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A Characterization of Low Luminance Static and Dynamic Modulation Transfer Function Curves for P-1, P-43, and P-53 Phosphors

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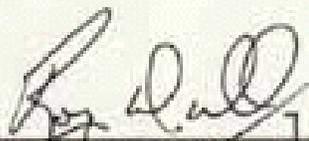
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Introduction

A number of different types of displays are used in various military applications. Currently, most of these displays are based on cathode ray tubes (CRTs), which use the cathodoluminescence process of phosphors to produce the display images. To ensure faithful reproduction of scenes on the displays, it is desirable to characterize a display's ability to perform this function. As argued by Rash and Verona (1987) and Verona et al. (1994), characterization must assess both the static and dynamic performance of the display.

Using contrast as the primary attribute of a scene, the modulation transfer function (MTF) is a standard metric used to evaluate display performance. Contrast, generally defined as a measure of the difference between the brightest and darkest regions of a scene, can be expressed in a number of ways. For CRT displays, modulation contrast, or Michelson contrast, often is considered an appropriate metric for describing the display's capacity to convey relative luminance (Task, 1979). Based on a sinusoidal input, modulation contrast (M_c), is defined as

$$M_c = (L_{\max} - L_{\min}) / (L_{\max} + L_{\min}),$$

where L_{\max} is the maximum luminance and L_{\min} is the minimum luminance. Modulation contrast can be related to the integer number of gray scales that an analog display is capable of reproducing.

The capacity of a display to reproduce contrast is spatial and temporal frequency dependent. Spatial frequency refers to the rate of luminance change over space, typically expressed for a display as the number of cycles per millimeter (mm) of display width. Temporal frequency refers to the rate of luminance change over time, which is expressed in Hertz. Temporal frequencies can be related to rates of motion within a scene or between the scene and sensor. Generally, modulation contrast values are measured for a specific display and for a selected temporal frequency. When expressed as ratios to the input modulation and plotted as a function of spatial frequency, the resulting curve (Figure 1) is referred to as the display's modulation transfer function (MTF) for the selected temporal frequency. For a static CRT image, the MTF can be interpreted as the MTF for the condition where the relative motion within the scene is zero. It has become customary to use the term dynamic MTF for temporal frequencies greater than zero.

In this evaluation, the static and dynamic MTFs of three phosphors were measured: P-1, P-43, and P-53. Table 1 provides a brief summary of each phosphor's characteristics. P-1 and P-43 are phosphors associated with the Integrated Helmet and Display

Sighting System (IHADSS) helmet-mounted display (HMD) used in the AH-64 Apache helicopter. (Note: P-1 was the phosphor selected originally for use in the IHADSS. This phosphor was replaced later by P-43. The replacement was prompted by image smearing which contributed to a flight mishap and was the result of the temporal characteristics of the P-1 phosphor.) P-53 is under consideration for use in the RAH-66 Comanche HMD, the Helmet Integrated Display Sight Subsystem (HIDSS).

For the purpose of this evaluation, the important difference between the phosphors is their persistence. Persistence is defined as the time required for the intensity to decay to some percentage of its maximum value following excitation. The 10 percent point is typically used. Table 1 shows the persistence values (10%) to be 1.2, 6.7, and 24 milliseconds (ms) for P-43, P-53, and P-1, respectively.

Table 1.

Phosphor characteristics

Phosphor number	Color	Range (nanometers)	Class	Persistence (10%)
1	Yellow-green	492 to 577	Medium	24.0 ms
43	Yellow-green	451 to 577	Medium-short	1.2 ms
53	Yellow-green	405 to 695	Medium	6.7 ms

Methodology

The instrumentation and procedures for measuring both the static and dynamic contrast modulation values were basically the same. Measurements were performed using the sinusoidal counter-phase modulation technique described in Verona et al., 1994.

Test displays

The displays evaluated were miniature 1-inch diameter CRTs (Figure 2). A single display was evaluated for each of the three phosphors. The CRTs were supplied by Honeywell, Inc.* The P-43 CRT was a production line IHADSS CRT. The P-1 and P-53 tubes were research and development test CRTs.

* See Appendix A.

