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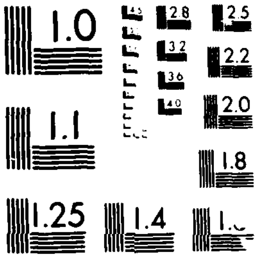

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DESIGN AND TESTING OF A LUMINANCE AND CHROMINANCE STABILIZATION SYSTEM FOR A COMPUTER-CONTROLLED COLOR DISPLAY (U)

WILLARD W. FARLEY, M.S.

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

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ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY
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FOR THE COMMANDER

CHARLES BATES, JR.
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The improvements in computer display technology have made it possible for researchers in color vision to make use of this technology to generate stimuli for color research. The early research has shown the tremendous advantages of this technique in the large number of different stimuli that can be presented in a single experiment. Unfortunately, the early research also highlighted several problems with the computer display system. One of the major problems is the computer display is not constant over time.

This report outlines a Feedback Control System that may be connected to any computer display system whose video bandwidth is lower than 50 MHz. The system receives light from a red, green, and blue area of the screen that is always commanded to the same intensity level via three detectors. The signal from the detectors is used as the reference signal in a feedback control system such that the luminance of each of the three guns of the display is made to have a constant output. A single-channel version can also be constructed to stablize the luminance of a monochrome CRT.

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PREFACE

This study was initiated by the Visual Display Systems Branch, Human Engineering Division, of the Harry G. Armstrong Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base. The research was conducted by the Human Factors Laboratory in the Department of Industrial Engineering and Operations Research, of Virginia Polytechnic Institute and State University in Blacksburg, Virginia, under Air Force Contract F33615-84-C-0510. Dr. Harry L. Snyder and Willard W. Farley were the principal investigators for Virginia Polytechnic Institute and State University. Dr. David L. Post was the Technical Monitor for the Armstrong Aerospace Medical Research Laboratory.

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I. INTRODUCTION

Recent improvements in computer display technology have made it feasible and advantageous to use color CRTs to generate calibrated color stimuli for use in psychophysical and human factors research. This simplifies the preparation and presentation of the stimuli, permits large numbers of stimuli to be used in a single experiment, and allows multiple experiments to be performed using the same hardware with a minimum number of physical modifications. Many researchers who have used this approach, however, have found that it can pose problems. The major problem is that the colorimetric behavior of CRTs is not stable over time.

Figure 1 shows a typical computer display system. The Host Computer contains the programs necessary for data collection and control of the image processor. The image processor consists of basically four parts: image memory, image look-up tables (LUTs), digital-to-analog converters (DACs), and circuity that is responsible for the generation of timing signals including the monitor's sync signal. The image memory is a semiconductor memory in which each memory location represents a location on the display. Each picture element's (pixel's) intensity is represented by the value of the image memory location. For example, the image processor used in this work has a screen resolution of 512 pixels horizontally by 512 pixels vertically. Thus, the image processor contains 262,144 locations, one for each of the pixel locations on the display. At the appropriate time the pixel value is read from memory and sent to the LUTs. The LUT is a memory with one location for each of the possible memory values. The output of the image memory is used as the address for this LUT memory. The LUT memory values are loaded from the Host Computer with whatever values are appropriate for the experiment. These values are addressed by the image memory and sent to the DAC where they are

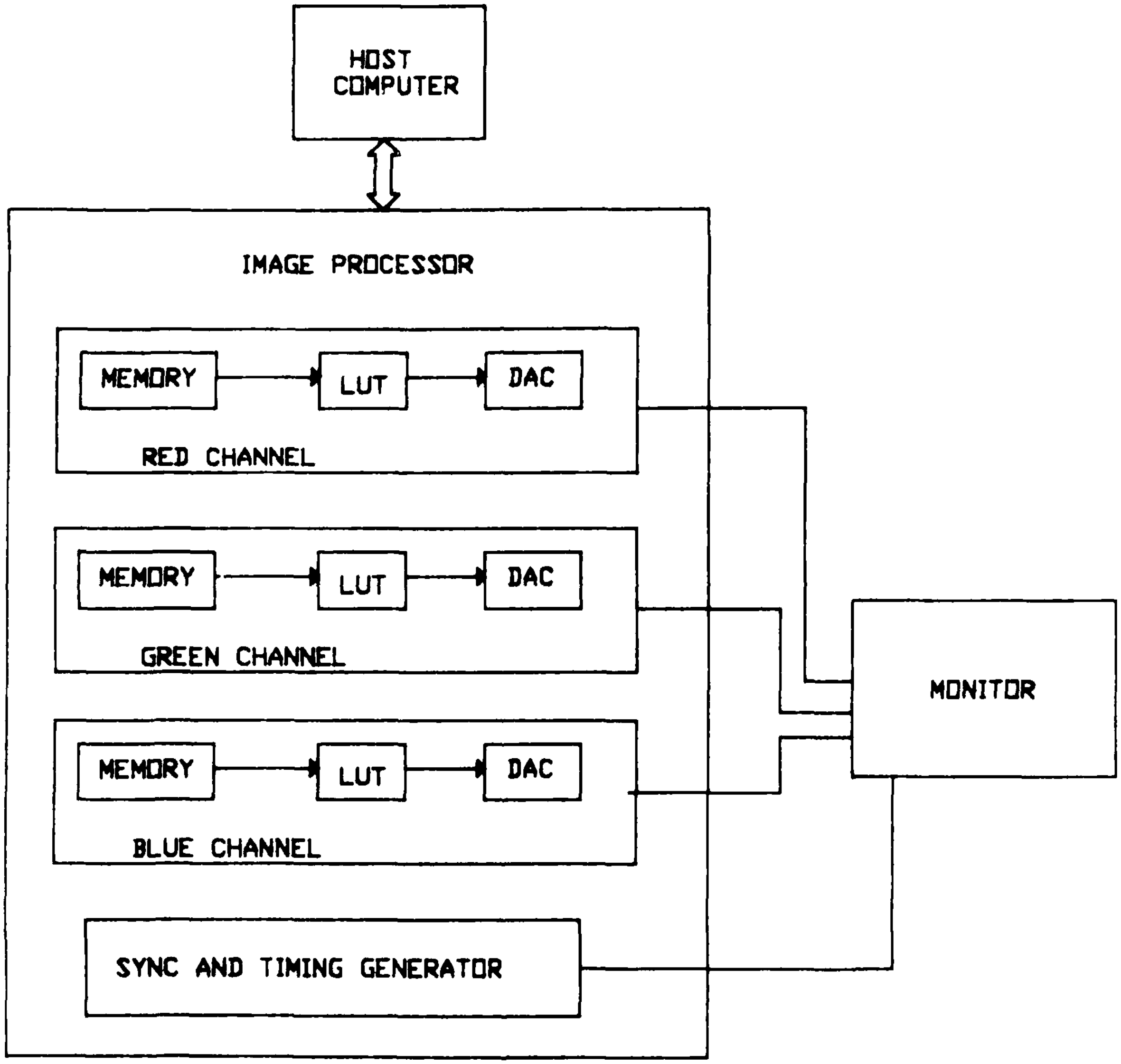


FIGURE 1 - THE COMPUTER DISPLAY SYSTEM

converted into analog voltages that drive the display. This arrangement of image memory, LUT, and DAC is often called a channel. If a monochrome system is being used then only one channel is needed. If a color system is being used then three channels are used with one channel each for red, green, and blue.

It should be noted that there are a great many variations on this general design with some employing several memories that can be switched between channels, multiple look-up tables, and image summing to list just a few. However, the basic channel is the same in all of the variations.

The display receives the analog signals from each of the three channels and the sync signal which generates the desired display stimulus.

To use the system efficiently one would like to know the relationship between the digital values (bits) sent to the DAC and the intensity of the screen for this value. This relationship of bits to intensity is the transfer function for the system. Once known, the transfer function can be used to compute the bit values required to give particular luminance and chromaticity coordinate values for any location on the display.

Prior to using the display system in this fashion one must find the transfer function of each of the red, green, and blue display channels. These transfer functions take the form of "bits to tristimulus values" and are stored in the computer system. Software, such as that developed in the Human Factors Laboratory at VPI & SU (Farley and Gutmann, 1980), then uses the transfer function and colorimetric equations to compute the red, green, and blue bit values necessary to cause the display of a specified color at any desired pixel location. A large amount of time (e.g., 8 to

16 hours) is often required to determine the transfer function. A problem arises, however, when the color monitor drifts from the point at which the transfer functions were measured. This drift changes the bits-to-tristimulus-value relations and thus causes the displayed colors to differ from the specified values. This problem prompts research into ways of making the computer display system more stable.

II. STATEMENT OF DISPLAY CHANGE PROBLEM

The display system changes are divided into two classes: spatial and temporal. Spatial changes result from changes over the surface of the display measured at the same time. If the display changes significantly from one location to another over the face of the CRT, then the transfer function or characterization will be valid only at the particular measurement location. Temporal change results from a change in the display transfer function at the same location over some time period. Temporal changes are further divided into (1) transient changes and (2) drift. A transient change is a change that occurs over a period of several hours or less as a result of a display change. Drift is a change that occurs over a time period of several hours to many days. All of the above display changes may be represented in terms of offset and gain, i.e., brightness and contrast controls.

To illustrate the concepts of offset and gain changes, let us assume that the transfer function of the display is linear. Figure 2 shows two transfer function curves. Curve "a" is the original transfer function measured during the system calibration. Curve "b" is the transfer function measured at some later time. Note that the slope of the two curves is the same; however, the offset value (intercept) has changed. Figure 3 also shows two transfer function curves. Again curve "a" is the original transfer function measured during the calibration and curve "b" is the transfer function measured at some later time. Notice that in Figure 3 the offset, or intercept, value has not changed but the slope of curve "b" is different from the slope of curve "a." This change in slope represents a gain change. It is also the case that a display may have both offset and gain changes

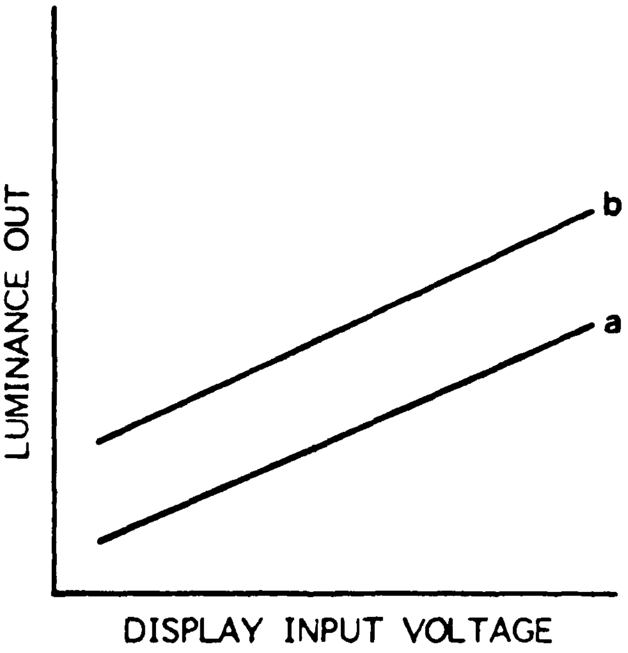


Figure 2. Offset (Brightness) Display Change

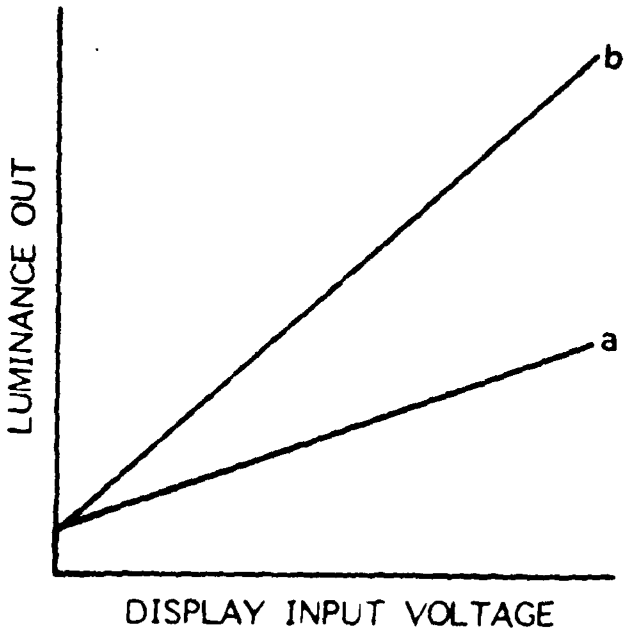


Figure 3. Gain (Contrast) Display Change

during the same time period. This case is shown in Figure 4.

