halation	2.2%	Not measured
Contrast Ratio with Halation (darkroom)	38:1	38:1
Luminance Nonuniformity	39% (57 to 94 fL)	43% (55.6 to 97.6 fL)
Luminance Chessboard Contrast Ratio	165 : 1	161 : 1
CIE 1936 Color Coordinates of white	x = .306, y = .338)	x = .302, y = .335
Color Uniformity of full screen white	.009 ? u'v' units	.008 ? u'v' units
Color tracking of grayscale from 1%Lmax to 100% Lmax	.040 ? u'v' units	.060 ? u'v' units
System Gamma	2.41	2.46
Luminance Stability, 11% to 100% full screen duty factor	3%	Not measured

C. Performance Related to Resolution of the Image on the Screen

NIDL pixels @ 50% Lmax		H-pixels	V-pixels	H-pixels	V-pixels
Text Threshold Cm=50%:	Center	740	494	719	478
	Periphery	569	395	560	397
	Screen avg	588	406	578	406
Imagery Threshold Cm=25%:	Center	1071	783	932	632

Periphery	832	578	767	543
Screen avg	859	601	785	553

AmPro 7400

– PERFORMANCE SUMMARY –

The projector excluding the screen produces light output (illuminance) of 1861 ANSI lumens at 810 x 560 ANSI pixel resolution.

Important performance characteristics of a projection display are resolution and light output. This projector and screen combination, as tested, exhibit the ability to display 39% of the number of pixels being addressed at 1280 x 1024, and 16% of the number of pixels being addressed at 2000 x 1340. A contrast modulation (C_m) of 25% or more is clearly perceivable and appropriate for the display of imagery. A contrast modulation of 50% or more is appropriate for the display of small-size alphanumeric information. Based on contrast modulation measurements for 1-pixel-on/1-pixel-off, 2-on/2-off, and 3-on/3-off patterns displayed at 50% Lmax, the average number of resolvable pixels over the entire screen are determined by linear interpolation to be:

2000 x 1340 Addressability	1280 x 1024 Addressability
• 785 x 553 @ C_m = 25%	• 859 x 601 @ C_m = 25%
• 578 x 406 @ C_m = 50%	• 588 x 406 @ C_m = 50%

SUMMARY COMMENTS ON MEASUREMENTS PERFORMED

1. **Illuminance, Luminance and Chromaticity Uniformity:** The illuminance* measured directly into the projector varies by up to 14% across the image. The full white screen luminance** measured on the projection screen (screen gain = 1.3) varies by up to 43% center to edge. Chromaticity variations ? u'v' across the white full screen were as great as 0.009 units (0.004 is visible) for a horizontal viewing angle of ±11°.

2. **Luminance Stability vs. Fill Factor:** A slight (3%) drop in luminance was measured on the screen when the video fill factor (average picture level) was increased from 11% to 100% full screen.

3. **Contrast Modulation:** For the 2000 x 1340 format, the average contrast modulation for 3-on/3-off white grille patterns at 50% Lmax was 36% x 39% (Horizontal xVertical) for nine sampled screen locations. Contrast modulation for 2-on/2-off grille patterns averaged only 7% x 11% (HxV). Contrast modulation for 1-on/1-off grille patterns was 4% or less, everywhere on the screen.

   For the 1280 x 1024 format, the average contrast modulation for 3-on/3-off white grille patterns at 50% Lmax was 69% x 61% (HxV) over the screen. Contrast modulation for 2-on/2-off grille patterns averaged 38% x 28% (HxV) and averaged 4% x 3% (HxV) for 1-on/1-off grille patterns.

4. **Resolvable pixels:** Based upon the average contrast modulations determined at nine screen locations for 1-on/1-off, 2-on/2-off, and 3-on/3-off grille patterns at 50% Lmax, the number of resolvable pixels is linearly interpolated for C_m values of 25% and 50% to be:

2000 x 1340 Addressability	1280 x 1024 Addressability
• 785 x 553 @ C_m = 25%	• 859 x 601 @ C_m = 25%
• 578 x 406 @ C_m = 50%	• 588 x 406 @ C_m = 50%

5. **Contrast ratio:** Full screen contrast ratio under dark room conditions measured at screen center is 38:1, including halation effects. Based upon the average luminance (in fL) of white and average luminance of dark rectangular targets simultaneously projected in a 4 x 4 chessboard configuration (ANSI IT7.215 test pattern A.3) at 100% Lmax, the display contrast ratio reflected by the projection screen, is 164:1.

6. **System Gamma:** The value found for gamma is 2.4 for white. The whitepoint chromaticity shifted by up to 0.060 ? u'v' units over the full range of grayscale. (A change of 0.004 ? u'v' units is visible.)

7. **Halation:** Halation was only 2.2% on a small black patch surrounded by a large full white area.

Notes:

* Illuminance (lux) refers to luminous flux from the projector. 1 lux = 1 lumen/square meter = 0.0929 footcandle.

** Luminance (fL) is a quantification of the brightness of a surface, in this case, luminous flux per unit solid angle per unit area emitted in a given direction from the surface of the front projection screen. 1 fL = 3.4263 candela per square meter (cd/m^2), 1 cd/m^2 = 1 lumen per steradian per square meter.

Example: A projector illuminance of 300 lux (27.9 footcandle) will lead to a screen luminance of 27.9 fL (95.6 candela per square meter), assuming the screen scatters light uniformly in all directions and does not absorb any light, i.e., screen gain = 1.

Section I
INTRODUCTION

The present study evaluates a production unit of the *AmPro 7400* high-resolution color CRT-addressed LCD light valve projector and *Stewart Studiotek 130* projection screen. Only photometric measurements were performed on this system. The primary emphasis of the measurements is the determination of the contrast modulation of the display for on/off grille patterns. In turn, the contrast modulation measurements provide an estimate of the number of resolvable pixels that are displayed on the projection screen. The number of *resolvable* pixels is typically less than the addressability of the display, which is the number of positions that are electronically *addressed.*

We provide below a description of the display that was evaluated and the details of the setup procedures used to prepare the display for measurement. Section II presents the data and results of the photometric measurements. Section III completes the report with analyses of the measurements and final conclusions.

The procedures and calibrations used in the measurements are detailed in the following ANSI standard:

> NAPM IT7227-1996 Draft 5, Revision and Redesignation of ANSI Standard IT7.215-1992, *For Audiovisual Systems - Data Projection Equipment and Large Screen Data Displays - Test Methods and Performance Characteristics.* American National Standards Institute, 11 West 42nd Street, New York, New York 10036.

Other procedures used are found in NIDL documents:

> 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,* July 12, 1995.

and

> 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,* July 12, 1995.

Other procedures are found in a draft standard currently being developed at the Video Electronics Standards Association:

> VESA FPDM136 Draft #7 Flat Panel Display measurements Standard (Proposal) Version 1.0P, Revision 0.0, November 10, 1997.