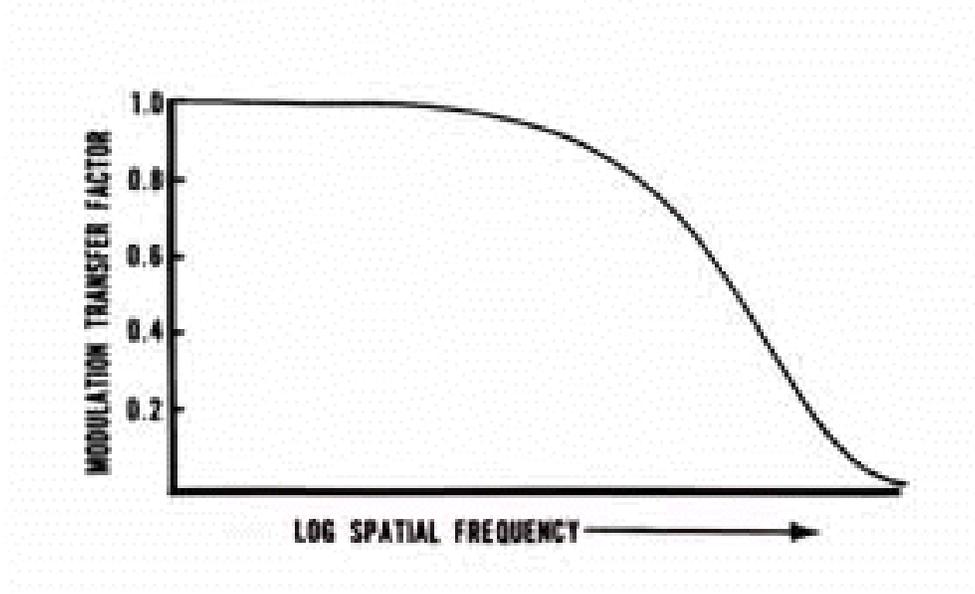


Figure 1. Typical modulation transfer function curve.



Figure 2. Miniature cathode ray tube.

Instrumentation

A pictorial diagram of the experimental setup is presented in Figure 3. Stimulus patterns were generated with a Hewlett-Packard* model HP-98731 Turbo-SRX computer graphics workstation. The output of the computer was fed to a Folsom Research, Inc.* model 8910 color graphics converter which produced a RS-170A NTSC video signal. This video signal was used to drive the display under evaluation. The software which produced the stimulus patterns was written in the C programming language running in a UNIX environment. Except for aliasing effects, the patterns theoretically could be generated at any desired spatial frequency and presented at any temporal frequency at or below 30 Hertz. For the evaluation presented here, combinations of the spatial and temporal frequencies presented in Table 2 were used.

