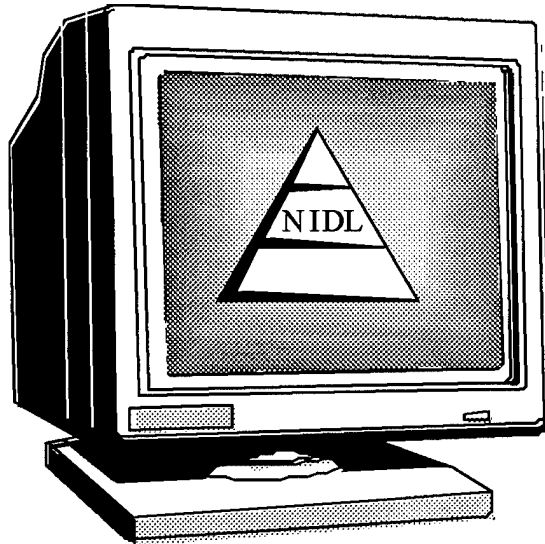


DISPLAY EVALUATION REPORT



A Survey of Twenty Color CRT Monitors

- Size range: 20 to 21 inch
- Addressability: 1600 x 1280
or 1600 x 1200

Monitors Included:

Aydin Controls 9010P
Barco CCID 121
Cornerstone Color 21/80
Goldstar 2010
Hitachi HM-6821-D
Iiyama MF-8221E
MAG InnoVision MX21F
MiTAC L2182
Mitsubishi Diamond Pro 21TX
Nanao FlexScan F780i•W
NEC MultiSync XP21
Nissei Sangyo SuperScan Supreme 21
Orwin C1632 (upgraded)
Panasonic Panasonic/Pro C-2192P
Philips 2130DC
Sampo AlphaScan GLX
Sigma ColorFX 21E
Sony Multiscan 20se
Tatung CM20MKR
ViewSonic 21PS

National Information Display Laboratory

at the

David Sarnoff Research Center
CN 5300, Princeton, NJ 08543-5300

January 17, 1997

Publication No. 5721096-053

Approved for public release; distribution is unlimited.

19990324 002

NOTICE:

This report was prepared on behalf of the National Information Display Laboratory (NIDL) by David Sarnoff Research Center, Inc. (SARNOFF) as an account of work sponsored by the United States Government. The United States Government, the NIDL and SARNOFF, and any person acting on their behalf:

- A. Makes no warranty or representation, expressed or implied, with respect to the use of any information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report is free from infringement of any third party rights; or
- B. Makes no endorsement of any of the products reported on herein; or
- C. Assumes no liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method, or process disclosed in this report.

DISPLAY EVALUATION REPORT

National Information Display Laboratory

INTRODUCTION: PURPOSE OF THIS REPORT	1
Understanding the Measurements and Charts.....	1
COMPARATIVE DATA ON TWENTY MONITORS.....	3
Luminance.....	3
Resolution.....	4
Misconvergence	9
Waviness.....	10
INDIVIDUAL DATA ON EACH OF TWENTY MONITORS.....	12
Aydin Controls 9010P.....	13
Barco CCID 121	15
Cornerstone Color 21/80.....	17
Goldstar 2010.....	19
Hitachi HM-6821-D.....	21
Iiyama MF-8221E	23
MAG InnoVision MX21F	25
MiTAC L2182	27
Mitsubishi Diamond Pro 21TX	29
Nanao FlexScan F780i•W.....	32
NEC MultiSync XP21.....	34
Nissei Sangyo SuperScan Supreme 21	36
Orwin C1632 (upgraded)	39
Panasonic Panasonic/Pro C-2192P	42
Philips 2130DC.....	44
Sampo AlphaScan GLX.....	46
Sigma ColorFX 21E.....	48
Sony Multiscan 20se	50
Tatung CM20MKR.....	52
ViewSonic 21PS.....	54

THIS PAGE INTENTIONALLY LEFT BLANK

FORWARD

On behalf of the government user community, the National Information Display Laboratory (NIDL) has prepared this report which surveys the performance of twenty color CRT monitors. All have addressability of either 1600 x 1280 or 1600 x 1200 pixels, and image sizes from 20 to 21 inches. The report presents summaries of the most important monitor parameters, plus comparisons of the twenty monitors based on those parameters.

The NIDL has also prepared a series of individual evaluations of high-resolution display monitors. These detailed reports help government users to obtain, at reasonable cost, display monitors with the required performance. The reports can be obtained from the NIDL at the address listed below.

Two companion documents that describe how the measurements are made are also available from the NIDL:

- *NIDL Publication No. 313794-024*
Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20,
Part 1: Monochrome CRT Monitor Performance, Draft Version 1.0.
- *NIDL Publication No. 313794-025*
Display Monitor Measurement Methods
under Discussion by EIA (Electronic Industries Association) Committee JT-20,
Part 2: Color CRT Monitor Performance, Draft Version 1.0.

The above measurement procedures were developed by the NIDL in collaboration with the display industry and are currently under review in EIA and ANSI Committees and with the National Institute of Standards and Technology.

Comments, suggestions, and questions about this report are welcome and encouraged.

The NIDL can be reached at:

National Information Display Laboratory
P. O. Box 8619
Princeton, NJ 08543-8619
Tel: (609) 951-0150
Fax: (609) 734-2313
e-mail: nidl@maca.sarnoff.com

THIS PAGE INTENTIONALLY LEFT BLANK

Introduction: Purpose of This Report

This report presents a survey of the performance of twenty color CRT monitors. All have addressability of either 1600 x 1280 or 1600 x 1200 pixels, and image sizes from 20 to 21 inches. The report provides:

- Comparisons of the performance of the twenty monitors
- A two page summary of the performance of each of the twenty monitors

The results are given in a standardized graphical format.

The purpose of the report is to provide an overview of the performance of these monitors. To do that, we have concentrated on the most important monitor parameters, providing the reader with information that will allow a rapid and timely review.

These parameters are:

- Luminance (brightness)
- Resolution (measured and interpreted in several ways)
- Convergence
- Waviness (distortion)

In color monitors, the desired image can beat with the phosphor dots or stripes leading to a disturbing pattern of wavy bars called Moiré. Moiré is difficult to quantify; it is very apparent to the eye in some images, but not in others. In this report we refer to Moiré only in the Comments sections of the individual monitor reports in the following section.

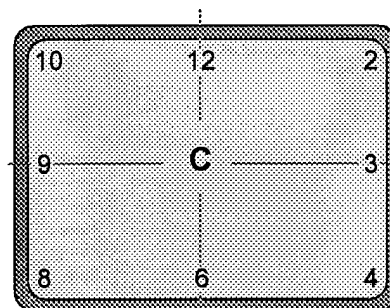
The NIDL has published a detailed description of the procedures used to make the measurements we report here, as well as many others needed for a complete characterization of a CRT monitor. [See references in Forward, p. iii.]

UNDERSTANDING THE MEASUREMENTS AND CHARTS

We provide a brief explanation of each measured parameter just before we present the measurements of that parameter. With the exception of waviness (geometric distortion), all measurements were made at nine positions on the monitor screens:

- the center of the screen,
- top and bottom (12 and 6 o'clock),
- right and left (3 and 9 o'clock),
- four corners (2, 4, 8, and 10 o'clock).

This allows us to assess both the behavior at the center of the screen and the variation as one moves around the screen.



For simplicity, measurements are reported using only four kinds of charts.

(1) A radar chart is used to show measurements at the nine positions across the screen for each monitor. The example in Fig. 1 shows luminance data for one monitor. (Luminance in foot-Lamberts, described later.) The radius of the shaded region indicates the magnitude of the parameter.

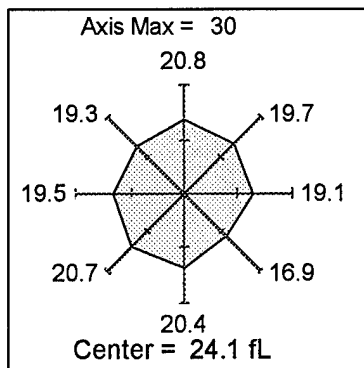


Figure 1. An example of a radar type of chart showing luminance at center and eight other positions on the screen. In this plot, luminance at screen center is 24.1 fL, at screen top it is 20.8 fL, etc. The full-scale length of each radial line is given as 30 fL.

(2) Horizontal high-low-center bar charts are used to compare monitors as in Fig. 2. Minimum and maximum values plus the value at center screen are shown in charts of the type illustrated in Fig. 2.

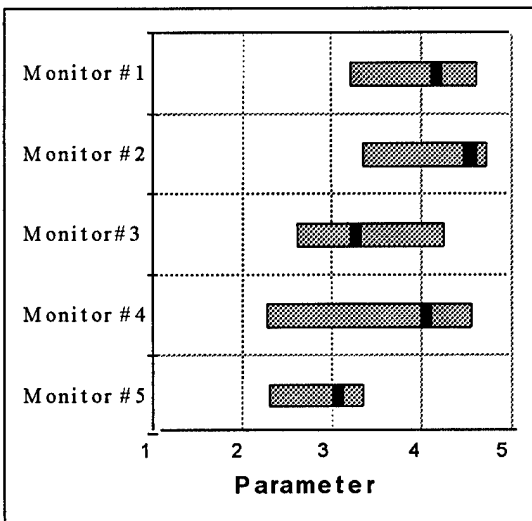


Figure 2. An example of a bar chart showing the range from the minimum to the maximum values measured, with the value at screen center indicated by the dark bar. This chart shows that the minimum and maximum values for Monitor #1 were 3.2 and 4.6 and the center screen value was 4.2.

(3) A conventional bar chart is illustrated in Fig. 3, in which the length of the bar indicates the value of the measured parameter. The left edge of the bar has no significance.

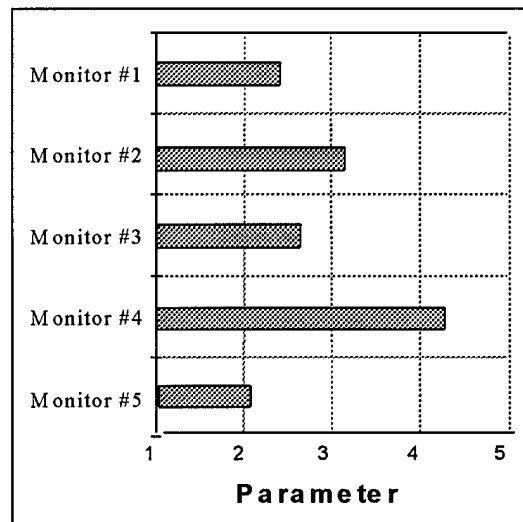


Figure 3. An example of a bar chart showing a value of 3.2 for Monitor #2.

(4) The final type of chart is used to show waviness, or geometric distortion. The irregular lines are exaggerations of the shape of perfect straight lines as displayed across the center and along the edges of the monitor.

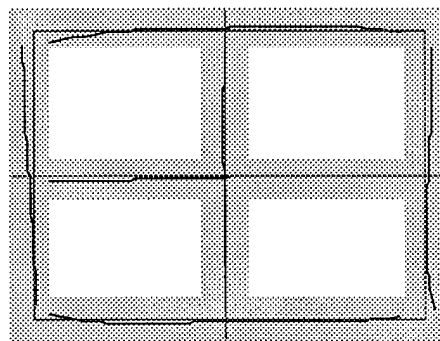


Figure 4. An example of the chart used to show waviness, or geometric distortion. The gray band indicates $\pm 1.0\%$ distortion.

Comparative Data on Twenty Monitors

LUMINANCE

Luminance is the technical name for the brightness of a monitor. It is measured in foot-Lamberts (fL). The typical home television receiver provides about 100 fL brightness. Most good quality color CRT monitors used with computers or other technical display applications have average luminances of 25 to 30 fL. The lower luminance is related to the higher resolution of these monitors.

Higher brightness is usually accompanied by a decrease in resolution and, sometimes, in contrast as well. When comparing monitor performance one needs to consider that all these parameters can be traded off. An ideal monitor achieves high resolution, brightness, and contrast simultaneously.

The values shown in Fig. 5 were measured using a PhotoResearch SpectraScan PR-704 spectroradiometer with the monitor set to the maximum drive specified by the manufacturer. The drive is maintained for the full screen.

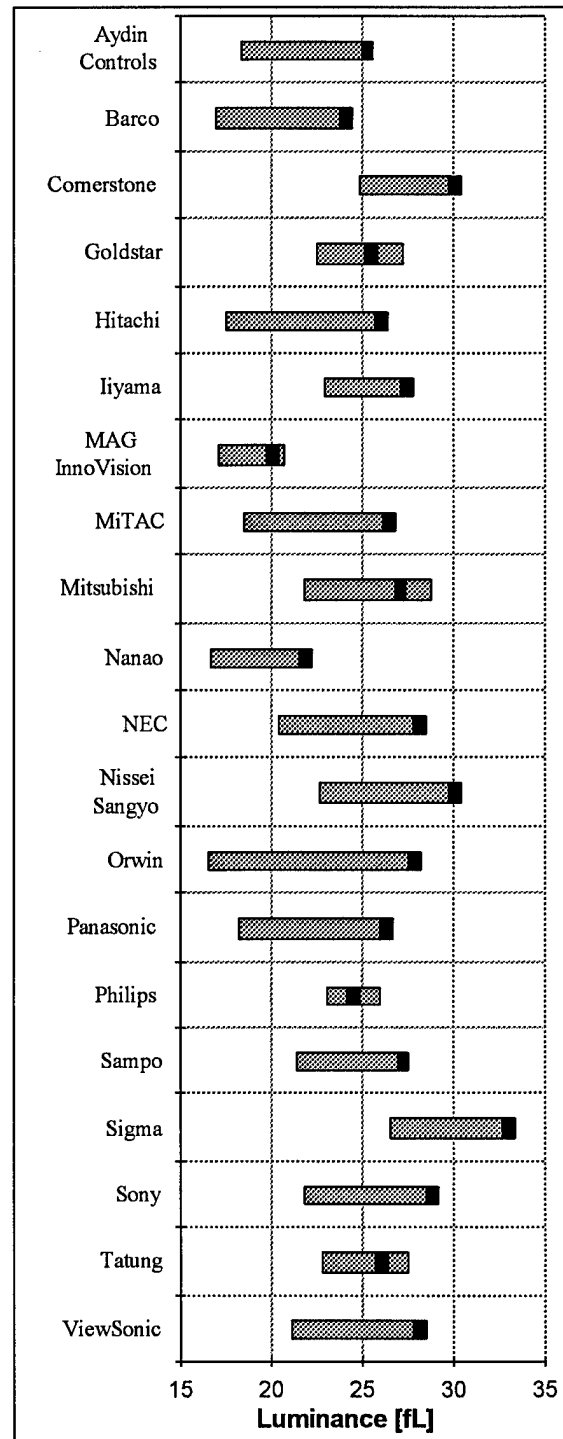


Figure 5. Measured luminance of the twenty monitors. Center screen luminance, indicated by the black bar, is usually also the maximum luminance.

RESOLUTION

Discussion of Resolution and Addressability

Resolution is often the first specification one asks about a monitor, but it is just one of the important parameters.

It is essential to distinguish between the concepts of *addressability* and *resolution*:

- *Addressability* states the number of locations at which a dot can be displayed on the screen. The displays in this report all have an addressability of 1600 positions horizontally and either 1200 or 1280 positions vertically. These are the numbers that monitor manufacturers often give in describing the display resolution. However, that does not guarantee that the spot of light is small enough to actually distinguish adjacent addressable spots.
- *Resolution* measures the actual number of spots or lines that can be distinguished across the screen. The electron beam that forms the spot on the screen has a finite width, causing the spot to grow. The video electronics also have finite risetime, stretching the spot along the scanning (horizontal) direction. As the spots grow and begin to overlap, the ability to discern them as individual spots decreases.

The resolution of a color CRT display is further limited by the pattern of red, green and blue dots or stripes on the screen. The spacing of the three color dots or stripes determines the minimum size that a white pixel can have. That sets the limit for the number of white pixels that can be displayed. For example a 20-inch diagonal tube with a viewable width of 14 inches (355 mm) and a phosphor stripe spacing of 0.3 mm (0.3 mm from one group of RGB stripes to the next) is limited to no more than 1183 white pixels horizontally.

The Concept of Contrast Modulation

Contrast modulation, C_m , is the best and most complete description of the ability of a monitor to display information. It directly measures the ability of the CRT to reproduce desired luminance patterns. The process is shown schematically below.

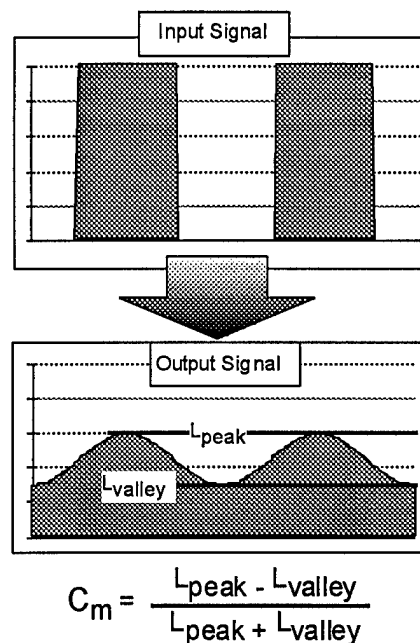


Figure 6. Contrast modulation, C_m . A fully modulated signal is input to the monitor. The contrast in the resulting screen pattern is measured.

C_m is reported here at just one frequency, although a complete characterization of a display requires C_m as a function of frequency. The frequency used in these measurements is called the 1-on/1-off frequency, and is the highest frequency that a display should produce. Adjacent pixels are turned full on and full off, in both the horizontal or vertical directions. The pattern produced is either vertical or horizontal stripes on the screen, each black or white stripe being one pixel wide. The extent to which the actual displayed light pattern changes from full white to full black is the Contrast Modulation, C_m , as indicated in Fig. 6.