A. The AmPro 7400

The projection system was set up with the following photometric and electrical parameters to display images:

1. Set-up parameters for 2000 x 1340 Addressable Pixels

Photometric Parameters:

- Display format is addressable pixels.
- Raster size is 73.13 x 49 inches
- Addressable pixel size is 36.6 x 36.6 mils.
- Full screen luminance of white is 97.57 fL at screen center.
- Full screen luminance of black is 0.462 fL at screen center.

Electrical Parameters:

- Line rate is 82.917 kHz.
- Frame rate is 59.998 Hz, progressive (non-interlaced).
- Video data rate is 209.117 MHz
- Pixel time is 4.782 nsec.
- Horizontal blanking time is 2.536 μS.
- Vertical blanking time is 452 μS.

2. Set-up parameters for 1280 x 1024 Addressable Pixels

Photometric Parameters:

- Display format is addressable pixels.
- Raster size is 61.25 x 49 inches
- Addressable pixel size is 47.9 x 47.9 mils.
- Full screen luminance of white is 92.8 fL at screen center.
- Full screen luminance of black is 0.462 fL at screen center.

Electrical Parameters:

- Line rate is 65.000 kHz.
- Frame rate is 60.018 Hz, progressive (non-interlaced) .
- Video data rate is 97.890 MHz.
- Pixel time is 10.215 nsec.

B. INITIAL DISPLAY SETUP

The display was set up in NIDL's display measurement facility using numerous controls accessible to the user on the menu driven remote control provided with the projector. A representative of AmPro performed the setup procedure and certified that the adjustments were in accordance with their specifications. *Brightness* and *Contrast* controls were adjusted to achieve visually distinguishable steps at both low and high luminance levels of the SMPTE RP-133 gray-scale test pattern. Other adjustments were made by the AmPro representative using the remote keypad: *Zone Dynamic Convergence*, *Zone Dynamic Luminance and Color*, *Linearity*, *Size*, *Trapezoid*, *Pincushion*, and *Zone Dynamic Focus*.

With the screen commanded to black (zero count level), the background raster, Lmin, was measured to be 0.5fL. Then, with the screen commanded to full white (255 count level), the maximum luminance, Lmax, was measured to be 100fL at screen center. Full correction of luminance uniformity was not possible within the limited range of the available dynamic zone correction.

All photometric measurements are taken from the a single viewing direction as depicted in Fig. II-1 instead of from infinity. Spatial resolution measurements were taken directly into the projector lens for the ANSI pixel measurements.

Section II
COLORIMETRIC MEASUREMENTS

Reference: Color CRT Monitor Performance, Draft Version 2.0 Section 3.0, page 9.
ANSI Standard No. NAPM IT7.227-1996 and IT.215-1992.

Instruments used in these measurements included:

- Photo Research SpectraScan PR-704 spectroradiometer, 0.5° aperture
- Photo Research Pritchard-1980A-CD photometer , 1° aperture
- Microvision Superspot 100 Display Characterization System with OM-1 optic module (linear photodiode array with photopic filter) imaging through a Canon TV Zoom lens, No. 11307, 1:2.8, V10 x 15, 150mm aperture (variable 15 - 150mm), f = 5.6 (variable), focal length 12 ft.
- Graseby Optronics S370 Optometer with Model 268P illuminance sensor.
- Quantum Data 8701 test pattern generator, 400 MHz pixel-rate

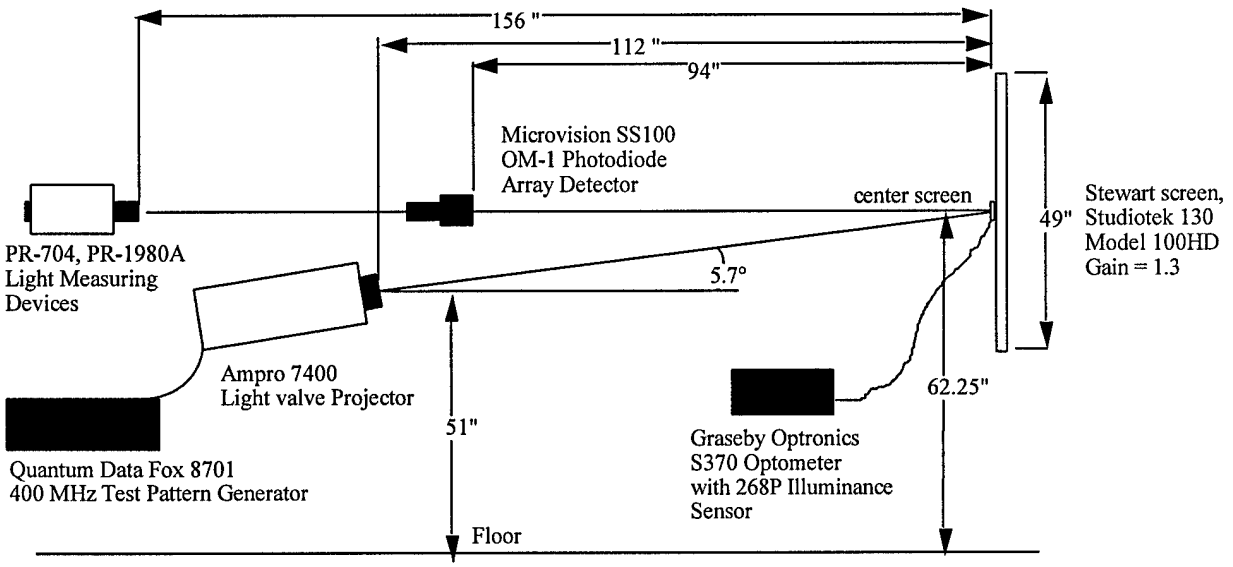


Fig. II-1. Test set up.

A. ILLUMINANCE, LUMINANCE AND CHOMATICITY UNIFORMITY

Reference: Color CRT Monitor Performance, Version 2.0 Section 4.4, page 11.
ANSI Standard No. NAPM IT7.227-1996 and IT7.215-1992.

The illuminance varies by up to 14% across the screen. The full screen luminance varies by up to 43% across the screen at the highest luminance setting. Chromaticity variations, ?u'v' across a white full screen were as great as 0.009 units (0.004 is visible).

Illuminance measured according to the ANSI procedure yielded a 9-point average of 1861 ANSI lumens with a variation of 7.4% greater than average, and 7.6% less than average for the thirteen ANSI screen locations shown in Figure II.A-1.

Illuminance, luminance and chromaticity coordinate measurements were taken at nine screen positions shown in Figure II.A-2 for the maximum luminance for a full white field and at five screen positions for the Quantum Data "Brightness" test pattern. The data for 2000 x 1340 are shown in Table II.A-1 and in the Figures II.A-3 through II.A-5. The data for 1280 x 1024 are shown in Table II.A-2 and in the Figures II.A-6 through II.A-8.

For both test patterns, the center position showed the highest illuminance. The center to edge variation in screen illuminance was not found to be dependent on the test pattern. For both the full white screen test pattern and the "Brightness" test pattern, the maximum variation in illuminance was found to be 14%.

From a single viewing point, the entire screen is contained within ±9° vertically and ±11° horizontally. The variation in full white illuminated projection screen with gain of 1.3 (specified by the manufacturer) was found to be as much as 43% compared to 44% for the lower duty cycle "Brightness" test pattern.