Any of the above mentioned changes act to change the bits-to-tristimulus value transfer function. This means that color selected by using the colorimetric software will no longer be correct and the colors that have already been selected will have changed.

Ordinarily, the only way to correct this problem is to recalibrate or readjust the bit values of each of the selected colors to bring them back to the original state. Both of these techniques require large amounts of time and are temporary solutions at best. The present research was undertaken to develop a way to eliminate the problem by eliminating or greatly reducing the temporal changes.

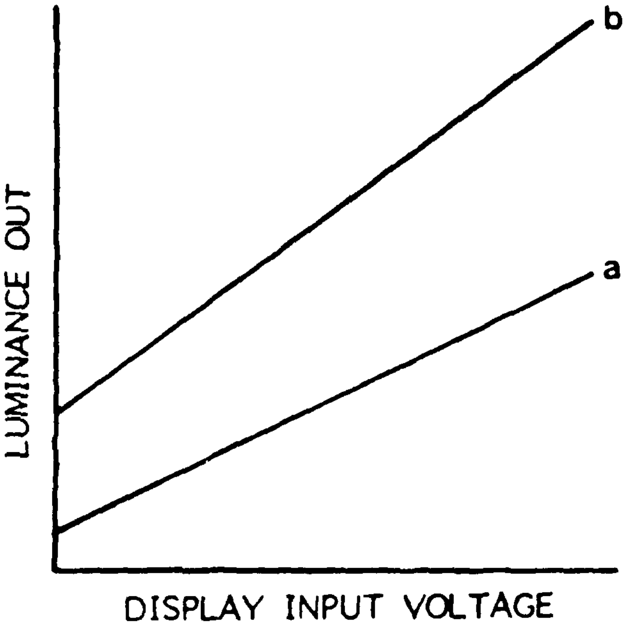


Figure 4. Offset and Gain Change

III. COMPUTER DISPLAY STABILITY SYSTEM DESIGN GOALS

Section II discussed the different types of display changes and how each adversely affects the computer display system when used as a research device. The researcher would prefer a display system with a response that is uniform across the area of the display and constant with time.

In the real world one generally specifies the limits under which a system must operate in order to produce useful data. The design goal for the Stability System was a system that will permit changes of no more than .005 in u' and v' chromaticity coordinates on the CIE 1976 uniform chromaticity scale (UCS) diagram (see Wyszecki and Stiles, 1982 for a description of the UCS diagram). The luminance should not change more than one percent of the original value. The luminance and chrominance tolerances should be maintained for at least two weeks. These design goals were not completely met, but the stability system came very close and did produce significant improvements in our tests.

This first generation stability system does not try to deal with spatial nonuniformities across the display area, although the magnitude of the spatial nonuniformity was measured to quantify this change with respect to the other changes.

This first generation stability system is portable and not specific to any one display or computer display system. With such a stability system integrated into the computer display system the researcher is able to control the experimental stimuli more accurately and spend less time on measurement, thus improving the accuracy of results and increasing the number of colors which can be used in a study. Also, a single channel of the stability system may be used to enhance the luminance stability of monochrome CRTs.

IV. QUANTIFICATION OF NON-UNIFORMITY

Display non-uniformity is defined here to be any temporal or spatial change in the measured luminance and chromaticity of the display.

MEASUREMENT SYSTEM TEMPORAL NON-UNIFORMITY

Section II discussed the several ways in which the display can change. Since there is no way to separate temporal non-uniformity in the measurement system from temporal non-uniformity in the display, one must first determine the repeatability of the spectroradiometric measurement system. The measurement system used in this study was manufactured by Gamma Scientific, now EG&G Gamma, and included an NM-5 monochrometer with a 5-nm sampling bandwidth, an SC-1 controller to position the monochrometer, a DR-2 radiometer, and a Hoffman Engineering standard source as well as a standard source designed and built at VPI & SU. The radiometric measurement system underwent several tests to determine its repeatability. It should be noted here that its absolute color accuracy is not a question that was addressed. For the purpose of this study it was the repeatability of the radiometric measurement system that was important. Thus, these measurements were to determine the system's repeatability, not the absolute accuracy of the displayed colors.

In the first set of tests, several measurements were made in succession for a period of approximately one hour. The light source was a standard light source developed at VPI & SU. The measurements were made in the following manner: the measurement system was calibrated from the standard source and then the standard light source was measured repeatedly for 60 minutes. The results showed a variation of .0001 in u' and v' UCS and -0.1% to 0.2% in luminance.

Another set of measurements as made to check the measurement system under the conditions of different colors and different intensities. The different colors of light were produced by placing one of a set of four Stimsonite filters in front of the Hoffman standard source. The Stimsonite filters are calibrated in terms of their spectral transmission, which makes them ideal for checking the system. The test was conducted by first calibrating the system to the Hoffman standard source. The source was then set to one of three luminance values: 50 candelas per square meter (nits), 100 nits, or 200 nits. Three spectral measurements of the standard source without any filter and with each of the four filters (red, green, blue, and yellow) were made.

The results of the three measurements with the source set at 200 nits were averaged and the mean values entered into Table 1. The first column shows the mean luminance for the three measurements. The next column shows the percent luminance transmission for each filter. This value is found on the calibration sheet for the filter. The next column is the computed luminance which is found by multiplying the luminance setting by the percent transmission. The next column is the percent luminance error. This is found by taking the percent difference of the computed luminance error as an indication of the ability of the system to make an accurate measurement. The next four columns are the (x,y) CIE chromaticity coordinates and the (u',v') UCS CIE chromaticity coordinates. The numbers in parentheses are the values from the calibration sheet. The next four columns are the difference of each of the chromaticity coordinates from the calibration sheet values. Tables 2 and 3 show the same information for the luminance settings of 100 nits and 50 nits.

FILTER	Measured Luminance (nits)	Filter Transmitter (%)	Computed Filter Luminance	Luminance Error (comp.-meas) / computed	CHROMATICITY COORDINATES MEASURED (DATA SHEET)				CHROMATICITY COORDINATE DIFFERENCE MEASURED - (DATA SHEET)			
					x	y	u'	v'	Δ x	Δy	Δu'	Δ v'
NONE	203.22	100	200	-1.61	.4518 (.4507)	.4136 (.4137)	.2560 (.2552)	.5273 (.5272)	.0011	-.0001	.0008	.0001
RED	50.05	24.71	49.42	-1.27	.6616 (.6641)	.3318 (.3291)	.4677 (.4726)	.5277 (.5269)	-.0025	.0027	-.0049	.0008
GREEN	36.88	18.36	36.72	-0.44	.1989 (.1971)	.6572 (.6548)	.0759 (.0753)	.5639 (.5632)	.0018	.0024	.0006	.0007
BLUE	9.04	4.66	9.32	3.00	.2088 (.2066)	.2141 (.2056)	.1621 (.1635)	.3740 (.3661)	.0022	.0085	-.0014	.0079
YELLOW	149.41	73.43	146.86	-1.74	.5471 (.5469)	.4438 (.4443)	.3026 (.3022)	.5523 (.5525)	.0002	-.0005	.0004	-.0002

TABLE 1. Result of Measurements of Stimsonite Filters with Hoffman Source Set at 200 nits.

FILTER	Measured Luminance (nits)	Filter Transmitter (%)	Computed Filter Luminance	Luminance Error (comp.-meas / computed)	CHROMATICITY COORDINATES MEASURED (DATA SHEET)				CHROMATICITY COORDINATE DIFFERENCE MEASURED - (DATA SHEET)			
					x	y	u'	v'	Δx	Δy	Δu'	Δv'
NONE	101.79	100	100.00	-1.79	.4520 (.4507)	.4136 (.4137)	.2561 (.2552)	.5273 (.5272)	.0013	-.0001	.0009	.0001
RED	25.49	24.71	24.71	-3.16	.6618 (.6641)	.3317 (.3291)	.4680 (.4726)	.5277 (.5269)	-.0023	.0026	-.0046	.0008
GREEN	18.43	18.36	18.36	0.38	.1975 (.1971)	.6570 (.6548)	.0753 (.0753)	(.5637) (.5632)	.0004	.0022	.0000	.0005
BLUE	4.49	4.66	4.66	3.65	.2081 (.2066)	.2132 (.2056)	.1619 (.1635)	.3731 (.3661)	.0015	.0076	-.0016	.0070
YELLOW	74.76	73.43	73.43	-1.81	.5467 (.5469)	.4443 (.4443)	.3021 (.3022)	.5524 (.5525)	-.0002	.0000	-.0001	-.0001

TABLE 2. Results of Measurements of Stimsonite Filters with Hoffman Source Set at 100 nits.

FILTER	Measured Luminance (nits)	Filter Transmitter (%)	Computed Filter Luminance	Luminance Error $\frac{\text{(comp.-meas)}}{\text{computed}}$	CHROMATICITY COORDINATES MEASURED (DATA SHEET)				CHROMATICITY COORDINATE DIFFERENCE MEASURED - (DATA SHEET)			
					x	y	u'	v'	Δ x	Δy	Δu'	Δ v'
NONE	50.63	100	50.00	-1.26	.4516 (.4507)	.4135 (.4137)	.2559 (.2552)	.5272 (.5272)	.0009	-.0002	.0007	.0000
RED	12.75	24.71	12.36	-3.16	.6621 (.6641)	.3322 (.3291)	.4677 (.4726)	.5280 (.5269)	-.0020	.0031	-.0049	.0011
GREEN	9.15	18.36	9.18	0.33	.1958 (.1971)	.6573 (.6548)	.0746 (.0753)	.5636 (.5632)	-.0013	.0025	-.0007	.0004
BLUE	2.23	4.66	2.33	4.29	.2071 (.2066)	.2127 (.2056)	.1612 (.1635)	.3726 (.3661)	.0005	.0071	-.0023	.0065
YELLOW	37.42	73.43	36.72	-1.91	.5470 (.5469)	.4444 (.4443)	.3023 (.3022)	.5525 (.5525)	.0001	.0001	.0001	.0000

TABLE 3. Results of Measurements of Stimsonite Filters with Hoffman Source Set at 50 nits.

The results show that the measurement system's absolute accuracy is degraded somewhat when measuring the Hoffman source with the red and blue filters in place. More pertinent to the present discussion, however, is the repeatability of the measured chromaticity coordinates across the various measuring conditions. Table 4 summarizes these results. It shows the maximum differences in measured chromaticity coordinates across all filtering conditions and luminances. For example, the largest change in u' occurred for the green filter at 200 versus 50 nits and was 0.0013. The largest change in v' occurred for the blue filter at 200 versus 50 nits and was 0.0014. These values indicate the maximum variability in a measurement that can be attributed to measurement system instability for colors having broad smooth spectra and luminances ranging from 50 to 200 nits. This is representative of many (but not all) colors that are typically generated on a color CRT.

There is a problem with measuring the display that is not encountered when the standard source is used. While the standard source is a constant light source and very stable, the CRT display is a light source that is being refreshed at the rate (typically) of 60 Hz. This time varying display light is not the same as the temporally constant source light, and care must be taken such that there are no interactions between the sampling rate of the measurement system and the refresh rate of the display. This potential problem was avoided in the present research via methods which are discussed in Appendix B.

Past experience with the measurement system has indicated that its repeatability is approximately 0.002 in u' and v' over periods as long as 30 days. The results from the present measurements show that the repeatability is even better over briefer periods. It therefore seems reasonable to conclude that, for most practical purposes, the

TABLE 4. Summary of Filter Measurements to Determine Chromatic Repeatability of Measurement System: Maximum Difference 50 nit, 100 nit, and 200 nit Hoffman Luminance

FILTER	u'	v'
NONE	.0002	.0001
RED	.0003	.0005
GREEN	.0013	.0006
BLUE	.0009	.0014
YELLOW	.0005	.0002

repeatability may be characterized as being within 0.002 in u' and v'. Examination of Tables 1-3 also indicates that the luminance repeatability is within 0.5%.

DISPLAY TEMPORAL NON-UNIFORMITY

Before a design of a system to stabilize the display (stabilization system) was undertaken, measurements of the display itself were taken to determine what changes were occurring within the display. A CRT measurement system was designed and built to measure (1) the input video signal, (2) the first grid of the CRT, (3) the second grid of the CRT, (4) the cathode current of the CRT, and (5) the luminance of the CRT screen. A block diagram of the CRT measurement system is shown in Figure 5.