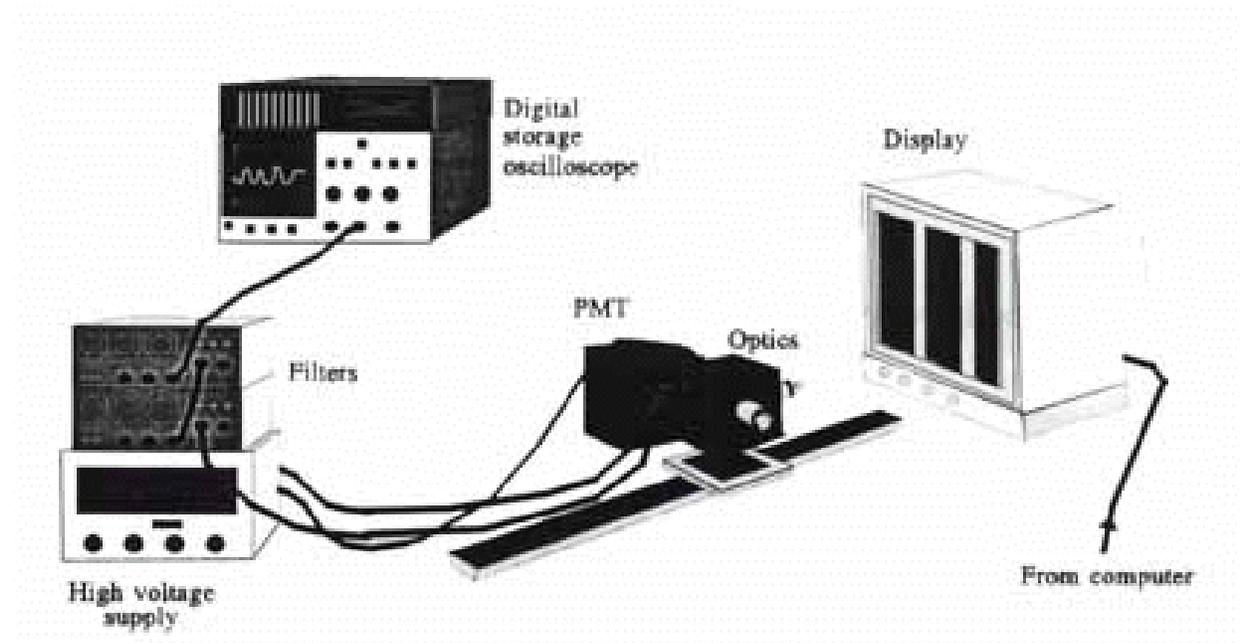


Figure 3. Pictorial diagram of the experimental setup.

An EG&G Gamma Scientific, Inc.* model DR-2 digital radiometer, model D-46A photomultiplier tube (PMT) assembly with 4 mhz high frequency amplifier, and model 700-10 photometric microscope (5X) with a 25 X 8000 micron slit were used as an effective photometer to convert the spatial and temporal luminance values into an electrical signal which was measured using a Tektronix* model 2440 digital storage oscilloscope. The model DR-2 radiometer was used only as a source of high voltage for the PMT. A high voltage value of 700 volts was used. The output of the high frequency amplifier of the PMT was filtered by two Frequency Devices, Inc.*, model 901F electronic filters before being fed to the oscilloscope. The filters, connected in series, acted as a low pass filter with a cutoff frequency of 35 Hertz and provided 40 dB of gain.

Table 2.

Spatial and temporal frequencies

Spatial (Cycles/millimeters)					Temporal (Hertz)
0.2,	0.4,	0.6,	0.8,	1.0,	0, 1.875,
1.3,	1.7,	1.9,	2.1,	2.5,	3.75, 5.0,
3.8,	4.2,	5.0,	6.2,	7.5,	7.5, 10.0
8.4,	9.4,	10.5			

The temporal response of the photometer is very critical for the dynamic measurements. The limited range of response speeds typically encountered in off-the-shelf photometers is inadequate for reliable dynamic measurements; therefore, the video or high frequency output of the photometer was used. The electronic filters provided amplification and filtered out high frequency noise, improving the signal-to-noise ratio. The output of the filter was displayed on a digital storage oscilloscope.

Display setup

Each phosphor was characterized for operating parameter values which equated to night viewing conditions. For the simulated night environment, a value of 15 footlamberts was chosen. Using a white/black ratio of 100:1, this required the black level luminance to be 0.15 footlambert. Following adjustment of focus and aspect ratio using the manufacturer's recommended procedures, the display's brightness and contrast were set using the following procedure.

Brightness and contrast controls were adjusted to their minimum settings (fully counterclockwise). Inputting a low spatial frequency square wave 1-volt peak-to-peak video signal (RS-170A, NTSC 525-line rate), the brightness control was increased until the raster barely was visible. The contrast control then was advanced to a setting which produced a 15-footlambert luminance value at the peak of the pattern (maximum video level). The black level luminance (minimum video level) was examined to see if the 0.15-footlambert value was present. As required, the brightness and contrast controls were adjusted, alternately, to achieve the 100:1 ratio. For each display, the minimum and maximum luminance values were verified to be 0.15 and 15 footlamberts, respectively, using an EG&G model 3100 photometric system.

In addition to the low luminance measurement for the three phosphors, the P-53 phosphor also was evaluated for a representative high output luminance. This additional evaluation was performed because the P-53 phosphor is the proposed phosphor for use in the RAH-66 Comanche helmet-mounted-display, the Helmet Integrated Display Sight Subsystem. This system currently has relay optics based on a low efficiency catadioptric design. To compensate for this low throughput, the CRT may be required to operate at the high end of its luminance range. To investigate the impact of this possibility on the phosphor's MTF, an additional

measurement was performed with the P-53 peak luminance set to 309.7 footlamberts. With the contrast maximized for best picture, the black level luminance was measured to be 7.3 footlamberts, producing a white/black ratio of approximately 42:1.