With the "Brightness" test pattern displayed at the highest luminance level measured, the largest departures from the chromaticity of the center occurred at the top-right corner position and reached 0.0135 ?u'v' units. The results are shown in Fig. II.A-8 in terms of the chromaticity error.

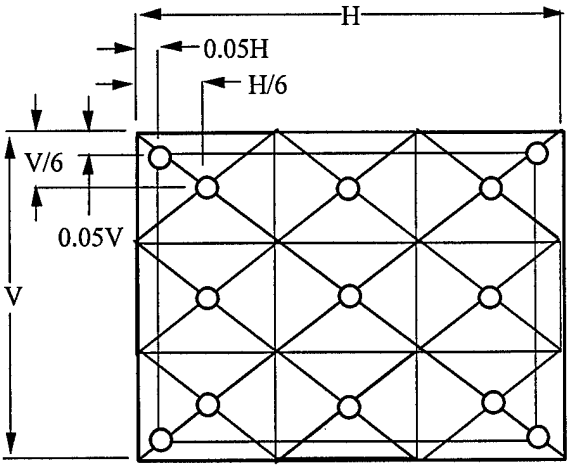


Fig. II.A-1 ANSI screen locations for measurement of light output in ANSI lumens.

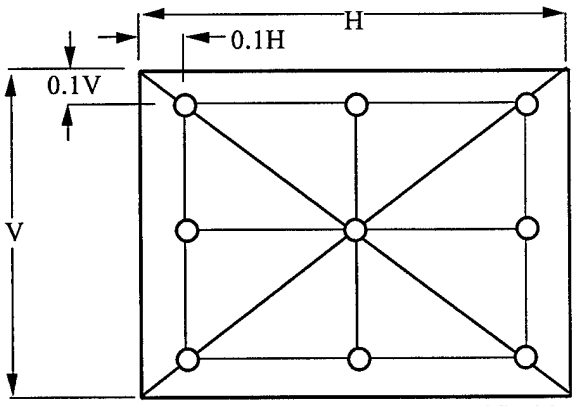


Fig. II.A-2 Nine screen locations specified in ISO, IEC, ANSI-HFES, EIAJ, and VESA standards for measurement of spatial uniformity of illuminance, luminance and chromaticity.

Table II.A-1. Spatial Uniformity of Luminance and Color for 2000 x 1340 Format

Illuminance (in Lux) and luminance (in fL) taken at five and nine screen positions for 100% Lmax.

FOX "Brightness" test pattern

Illuminance of projector (in Lux)		
790		710
	815	
835		710

Luminance from screen (in fL)		
60.2		56.06
	100.1	
70.42		63.15

Full Screen

Illuminance (in Lux) for white		
814	873	781
780	815	770
814	830	751

Luminance (in fL) of white		
59.2	72.42	55.65
65.9	97.57	60.66
68.45	93.59	62.76

Illuminance (in Lux) for black		
3.6	3.9	3.8
3.5	3.8	3.5
4.9	4.0	5.5

Luminance (in fL) of black		
369	342	341
278	462	307
517	452	598

Illuminance contrast ratio for full screen		
229	225	206
224	217	222
165	208	136

Luminance contrast ratio for full screen		
160	212	163
237	211	198
132	207	105

Illuminance* of Projector for full white

min	751 lux
max	873 lux
uniformity (relative to center)	14%
Avg. screen	803 lux
Screen area	2.31 square meters
Avg. Luminous flux	1857 lumens
ANSI Lumens	1861 +7.4%,-7.6%

Luminance of Screen for full white**

min	55.65 fL
max	97.57 fL
uniformity (relative to center)	43%
Avg screen	70.69 fL
Screen gain	1.3
Viewing angle	±7° vertical ±11° horizontal

Notes:

* Illuminance (lux) refers to the amount of light falling upon a surface, in this case, luminous flux from the projector incident on the surface per unit area of the front projection screen. 1 lux = 1 lumen/square meter = 0.0929 footcandle.

** Luminance (fL) is a quantification of the brightness of a surface, in this case, luminous flux per unit solid angle per unit area emitted in a given direction from the surface of the front projection screen. 1 fL = 3.4263 candela per square meter (cd/m^2), 1 cd/m^2 = 1 lumen per steradian per square meter.

Example: A projector illuminance of 300 lux (27.9 footcandle) will lead to a screen luminance of 27.9 fL (95.6 candela per square meter), assuming the screen scatters light uniformly in all directions and does not absorb any light.

AmPro 7400 projector and Stewart Studiotek 130 projection screen

2000 x 1340

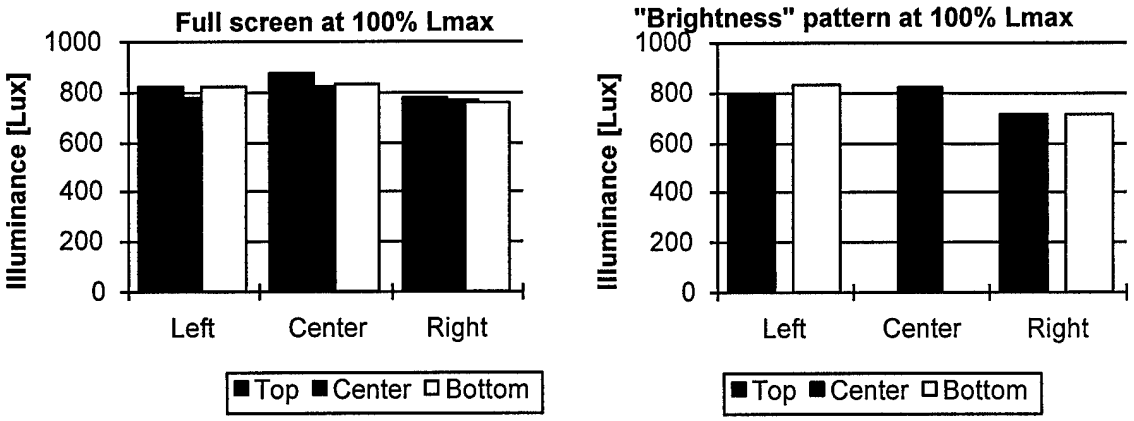


Fig. II.A-3 Spatial Uniformity of Illuminance.