Each of the above mentioned values, as well as a stable reference voltage, is connected to a relay. Relays are used to give absolute isolation of the different inputs because the inputs vary over several hundred volts. The relays are very good at isolating these values. The relays chosen are DIP relays with a 1-ms switching time.

The CRT Measurement System Control (MSC) receives a signal from the computer telling it to take a measurement of one of the parameters. The CRT MSC sends the command to the appropriate relay, causing it to be connected to the Buffer Amplifier. The Buffer Amplifier provides isolation between the CRT and the CRT Measurement System. The output of the Buffer Amplifier is sent to the input of the Sample/Hold. The Sample/Hold circuit normally will pass the signal unaltered to the analog output until it receives a Hold signal. It holds its output at the level of the input at the instant that the Hold signal is received. The CRT MSC then causes the Sample/Hold circuit to hold the value that occurs at the time the CRT electron beam is under the light

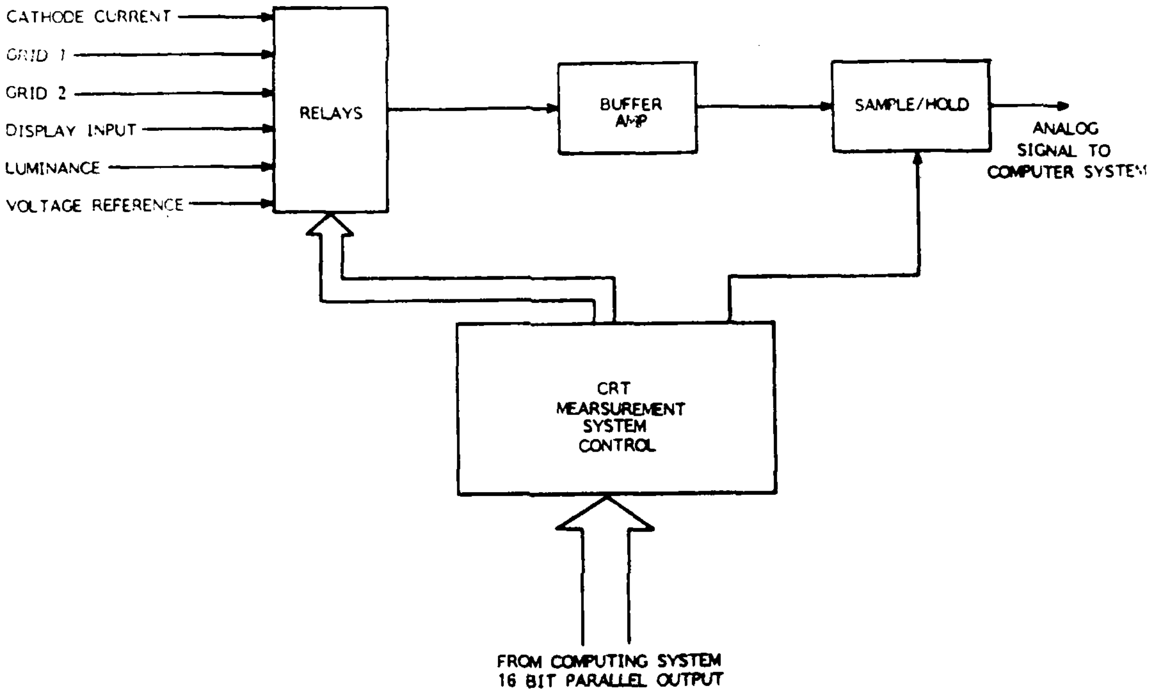


Figure 5. CRT Measurement System Block Diagram

gathering probe. This approach prevents any spatial non-uniformity that might be present on the CRT from affecting the measurements.

An extensive set of measurements was made of an Aydin 8025 display. The results show that the image processing system's signal is modulated by a signal with an amplitude of 8 mV and a period of about 2 min. The origin of this signal is somewhere within the image processing system. Since the image processor has an output of approximately 1 mV per bit this change is equivalent to 8 bits of change. This is not a large change but it neither is it insignificant. The magnitude of the luminance error will depend upon the display and how the display is adjusted. Since the bits-to-luminance transfer function approximates a quadratic function, the effect at the CRT screen of this change will depend upon the commanded bit level. The magnitude of the luminance error may be computed if the bits-to-luminance transfer function is known. One may estimate the percent luminance change for the 8 mV input change by assuming the bits-to-luminance transfer function is

$$L = A\ (\text{bits})^2. \tag{1}$$

The Aydin 8025 display as set up for the Version 2 Display Stabilization System may serve as an example. Each gun was driven at a level of 600 bits and the resulting red, green, and blue luminance values were 16.9, 12.9, and 6.8 nits respectively. Using the above equation the percent luminance errors at 300, 600, and 1000 bits are 5.4%, 2.6%, and 1.6%, respectively. Since the measurement system will detect luminance differences of 0.5%, this image processor temporal non-uniformity will be detected at the CRT screen. Much time was spent trying to reduce this temporal non-uniformity. A new and better regulated power supply was installed. Power and grounds were checked. Filtering on the DAC board was improved. None of the attempts to reduce the 8 mV change in image processor output were successful. Since a solution to the time varying image processor output could not be found, the research had to be conducted with the 8 mV change present. It should be noted that all subsequent measurements will be affected by this change even though it is not in the display. The stabilization system will compensate for this change just as it would for a change resulting from within the monitor if the system time constant is shorter than the period of the change.

Both the grid voltages were found to be stable to within the limits of the measurement system. A significant finding of the display measurements is that the cathode current is very well correlated with the display luminance. Another significant display temporal non-uniformity is the settling (transient) response after changing from a dark screen to a bright screen. Although the transient response is considered in great detail in Section VII, it is sufficient here to indicate that in all cases the cathode current tracked the luminance change.

Although much smaller, the long term temporal display non-uniformity (drift) also was tracked by the cathode current of the CRT. The implications of the cathode current's relation to the display's output and stability will be addressed in Section VIII.

DISPLAY SPATIAL NON-UNIFORMITY

The second largest display non-uniformity was the spatial change. The display spatial non-uniformity was measured by driving the display with a uniform field of 600 bits for each gun. Each of the three guns was measured in turn with the remaining two guns off. Figures 6, 7, and 8 show the spatial patterns of luminance for the red, green, and blue guns, respectively. It should be noted that each of the guns has

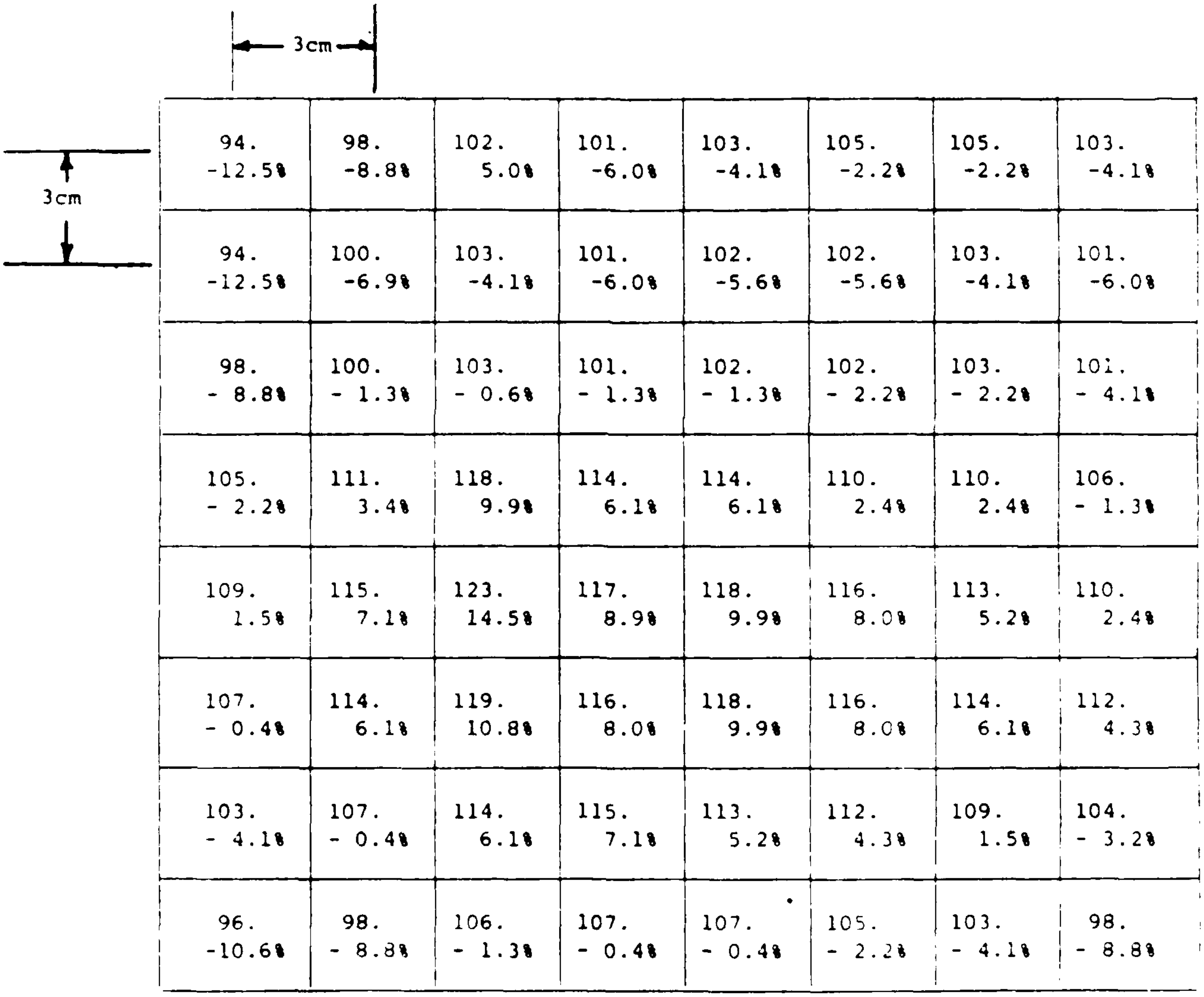
Figure 6. Luminance of the Red Gun as a Function of Display Location. The mean luminance is 13.86 nits with a standard deviation of 0.730 nits. Each box on the chart corresponds to a display location with the top number indicating the luminance of the location and the bottom number indicating the percent difference from the mean luminance.