Procedure

The evaluation was performed in a fully darkened laboratory. The test displays were driven by computer generated static and dynamic vertical sine wave spatial patterns, i.e., the long dimension of the pattern at a 90° angle (vertical) to the display's scan line structure.

To evaluate the static case, zero Hertz temporal frequency, contrast measurements were made over the spatial frequency range of approximately three cycles per display width (0.2 cycles/mm) to the cutoff frequency, where the modulation contrast approached zero. For each spatial frequency, a peak of the sine wave was positioned in front of the photometer and the resulting maximum output was read from the display of the oscilloscope and recorded; then a trough of the sine wave was positioned and the resulting minimum output was read and recorded. These data, when used to calculate the contrast values, represent the sine wave response of the display for the static image condition.

For the dynamic case, the spatial sine wave patterns also were modulated temporally at selected sinusoidal frequencies. One temporal cycle of the stimulus consisted of the luminance at a position on the display changing from its brightest value to its darkest value and back to its brightest value (counterphase). The luminance variations on the display were sinusoidal in both spatial and temporal domains.

The first nonzero temporal frequency was selected and the appropriate input signal was applied to the display at each spatial frequency. For each spatial frequency, the photometer output signal was acquired using the oscilloscope. From the digitized waveform, the peak and trough values were obtained and used to calculate the modulation contrast value. This procedure was repeated for each temporal frequency.

Modulation transfer ratios were calculated from the input and output modulation contrast data for all spatial and temporal frequency combinations and presented as MTF curves. The input contrast modulation values were obtained by inputting each spatial and temporal frequency combination signal to the oscilloscope and reading the respective peak and trough values.

Results and discussion

Families of MTF curves for the P-1, P-43, P-53 (low and high luminance) phosphors are presented in Figures 4-7, respectively. Each family consists of six MTF curves, one for each temporal frequency. Graphs comparing the 0 Hz and 10 Hz MTF curves for all of the phosphors (and conditions) are presented in Figures 8 and 9, respectively.

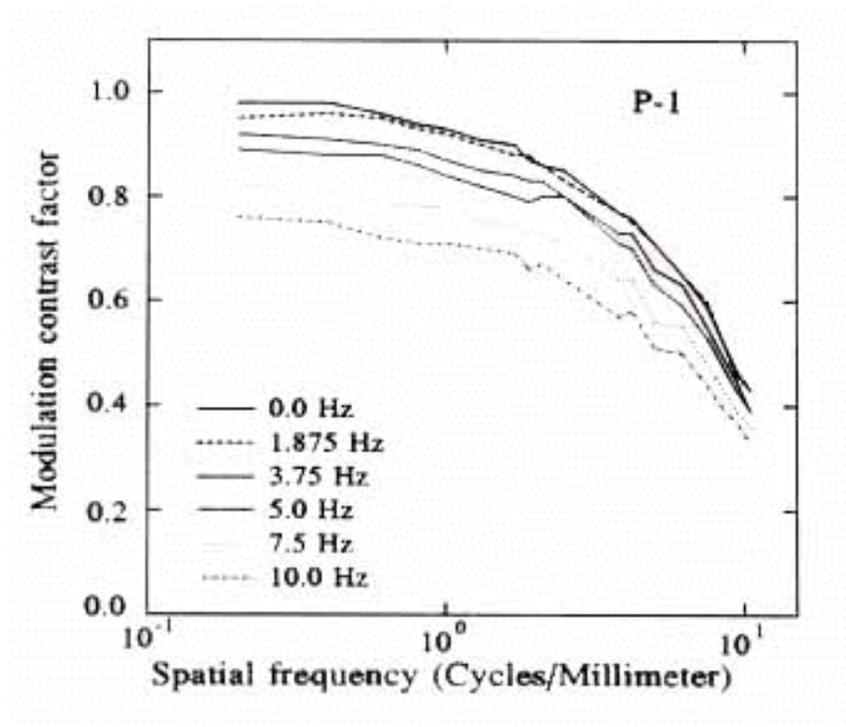


Figure 4. Modulation transfer function curves for P-1 phosphor display.