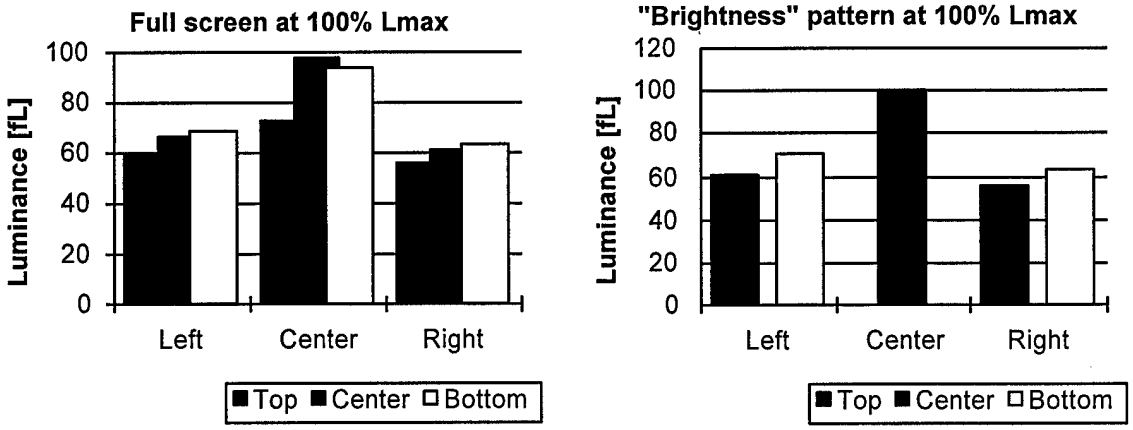


Fig. II.A-4 Spatial Uniformity of Luminance

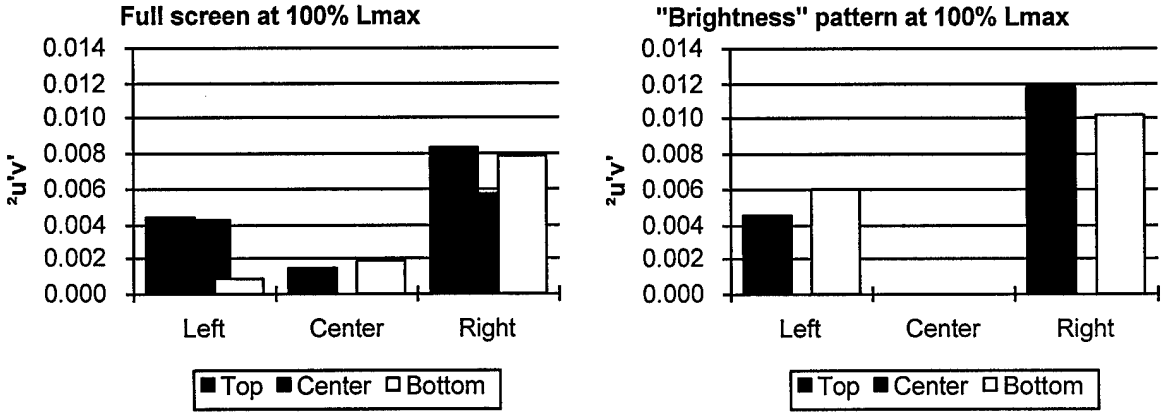


Fig. II.A-5 Spatial Uniformity of Color (vs. Center)
A chromaticity error, ?u'v', of 0.004 is visible.

Table II.A-2. Spatial Uniformity of Luminance and Color for 1280 x 1024 Format

Illuminance (in Lux) and luminance (in fL) taken at five and nine screen positions for 100% Lmax.

FOX "Brightness" test pattern

Illuminance of projector (in Lux)

-	-	-
-	-	-
-	-	-

Luminance from screen (in fL)

62.42		56.04
	95.42	
70.00		61.07

Full Screen

Illuminance (in Lux) for white

841	895	805
835	905	805
858	897	790

Luminance (in fL) of white

64.08	73.95	57.00
71.87	92.79	64.05
71.42	94.01	62.7

Illuminance (in Lux) for black

3.9	4.1	4.4
3.5	4.4	3.9
5.0	4.3	6.0

Luminance (in fL) of black

307.4	329.3	330.9
309.3	462.4	310.5
450.8	416.4	476.9

Illuminance contrast ratio for full screen

217	218	182
238	208	206
172	206	131

Luminance contrast ratio for full screen

208	225	172
232	201	206
158	226	131

Illuminance of Projector

min	790 lux
max	905 lux
uniformity (relative to center)	13%
Avg screen	848 lux
Screen area	1.94 square meters
Luminous flux	1642 lumens

Luminance of Screen

min	57 fL
max	94.01 fL
uniformity (relative to center)	39%
Avg screen	72.43 fL
Screen gain	1.3
Viewing angle	±7° vertical ±9° horizontal

AmPro 7400 projector and Stewart Studiotek 130 projection screen

1280 x 1024

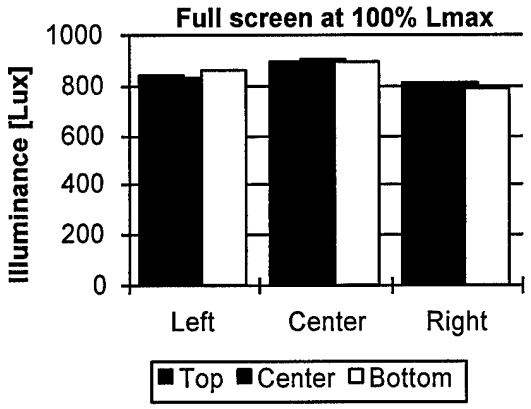


Fig. II.A-6 Spatial Uniformity of Illuminance.