Contrast Modulation Results

For this report, Cm was measured using a MicroVision Display Characterization system, a line-scan camera that scans the tube face and maps out the intensity of the pattern.

If the display were perfect, the screen would show a series of full white bars with perfectly black bars between them, yielding a Cm of 100%. In reality, several factors combine to spread the light out so that the pattern is one of light and dark gray bars, not black and white. Among these are:

- The ability of the display to form a narrow line.
- The accuracy with which the three color beams come together, called convergence (discussed below).
- Halation - the leakage of light from bright areas of the image into the dark areas because of reflections off the glass and the phosphor surface.

The comparison of Cm for the twenty monitors is shown in Fig. 7. A perfect display would have Cm = 100%, but that is not expected in any real display. The significance of Cm in the range of 25 to 50% is discussed in the following section.

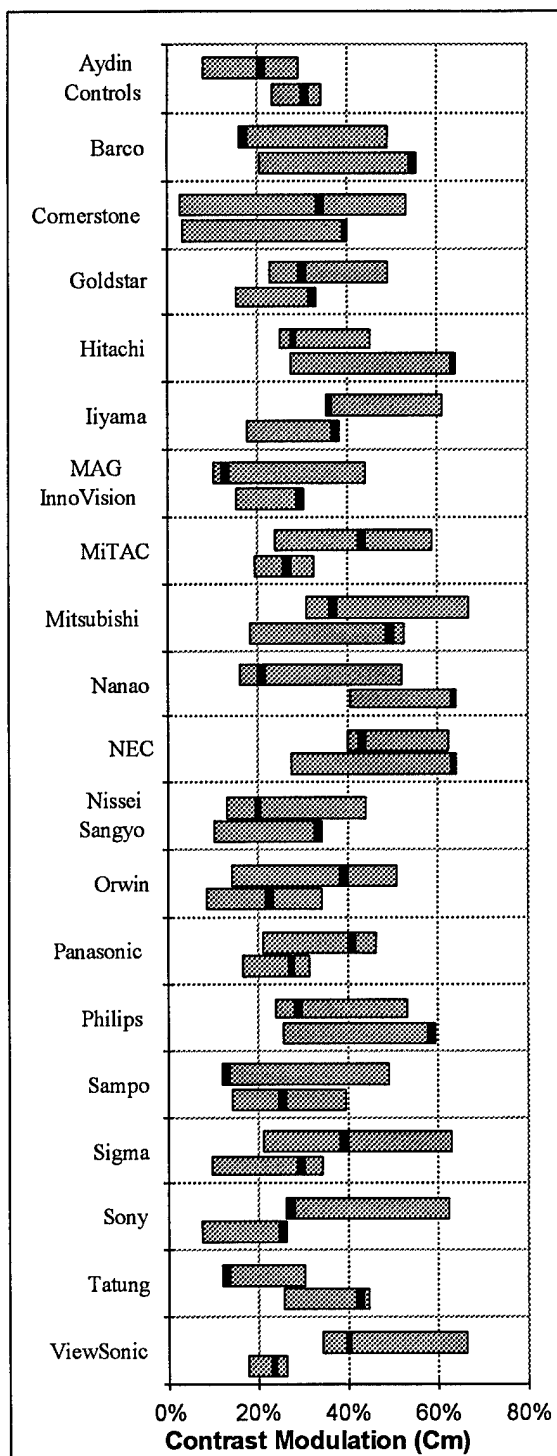


Figure 7. Measured contrast modulation Cm of the twenty monitors for the 1-on/1-off test pattern. The upper bar shows vertical modulation (horizontal stripes); the lower bar shows horizontal modulation (vertical stripes).

Realizable resolution: a simple number

For more information see the publications on Page *iii*.

Describing resolution with a simple number, such as 1600 x 1200 pixels, is an approximation to a complicated subject. To be meaningful, that number must be defined precisely. We define resolution here as the number of alternate black and white lines that can be displayed with a stated minimum contrast modulation, reducing visibility. Displaying more pixels than that will lower the contrast below the minimum.

We use two criteria to allow us to assign meaningful numbers to realizable resolution for two common applications. We state the total number of black lines plus white lines, and give the values for horizontal and vertical resolution separately.

- *Text resolution* (and graphics) require crisp edge definition and clear whites and blacks. We define the resolution for this use as the maximum number of alternating black and white lines that can be displayed with a Cm of 50% or more. A Cm of 50% produces alternating lines that are highly visible.
- *Image resolution* typically does not require sharp changes in luminance. For monitors displaying images rather than text, we define the resolution using a minimum Cm of only 25%. A pattern of alternating black and white lines with 25% contrast is still visible.

Since these definitions demand a higher Cm for text than for images, the stated resolution is always lower for text.

The comparison of realizable resolution for the twenty monitors is shown in Fig. 8.

Using the 25% Cm imaging criterion, a few of the monitors achieve approximately the full 1600 x 1280 or 1200 resolution one might expect from the addressability. None of them reaches that resolution if the 50% Cm criterion is used.

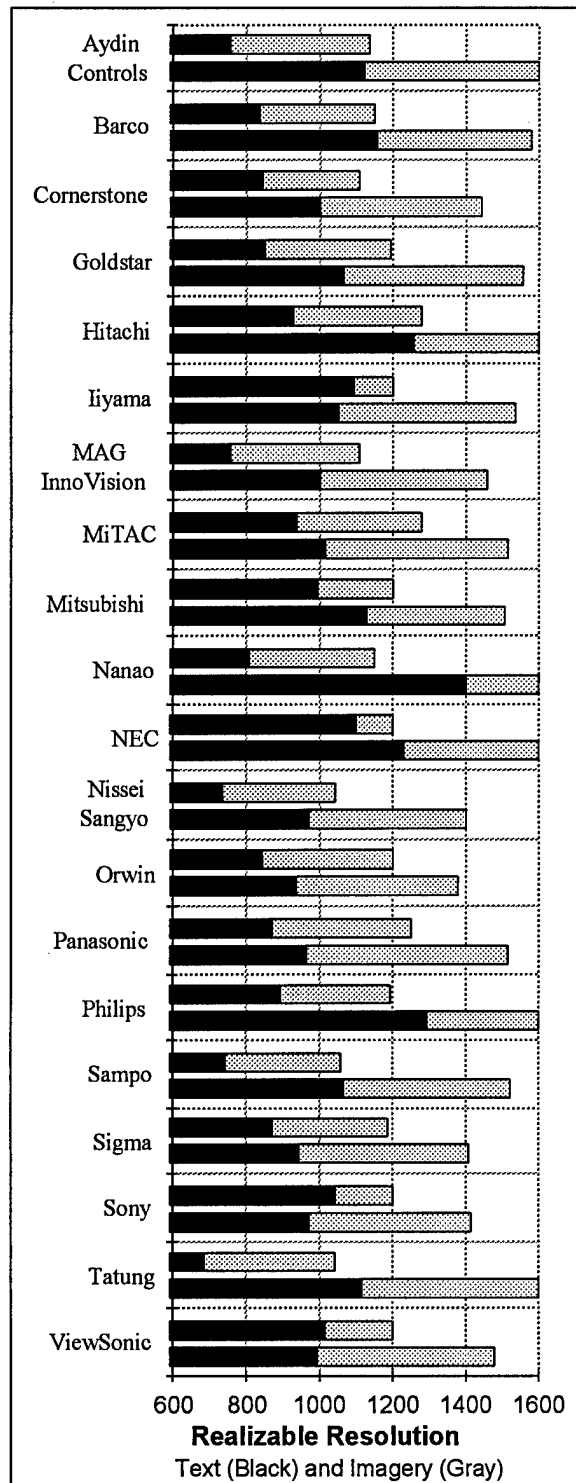


Figure 8. Realizable resolution. The upper bar shows vertical modulation (horizontal stripes), the lower bar shows horizontal modulation (vertical stripes).

Resolution-Addressability Ratio (RAR)

Another well known measure of monitor performance is called the *Resolution-Addressability Ratio* or RAR. It is the ratio of the size of the actual spot (or line) produced to the size of the pixel. The size of the pixel is determined by the scanned image size divided by the addressable number of pixels. RAR can also be thought of as the width of the line measured in addressable pixels. An RAR of 1.0 would mean that the addressability and resolution are equal, i.e. that the spot is just small enough to display the addressable number of pixels as separated individual dots. If the RAR is greater than one, then the spot is too large to display each pixel separately. However, in a typical display, RAR is set to be between 1.2 and 1.3. The slightly larger spot causes adjacent spots to overlap a little, and reduces the Cm to about 50%, but reduces Moiré and the visibility of scan lines. As the RAR increases beyond 1.5, the Cm decreases markedly. Thus an RAR of 1.5 or more shows that the monitor cannot produce an image as sharp as the addressability implies.

The comparison of RAR for the twenty monitors is shown in Fig. 9. Note that the RARs for many of the monitors are between the desirable limits of 1.2 and 1.5 at screen center. Remember that in this style of chart, the ends of the indicated bar are the minimum and maximum values, which may occur at only a small portion of the screen.

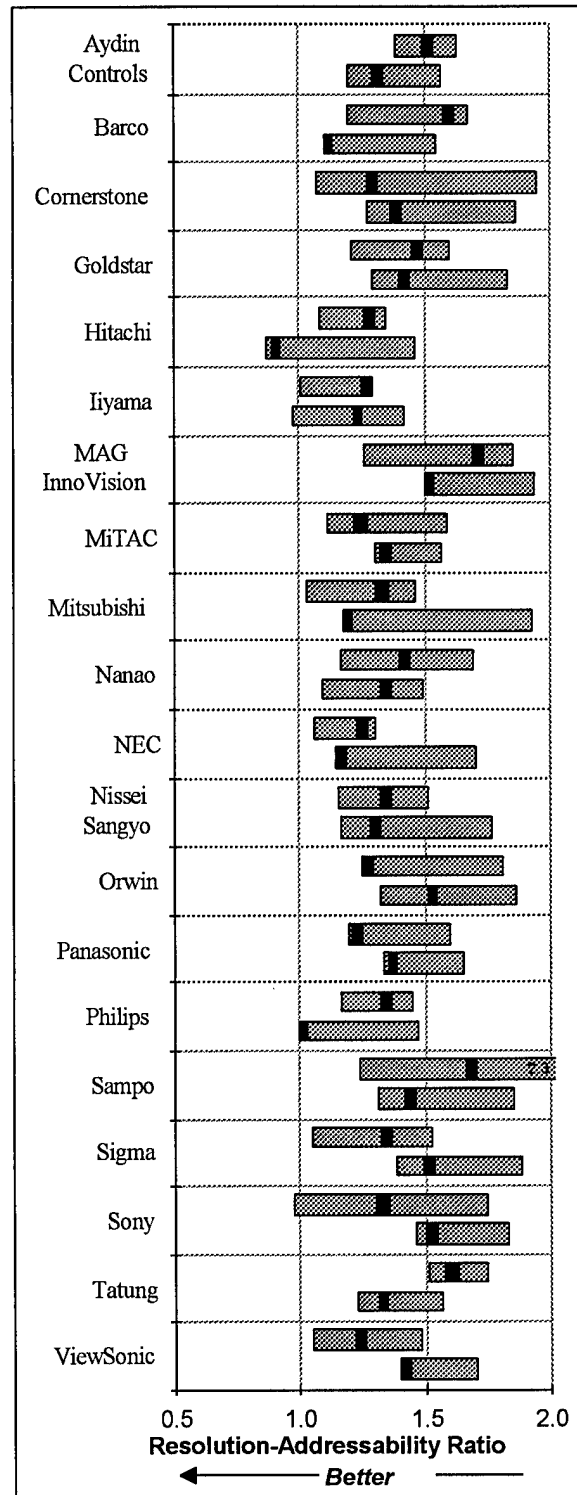


Figure 9. Resolution-Addressability Ratio or RAR. RAR of 1.2 is considered optimum. For RAR larger than 1.5, the spot is too large to display all the addressable pixels. The upper bars show vertical resolution, the lower bars horizontal.

MISCONVERGENCE

Color CRTs make a given hue by combining precise amounts of red, green, and blue light, generated by appropriate phosphors excited by three separate electron beams. For the color rendition to be correct and to minimize the effective size of the resultant white spot, the three beams must overlap completely at each addressable position on the screen. Because of the limitations in the beam deflection system, perfect registration, called *convergence* in CRTs, is not possible. The misconvergence parameter as used here describes the larger of the difference in the landing position between the red and green beams or the blue and green beams. Clearly a misconvergence of more than a pixel will result in noticeable degradation of the display.

The comparison of misconvergence for the twenty monitors is shown in Fig. 10.

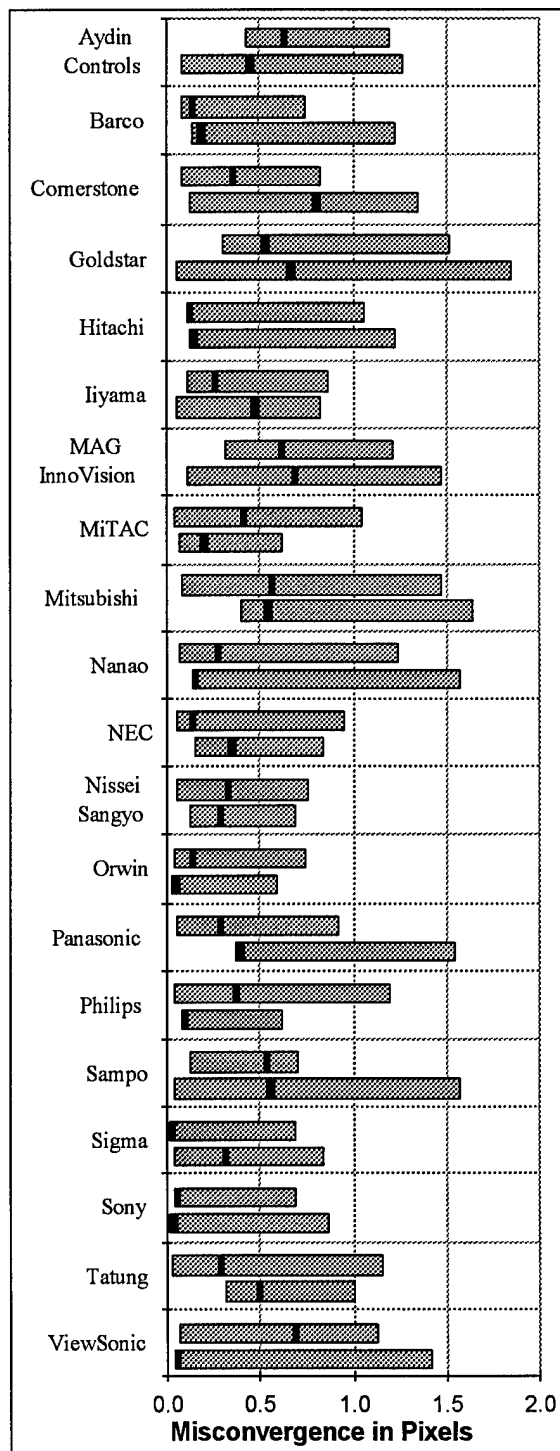


Figure 10. Comparison of misconvergence for the twenty monitors. For each monitor, the upper bar shows vertical misconvergence and the lower bar horizontal.

WAVINESS

The magnetic deflection system that moves the electron beam across the face of the tube does not produce perfectly straight lines. *Waviness* measures how much the display of a straight line varies from true straightness. This is sometimes called *geometric distortion*.

In the individual reports that follow we show the waviness of horizontally scanned lines at the top, center, and bottom of the display and for vertically scanned lines at the right side, center, and left side of the screen. In the comparison chart in Fig. 11, we show only the worst case waviness. A good display deviates from a straight line by less than 0.5% of the screen height.

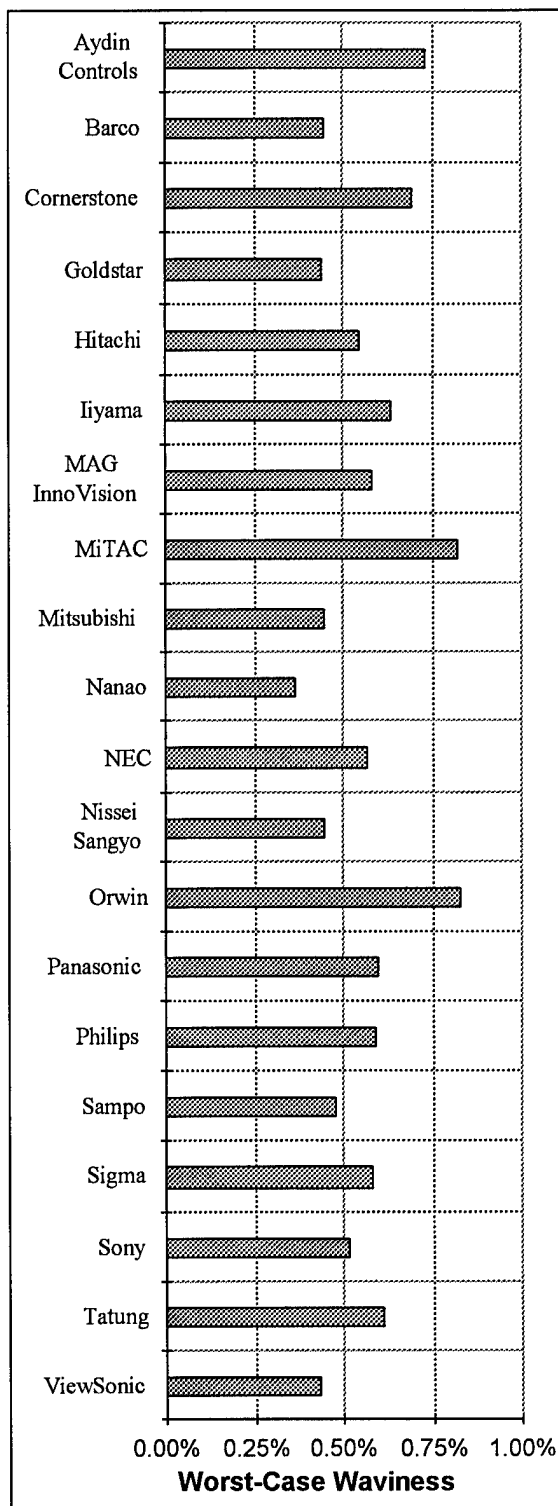


Figure 11. The length of the bar indicates worst-case waviness, or geometric distortion. Data for individual monitors in the next section show the actual form of the waviness.