3cm

3cm

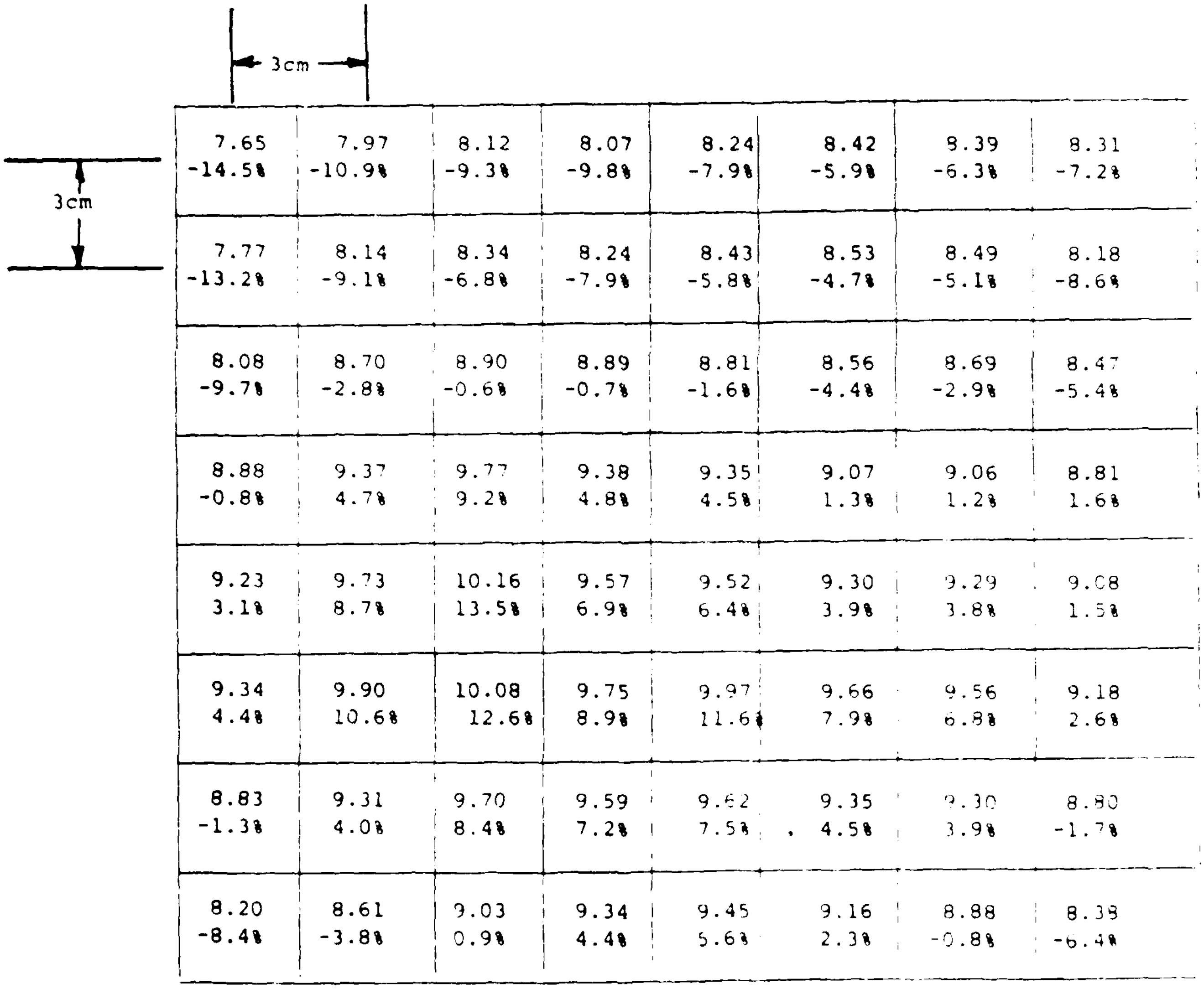
12.5 -9.8%	12.9 -6.9%	13.6 -1.9%	13.4 -3.3%	13.5 -2.6%	13.8 -0.5%	14.1 1.7%	[illegible]
12.6 -9.1%	12.9 -6.9%	13.4 -3.3%	13.3 -4.1%	13.5 -2.6%	13.5 -2.6%	13.[illegible] -1.[illegible]	[illegible]
12.8 -7.7%	13.6 -1.9%	14.1 -1.7%	13.6 -1.9%	13.7 -1.2%	13.8 -0.5%	13.8 -0.5%	13.6 -1.4%
13.6 -1.9%	14.2 2.4%	15.1 8.9%	14.7 6.0%	14.6 5.3%	14.2 2.4%	14.1 1.7%	13.8 -0.5%
13.9 0.3%	14.3 3.2%	15.5 11.8%	14.9 7.5%	15.0 8.2%	14.7 6.0%	14.[illegible] 4.[illegible]	14.[illegible] [illegible]
13.7 -1.1%	14.5 4.6%	15.1 8.9%	14.9 7.5%	15.1 8.9%	14.8 6.8%	14.[illegible] [illegible]	14.[illegible] 2.[illegible]
13.[illegible] -6.2%	13.5 -2.6%	14.1 1.7%	14.2 2.4%	14.3 3.2%	14.[illegible] [illegible]	14.1 1.7%	13.[illegible] [illegible]
12.1 -12.7%	12.2 -12.0%	13.1 -5.5%	13.8 -0.5%	14.[illegible] 1.[illegible]	13.6 -1.9%	13.5 -2.6%	12.[illegible] [illegible]

Figure 7. Luminance of the Green Gun as Function of Display Location. Mean Luminance is 107.4 nits with a standard deviation of 6.67 nits. Each box on the chart corresponds to a display location with the top number indicating the luminance of the location and the bottom number indicating the percent difference from the mean luminance.



94. -12.5%	98. -8.8%	102. 5.0%	101. -6.0%	103. -4.1%	105. -2.2%	105. -2.2%	103. -4.1%
94. -12.5%	100. -6.9%	103. -4.1%	101. -6.0%	102. -5.6%	102. -5.6%	103. -4.1%	101. -6.0%
98. - 8.8%	100. - 1.3%	103. - 0.6%	101. - 1.3%	102. - 1.3%	102. - 2.2%	103. - 2.2%	101. - 4.1%
105. - 2.2%	111. 3.4%	118. 9.9%	114. 6.1%	114. 6.1%	110. 2.4%	110. 2.4%	106. - 1.3%
109. 1.5%	115. 7.1%	123. 14.5%	117. 8.9%	118. 9.9%	116. 8.0%	113. 5.2%	110. 2.4%
107. - 0.4%	114. 6.1%	119. 10.8%	116. 8.0%	118. 9.9%	116. 8.0%	114. 6.1%	112. 4.3%
103. - 4.1%	107. - 0.4%	114. 6.1%	115. 7.1%	113. 5.2%	112. 4.3%	109. 1.5%	104. - 3.2%
96. -10.6%	98. - 8.8%	106. - 1.3%	107. - 0.4%	107. - 0.4%	105. - 2.2%	103. - 4.1%	98. - 8.8%

Figure 8. Luminance of the Blue Gun as a Function of Display Location. Mean Luminance is 8.95 nits with a standard deviation of 0.61 nits. Each box on the chart corresponds to a display location with the top number indicating the luminance of the location and the bottom number indicating the percent difference from the mean luminance.



7.65 -14.5%	7.97 -10.9%	8.12 -9.3%	8.07 -9.8%	8.24 -7.9%	8.42 -5.9%	8.39 -6.3%	8.31 -7.2%
7.77 -13.2%	8.14 -9.1%	8.34 -6.8%	8.24 -7.9%	8.43 -5.8%	8.53 -4.7%	8.49 -5.1%	8.18 -8.6%
8.08 -9.7%	8.70 -2.8%	8.90 -0.6%	8.89 -0.7%	8.81 -1.6%	8.56 -4.4%	8.69 -2.9%	8.47 -5.4%
8.88 -0.8%	9.37 4.7%	9.77 9.2%	9.38 4.8%	9.35 4.5%	9.07 1.3%	9.06 1.2%	8.81 1.6%
9.23 3.1%	9.73 8.7%	10.16 13.5%	9.57 6.9%	9.52 6.4%	9.30 3.9%	9.29 3.8%	9.08 1.5%
9.34 4.4%	9.90 10.6%	10.08 12.6%	9.75 8.9%	9.97 11.6%	9.66 7.9%	9.56 6.8%	9.18 2.6%
8.83 -1.3%	9.31 4.0%	9.70 8.4%	9.59 7.2%	9.62 7.5%	9.35 4.5%	9.30 3.9%	8.80 -1.7%
8.20 -8.4%	8.61 -3.8%	9.03 0.9%	9.34 4.4%	9.45 5.6%	9.16 2.3%	8.88 -0.8%	8.38 -6.4%

significant changes in luminance over the surface of the CRT. The red gun has a mean luminance of 13.86 nits. The standard deviation of the red surface luminance measurements is 0.73 nit. The second number for each location in Figures 6, 7 and 8 is the percent difference from the means of all locations. The range of this difference is from -12.7% to 11.8% for the red gun. There is a general trend in the change of luminance over the face of the CRT with the center showing the higher luminance values and the edges showing less luminance. Also, the left side of the CRT is less luminous than is the right side of the CRT.

The green gun has a mean luminance of 107.4 nits with a standard deviation of 6.67 nits over the surface of the CRT. The pattern of the CRT having more luminance in the center is also present in the green gun. The left and right sides are more balanced in the green gun measurements than they are in the red gun measurements. The range of percent luminance difference for the green gun is -12.5% to 14.5%.

The blue gun has a mean luminance of 8.95 nits with a standard deviation of 0.61 nit. The range of the percent difference for the blue gun is from -14.5% to 13.5%. The pattern for the blue gun shows the center of the CRT to have the higher luminance values, but there is more of an increase top to bottom than from left to right, as was found in the red and green guns. To examine this change the red and green, green and blue, and blue and red screen position values were correlated. The R value for red-green was .926 ($\underline{p} < .0001$). The correlation for green-blue was .918 ($\underline{p} < .0001$). The correlation for red-blue was .818 ($\underline{p} < .0001$). As expected, the screen position values are highly correlated with each other across the three primaries. One should realize that unless the three guns vary in the same manner, not only will the luminance change over the CRT surface, but the color will change as well.

The results of the non-uniformity tests show that the measurement system is not as stable as one would like in chromaticity coordinates, having a repeatability of .002 in u' and v'. The luminance repeatability of 0.5% is, however, adequate considering the luminance changes encountered in this work range from 2.4% to 15%. The largest of the non-uniformity changes was the spatial non-uniformity which ranged from -14.5% to 13.5% of the average screen luminance. The settling time temporal non-uniformity was the next largest non-uniformity with a change of 11%. The non-uniformity from the image processor might be expected to cause a temporal non-uniformity of 2.6% for the experimental configuration of the Version 2 tests. The temporal non-uniformity for the long term (drift) tests, detailed in Section VII, showed that the luminance non-uniformity ranges from 2% to 8.2%.

V. STABILITY SYSTEM DESIGN

We now have the data necessary to begin the initial design. Since the device must be portable and not specific to any one display monitor, the video signal must be the vehicle for stabilization of the display. One possible solution is to set aside three areas on the display which will always be given the same bit value. One area will have a constant red bit value, one area will have a constant green bit value, and the last area will have a constant blue bit value. The intensity of each area may be detected using a silicon detector. These intensities can then be used as the reference signal for a feedback control system. When the display changes the intensity of the reference areas will change, thus causing a change in the detector signal. This difference is used to change the video signal such that the display returns to its original state, thus completing a feedback loop.

There is nothing in the previous measurements to indicate that such a system would not be useful at reducing the long term drift and the transient drift. It obviously would not help the spatial nonuniformity. There is a problem determining what to control. Once could control for gain changes, offset changes, or both. To control for both would require nine display areas and nine detectors. The information from the detectors would have to be analyzed to determine how much of the change was gain and how much was offset. The results of this analysis could then be applied to the video signal which would bring the display back to its original state. However, such a complex system is beyond the scope of this initial effort.

From the measurements described in Section IV, we discovered that the majority of the change was offset change. This was determined by taking the changes and working backwards through the transfer function. This indicated that the offset was the best candidate for stabilization, although the design includes the provision for testing a gain controlled system with as few circuit changes as possible.

To understand the method used to control the offset instability, one must understand how the video signal conveys the picture information. Figure 9 shows one line of an image displayed upon a CRT. The line may be divided into two basic intervals, the blanking interval and the video interval. The video interval contains the picture information for each line. The intensity of the image at any point on the line is proportional to the amplitude difference between the video signal at the time that corresponds to the spatial point and the black reference. The second interval of the video signal is the blanking interval. The blanking interval receives its name because it is during this time that the electron beam is turned off (blanked) and the beam is moved from the end of one line back across the CRT to the beginning of the next line. The blanking interval consists of three parts: the front porch, the back porch, and the sync tip. Since monitors of most high quality display systems use external sync, the sync tip is missing from typical video signals.