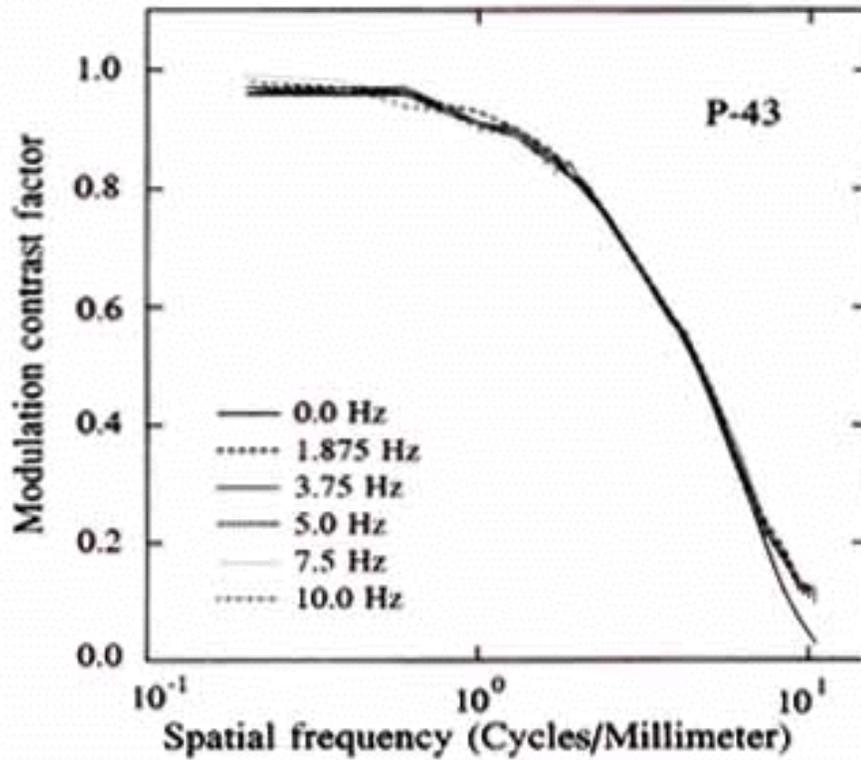


Figure 5. Modulation transfer function curves for P-43 phosphor display.

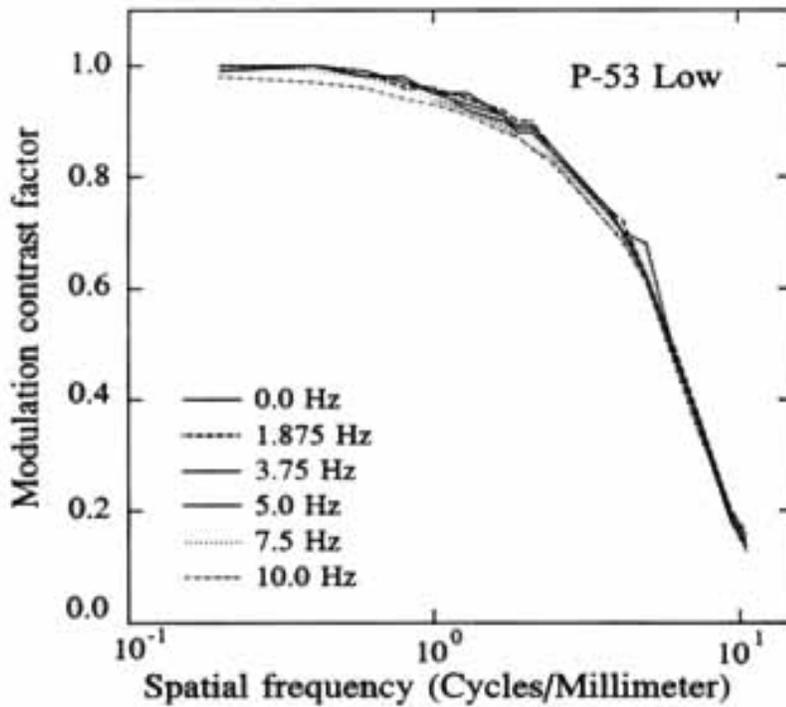


Figure 6. Modulation transfer function curves for P-53 phosphor display at low luminance.