THIS PAGE INTENTIONALLY LEFT BLANK

Individual Data on Each of Twenty Monitors

Aydin Controls 9010P
Barco CCID 121
Cornerstone Color 21/80
Goldstar 2010
Hitachi HM-6821-D
Iiyama MF-8221E
MAG InnoVision MX21F
MiTAC L2182
Mitsubishi Diamond Pro 21TX
Nanao FlexScan F780i • W
NEC MultiSync XP21
Nissei Sangyo SuperScan Supreme 21
Orwin C1632 (upgraded)
Panasonic Panasonic/Pro C-2192P
Philips 2130DC
Sampo AlphaScan GLX
Sigma ColorFX 21E
Sony Multiscan 20se
Tatung CM20MKR
ViewSonic 21PS

AYDIN CONTROLS 9010P**Manufacturer's Data**

Manufacturer Name	Aydin Controls
Model Number	9010P
Price	\$2,300
Screen Diagonal	20 inches
Horizontal Scan Rate	79.18 kHz
Vertical Scan Rate	59.98 Hz
Image Size (H x V)	14.9 x 10.9 inches
Addressable Pixel Number	1600 x 1280
Pixel Size	9.30 x 8.52 mils (0.236 x 0.216 mm)
Dot Pitch	11.0 mils (0.28 mm)

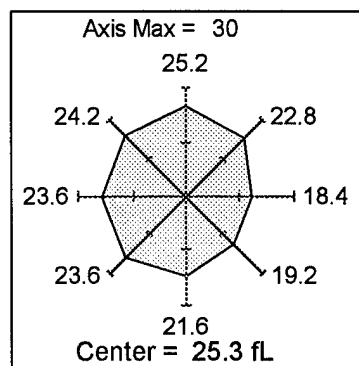
Summary Comments:

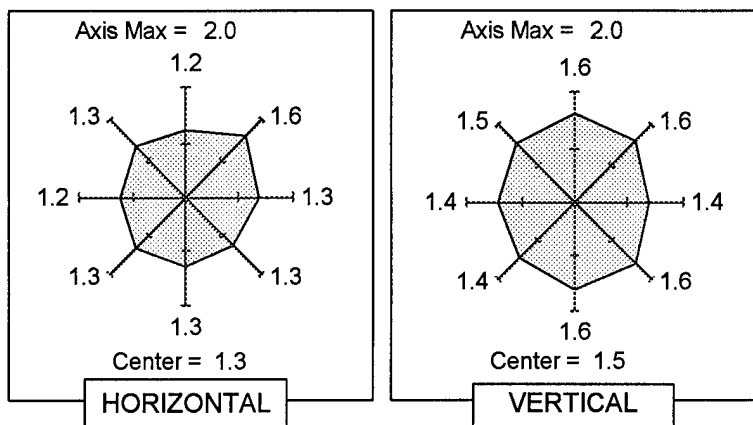
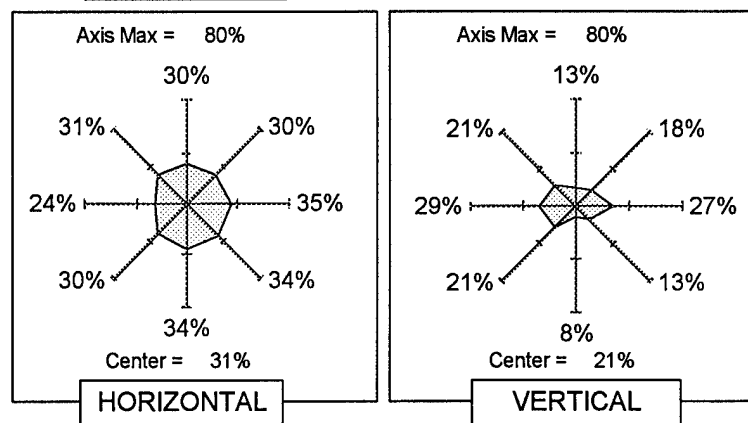
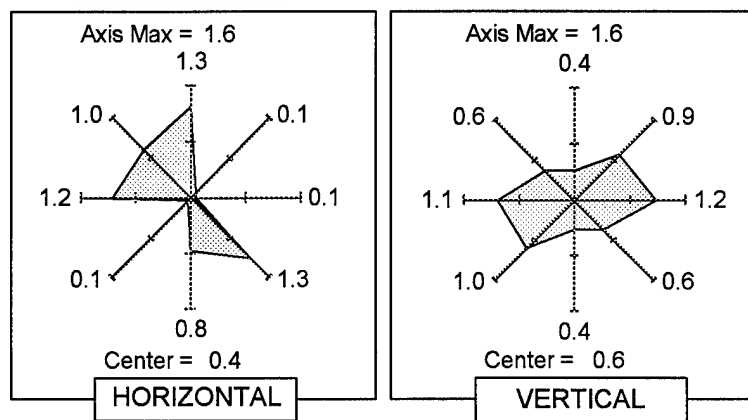
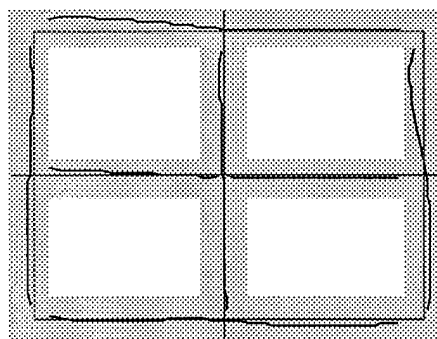
- This monitor exhibited high waviness (0.73% of horizontal pincushion).
- Based on a $C_m = 25\%$, this monitor resolved 88% of the addressable pixels.

Detailed Performance Data**Display Resolution**

<u>Display Content</u>	<u>C_m Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	$C_m = 25\%$	1597 x 1133
Text and Graphics	$C_m = 50\%$	1138 x 767

**Maximum Luminance
in Foot Lamberts**



Linewidth in Pixels (RAR)**Contrast Modulation****Misconvergence in Pixels****Waviness**

Gray band indicates $\pm 1\%$ distortion.

BARCO CCID 121

Manufacturer's Data

Manufacturer Name	Barco
Model Number	CCID 121
Price	\$6,000
Screen Diagonal	21 inches
Horizontal Scan Rate	74.98 kHz
Vertical Scan Rate	60.03 Hz
Image Size (H x V)	14.7 x 11.0 inches
Addressable Pixel Number	1600 x 1200
Pixel Size	9.18 x 9.19 mils (0.233 x 0.233 mm)
Dot Pitch	11.0 mils (0.28 mm)

Summary Comments:

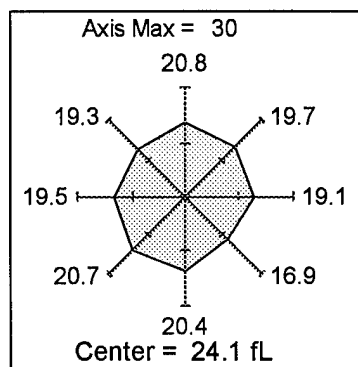
- This monitor is referred to as the 'The Reference Calibrator'. It employs an automatic feedback circuit that maintains the luminance level and color balance, a feature not in the other monitors tested. This feature contributes to the cost of this monitor, one of the highest in the survey (\$6,000).
- Based on a $C_m = 25\%$, this monitor resolved 94% of the addressable pixels.

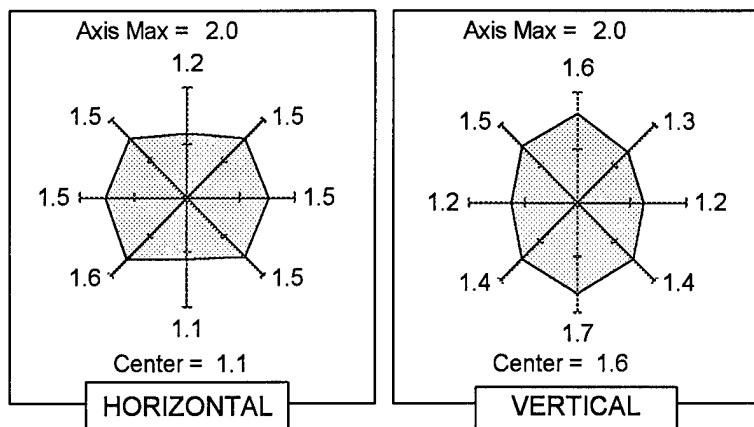
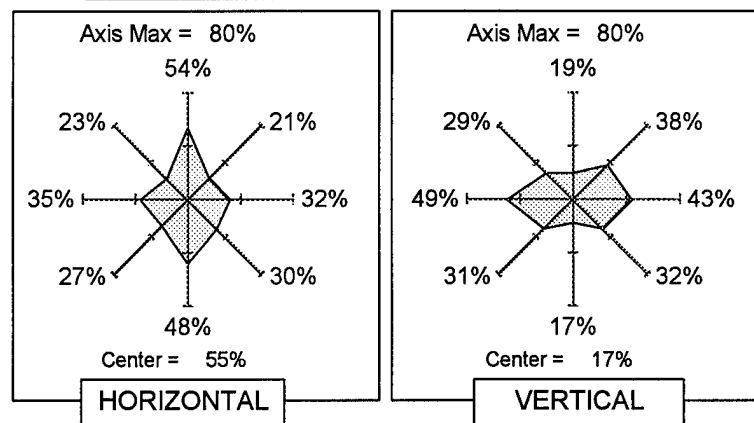
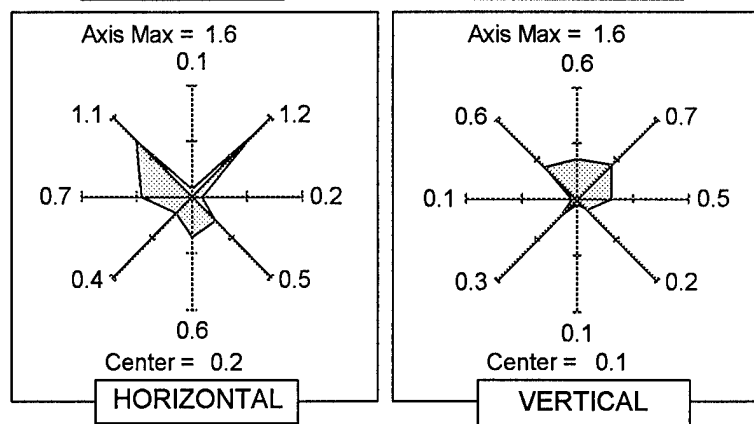
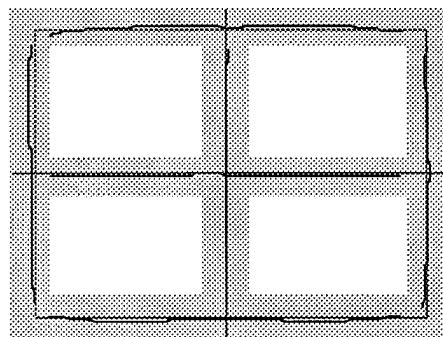
Detailed Performance Data

Display Resolution

<u>Display Content</u>	<u>C_m Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	$C_m = 25\%$	1576 x 1149
Text and Graphics	$C_m = 50\%$	1171 x 847

Maximum Luminance
in Foot Lamberts



Linewidth in Pixels (RAR)**Contrast Modulation****Misconvergence in Pixels****Waviness**

Gray band indicates $\pm 1\%$ distortion.

CORNERSTONE COLOR 21/80**Manufacturer's Data**

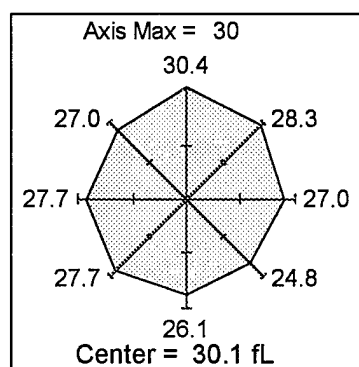
Manufacturer Name	Cornerstone
Model Number	Color 21/80
Price	\$2,622
Screen Diagonal	21 inches
Horizontal Scan Rate	106.65 kHz
Vertical Scan Rate	80.31 Hz
Image Size (H x V)	15.1 x 11.5 inches
Addressable Pixel Number	1600 x 1280
Pixel Size	9.46 x 8.99 mils (0.240 x 0.228 mm)
Dot Pitch	11.0 mils (0.28 mm)

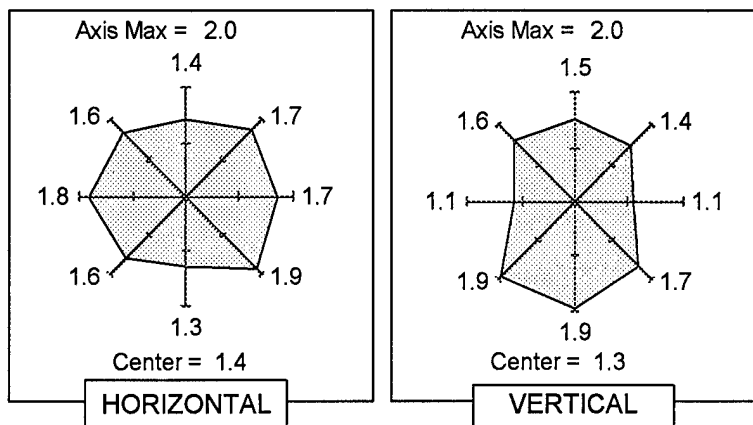
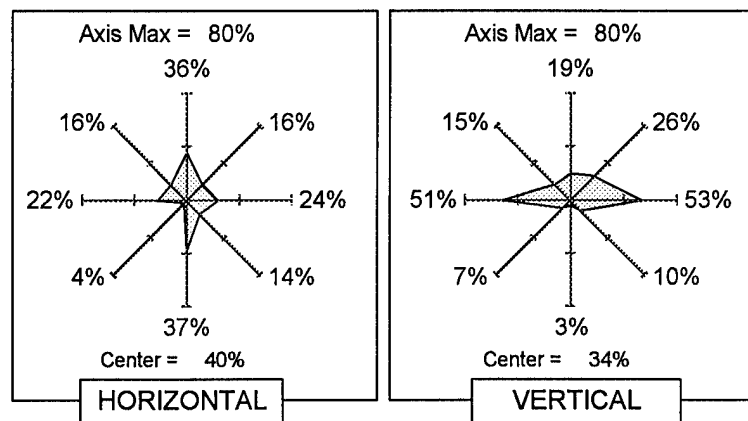
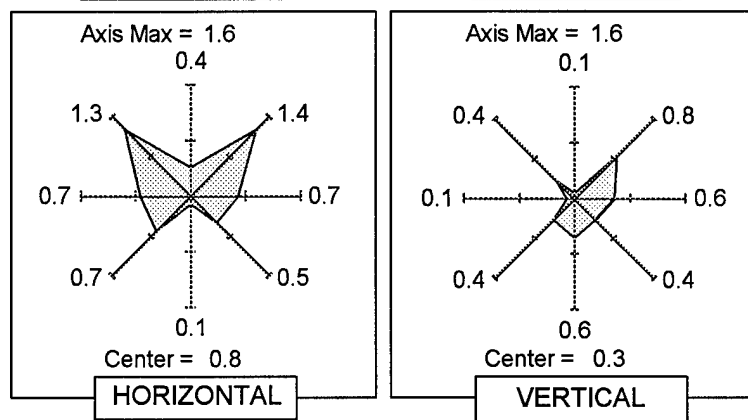
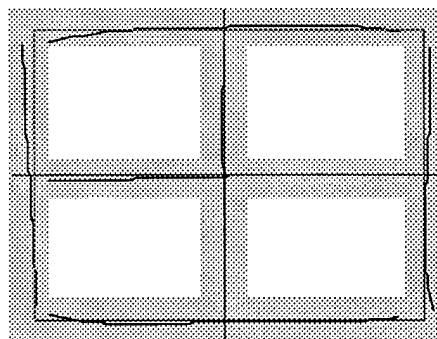
Summary Comments:

- The screen center luminance of 30.1 fL is one of the highest tested.
- The vertical Cm is degraded by Moiré and high RAR values at some screen edges.
- The 80 Hz refresh rate was among the highest tested.
- Based on a Cm = 25%, this monitor resolved 78% of the addressable pixels.

Detailed Performance Data**Display Resolution**

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	Cm = 25%	1440 x 1109
Text and Graphics	Cm = 50%	1014 x 852

**Maximum Luminance
in Foot Lamberts**

Linewidth in Pixels (RAR)**Contrast Modulation****Misconvergence in Pixels****Waviness**

Gray band indicates $\pm 1\%$ distortion.