The video signal is capacitively coupled. Capacitive coupling means that the video signal has a mean, or DC, level of zero volts. This causes the video signal to have no absolute reference for the black intensity. Therefore, one of the locations in the blanking interval, usually the back porch or sync tip, is used as the black reference value. Let us assume for the moment that the monitor uses the back porch as the black reference for the display. There are circuits within the display that detect the voltage difference between the back porch level and the video signal level. The magnitude of this difference is translated directly into the

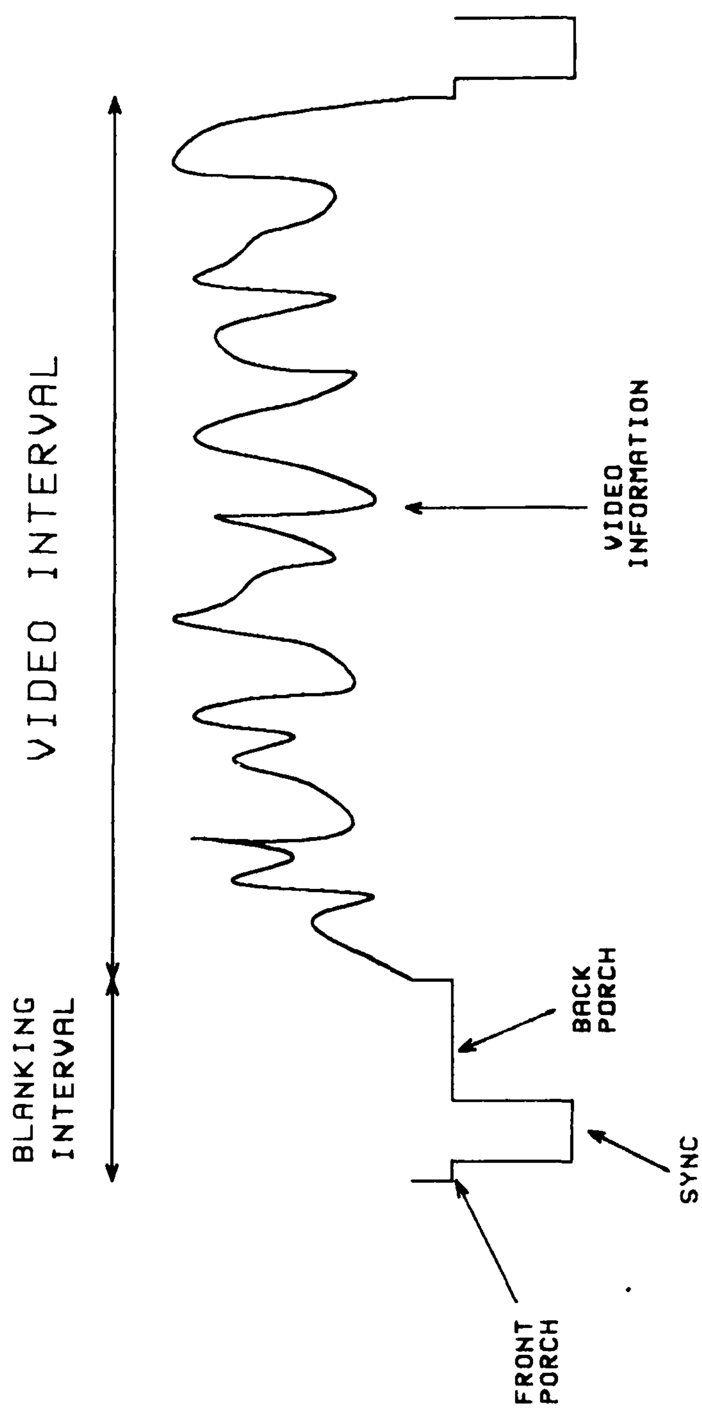


FIGURE 9 - THE VIDEO SIGNAL FOR ONE HORIZONTAL LINE

intensity of the displayed signal. The technique used in the Feedback Control System is to modify the DC level during the blanking interval to control the intensity of the display. Therefore, it does not matter whether the display uses the front porch, back porch, or sync tip to obtain the black level. Thus, the picture portion of the signal will remain unaltered.

A complete and detailed description of the Feedback Control System is given in Appendix C. A bread-board Feedback Control System was constructed and preliminary tests were conducted. Printed circuit boards were then designed and built for the final version. A metal box to house the feedback system was built with separate isolated compartments for each of the DC and video circuits.

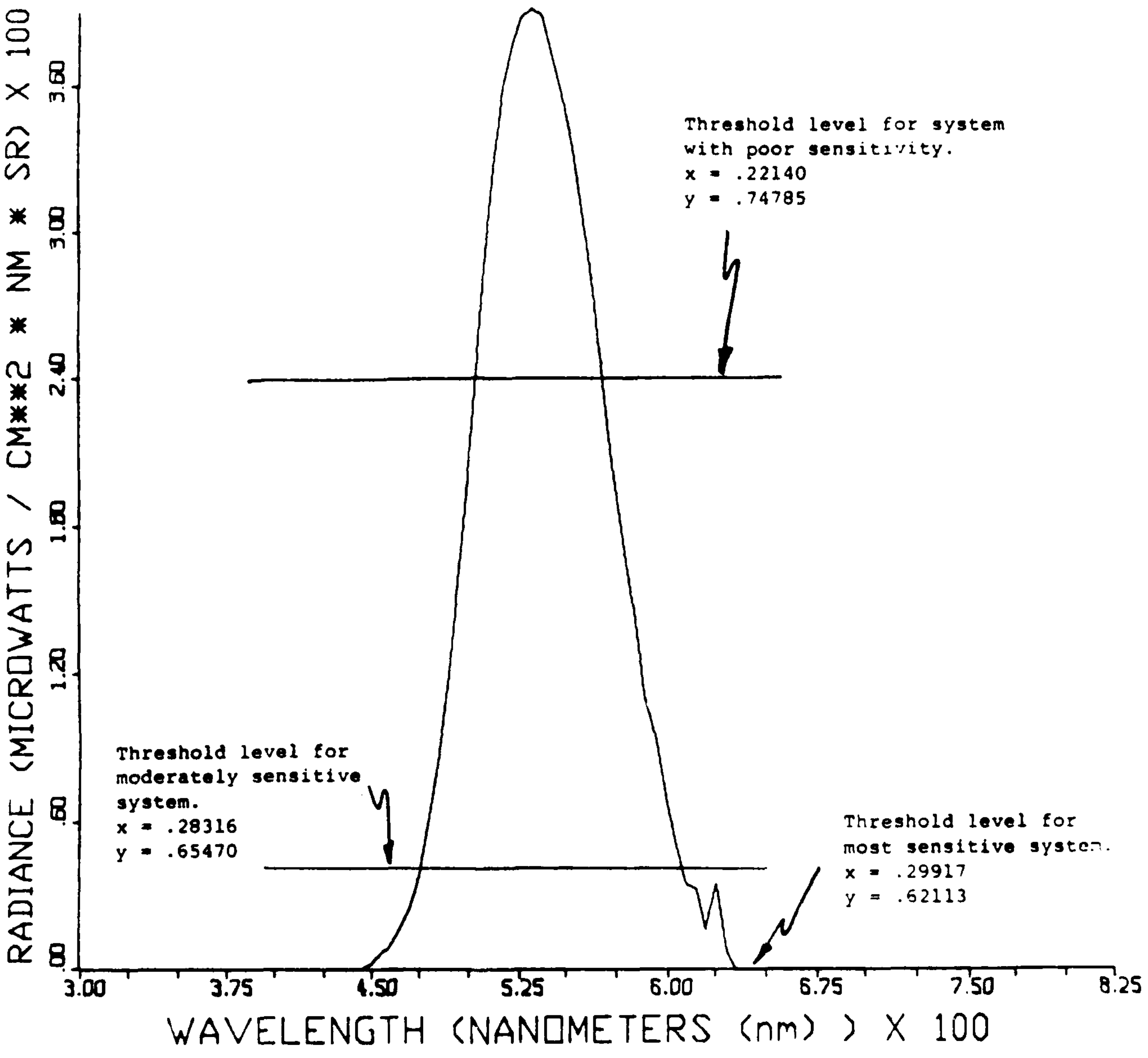
VI. PHOSPHOR STABILITY

For the stabilization system, outlined in the previous section, to work as desired, the spectrum of the phosphor cannot change. That is, the amplitude of the spectrum may change, but the normalized spectrum must remain constant. If the normalized spectrum were to change, the tristimulus values would differ and therefore the commanded chromaticities would change even if the luminance was held constant. If, however, the normalized spectrum is constant and the luminance is held constant then the tristimulus values will not change and the commanded colors will be constant. This is of course the desired situation.

The study of phosphor stability was accordingly broken down into two areas. The first area of investigation centered on the phosphor stability with changing intensity. The second area of investigation centered on the phosphor stability over time.

It should be noted first that investigating the stability of the phosphor with varying intensity is complicated by the measurement system's sensitivity, which is determined by many factors. The sensitivity of the system determines a "threshold level" for the measurements. This threshold level is the smallest value of radiance the system can resolve. Any radiance value below this value will be recorded as the "threshold value." This usually means that measurements of radiances below the threshold level are overwhelmed by noise. In the following example the noise is not shown so that the threshold effect may be seen clearly.

Figure 10 illustrates the effect of different system sensitivities on the measured radiance spectrum. The spectrum of a green phosphor measured with a sensitive system is shown in Figure 10, which also indicates threshold levels



Threshold level for system with poor sensitivity.
x = .22140
y = .74785

Threshold level for moderately sensitive system.
x = .28316
y = .65470

Threshold level for most sensitive system.
x = .29917
y = .62113

Figure 10. Radiometric Spectrum of Green Phosphor Showing the Effect of Measurement Systems with Different Sensitivities.

for two less sensitive systems. As shown, the spectra returned from the less sensitive systems are quite different and yield different chromaticity coordinates even though the actual phosphor emission spectrum is the same.

PHOSPHOR STABILITY AT VARYING INTENSITIES

A delta gun color monitor, Aydin 8025, was used to make a series of measurements to determine the phosphor stability with varying intensity. The monitor was commanded to a uniform green at an intensity of 1000 bits out of a possible 1023. The spectrum was measured three times in succession to give a indication of the variability of the system with the same input. The spectrum was also measured for bit values of 800 bits, 600 bits, 400 bits, and 300 bits. For each bit value, the spectrum was measured three times in succession. A complete set of plots and a summary table for all of the measurements may be found in Appendix A.

The results of the spectral measurements with different intensities show that for the higher bit values the chromaticity coordinates remain relatively constant. As the bit value is reduced, however, the chromaticity coordinates differ by a greater amount. The very small differences among the chromaticity coordinates obtained at the same bit value indicate that the system is quite repeatable for that bit value, but that intensity differences yield measurable chromaticity shifts. It is very likely that part of the difference is a result of the sensitivity problem discussed above.

PHOSPHOR STABILITY OVER TIME

The phosphor stability over time was studied by measuring the spectrum over an extended period of time. On each day the spectrum of the phosphor was measured three times in

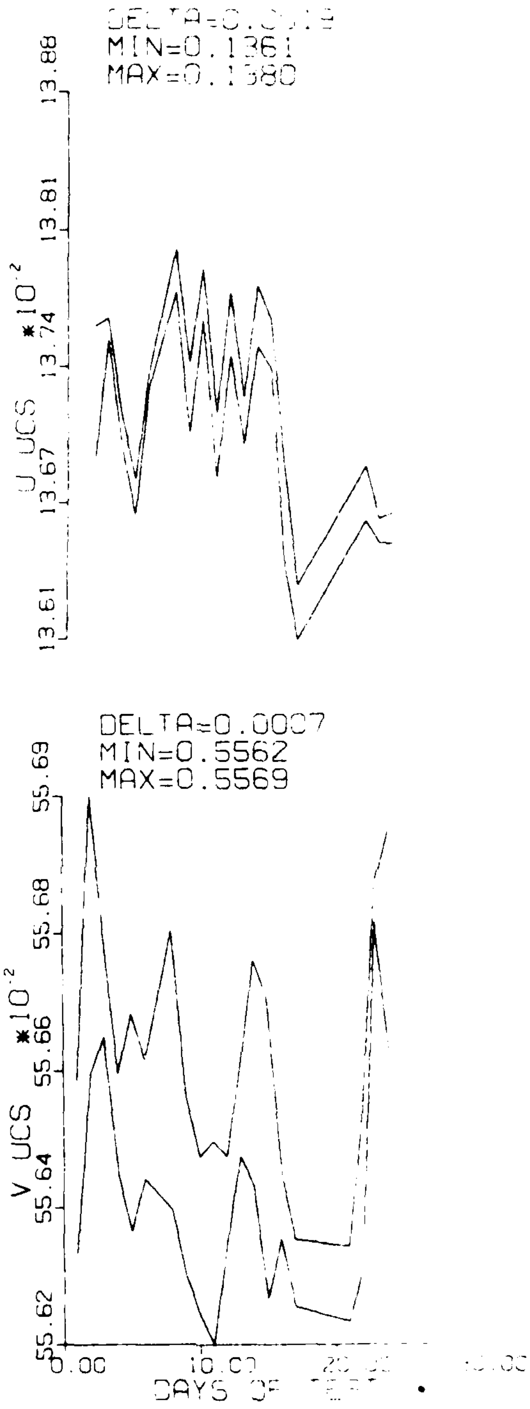


Figure 11. Change Over Time in u' and v'.

succession. The results are shown in Figure 11. The maximum value of the three measurements for the day is indicated by the top curve. The minimum of the three measurements for the day is indicated by the bottom curve. This shows the difference between the maximum and minimum scans for each day at the same scale as the variations from day to day. Figure 11 also indicates the maximum and minimum value of u' and v' across all measurements. The difference between this maximum and minimum value is also indicated as "delta." An equipment failure and an illness caused two gaps in the data, but these are not thought to be significant. Note that the u' change is only .0019 and the v' change is only .0007. These small changes are below the measurement system's repeatability and demonstrate that the assumption of phosphor stability over time is quite valid within the limits of .002 in UCS chromaticity coordinates.