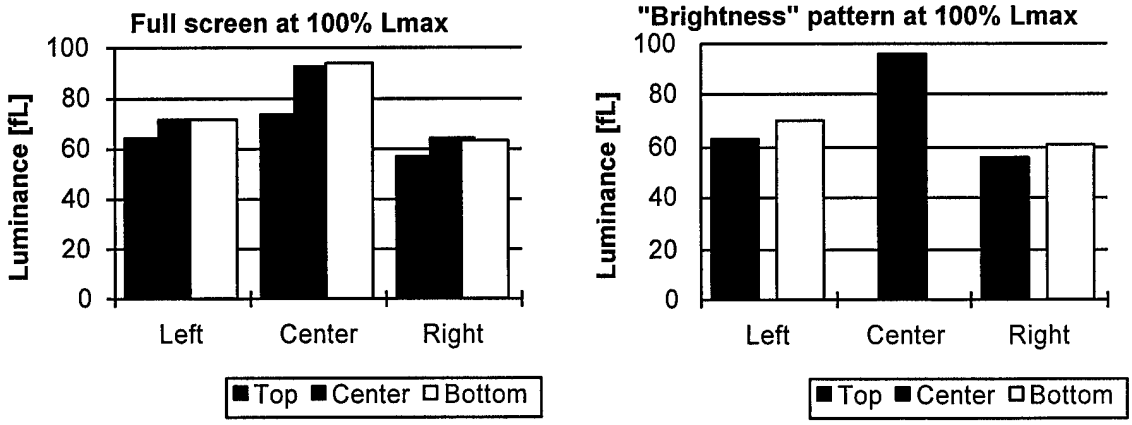


Fig. II.A-7 Spatial Uniformity of Luminance

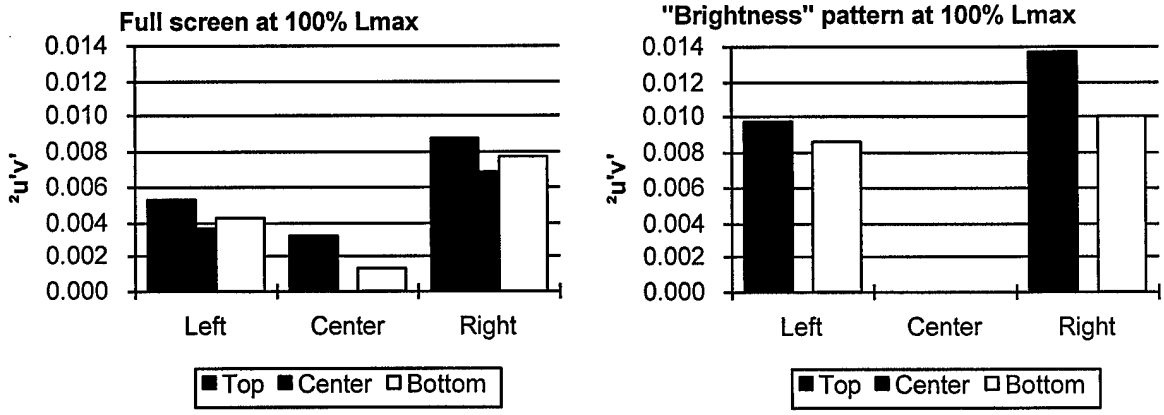


Fig. II.A-8 Spatial Uniformity of Color (vs. Center).
A chromaticity error, ?u'v', of 0.004 is visible.

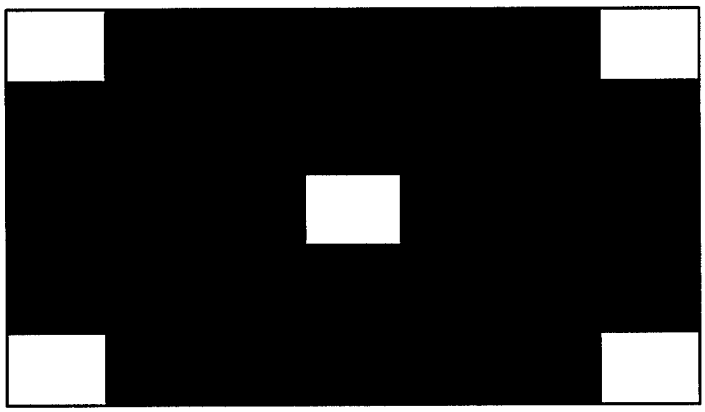
B. LUMINANCE STABILITY VS. FILL FACTOR

Reference: Color CRT Monitor Performance, Draft Version 2.0 Section 4.3, page 11.

There is only a 3% change in luminance with increasing fill factor from 11% to full screen.

Center screen luminance was measured for white patches on a black background (Quantum Data "Brightness" test pattern) and for the full screen. The change in center screen luminance with increasing fill factor (increasing percentage of screen that is white) is quite small, less than 3%.

73" x 49" active projected image



9.8" x 8.25" white targets, 5 places

Fig. II.B-1 Quantum Data "Brightness" test pattern with 11% duty factor depicted as projected onto the Stewart Studiotek 130 screen using the AmPro 7400 projector.

C. CONTRAST MODULATION

Reference: Color CRT Monitor Performance, Draft Version 2.0 Section 5.2, page 23.

For the 2000 x 1340 format, the average contrast modulation for 3-on/3-off white grille patterns at 50% Lmax was 36% x 39% (Horizontal xVertical) for nine sampled screen locations. Contrast modulation for 2-on/2-off grille patterns averaged 7% x 11% (HxV) and was 4% or less for 1-on/1-off grille patterns.

For the 1280 x 1024 format, the average contrast modulation for 3-on/3-off white grille patterns at 50% Lmax was 69% x 61% (HxV). Contrast modulation for 2-on/2-off grille patterns averaged 38% x 28% (HxV) and averaged 4% x 3% (HxV) for 1-on/1-off grille patterns.

Contrast modulation was measured in both horizontal and vertical directions at nine screen positions for white in two formats, 2000 x 1340 and 1280 x 1024. The screen luminance was commanded to 50% maximum level. Four video modulation frequencies were examined using full screen grille test patterns consisting of alternating lines with n pixels on, n pixels off (n=1,2,3,4).

The contrast modulation for white grilles at screen center, and averaged over the eight peripheral screen positions, for 2000 x 1340 and 1280 x 1024 formats are presented graphically in Figures II.C-1 and II.C-2.

The 2000 x 1340 data is listed in Table II.C-1. The contrast modulation, C_m, is reported (the defining equation is given in the Table). For horizontal and vertical 3-on/3-off grilles the C_m is generally good (ranging from 26% to 56%, with only one exception at the bottom-right corner screen point) and the grilles are readily resolved over the entire screen. For the 2-on/2-off grille patterns, the modulation dropped as low as 2%. Contrast modulation (HxV) for 1-on/1-off grille patterns was only 4% or less at each of the nine screen locations including the center.

The 1280 x 1024 data is displayed in Table II.C-2. For horizontal and vertical 3-on/3-off grilles the C_m is generally quite high (ranging from 49% to 85%, and the grilles are readily resolved over the entire screen. For the 2-on/2-off grille patterns, the modulation dropped as low as 13%. Contrast modulation (HxV) for 1-on/1-off grille patterns was only 9% or less at each of the nine screen locations including the center.

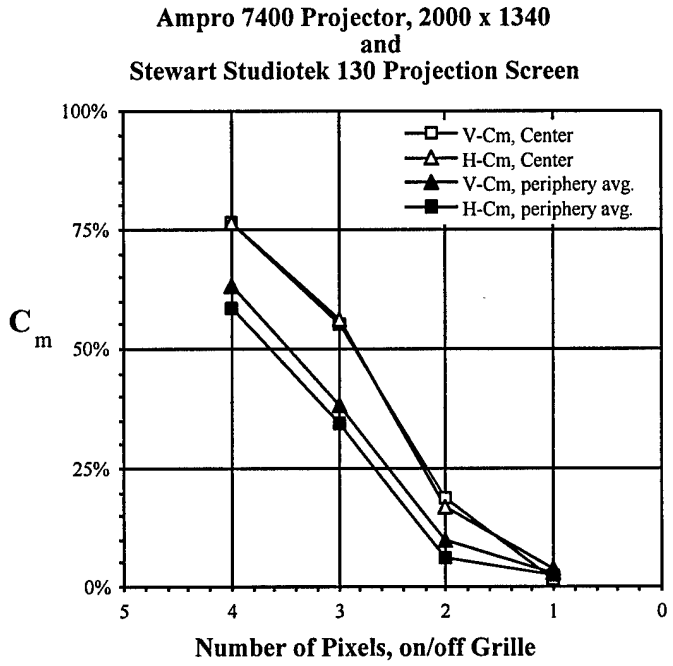


Fig. II.C-1 Plot of contrast modulation of white grilles at screen center obtained from test results for 2000 x 1340 format.

Table II.C-1. Contrast Modulation

Contrast Modulation (in %) at nine screen positions for four frequencies.

$C_m = (L_{peak} - L_{valley})/(L_{peak} + L_{valley})$

Screen positions as indicated by position of data on page.

n x n indicates lines n pixels wide separated by n-pixel spaces (n-on / n-off).

Microvision OM-1 optic module used with Canon TV Zoom lens.