GOLDSTAR 2010**Manufacturer's Data**

Manufacturer Name	Goldstar
Model Number	2010
Price	\$1,430
Screen Diagonal	20 inches
Horizontal Scan Rate	81.25 kHz
Vertical Scan Rate	65.00 Hz
Image Size (H x V)	14.4 x 10.6 inches
Addressable Pixel Number	1600 x 1200
Pixel Size	9.00 x 8.83 mils (0.229 x 0.224 mm)
Dot Pitch	11.0 mils (0.28 mm)

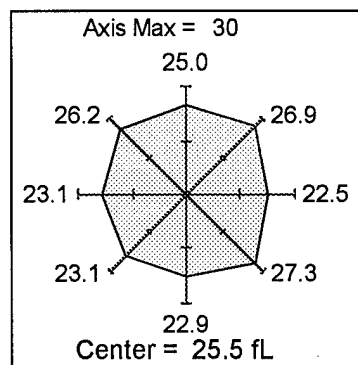
Summary Comments:

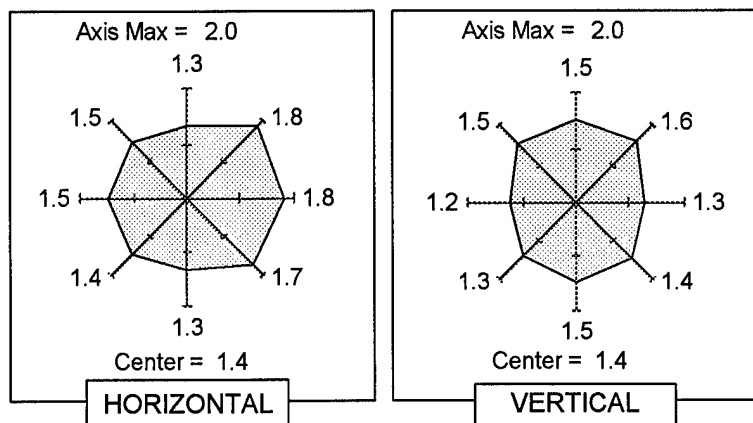
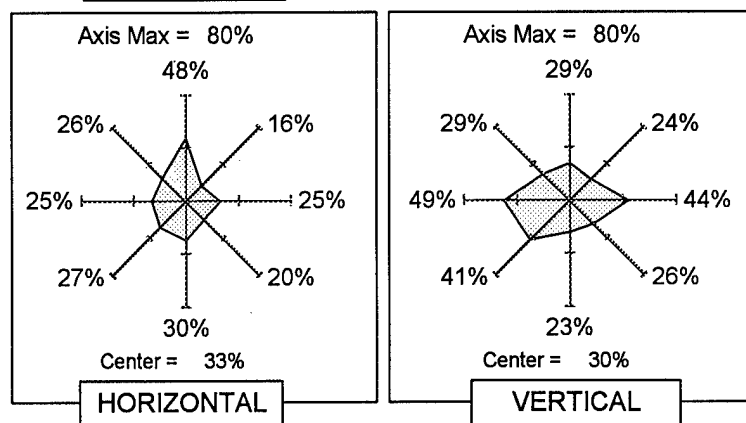
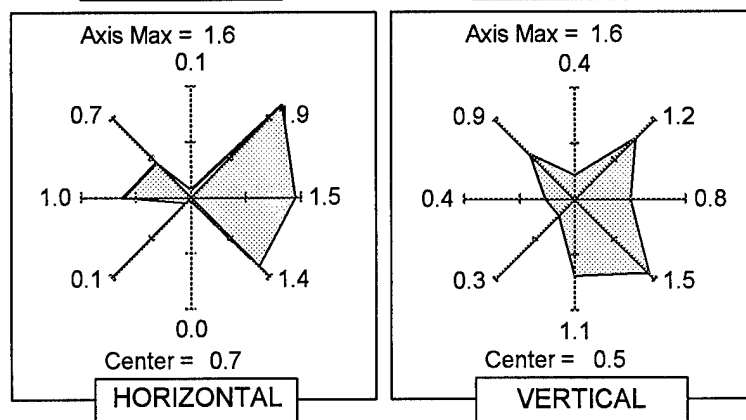
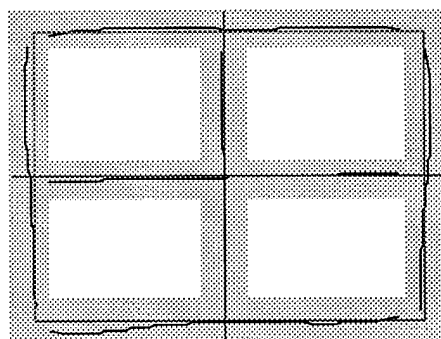
- This is one of the lowest-cost monitors in the survey (\$1,430), but its performance was about average.
- Misconvergence exceeded 1.5 pixels at several places on the screen.
- Based on a $C_m = 25\%$, this monitor resolved 96% of the addressable pixels.

Detailed Performance Data**Display Resolution**

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	$C_m = 25\%$	1554 x 1191
Text and Graphics	$C_m = 50\%$	1075 x 862

**Maximum Luminance
in Foot Lamberts**



Linewidth in Pixels (RAR)**Contrast Modulation****Misconvergence in Pixels****Waviness**

Gray band indicates $\pm 1\%$ distortion.

HITACHI HM-6821-D**Manufacturer's Data**

Manufacturer Name	Hitachi
Model Number	HM-6821-D
Price	\$2,650
Screen Diagonal	21 inches
Horizontal Scan Rate	106.08 kHz
Vertical Scan Rate	80.00 Hz
Image Size (H x V)	15.0 x 11.2 inches
Addressable Pixel Number	1600 x 1280
Pixel Size	9.35 x 8.76 mils (0.237 x 0.223 mm)
Dot Pitch	0.22 mm horizontal/0.16 mm vertical

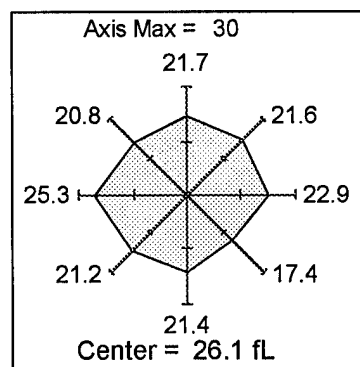
Summary Comments:

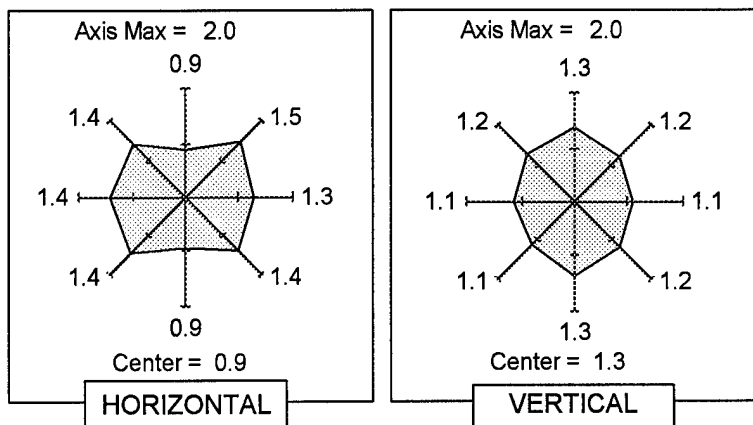
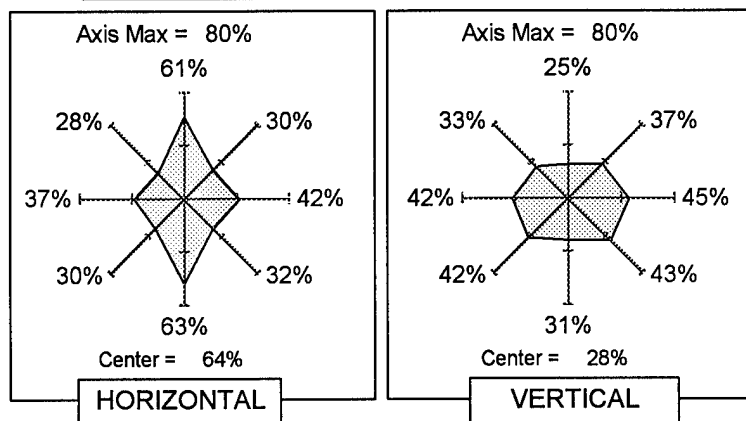
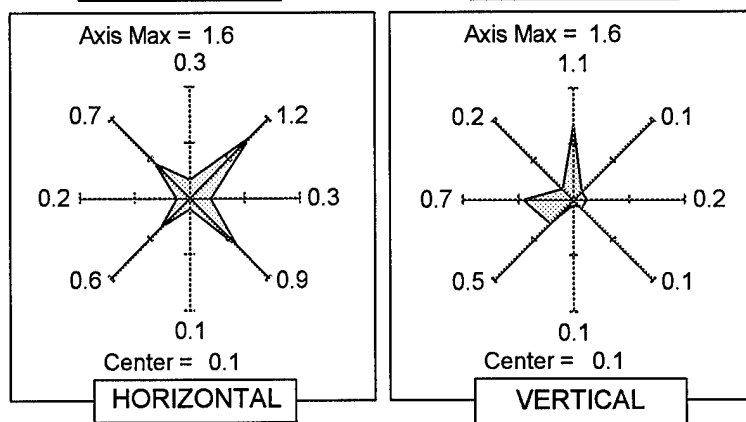
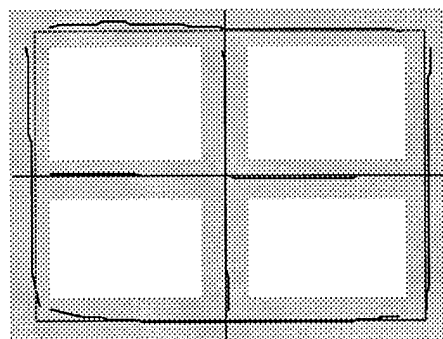
- The CRT features an UltraFine dot pitch (0.22 mm horizontal/0.16 mm vertical).
- The 80 Hz refresh rate was among the highest tested.
- Based on a $C_m = 25\%$, this monitor resolved all of the addressable pixels.

Detailed Performance Data**Display Resolution**

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	$C_m = 25\%$	1600 x 1280
Text and Graphics	$C_m = 50\%$	1270 x 941

**Maximum Luminance
in Foot Lamberts**



Linewidth in Pixels (RAR)**Contrast Modulation****Misconvergence in Pixels****Waviness**

Gray band indicates $\pm 1\%$ distortion.

IYAMA MF-8221E**Manufacturer's Data**

Manufacturer Name	Iiyama
Model Number	MF-8221E
Price	\$2,049
Screen Diagonal	21 inches
Horizontal Scan Rate	93.75 kHz
Vertical Scan Rate	75.00 Hz
Image Size (H x V)	15.0 x 11.2 inches
Addressable Pixel Number	1600 x 1200
Pixel Size	9.35 x 9.34 mils (0.237 x 0.237 mm)
Dot Pitch	11.0 mils (0.28 mm)

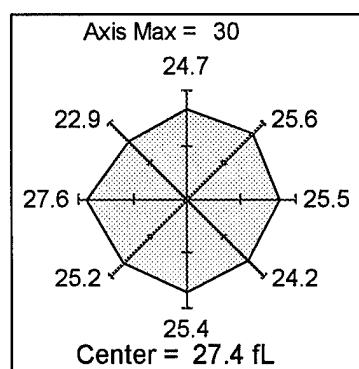
Summary Comments:

- Vertical Cm is among the best tested. Horizontal Cm was degraded by the presence of Moiré on 1-on/1-off vertical grille patterns.
- Moiré correction circuitry available on this monitor was not evaluated and was instead set to the OFF position during testing.
- Based on a Cm =25% this monitor resolved 96% of the addressable pixels.

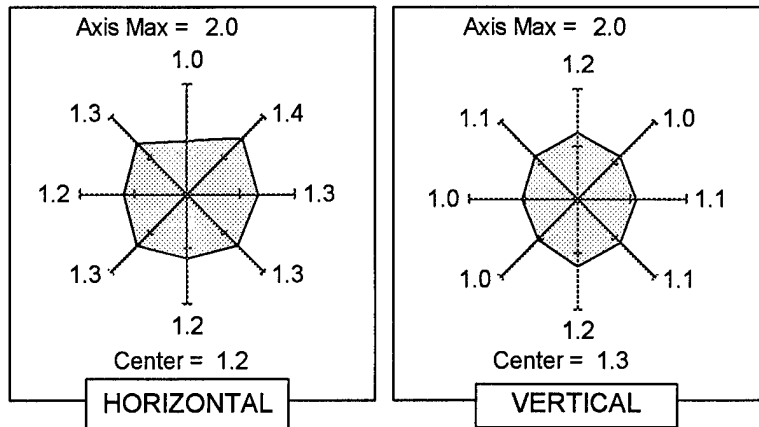
Detailed Performance Data**Display Resolution**

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	Cm = 25%	1539 x 1200
Text and Graphics	Cm = 50%	1063 x 1108

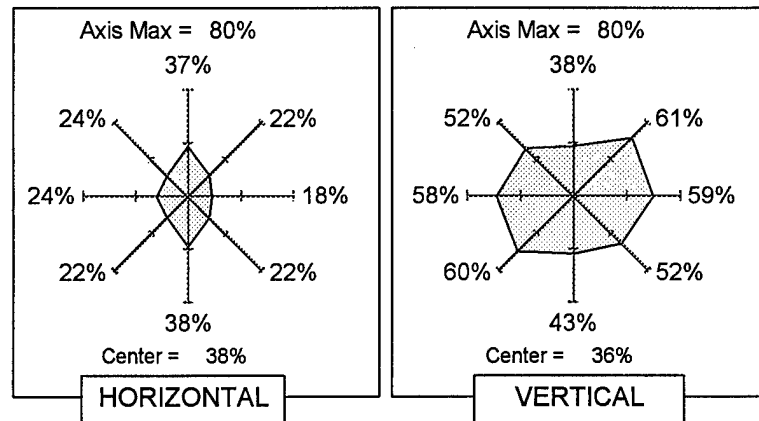
**Maximum Luminance
in Foot Lamberts**



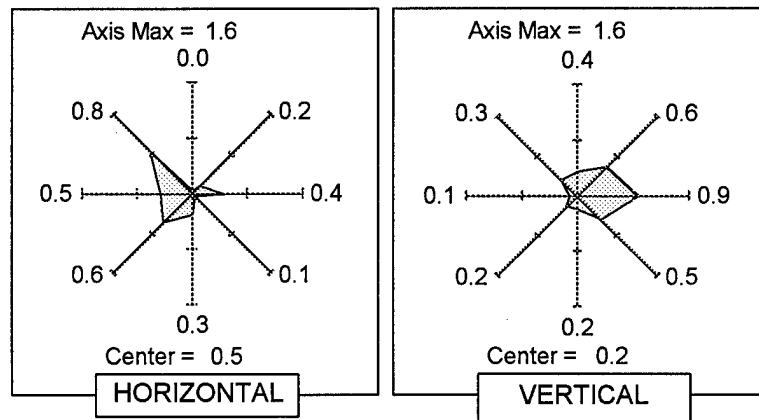
Linewidth in Pixels (RAR)



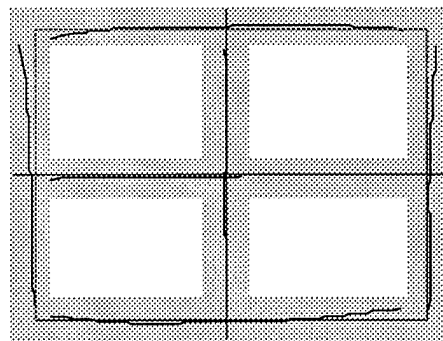
Contrast Modulation



Misconvergence in Pixels



Waviness



Gray band indicates $\pm 1\%$ distortion.

MAG INNOVISION MX21F

Manufacturer's Data

Manufacturer Name	MAG InnoVision
Model Number	MX21F
Price	\$1,971
Screen Diagonal	21 inches
Horizontal Scan Rate	75.00 kHz
Vertical Scan Rate	60.00 Hz
Image Size (H x V)	15.0 x 11.2 inches
Addressable Pixel Number	1600 x 1200
Pixel Size	9.36 x 9.35 mils (0.238 x 0.237 mm)
Dot Pitch	11.0 mils (0.28 mm)

Summary Comments:

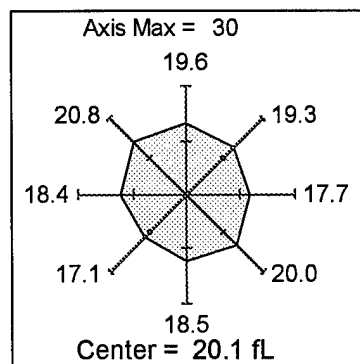
- The luminance was the lowest in this survey, less than 21 fL everywhere.
- Horizontal Cm was degraded by the presence of Moiré on vertical grille patterns.
- Based on a Cm = 25%, this monitor resolved 84% of the addressable pixels.
- The original purchase price to NIDL for this monitor was \$1,971. The manufacturer now offers this monitor at a suggested retail of \$1,799.