VII. STABILIZATION SYSTEM EVALUATION

METHOD

Three monitors were used in the evaluation of the stability system (Aydin 8025 High Resolution Delta Gun Monitor, Aydin 8830 High Resolution In Line Gun Monitor, and the Conrac 5411 Low Resolution Delta Gun Monitor). Three different monitors were used to investigate any differences due to the different technologies incorporated into their designs.

Upon completing construction of the feedback control system, the monitors were measured to evaluate their stability over many days with and without the Feedback Control System operating. The measurements made with the Feedback Control System and the measurements made without the Feedback Control System were conducted in the same manner, as follows.

The three monitors were connected to the image processor via looping the red channel, green channel, blue channel, and sync through the Conrac monitor to the Aydin in-line monitor and finally to the Aydin 8025 monitor where the signals were terminated. The displays were set up for the most uniform gray field possible. However, no special care was taken to arrive at an absolute achromatic display.

The display monitor under test at the moment was driven by the image processor as described below. Figure 12 shows a diagram of the display during the test. A constant red, green, and blue reference area was displayed at the bottom of the display. These areas were not changed during the entire test and were viewed by the three stabilization system detectors. The rest of the display area would normally contain the experimental stimuli during an experiment. For the long term drift test, this test area was made to

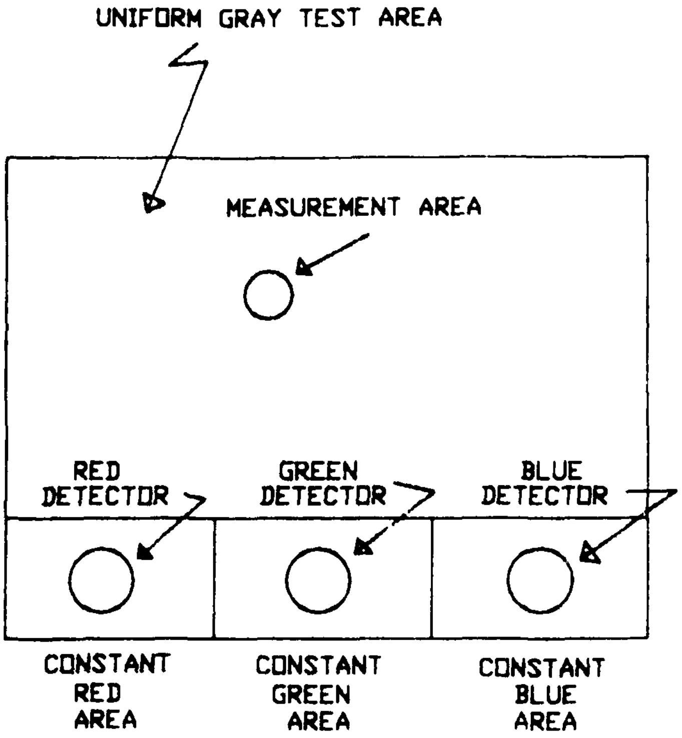


FIGURE 12 - STABILIZATION SYSTEM TEST DISPLAY CONFIGURATION

display a uniform gray by commanding 600 bits each of red, green, and blue. The display monitor setup was not changed over the entire time of the long term drift tests. During the first part of the test the stabilization system was not connected.

Each day the measurements were made in the same manner. First the measurement probe was located in front of the Conrac monitor. The measurement location was maintained via a set of location marks on the CRT screen. The three measurements were made for the day. The measurement probe was then moved to the Aydin in-line monitor where its three measurements were made for the day. Finally, the probe was moved to the Aydin 8025 where its three measurements were made for the day. These steps were repeated for each day until the measurements without the stabilization system were complete. After the last day of measurements without the stabilization system were complete, the stabilization system was installed. The same steps were followed for the measurements with stabilization as were followed for the measurements without the stabilization system except the detectors had to be moved from display to display each day. This required each of the monitors to have red, green, and blue luminance values that were very close at the 600 bit detector area setting. The gains of the three monitors also needed to be at approximately the same value. These adjustments compromised the Aydin in-line monitor somewhat but were necessary to shorten the measurement time to a reasonable length of time. The results of these tests are discussed in the next section.

During the transient tests which followed the long term tests, the display area was caused to change during the measurement so that the transient response of the stabilization system could be measured. Specialized software was written that caused the display luminance to change without changing the three reference areas. This software also recorded the luminance changes by monitoring the output of a photometric measurement system. This system consisted of a photo-multiplier tube with filter to cause the tube's response to be equal to the photopic response curve, thus allowing the device to measure luminance directly. The only problem with this system is that the photomultiplier tube has an amount of noise sufficient to show up in the measurements. This is especially true for measurements of small percentage changes. The only solution to this problem is to electronically filter the response of the photomultiplier tube. The filtering slows the transient response of the measurement system, adversely affecting the measurements. Therefore, the PMT output was left unfiltered.

RESULTS

Feedback System Long-Term Results

The results of the measurements without the Feedback Control System, which will be referred to as the baseline measurements, and the results of the measurements with the Feedback Control System, which will be referred to as the compensated system, are plotted on the same scale so that they may be easily compared. Each of Figures 13 through 27 shows the results of the long-term test for a particular monitor in terms of either x, y, or u', v', or percent luminance change from the maximum luminance value. Each day three measurements were taken in succession. The maximum value for each day is plotted and can be seen as the top curve in each figure. The minimum value for each day was also plotted and can be seen as the bottom curve. This allows the reader to examine the long term changes in relation to very short term changes. The maximum and minimum values for the entire measurement time are annotated as well as their difference (delta) value. It should be noted that the percent luminance change from the maximum luminance value is given and not the absolute luminance. This allows for an easier comparison between monitors.

The results of the tests for the Aydin 8025 monitor are shown in Figures 13 through 17, the results of the tests for the Aydin in-line monitor are shown in Figures 18 through 22, and the results for the Conrac monitor are shown in Figures 23 through 27. A summary of all of the tests is given in Table 5.

It should be noted that the Aydin 8025 baseline measurements extended over a longer period of time than did the stabilized measurements. The improvement in stability which the stabilization system produced for the CIE x chromaticity coordinate is minimal when the time difference is taken into account. The improvements in CIE y, UCS u' and v', and luminance are significant even over the shorter time period.

The Conrac monitor shows an improvement across all of the values. The Aydin in-line monitor shows an improvement in luminance but no significant improvement in y and v'. In fact the baseline measurements are better for x an u'. One possible explanation for these results is that the Aydin in-line monitor was adjusted to make it similar to the Aydin delta gun monitor and the Conrac monitor. This adjustment may have affected its performance such as to cause this eratic behavior due to the gain and offset being adjusted to their maximum values.

There are several facts to consider when reviewing these data. The measurement system's performance was not as repeatable as one would like. A better measurement system would allow for the measurement of smaller u' and v' changes. Measurements made at the beginning of the Version 2 tests indicated that the repeatability was unchanged. Also, it is

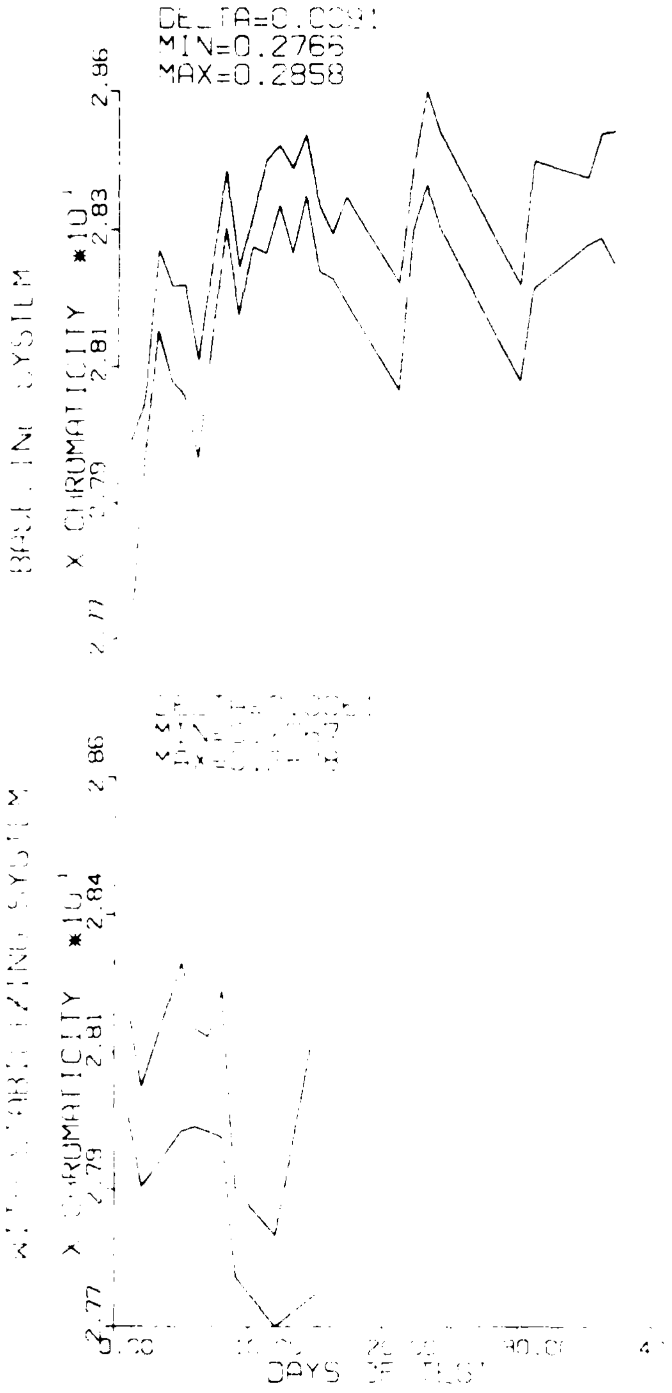


Figure 13. Comparison Using Aydin 8025 Delta Gun Monitor of Long-Term Drift in x CIE Chromaticity Coordinate Between Baseline and Compensated Display System.

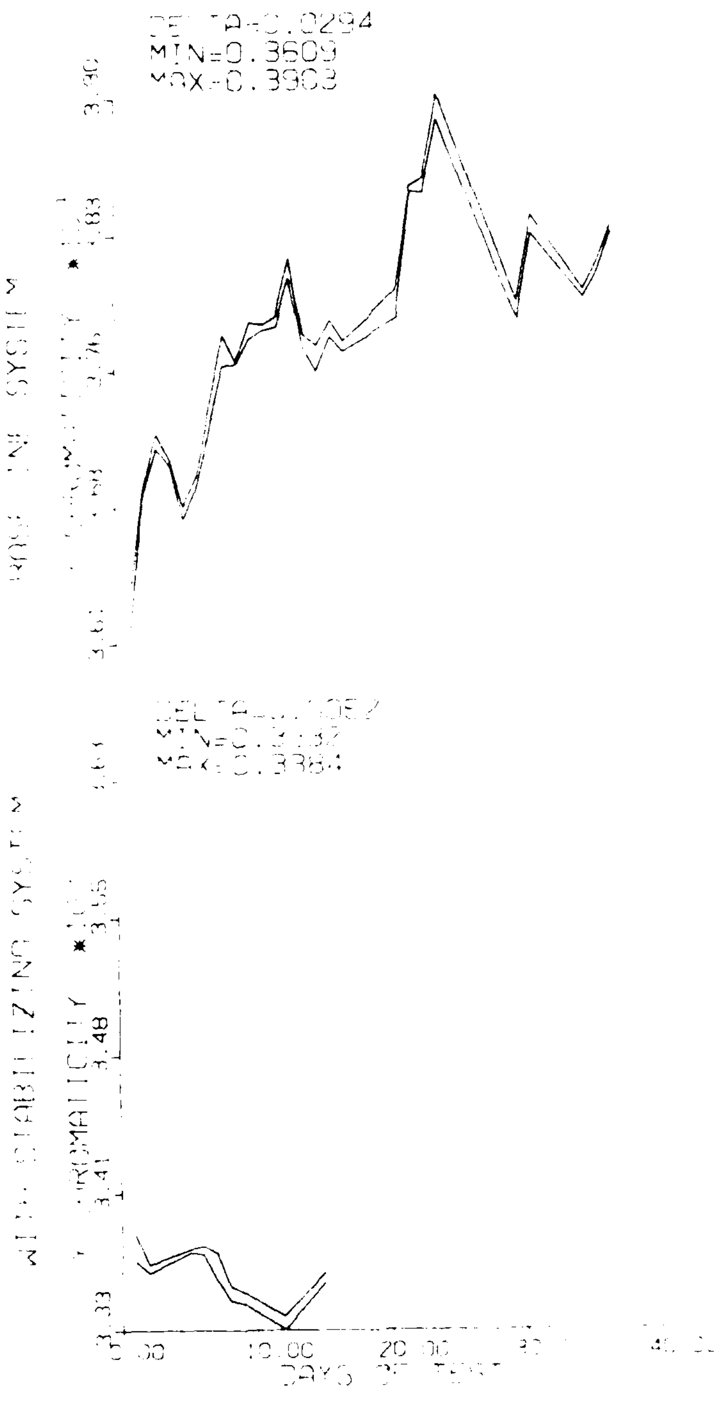


Figure 14. Comparison Using Aydin 8025 Delta Gun Monitor of Long-Term Drift in y CIE Chromaticity Coordinate Between Baseline and Compensated Display System.