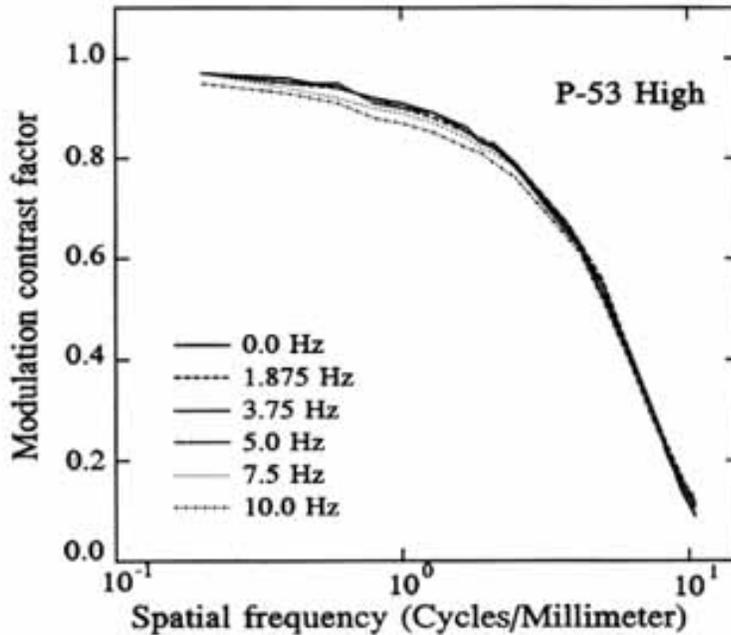


Figure 7. Modulation transfer function curves for P-53 phosphor display at high luminance.

The P-43 curves (Figure 5) do not appear to show any differences for the various temporal frequencies. This is expected due to the relatively short P-43 persistence value of 1.2 ms. P-53, with the somewhat longer persistence value of 6.7 ms, appears to show a loss of modulation transfer at 10 Hz for the low luminance condition (Figure 6). For the P-53 high luminance condition (Figure 7), the data suggest the MTF curves for both the 7.5 and 10 Hz temporal frequencies demonstrate reductions. This additional fall off for 7.5 Hz most likely is due to blooming resulting from the higher luminance. The curves for the P-1 phosphor (Figure 4) with its 24 ms persistence appear to show distinct differences between each temporal frequency.

In Figures 8 and 9, the modulation transfer function curves are compared for the 0 and 10 Hz temporal frequencies, respectively. The most obvious feature of these comparisons is the crossover of the MTF curve of the P-1 phosphor. The significance of this crossover is a greater contrast modulation transfer at the higher spatial frequencies for the P-1 phosphor over the other phosphors. While the cause of this phenomenon is debatable, it is thought to be based on the particulate size of the phosphor material. In other words, it is suspected that the P-1 phosphor has smaller particulate size, thereby increasing its higher spatial frequency response.

In summary, the family of MTF curves measured for each phosphor generally supports the supposition that phosphor persistence is a critical parameter in the ability of a CRT display to accurately reproduce contrast modulation transfer in dynamic environments.