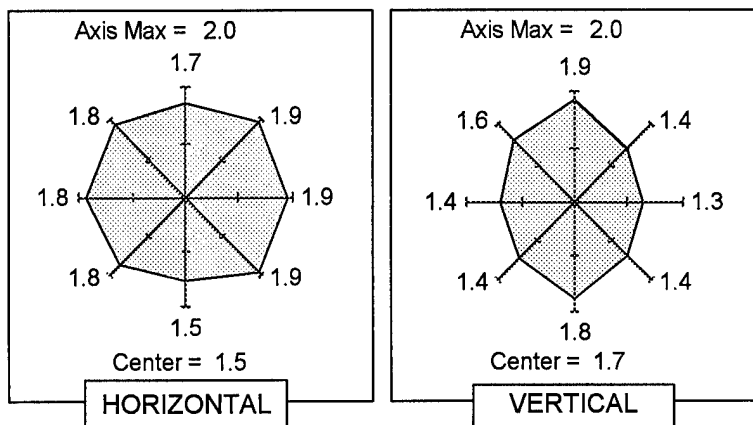
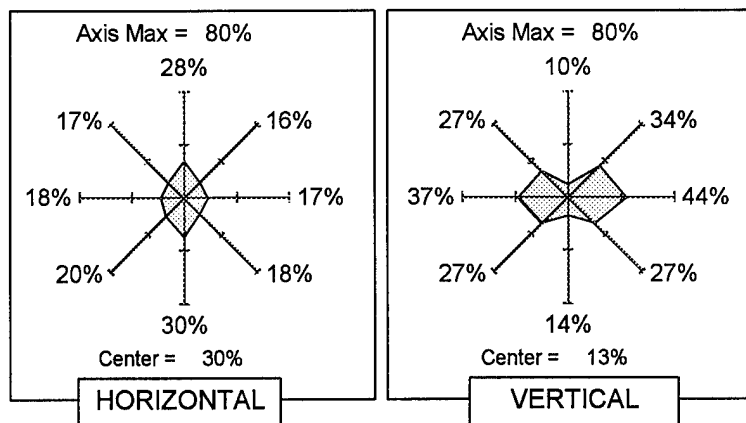
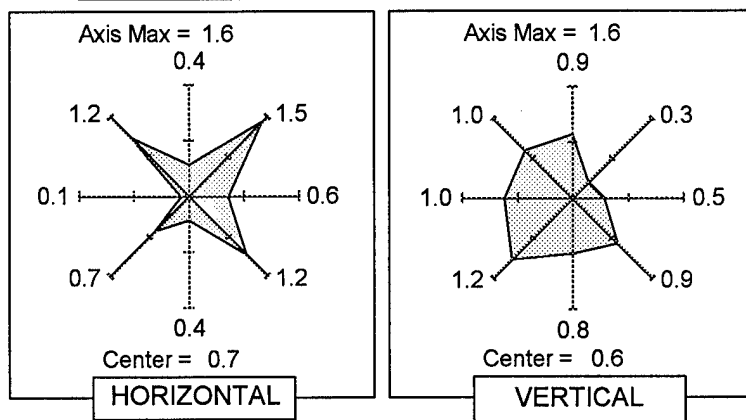
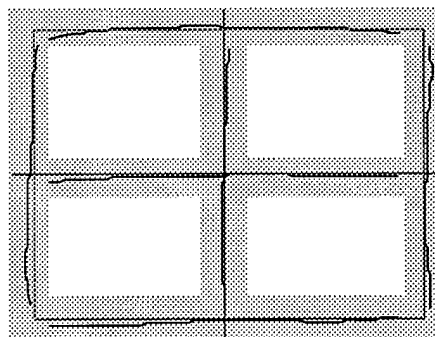
Detailed Performance Data

Display Resolution

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	Cm = 25%	1461 x 1110
Text and Graphics	Cm = 50%	1017 x 770

**Maximum Luminance
in Foot Lamberts**



Linewidth in Pixels (RAR)**Contrast Modulation****Misconvergence in Pixels****Waviness**

Gray band indicates $\pm 1\%$ distortion.

MiTAC L2182**Manufacturer's Data**

Manufacturer Name	MiTAC
Model Number	L2182
Price	\$2,070
Screen Diagonal	21 inches
Horizontal Scan Rate	82.01 kHz
Vertical Scan Rate	62.08 Hz
Image Size (H x V)	15.0 x 11.2 inches
Addressable Pixel Number	1600 x 1280
Pixel Size	9.34 x 8.76 mils (0.237 x 0.223 mm)
Dot Pitch	9.8 mils (0.25 mm)

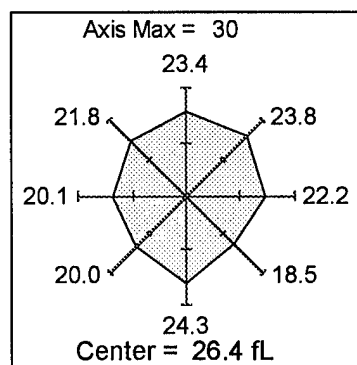
Summary Comments:

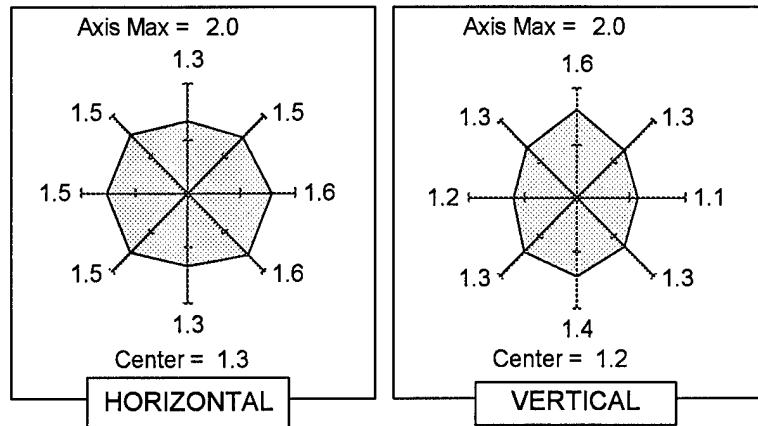
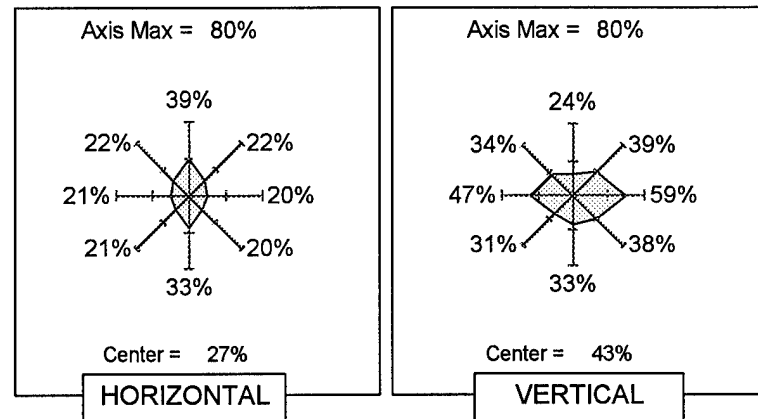
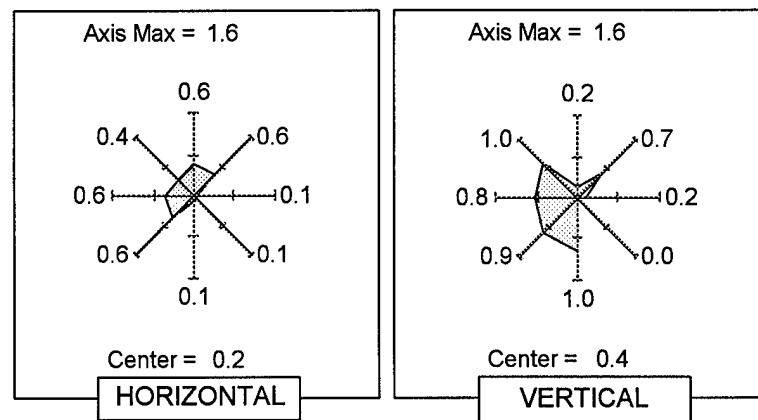
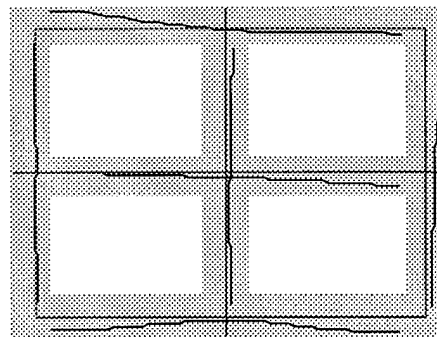
- The monitor exhibited high waviness (geometric distortion); vertical pincushion was 0.82%.
- Based on a $C_m = 25\%$, this monitor resolved 94% of the addressable pixels.
- Moiré correction circuitry available on this monitor was not evaluated and was instead set to the OFF position during testing.

Detailed Performance Data**Display Resolution**

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	$C_m = 25\%$	1513 x 1276
Text and Graphics	$C_m = 50\%$	1024 x 945

**Maximum Luminance
in Foot Lamberts**



Linewidth in Pixels (RAR)**Contrast Modulation****Misconvergence in Pixels****Waviness**

Gray band indicates $\pm 1\%$ distortion.

MITSUBISHI DIAMOND PRO 21TX**Manufacturer's Data**

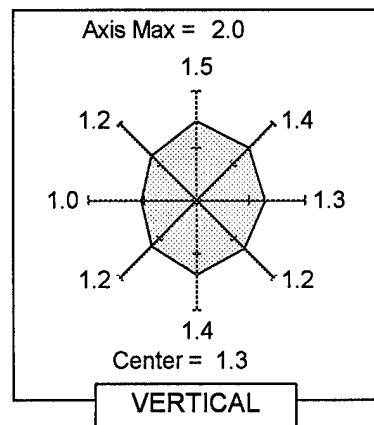
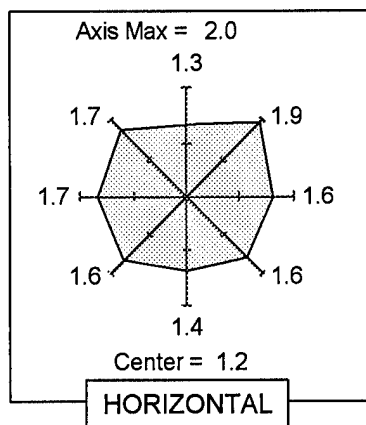
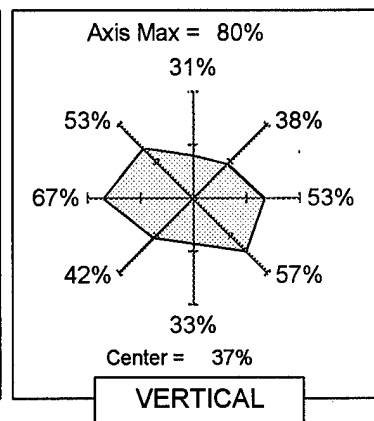
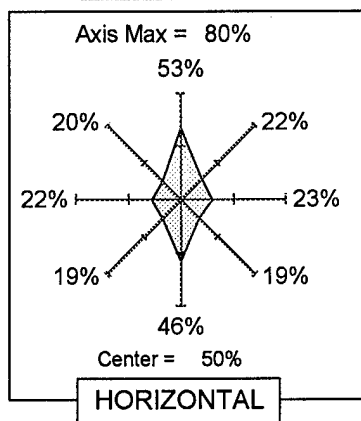
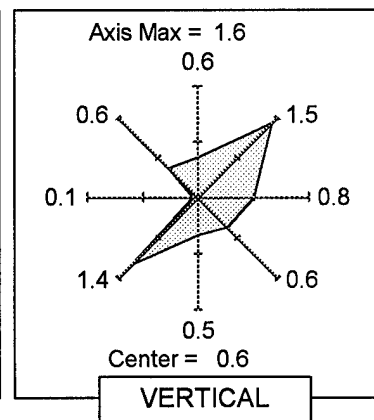
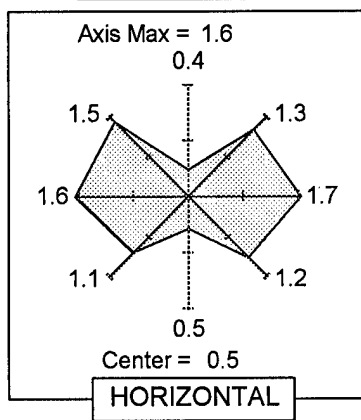
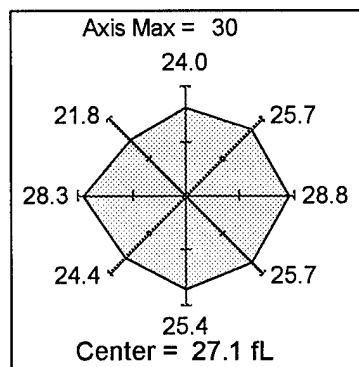
Manufacturer Name	Mitsubishi
Model Number	Diamond Pro 21TX
Price	\$2,100
Screen Diagonal	21 inches
Horizontal Scan Rate	92.77 kHz
Vertical Scan Rate	75.00 Hz
Image Size (H x V)	15.0 x 11.2 inches
Addressable Pixel Number	1600 x 1200
Pixel Size	9.36 x 9.32 mils (0.238 x 0.237 mm)
Stripe Pitch	11.8 mils (0.30 mm)

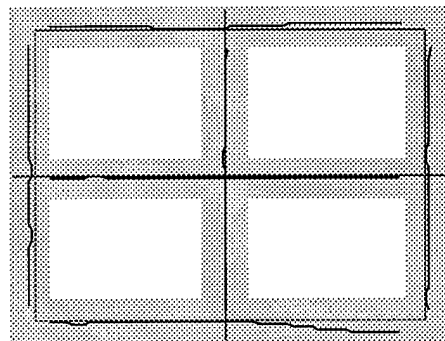
Summary Comments:

- The monitor features the DIAMONDTRON aperture grille.
- Horizontal Cm was degraded by Moiré and varied significantly over the screen.
- The horizontal waviness was minimal (0.14% for horizontal pincushion).
- Based on a Cm = 25%, this monitor resolved 94% of the addressable pixels.
- Moiré correction circuitry available on this monitor was not evaluated and was instead set to the OFF position during testing.

Detailed Performance Data**Display Resolution**

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	Cm = 25%	1506 x 1200
Text and Graphics	Cm = 50%	1145 x 1007

Linewidth in Pixels (RAR)**Contrast Modulation****Misconvergence in Pixels****Maximum Luminance
in Foot Lamberts**

Waviness

Gray band indicates $\pm 1\%$ distortion.

NANAO FLEXSCAN F780i•W**Manufacturer's Data**

Manufacturer Name	Nanao
Model Number	FlexScan F780i•W
Price	\$3,300
Screen Diagonal	21 inches
Horizontal Scan Rate	96.52 kHz
Vertical Scan Rate	77.41 Hz
Image Size (H x V)	15.0 x 11.2 inches
Addressable Pixel Number	1600 x 1200
Pixel Size	9.35 x 9.35 mils (0.237 x 0.237 mm)
Dot Pitch	10.2 mils (0.26 mm)

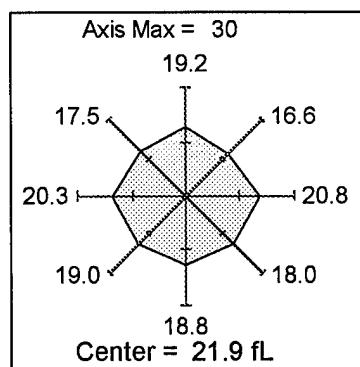
Summary Comments:

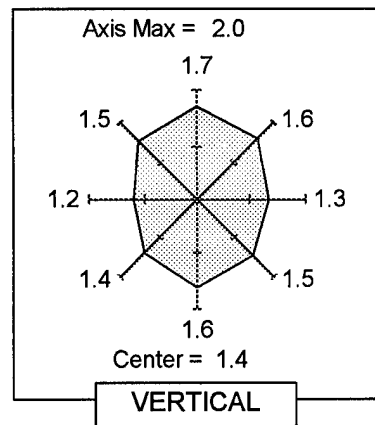
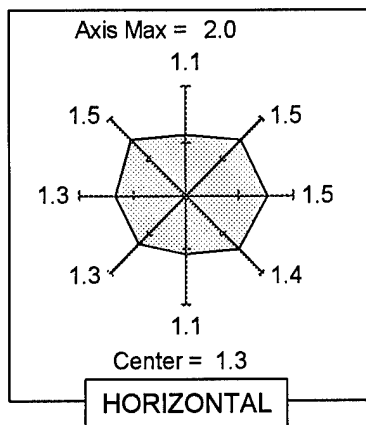
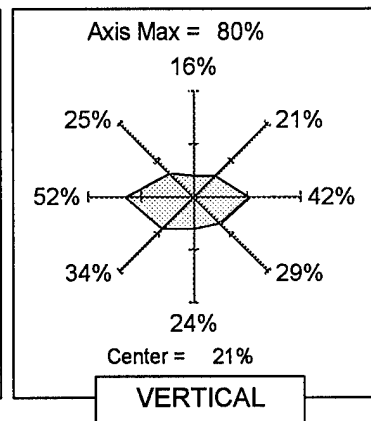
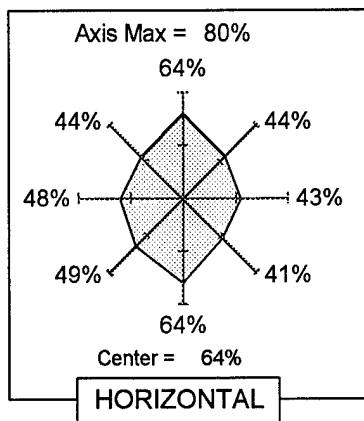
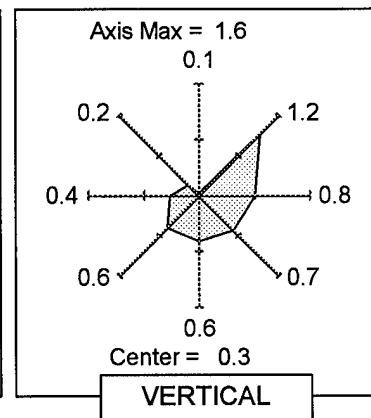
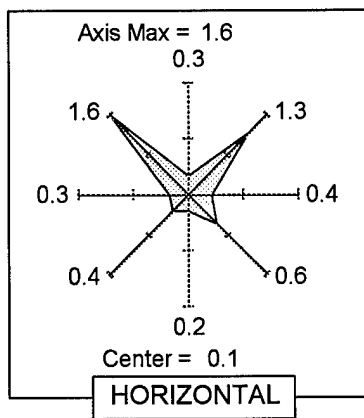
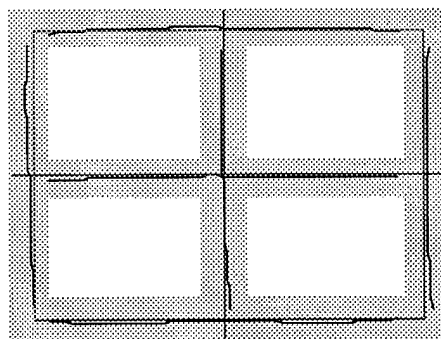
- Screen center luminance was one of the lowest in this survey (21.9 fL).
- The monitor showed high horizontal Cm.
- Based on a Cm = 25%, this monitor resolved 96% of the addressable pixels.

Detailed Performance Data**Display Resolution**

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	Cm = 25%	1600 x 1151
Text and Graphics	Cm = 50%	1417 x 821

**Maximum Luminance
in Foot Lamberts**



Linewidth in Pixels (RAR)**Contrast Modulation****Misconvergence in Pixels****Waviness**

Gray band indicates $\pm 1\%$ distortion.