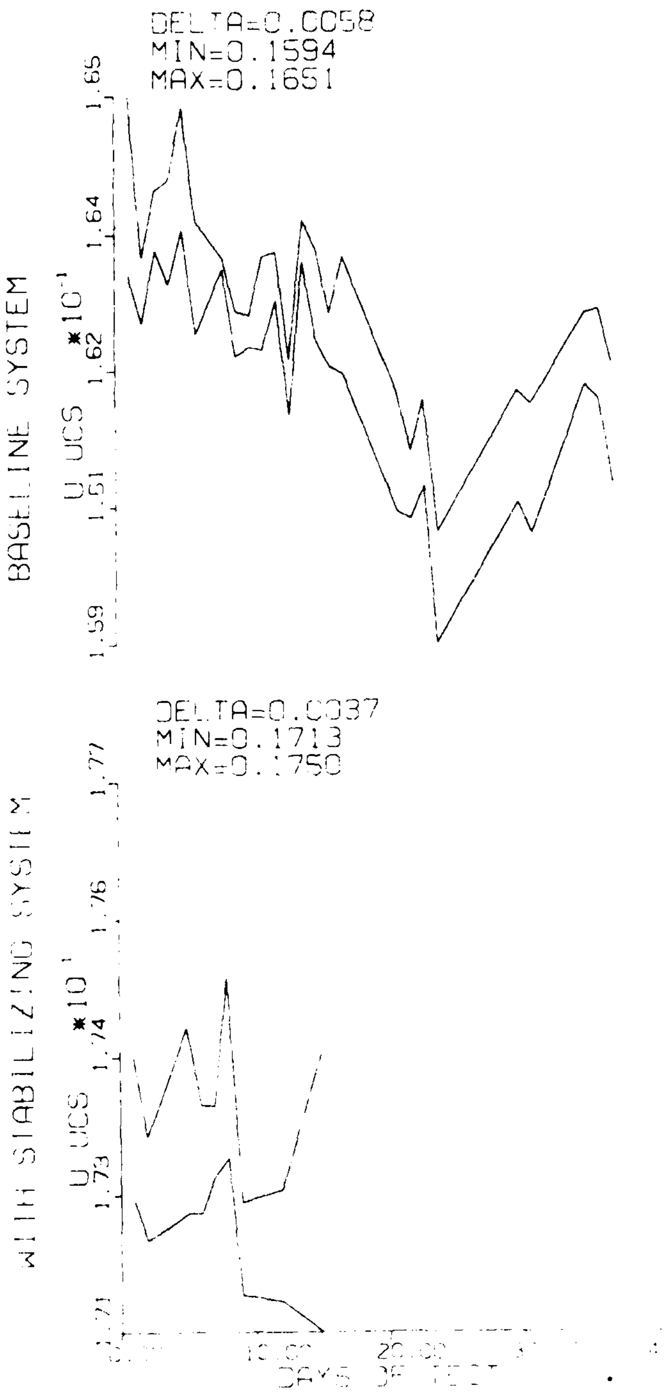


Figure 15. Comparison Using Aydin 8025 Delta Gun Monitor of Long-Term Drift in u' CIE UCS Coordinate Between Baseline and Compensated Display System.

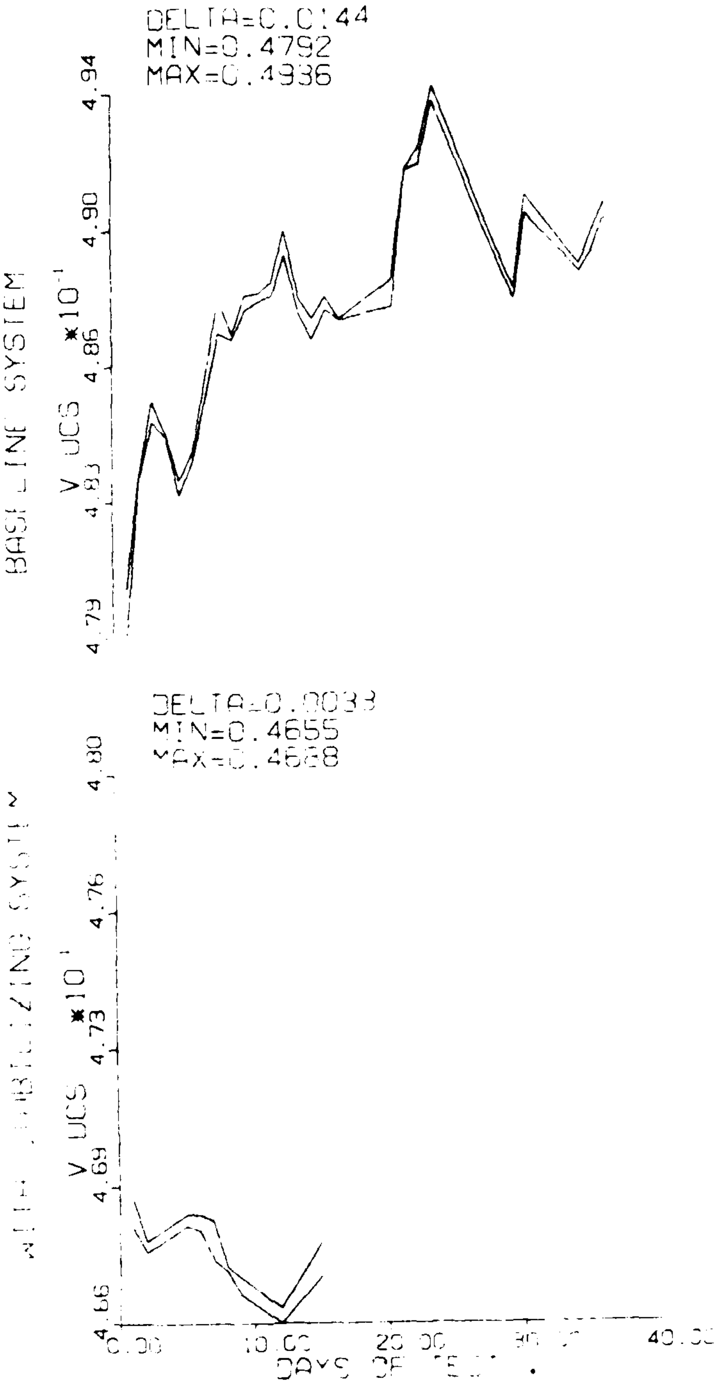


Figure 16. Comparison Using Aydin 8025 Delta Gun Monitor of Long-Term Drift in v' CIE UCS Coordinate Between Baseline and Compensated Display System.

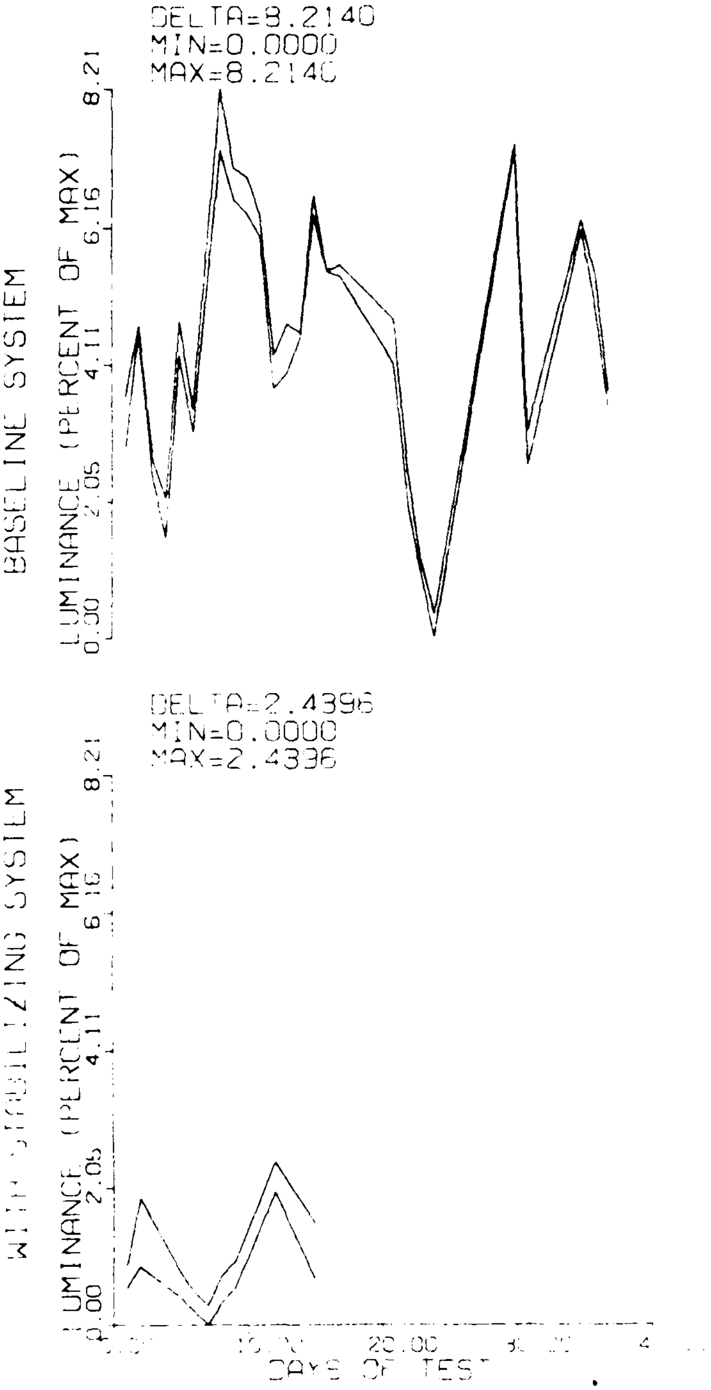


Figure 17. Comparison Using Aydin 8025 Delta Gun Monitor of Long-Term Drift in Percent Luminance Change from the Maximum Luminance Between Baseline and Compensated System.

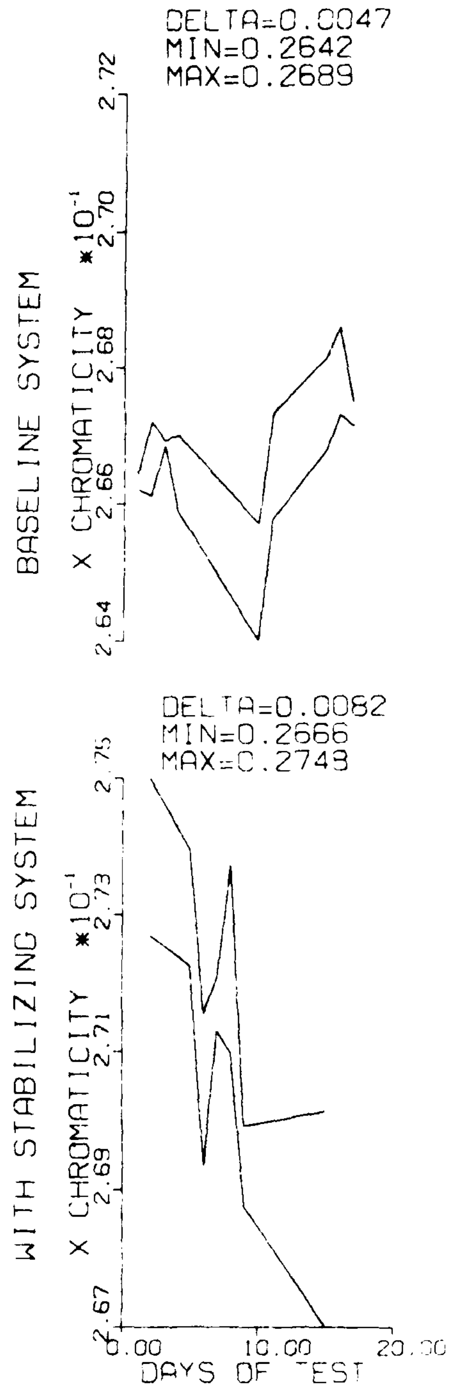


Figure 18. Comparison Using Aydin Inline Gun Monitor of Long-Term Drift in x CIE Chromaticity Coordinate Between Baseline and Compensated Display System.