H = modulation in horizontal direction (vertical bars); V= modulation in vertical direction (horizontal bars).

C_m (%) - White at 50% Lmax for 2000 x 1340 Format

Screen luminance at 50% Lmax.

n x n	Hgrille V-Cm	Vgrille H-Cm	Hgrille V-Cm	Vgrille H-Cm	Hgrille V-Cm	Vgrille H-Cm
4	60%	59%	64%	68%	55%	53%
3	33%	35%	39%	41%	28%	28%
2	10%	5%	12%	7%	6%	5%
1	4%	2%	2%	3%	4%	4%
4	70%	64%	77%	76%	69%	49%
3	48%	38%	55%	56%	47%	29%
2	15%	6%	19%	17%	12%	5%
1	1%	1%	2%	4%	4%	3%
4	63%	71%	68%	69%	56%	36%
3	40%	45%	44%	45%	26%	16%
2	10%	8%	13%	11%	4%	2%
1	3%	1%	2%	1%	2%	2%

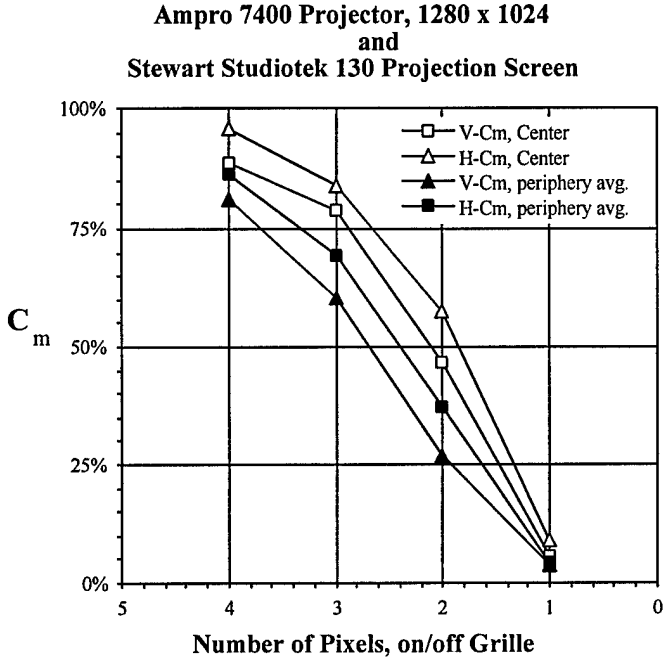


Fig. II.C-2 Plot of contrast modulation of white grilles at screen center obtained from test results for 1280 x 1024 format.

Table II.C-2. Contrast Modulation

Contrast Modulation (in %) at nine screen positions for four frequencies.

$C_m = (L_{peak} - L_{valley})/(L_{peak} + L_{valley})$

Screen positions as indicated by position of data on page.

n x n indicates lines n pixels wide separated by n-pixel spaces (n-on / n-off).

Microvision OM-1 optic module used with Canon TV Zoom lens.

H = modulation in horizontal direction (vertical bars); V= modulation in vertical direction (horizontal bars).

Cm (%) - White at 50% Lmax for 1280 x 1024 Format

n x n	Hgrille V-Cm	Vgrille H-Cm	Hgrille V-Cm	Vgrille H-Cm	Hgrille V-Cm	Vgrille H-Cm
4	74%	83%	81%	96%	73%	83%
3	49%	65%	57%	85%	50%	63%
2	17%	29%	27%	57%	13%	32%
1	2%	3%	4%	7%	4%	4%
4	88%	89%	89%	96%	92%	80%
3	71%	73%	79%	84%	74%	58%
2	40%	40%	47%	58%	38%	25%
1	4%	2%	6%	9%	4%	4%
4	81%	87%	88%	95%	73%	76%
3	63%	71%	71%	83%	50%	56%
2	27%	34%	36%	56%	17%	23%
1	2%	4%	4%	8%	5%	2%

D. CONTRAST RATIO

Reference: ANSI Standard No. IT7.227 and IT7.215.

Full screen luminance contrast ratio is 38:1 at screen center, including halation effects under dark room conditions. The average luminance contrast ratio for 4 x 4 chessboard patterns displayed at 100% Lmax was 163:1 over the projection screen.

Luminance was measured in both horizontal and vertical directions at 16 screen positions for white and black rectangular targets simultaneously displayed in a 4 x 4 chess board configuration as specified by ANSI IT7.215. The screen luminance was commanded to 100% maximum level.

The data is displayed in Table II.D-1. The contrast ratio, CR is reported (the defining equation is given in the Table).

Contrast ratio computed from measurements made under dark room conditions for full screen white (97.57 fL) and black (0.462 fL) is reduced from 211:1 to 38:1 when halation effects of 2.2% are included.

2000 X 1340

Table II.D-1. Contrast Ratio = (L_{white} / L_{black})

Screen positions as indicated by position of data on page.

ANSI Chessboard Luminance (in fL) Includes projection screen.

64.7	0.30	70.7	0.33
0.29	92.54	0.46	65.51
79.42	0.72	96.77	0.45
0.80	99.98	0.62	68.04

	Luminance of projector and screen
Avg white	79.7 fL
Avg black	0.496 fL
Avg CR	161
Min black	0.29 fL
Max black	0.80 fL
Nonuniformity	64%
Min white	64.7 fL
Max white	100.0 fL
Nonuniformity	35%
Min CR	81
Max CR	345
Nonuniformity of CR	77%

1280 X 1024

Table II.D-2. Contrast Ratio = (L_{white} / L_{black})

Screen positions as indicated by position of data on page.

ANSI Chessboard Luminance (in fL) Includes projection screen.

66.8	0.26	71.9	0.879
0.263	89.1	0.442	65.4
78.5	0.596	95.3	0.294
0.562	95.9	0.511	66.1

	Luminance of projector and screen
Avg white	78.6 fL
Avg black	0.476 fL
Avg CR	165
Min black	0.26 fL
Max black	0.88 fL
Nonuniformity	70%
Min white	65.39 fL
Max white	95.9 fL
Nonuniformity	32%
Min CR	74
Max CR	369
Nonuniformity of CR	80%

E. SYSTEM GAMMA

Reference: Color CRT Monitor Performance, Version 2.0 Section 4.2, page 11.

The value found for gamma of white is 2.41 to 2.46 . The whitepoint chromaticity shifted by up to 0.060 ? u'v' units over the full range of grayscale. (A change of 0.004 ? u'v' units is visible.)

Luminance at center screen for a 100% full screen size box was measured for twenty different input voltage levels ranging from 0 to 255 digital counts. Table II.E-1 shows the data. Figures II.E-1 and II.E-2 illustrate the white luminance and chromaticity data, respectively. The system gamma is defined as the slope of the curve in the log-log plot. Since the curve is nonlinear, a unique value of gamma does not exist. A single value was derived for the high-end luminance range.

The gamma value obtained for white in 2000 x 1340 format was 2.46 from about 0.4926 to 89.44 fL (23 to 255 counts). The gamma value obtained for the 1280 x 1024 format was 2.41.