NEC MULTISYNC XP21

Manufacturer's Data

Manufacturer Name	NEC
Model Number	MultiSync XP21
Price	\$2,245
Screen Diagonal	21 inches
Horizontal Scan Rate	87.50 kHz
Vertical Scan Rate	70.00 Hz
Image Size (H x V)	14.8 x 11.1 inches
Addressable Pixel Number	1600 x 1200
Pixel Size	9.26 x 9.26 mils (0.235 x 0.235 mm)
Dot Pitch	11.0 mils (0.28 mm)

Summary Comments:

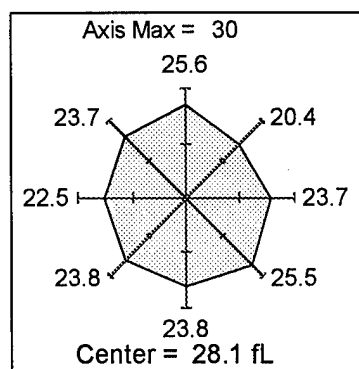
- Contrast modulation and resolution limit are among the best tested.
- Based on a $C_m = 25\%$, this monitor resolved all of the addressable pixels.

Detailed Performance Data

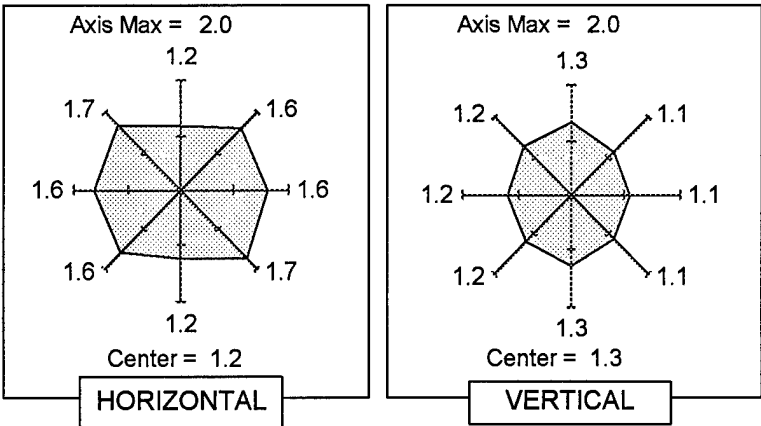
Display Resolution

<u>Display Content</u>	<u>C_m Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	$C_m = 25\%$	1600 x 1200
Text and Graphics	$C_m = 50\%$	1245 x 1117

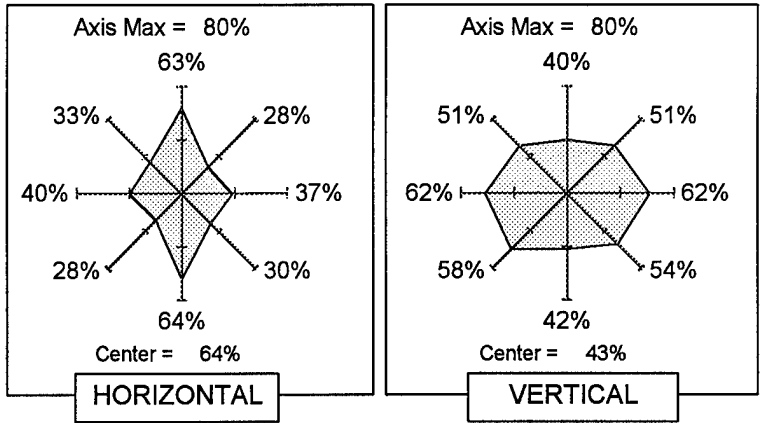
**Maximum Luminance
in Foot Lamberts**



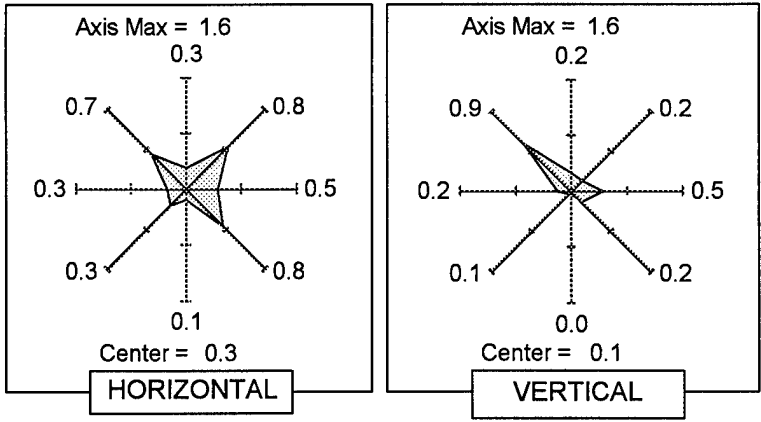
Linewidth in Pixels (RAR)



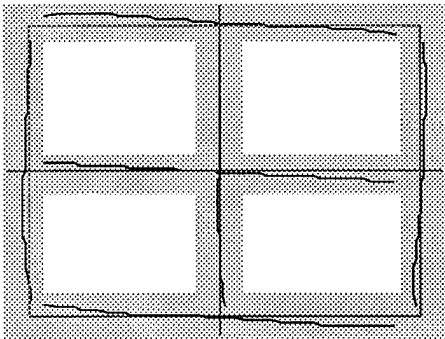
Contrast Modulation



Misconvergence in Pixels



Waviness



Gray band indicates $\pm 1\%$ distortion.

NISSEI SANGYO SUPERSCAN SUPREME 21

Manufacturer's Data

Manufacturer Name	Nissei Sangyo (also known as NSA Hitachi)
Model Number	SuperScan Supreme 21
Price	\$2,895
Screen Diagonal	21 inches
Horizontal Scan Rate	106.25 kHz
Vertical Scan Rate	85.00 Hz
Image Size (H x V)	15.6 x 11.6 inches
Addressable Pixel Number	1600 x 1200
Pixel Size	9.72 x 9.68 mils (0.247 x 0.246 mm)
Dot Pitch	10.2 mils (0.26 mm)

Summary Comments:

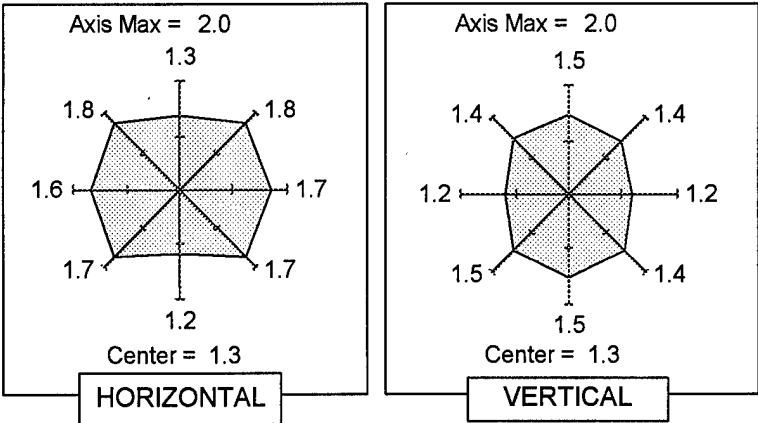
- The screen center luminance of 30.1 fL is one of the highest tested.
- The monitor showed low waviness (0.25% for vertical pincushion).
- The 85 Hz refresh rate was among the highest tested.
- Based on a $C_m = 25\%$, this monitor resolved 76% of the addressable pixels, the lowest value in the survey.
- Moiré correction circuitry available on this monitor was not evaluated and was instead set to the OFF position during testing.

Detailed Performance Data

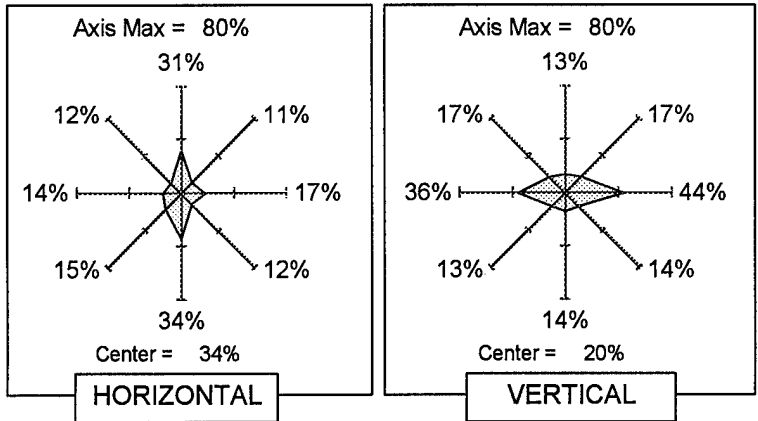
Display Resolution

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	$C_m = 25\%$	1397 x 1045
Text and Graphics	$C_m = 50\%$	985 x 748

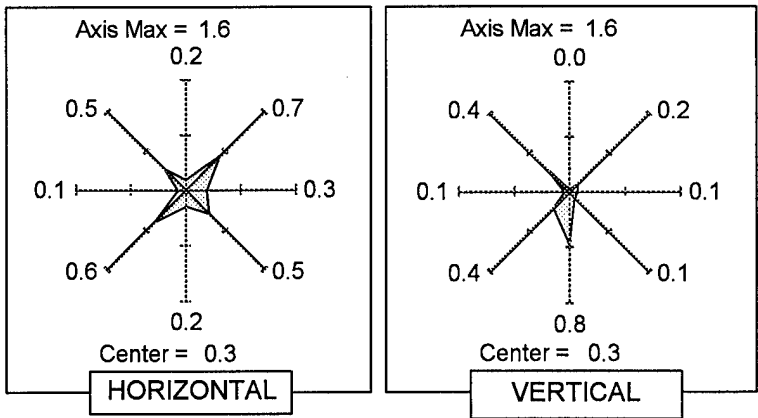
Linewidth in Pixels (RAR)



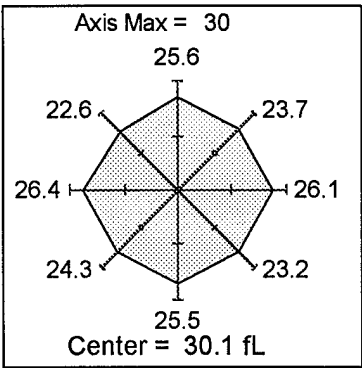
Contrast Modulation



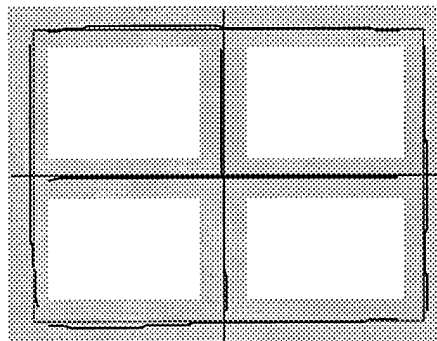
Misconvergence in Pixels



Maximum Luminance
in Foot Lamberts



Waviness



Gray band indicates $\pm 1\%$ distortion.

ORWIN C1632 (UPGRADED)**Manufacturer's Data**

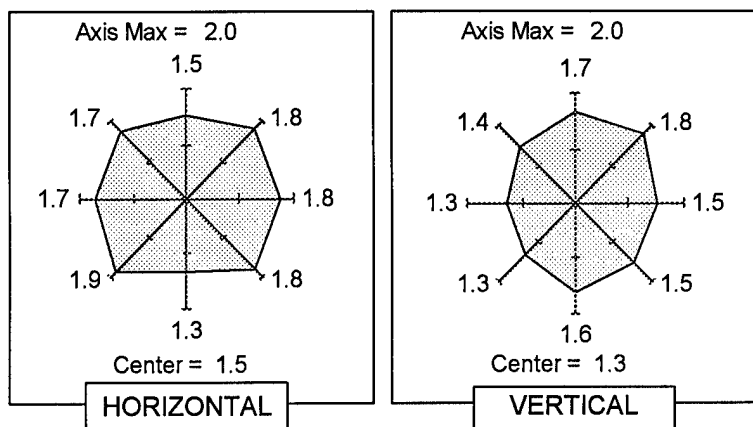
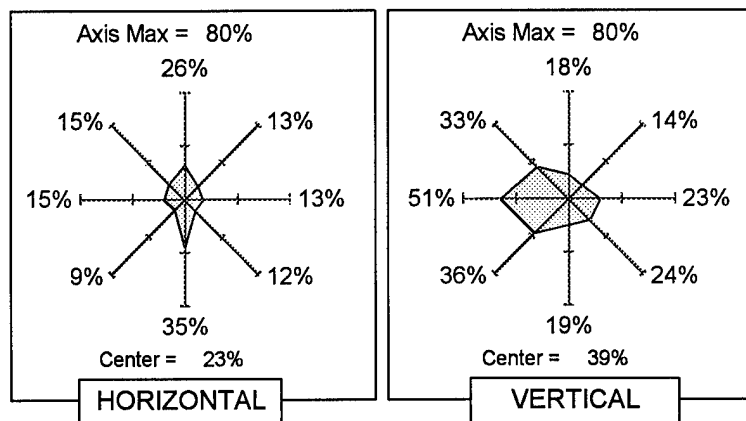
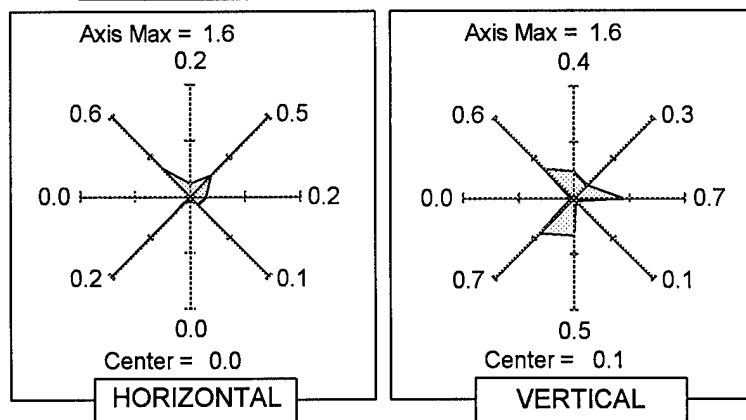
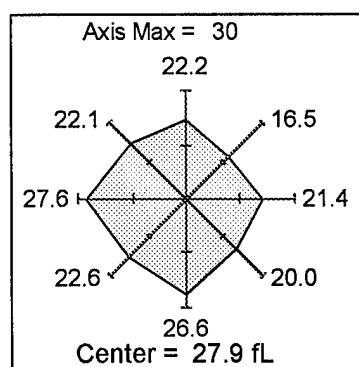
Manufacturer Name	Orwin
Model Number	C1632 (Upgraded)
Price	\$7,000 (Quantity pricing)
Screen Diagonal	21 inches
Horizontal Scan Rate	95.61 kHz
Vertical Scan Rate	72.00 Hz
Image Size (H x V)	14.9 x 11.6 inches
Addressable Pixel Number	1600 x 1280
Pixel Size	9.30 x 9.06 mils (0.236 x 0.230 mm)
Dot Pitch	10.2 mils (0.26 mm)

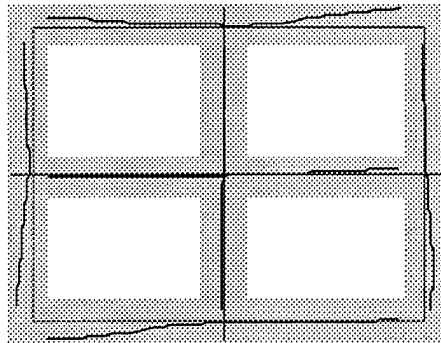
Summary Comments:

- This was the only ruggedized monitor in the survey. That certainly contributes to the high cost, which should not be compared to the other, non-ruggedized monitors.
- The deflection system on this unit was upgraded by Orwin to achieve 1600 x 1280 addressable pixels, but resolution was still lower than 1600 x 1280.
- The video amplifier in this monitor is intended for 1280 x 1024 addressable pixels and may not have sufficient bandwidth to support 1600 x 1280 format. The manufacturer offers an optional higher bandwidth video amplifier intended for 1600 x 1280 applications.
- Horizontal Cm was degraded by Moiré on vertical grille patterns.
- The monitor exhibited high waviness of 0.83% for vertical pincushion.
- Based on a Cm = 25%, this monitor resolved 81% of the addressable pixels.

Detailed Performance Data**Display Resolution**

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	Cm = 25%	1380 x 1198
Text and Graphics	Cm = 50%	950 x 852

Linewidth in Pixels (RAR)**Contrast Modulation****Misconvergence in Pixels****Maximum Luminance
in Foot Lamberts**

Waviness

Gray band indicates $\pm 1\%$ distortion.