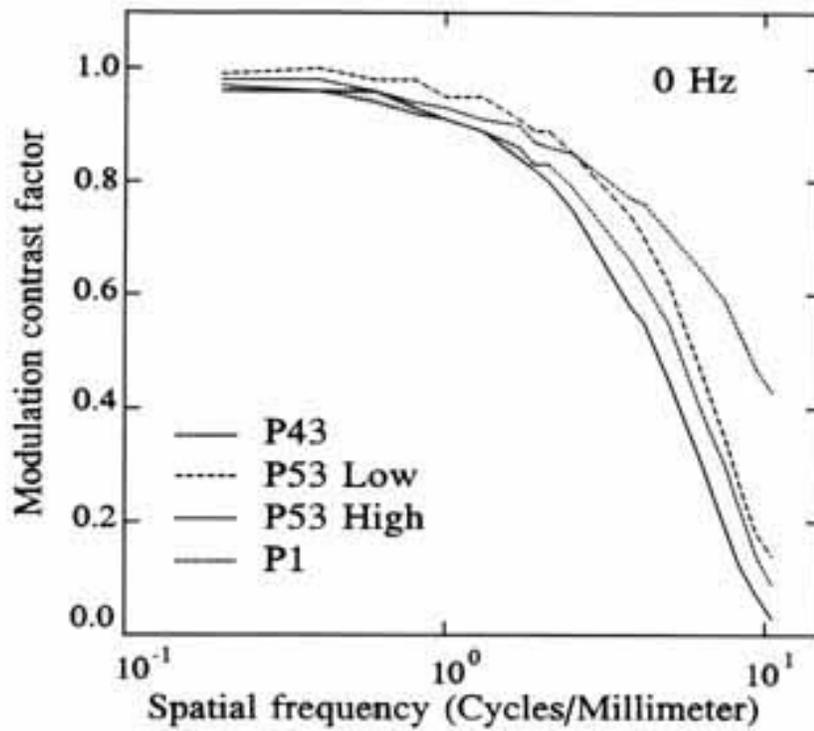


Figure 8. A comparison of modulation transfer function curves for 0 Hz.

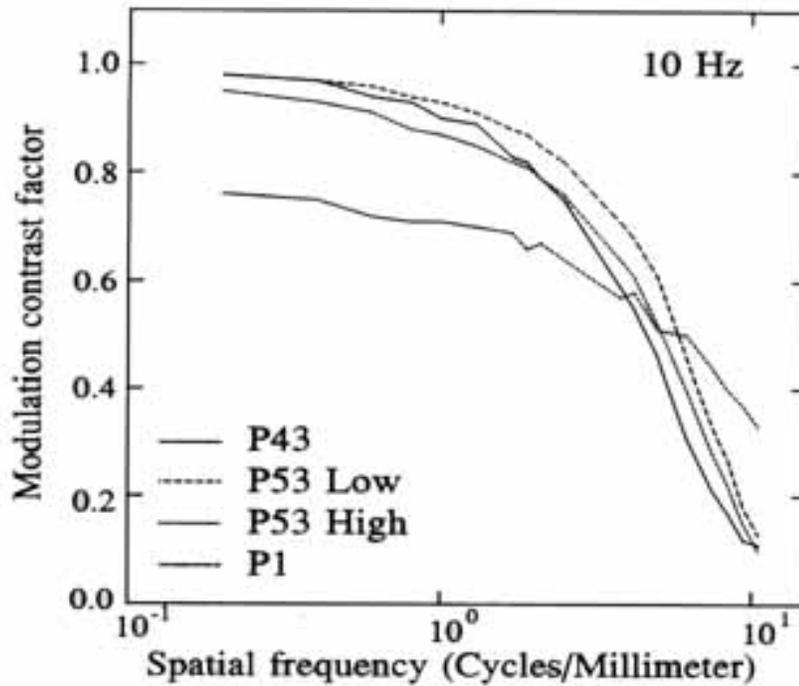


Figure 9. A comparison of modulation transfer function curves for 10 Hz.

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- Task, H. L. 1979. An evaluation and comparison of several measures of image quality for television displays. Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratory, AMRL TR-79-7-9.
- Verona, R. W., Beasley, H. H., Martin, J. S., Klymenko, V., and Rash, C. E. 1994. Dynamic sine wave response measurements of CRT displays using sinusoidal counterphase modulation. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 94-22.

Appendix A
List of equipment manufacturers

EG&G Gamma Scientific, Inc.
3777 Ruffin Road
San Diego, CA 92123

Frequency Devices, Inc.
25 locust Street
Haverhill, MA 01830

Folsom Research, Inc.
526 E. Bidwell Street
Folsom, CA 95630

Hewlett-Packard Co.
4700 Bayou Blvd.
Pensacola, FL 32503

Honeywell, Inc
1625 Zarthan Ave.
St. Louis Park, MN 55416

Tektronix, Inc.
P.O. Box 500
Beaverton, OR 97077