The maximum grayscale shift in chromaticity of the whitepoint occurred for 2000 x 1340 format around 3% Lmax (2.7 fL) and exceeded 0.060 ? u'v' units relative to 100% Lmax (89 fL). ? u'v' of 0.004 units is visible.

Table II.E-1. System Gamma

Luminance (in fL) of projector and screen at center screen as a function of input counts.

Input level Counts	Full Screen 2000 x 1340 L (fL)	CIE x	CIE y	CCT °K	Full Screen 1280 x 1024 L (fL)	CIE x	CIE y	CCT °K
Black, 0	.3823	.2605	.2973	11755	.3746	.2647	.2998	11079
1	.3770	.2620	.2983	11489	.3774	.2654	.2999	10987
2	.3806	.2623	.2981	11466	.3797	.2664	.2998	10872
3	.7794	.2614	.2978	11601	.3844	.2663	.2994	10912
7	.3895	.2615	.2963	11788	.3942	.2675	.2977	10889
15	.4185	.2603	.2921	12233	.4322	.2708	.2945	10714
23	.4926	.2589	.2859	13101	.5338	.2773	.2917	10161
31	.6147	.2560	.2759	15119	.7105	.2826	.2869	9849
39	.8424	.2555	.2652	17674	1.048	.2896	.2832	9272
47	1.217	.2570	.2561	20378	1.533	.2875	.2761	9920
63	2.740	.2583	.2477	24377	3.780	.2876	.2762	9907
79	5.902	.2629	.2545	18602	7.79	.2821	.2772	10530
95	10.93	.2644	.2632	15664	13.56	.2787	.2805	10735
111	17.51	.2668	.2718	13545	21.27	.2786	.2884	10218
127	25.43	.2701	.2820	11794	29.23	.2791	.2929	9900
143	33.00	.2724	.2875	11033	37.29	.2801	.2970	9581
159	41.14	.2752	.2941	10250	45.4	.2814	.3001	9320
191	58.03	.2810	.3034	9220	63.85	.2876	.3098	8447
223	76.04	.2925	.3211	7817	80.11	.2978	.3252	7401
White, 255	89.44	.3024	.3348	7010	92.38	.3062	.3380	6773
Red, 255	16.46	.6462	.3409	n.a.	16.97	.6475	.3400	n.a.
Green, 255	67.04	.3282	.6331	n.a.	68.25	.3333	.6291	n.a.
Blue, 255	7.575	.1347	.0651	n.a.	9.834	.1302	.0761	n.a.

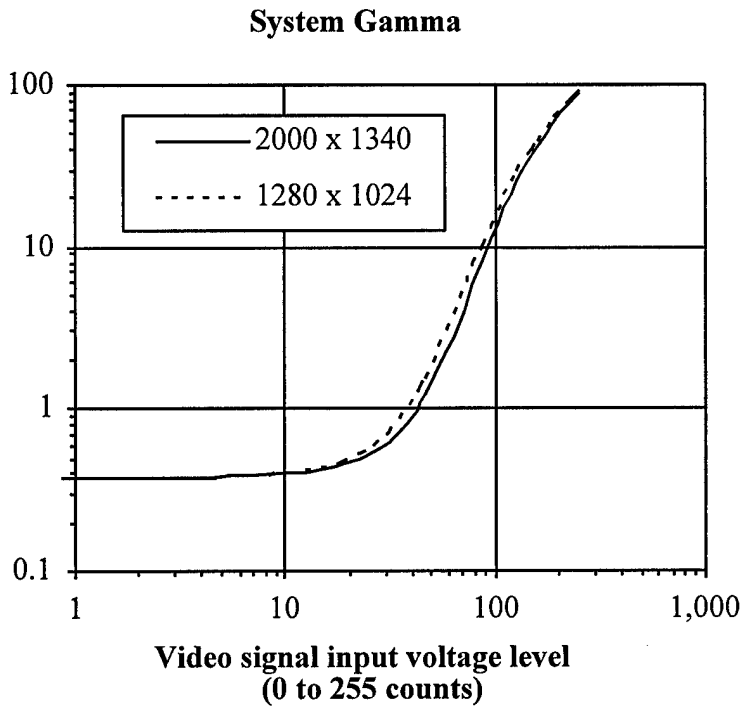


Fig. II.E-1. Log-log plot of input counts versus luminance for a white full screen.

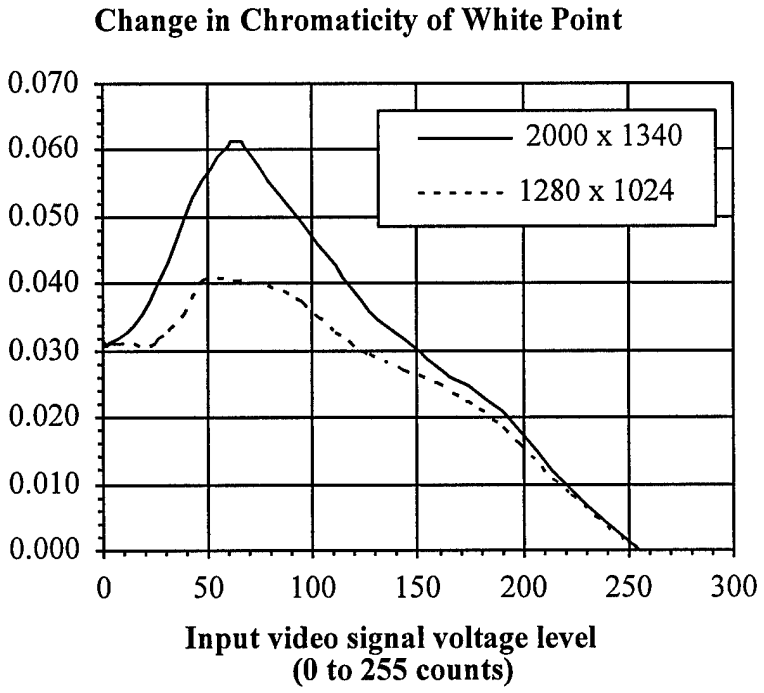


Fig. II.E-2. Plot of input counts versus chromaticity shift in ?u'v' units relative to white full screen at Lmax (input count 255).

F. HALATION

Reference: Color CRT Monitor Performance, Draft Version 2.0 Section 4.6, page 16.

Halation was only 2.2% on a small black patch surrounded by a large full white area.

Halation is the phenomenon by which the luminance of a given region of the screen is improperly increased by contributions from surrounding more luminous areas. Sources of halation include light scattering within the CRT phosphor layer and internal reflections inside the glass faceplate and the projector lens assembly. Halation is undesirable as it degrades the contrast of displays.

Halation is determined by measuring the luminance, L_b, of a small (50 pixels wide, approximately 0.2% of the screen area) square commanded to L_{min} when surrounded by an otherwise full white screen (1280 x 1024 pixels) commanded to L_{max}. In this case, full screen L_{max} is equal to 97 fL while full screen L_{min} is only 0.4 fL. Halation is then defined numerically as:

$$\% \, Halation = 100 \, x \, (L_b - L_{min}) / L_{max},$$

where L_{max} is the full screen white luminance, L_{min} is the full screen black luminance, and L_b is the measured luminance of the small square when the surrounding image area is commanded to white at L_{max}.