PANASONIC PANASONIC/PRO C-2192P**Manufacturer's Data**

Manufacturer Name	Panasonic
Model Number	Panasonic/Pro C-2192P
Price	\$1,848
Screen Diagonal	21 inches
Horizontal Scan Rate	82.01 kHz
Vertical Scan Rate	62.08 Hz
Image Size (H x V)	15.0 x 11.2 inches
Addressable Pixel Number	1600 x 1280
Pixel Size	9.37 x 8.78 mils (0.238 x 0.223 mm)
Dot Pitch	9.8 mils (0.25 mm)

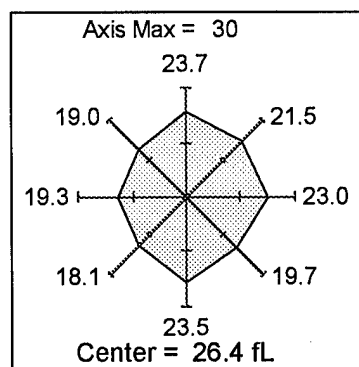
Summary Comments:

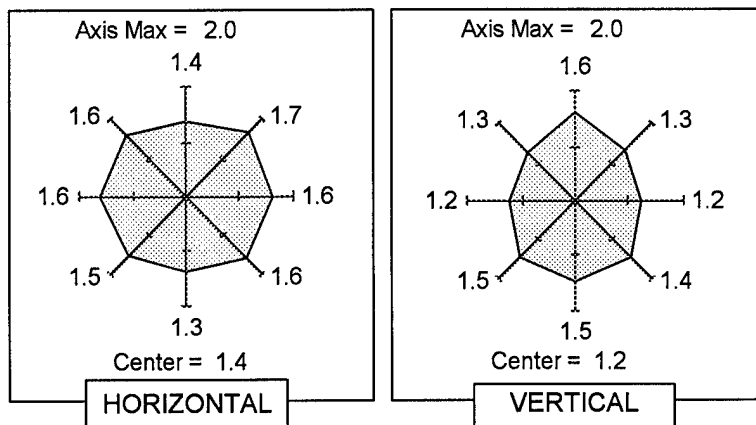
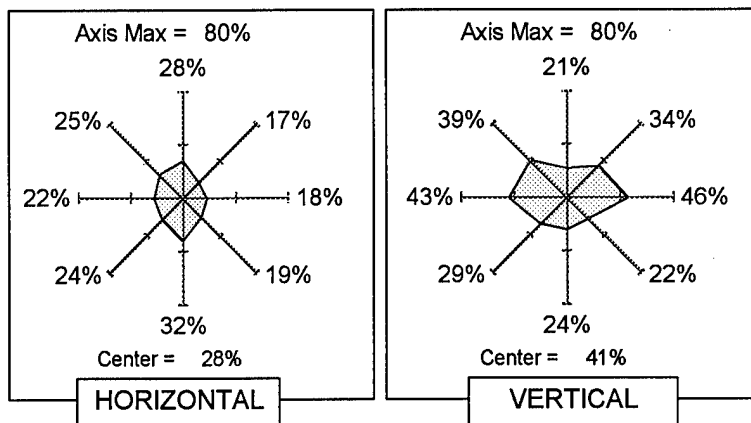
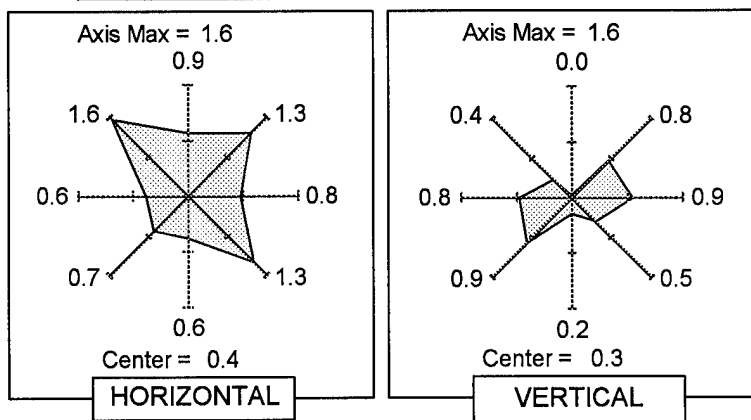
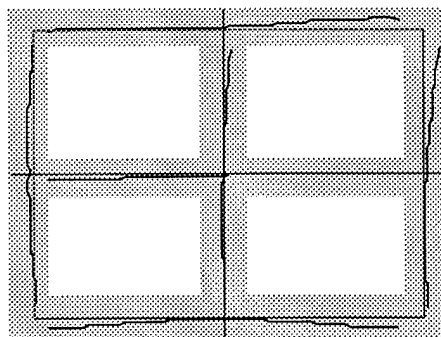
- Based on a $C_m = 25\%$, this monitor resolved 92% % of the addressable pixels.
- Moiré correction circuitry available on this monitor was not evaluated and was instead set to the OFF position during testing.

Detailed Performance Data**Display Resolution**

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	$C_m = 25\%$	1512 x 1252
Text and Graphics	$C_m = 50\%$	975 x 884

**Maximum Luminance
in Foot Lamberts**



Linewidth in Pixels (RAR)**Contrast Modulation****Misconvergence in Pixels****Waviness**

Gray band indicates $\pm 1\%$ distortion.

PHILIPS 2130DC**Manufacturer's Data**

Manufacturer Name	Philips
Model Number	2130DC
Price	\$2,699
Screen Diagonal	21 inches
Horizontal Scan Rate	89.81 kHz
Vertical Scan Rate	72.31 Hz
Image Size (H x V)	15.0 x 11.2 inches
Addressable Pixel Number	1600 x 1200
Pixel Size	9.36 x 9.36 mils (0.238 x 0.238 mm)
Dot Pitch	11.0 mils (0.28 mm)

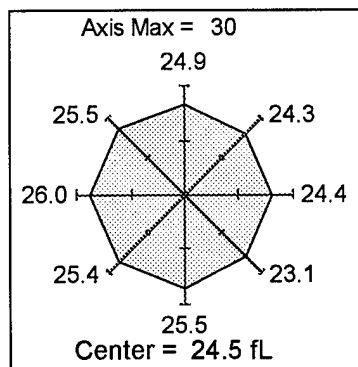
Summary Comments:

- The monitor showed the least luminance variation over the screen.
- Based on a $C_m = 25\%$, this monitor resolved all of the addressable pixels.

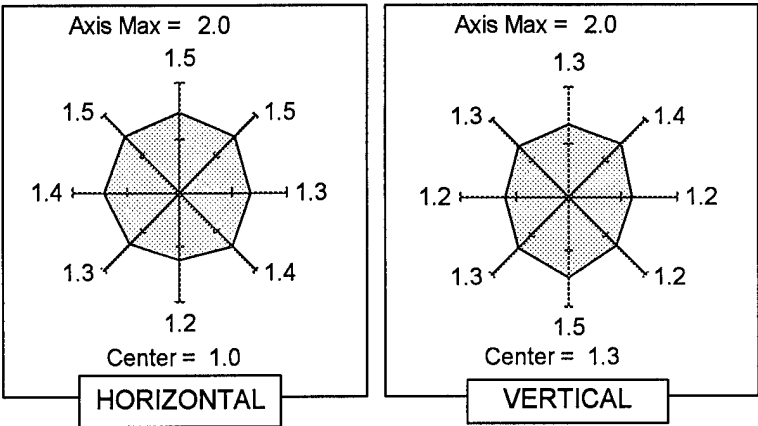
Detailed Performance Data**Display Resolution**

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	$C_m = 25\%$	1600 x 1194
Text and Graphics	$C_m = 50\%$	1310 x 907

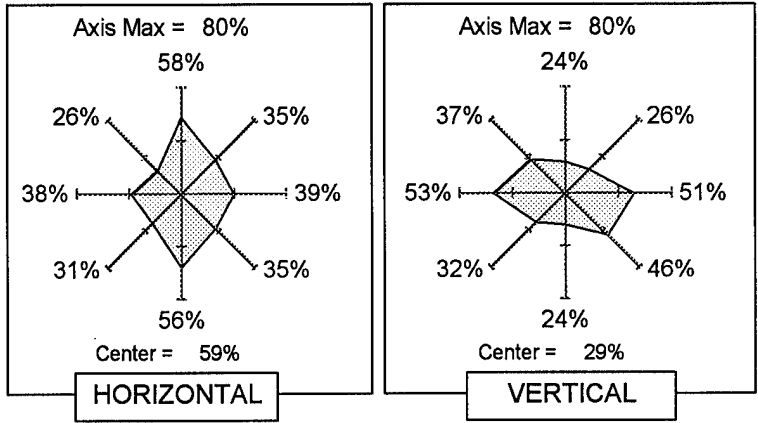
**Maximum Luminance
in Foot Lamberts**



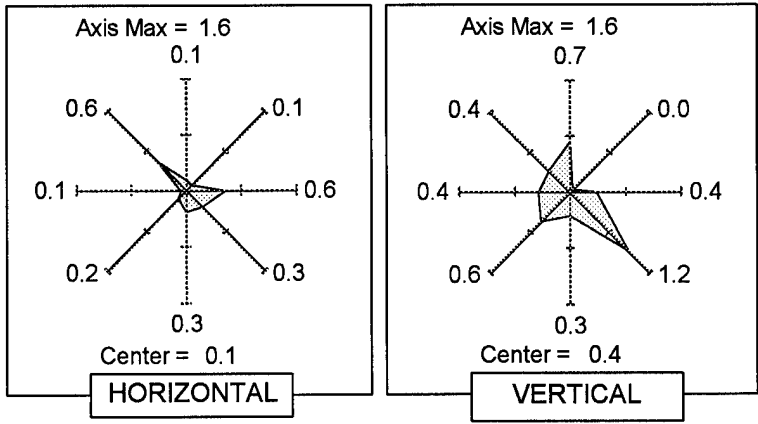
Linewidth in Pixels (RAR)



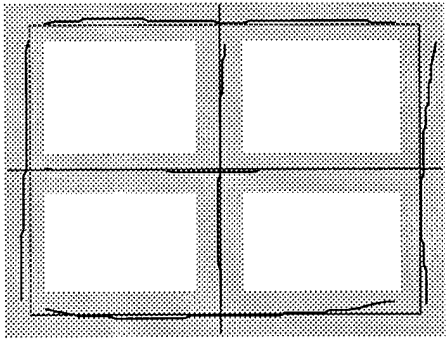
Contrast Modulation



Misconvergence in Pixels



Waviness



Gray band indicates $\pm 1\%$ distortion.

SAMPO ALPHASCAN GLX

Manufacturer's Data

Manufacturer Name	Sampo
Model Number	AlphaScan GLX
Price	\$1,365
Screen Diagonal	20 inch
Horizontal Scan Rate	82.00 kHz
Vertical Scan Rate	66.66 Hz
Image Size (H x V)	14.2 x 10.6 inches
Addressable Pixel Number	1600 x 1200
Pixel Size	8.86 x 8.85 mils (0.225 x 0.225 mm)
Dot Pitch	11.0 mils (0.28 mm)

Summary Comments:

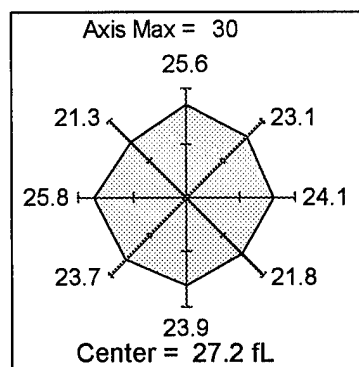
- This is the lowest-cost monitor in the survey (\$1,365).
- Based on a $C_m = 25\%$, this monitor resolved 84% of the addressable pixels.

Detailed Performance Data

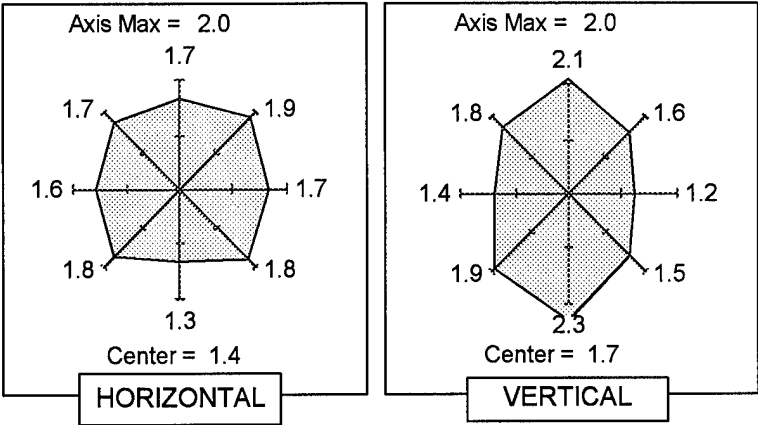
Display Resolution

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	$C_m = 25\%$	1521 x 1059
Text and Graphics	$C_m = 50\%$	1078 x 753

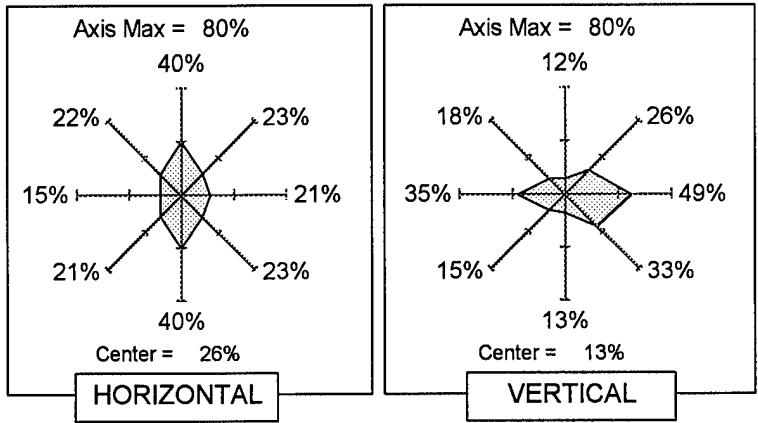
Maximum Luminance
in Foot Lamberts



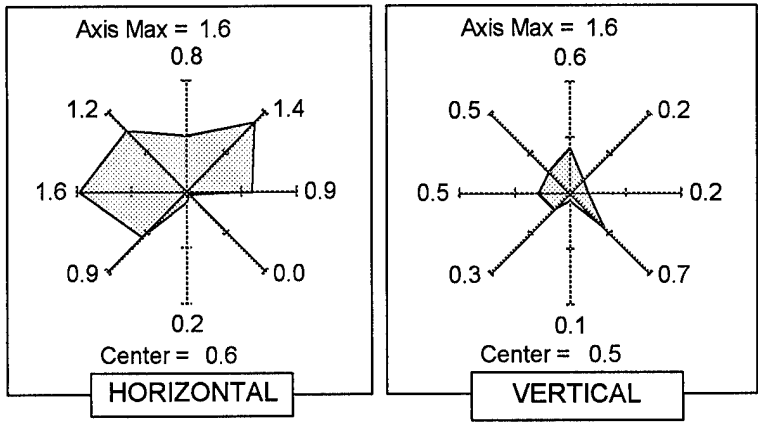
Linewidth in Pixels (RAR)



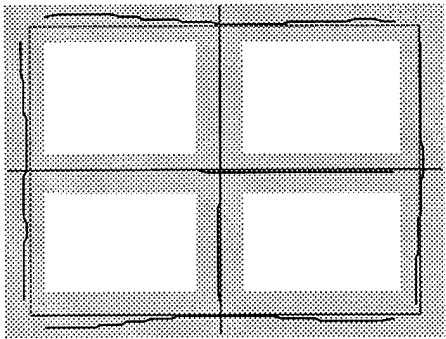
Contrast Modulation



Misconvergence in Pixels



Waviness



Gray band indicates $\pm 1\%$ distortion.

SIGMA COLORFX 21E

Manufacturer's Data

Manufacturer Name	Sigma
Model Number	ColorFX 21E
Price	\$2,585
Screen Diagonal	21 inches
Horizontal Scan Rate	106.25 kHz
Vertical Scan Rate	85.00 Hz
Image Size (H x V)	15.2 x 11.4 inches
Addressable Pixel Number	1600 x 1200
Pixel Size	9.47 x 9.51 mils (0.241 x 0.242 mm)
Dot Pitch	11.0 mils (0.28 mm)

Summary Comments:

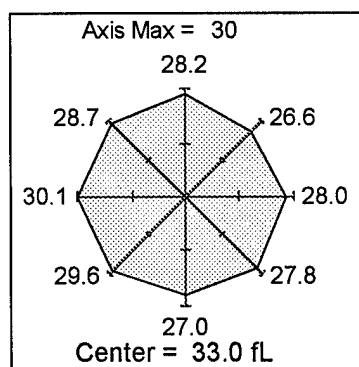
- The monitor had the highest screen center luminance of the monitors in this survey (33 fL).
- The 85 Hz refresh rate was among the highest tested.
- Based on a $C_m = 25\%$, this monitor resolved 87% of the addressable pixels.
- The original purchase price to NIDL for this monitor was \$2585. The manufacturer now offers this monitor at a suggested retail of \$1995

Detailed Performance Data

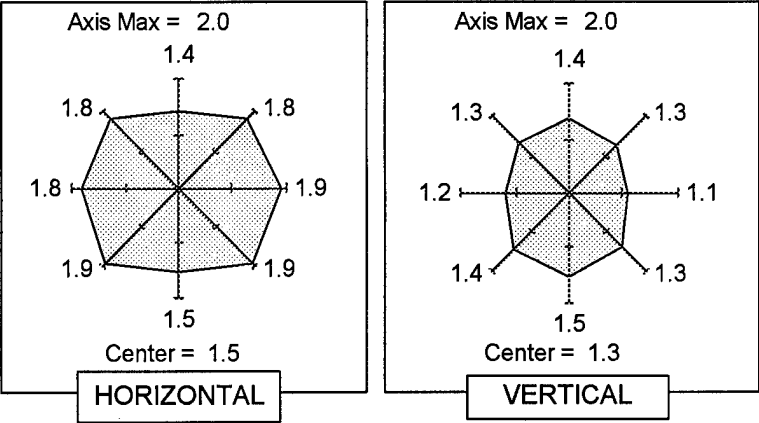
Display Resolution

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	$C_m = 25\%$	1410 x 1188
Text and Graphics	$C_m = 50\%$	956 x 886

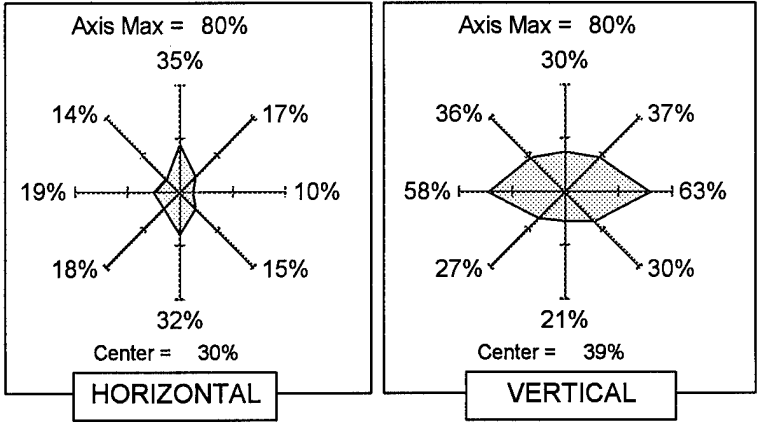
Maximum Luminance
in Foot Lamberts



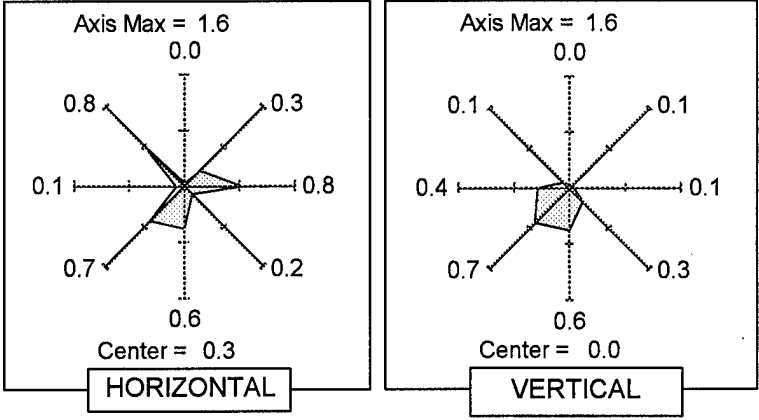
Linewidth in Pixels (RAR)



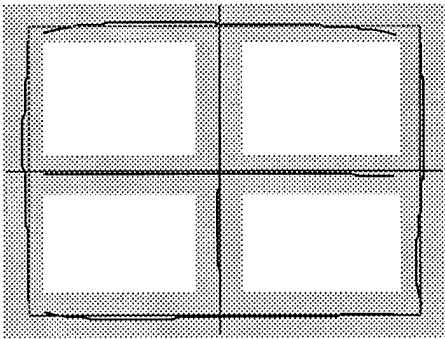
Contrast Modulation



Misconvergence in Pixels



Waviness



Gray band indicates $\pm 1\%$ distortion.