The measured data and derived values of halation are presented in Table II.K-1. The luminance of the small black square is seen to increase by 2.2% of L_{max} when the remaining portion of the screen displays L_{max}.

Table II.K-1. Halation

Lmin(fL)	Lmax (fL)	Lb(fL)	% Halation
0.406	97.17	2.507	2.2

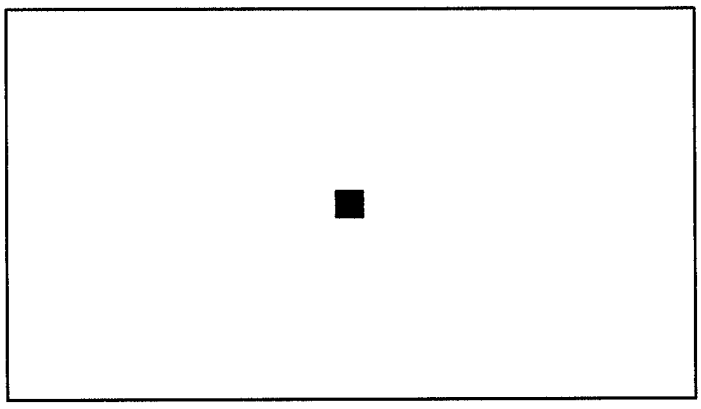


Fig. II.F-1. Halation test pattern: 50-pixel wide black square approximately 0.2% of the total image area on full white background of 1280 x 1024 pixels.

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Section III
ANALYSIS AND CONCLUSIONS

The most important performance characteristic of a projection display is resolution. Measures of resolution are the contrast modulation at the stated addressability and the number of resolvable pixels. At its tested addressability of 2000 x 1340 pixels, the AmPro 7400 projector and Stewart Studiotek 130 projection screen achieves a nine-point average white contrast modulation of less than 4% everywhere on the screen. Using linear interpolation and the contrast modulation measurements for 1-on/1-off, 2-on/2-off, and 3-on/3-off patterns, the number of resolvable pixels at 50% Lmax is:

2000 x 1340 addressability	1280 x 1024 addressability
• 785 x 553 @ C_m = 25%	• 859 x 601 @ C_m = 25%
• 578 x 406 @ C_m = 50%	• 588 x 406 @ C_m = 50%

A contrast modulation of 25% or more is clearly perceivable and appropriate for the display of imagery. A contrast modulation of 50% or more is appropriate for the display of small-size alphanumeric information.

For 2000 x 1340 format, the 3-on/3-off grilles (horizontal and vertical, of Table II.C-1) exhibited measured C_m values exceeding 25% in most places, showing that information at these frequencies is definitely resolved. For the white 2-on/2-off grilles, the Cm values fall below 10% in many areas.

A potential contribution to the loss of contrast modulation is misconvergence. The principal effect of misconvergence is the effective broadening of white lines. The misconvergence of the AmPro 7400 projected image was visually assessed to be on the order of less than one pixel size (36.6 x 36.6 mils) at all locations on the screen. Misconvergence >1.5 to 2 pixels can significantly degrade resolution. Misconvergence < 1.0 pixel is typically not an important factor because the relative perceived luminosities of red and blue are considerably less than that of green.

APPENDIX A
DEFINITIONS - MEASUREMENT TERMS

Addressability: Measure of the accuracy with which an electron beam spot is placed at discrete positions on the screen. The inter-pixel distance [TEP 192]. Defines how precisely one can position the electron beam spot on the screen.

ANSI Lumen Quantification of visible light power (in lumens) of a projection display, defined in ANSI standard IT7.228 as the average of nine illuminance values in lux measured at specified locations within the projected image area, multiplied by the area of the image in square meters.

ANSI Pixel Quantification of display resolution in pixels of a projection display, defined in ANSI standard IT7.228 as the highest spatial frequency (or greatest number of pixels) which does not degrade modulation depth below 30% of the low-frequency modulation depth, specifically that of the 4 x 4 checkerboard pattern. The modulation depth is defined in IT7.228 as the (peak - valley) luminance of a 1-on/1-off grille relative to the average (white - black) luminance of the ANSI large-area 4 x 4 checker board test pattern.

Chromaticity Uniformity Measure of how chromaticity vary across the screen. Chromaticity should be as uniform as possible.

Contrast Modulation (Cm): A measure of relative luminances, L_{peak}, L_{valley}, over a distance of multiple cycles of high and low states in a displayed grille test pattern.

Monitors with contrast modulation greater than 25% are generally acceptable for the display of images while the display of text generally calls for contrast modulation greater than 50%.

Contrast Ratio (CR) The ratio of a higher luminance to a lower luminance.

Convergence: Measure of the separation in landing positions of separate beams directed toward the same point on the screen. The main misconvergence errors involve blue-to-red separations and green-to-red-blue-average separations (coma), and are measured in both horizontal and vertical directions. Misconvergence errors exceeding pixel size degrade contrast modulation and may cause spurious color fringes at edges in images.

Halation Phenomenon by which the luminance of a given region of the screen is improperly increased by contributions from surrounding more luminous areas. Sources of halation include light scattering within the CRT phosphor layer and internal reflections inside the glass faceplate and the projector lens assembly. Halation is undesirable as it degrades the contrast of displays.

Illuminance	Refers to the amount of light falling upon a surface, in this case, luminous flux from the projector incident on the surface per unit area of the front projection screen. 1 lux = 1 lumen/square meter = 0.0929 footcandle.
Luminance	A quantification of the brightness of a surface, in this case, luminous flux per unit solid angle per unit area emitted in a given direction from the surface of the front projection screen. 1 fL = 3.4263 candela per square meter (cd/m^2), 1 cd/m^2 = 1 lumen per steradian per square meter.
Minimum Luminance (Lmin	Luminance of the display screen when the input signal corresponding to that portion of the screen is at the lowest level, e.g., level 0 for an 8-bit display.
Maximum Luminance (Lmax)	Luminance of the display screen when the input signal corresponding to that portion of the screen is at the highest level, e.g., level 255 for an 8-bit display.
Luminance Stability	Measure of variation in luminance as a function of the fraction of screen area that is being lit (i.e., the fraction of the frame time in which the electron beam is actually turned on).
Luminance Uniformity	Measure of how luminance varies across the screen. Luminance should be as uniform as possible.
Resolution:	Measure of the ability to delineate picture detail; i.e., ability to distinguish two adjacent spots on the screen.
Screen Gain	The ratio of the reflected or transmitted luminance of a projection screen to the luminance of a Lambertian reflector which reflects all of the incident light uniformly in all directions. Screen gain is usually specified for the viewing angle that is perpendicular to the surface of the screen.
System Gamma:	The slope of the curve in a log-log plot of output luminance vs. input drive *at the monitor terminals*. Note that this definition includes any modification to the drive curve by the internal boards on the monitor – thus the term *System Gamma.*
Warmup Characteristic:	Time required for the luminance to stabilize at some predetermined value (typically ±1%).

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