SONY MULTISCAN 20SE**Manufacturer's Data**

Manufacturer Name	Sony
Model Number	Multiscan 20se
Price	\$2,108
Screen Diagonal	20 inches
Horizontal Scan Rate	81.25 kHz
Vertical Scan Rate	65.00 Hz
Image Size (H x V)	14.7 x 11.0 inches
Addressable Pixel Number	1600 x 1200
Pixel Size	9.19 x 9.19 mils (0.233 x 0.233 mm)
Stripe Pitch	11.8 mils (0.30 mm)

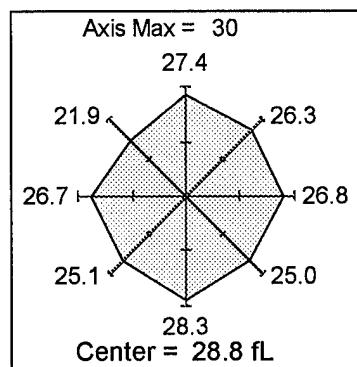
Summary Comments:

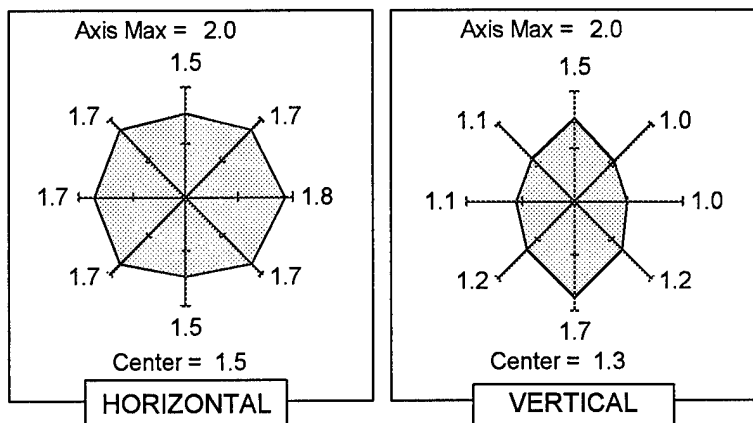
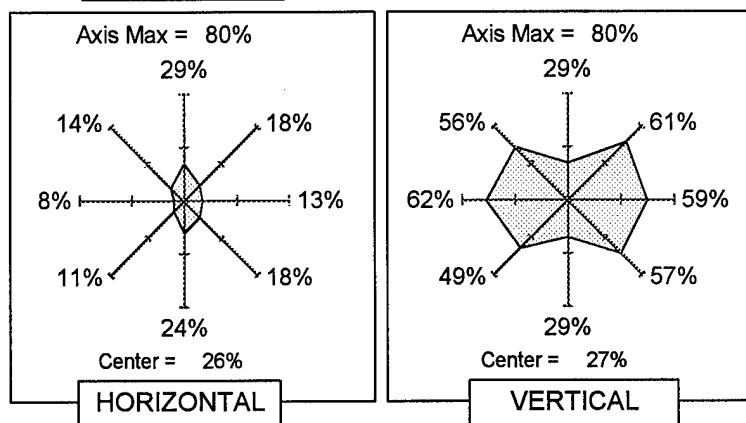
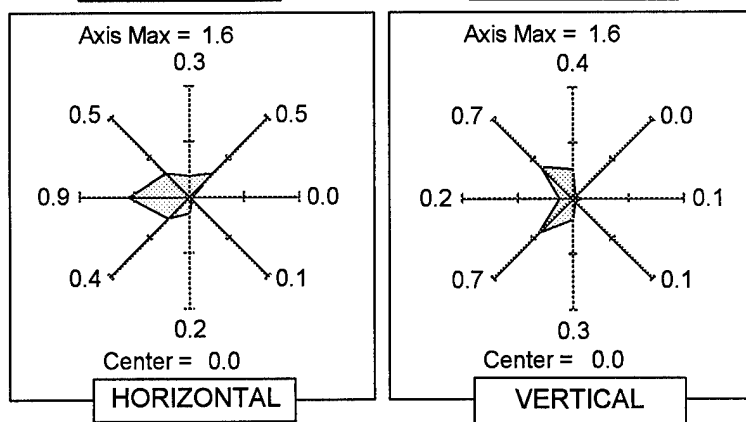
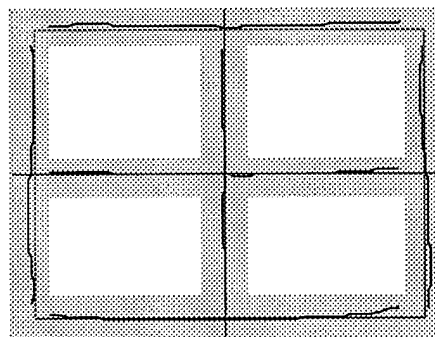
- This monitor features the Trinitron CRT aperture grille.
- Horizontal Cm was degraded by the presence of Moiré on vertical grille patterns.
- Based on a Cm = 25%, this monitor resolved 89% of the addressable pixels.

Detailed Performance Data**Display Resolution**

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	Cm = 25%	1417 x 1200
Text and Graphics	Cm = 50%	987 x 1057

**Maximum Luminance
in Foot Lamberts**



Linewidth in Pixels (RAR)**Contrast Modulation****Misconvergence in Pixels****Waviness**

Gray band indicates $\pm 1\%$ distortion.

TATUNG CM20MKR**Manufacturer's Data**

Manufacturer Name	Tatung
Model Number	CM20MKR
Price	\$1,686
Screen Diagonal	20 inches
Horizontal Scan Rate	75.72 kHz
Vertical Scan Rate	60.00 Hz
Image Size (H x V)	13.8 x 10.3 inches
Addressable Pixel Number	1600 x 1200
Pixel Size	8.61 x 8.60 mils (0.219 x 0.218 mm)
Dot Pitch	12.2 mils (0.31 mm)

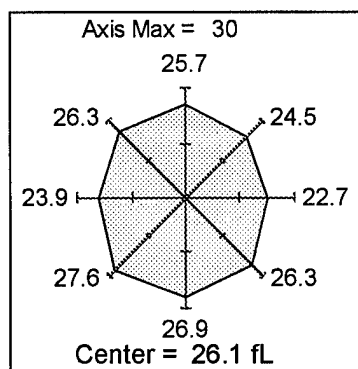
Summary Comments:

- The vertical Cm was the lowest tested.
- Based on a Cm = 25%, this monitor resolved 87% of the addressable pixels.

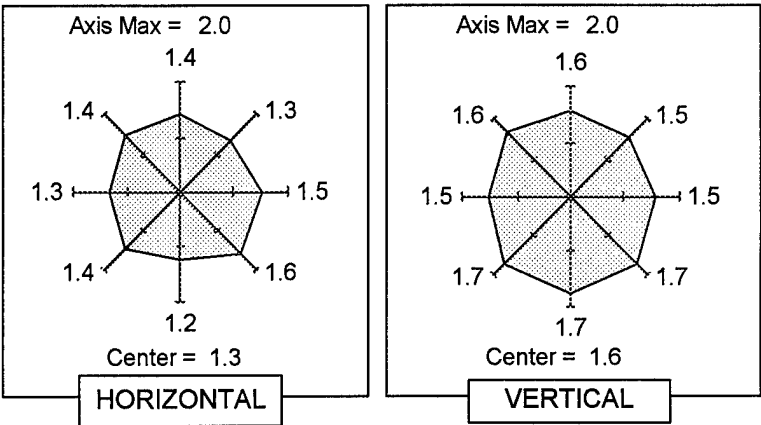
Detailed Performance Data**Display Resolution**

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	Cm = 25%	1600 x 1043
Text and Graphics	Cm = 50%	1127 x 693

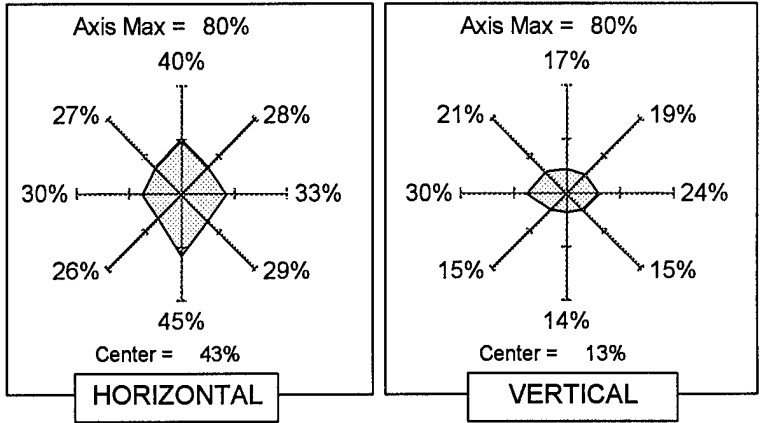
**Maximum Luminance
in Foot Lamberts**



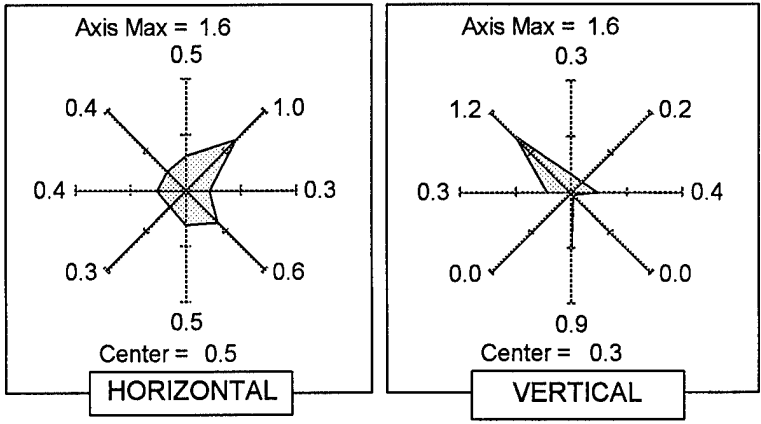
Linewidth in Pixels (RAR)



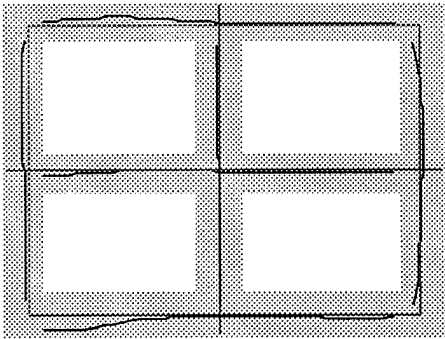
Contrast Modulation



Misconvergence in Pixels



Waviness



Gray band indicates $\pm 1\%$ distortion.

VIEWSONIC 21PS

Manufacturer's Data

Manufacturer Name	ViewSonic
Model Number	21PS
Price	\$1,919
Screen Diagonal	21 inches
Horizontal Scan Rate	81.25 kHz
Vertical Scan Rate	65.00 Hz
Image Size (H x V)	15.0 x 11.2 inches
Addressable Pixel Number	1600 x 1200
Pixel Size	9.35 x 9.34 mils (0.237 x 0.237 mm)
Dot Pitch	9.8 mils (0.25 mm)

Summary Comments:

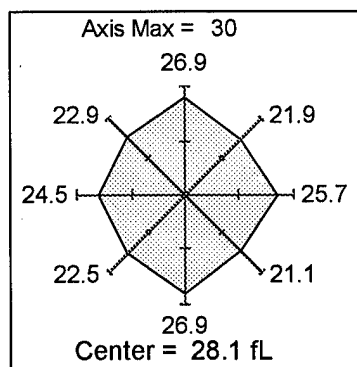
- Vertical contrast modulation was among the best measured.
- Horizontal Cm was degraded by the presence of Moiré on vertical grille patterns.
- Moiré correction circuitry available on this monitor was not evaluated and was instead set to the OFF position during testing.
- Based on a Cm = 25%, this monitor resolved 92% of the addressable pixels.

Detailed Performance Data

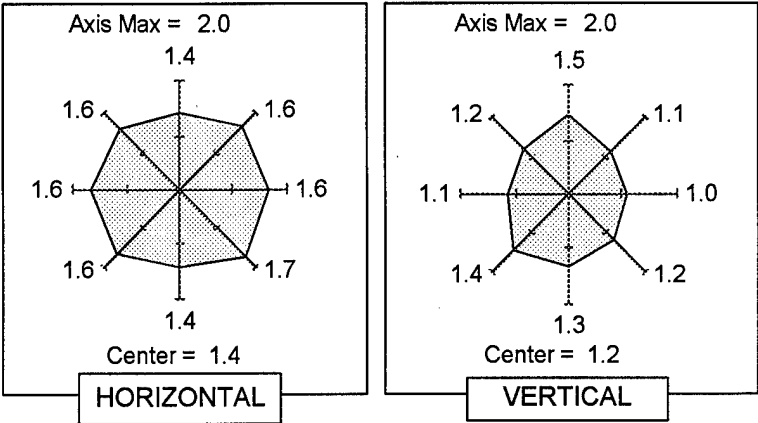
Display Resolution

<u>Display Content</u>	<u>Cm Required</u>	<u>Resolution Limit</u>
Grayscale Imagery:	Cm = 25%	1479 x 1200
Text and Graphics	Cm = 50%	1007 x 1028

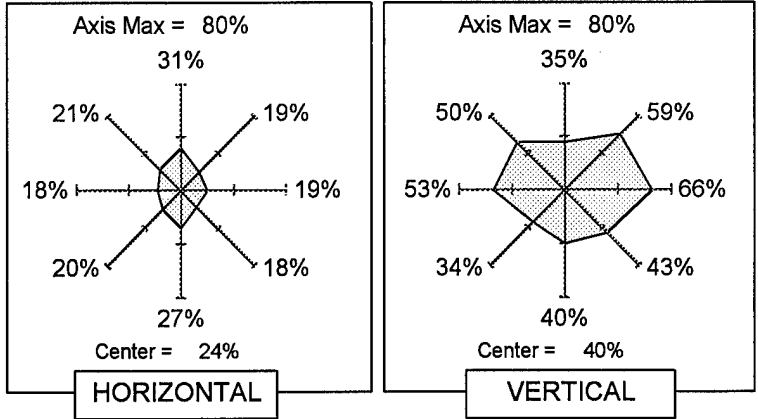
Maximum Luminance
in Foot Lamberts



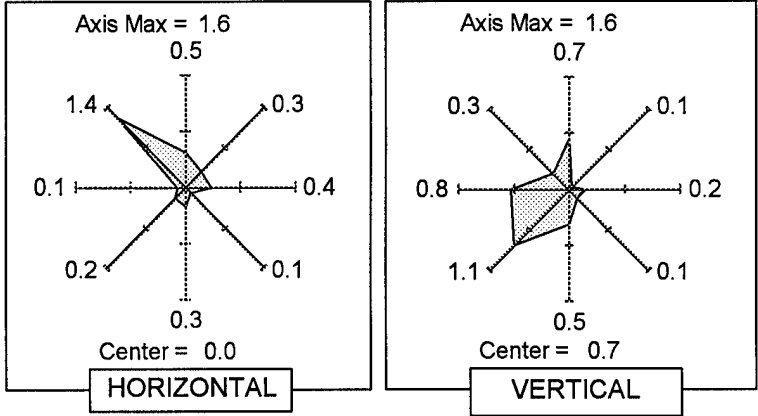
Linewidth in Pixels (RAR)



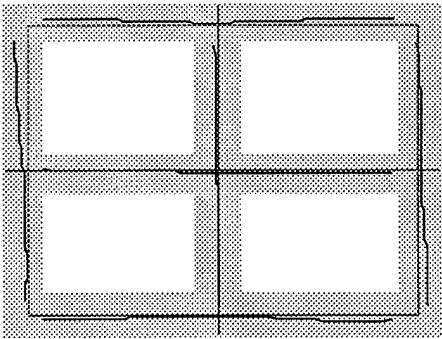
Contrast Modulation



Misconvergence in Pixels



Waviness



Gray band indicates $\pm 1\%$ distortion.