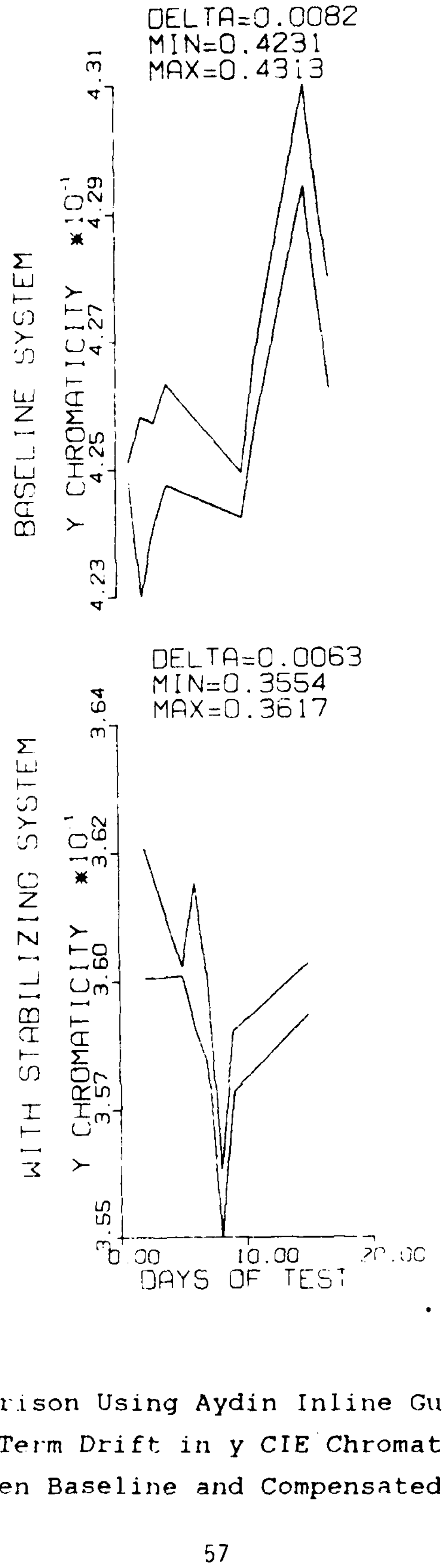


Figure 19. Comparison Using Aydin Inline Gun Monitor of Long-Term Drift in y CIE Chromaticity Coordinate Between Baseline and Compensated Display System.

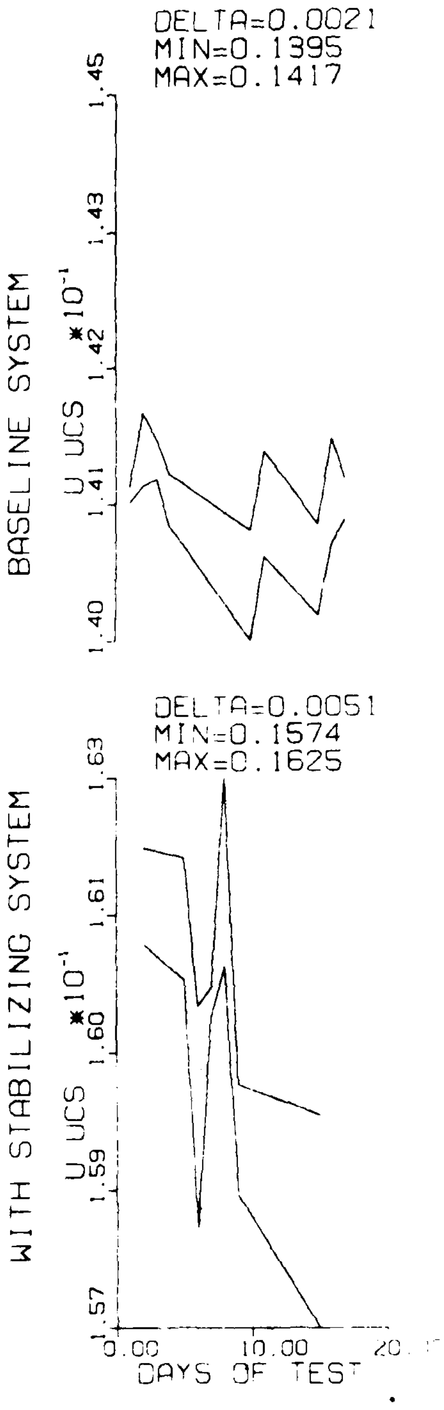


Figure 20. Comparison Using Aydin Inline Gun Monitor of Long-Term Drift in u' CIE UCS Coordinate Between Baseline and Compensated Display System.

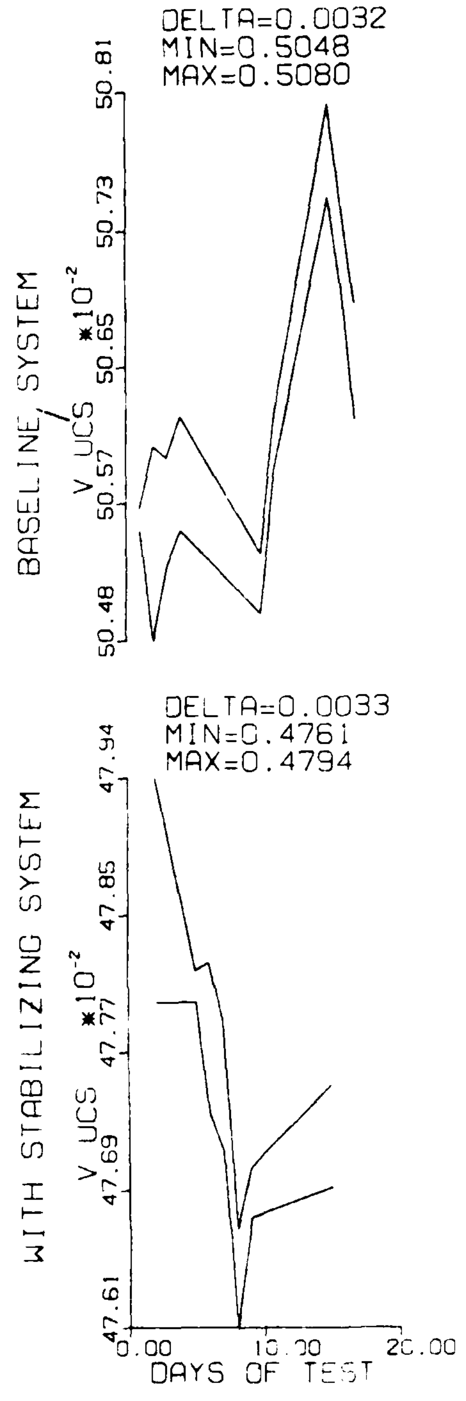


Figure 21. Comparison Using Aydin Inline Gun Monitor of Long-Term Drift in v' CIE UCS Coordinate Between Baseline and Compensated Display System.

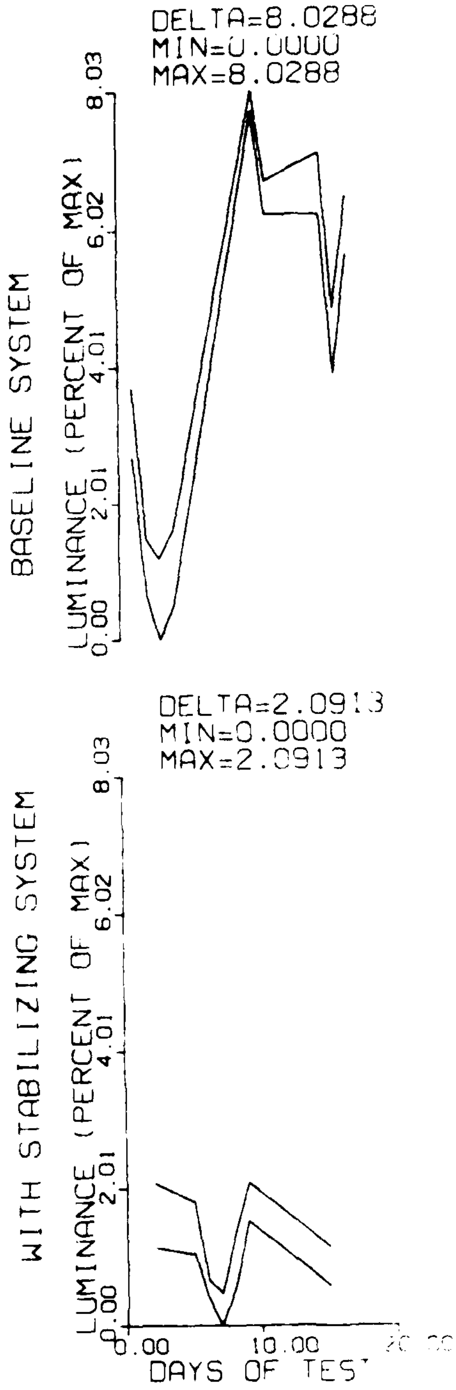


Figure 22. Comparison Usinig Aydin Inline Gun Monitor of Long-Term Drift in Percent Luminance Change from the Maximum Luminance Value Between Baseline and Compensated System.

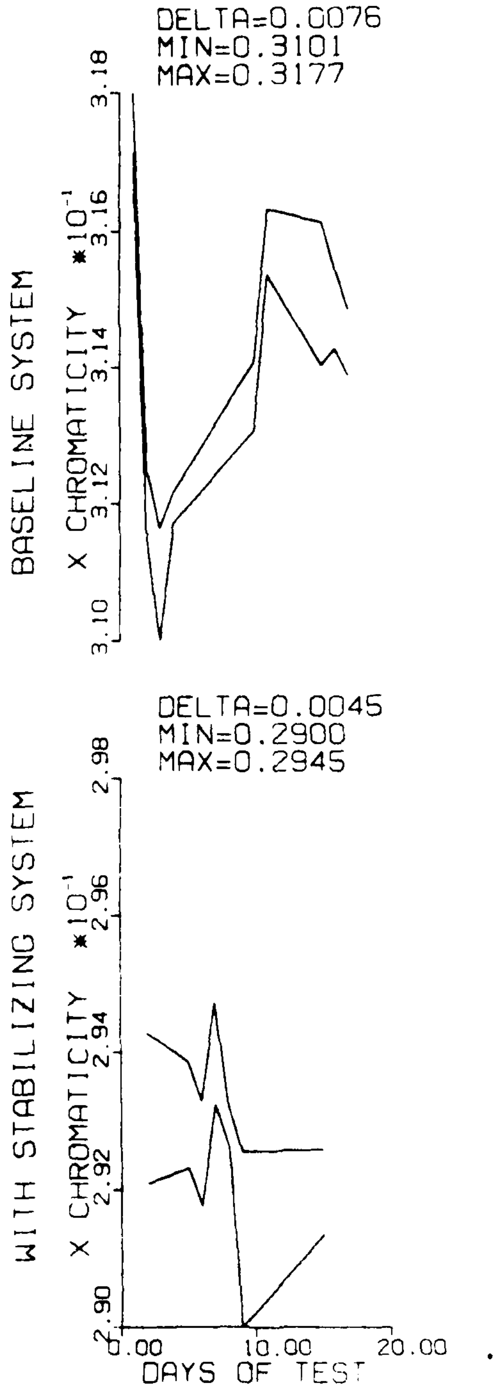


Figure 23. Comparison Using Conrac Monitor of Long-Term Drift in x CIE Chromaticity Coordinate Between Baseline and Compensated Display System.

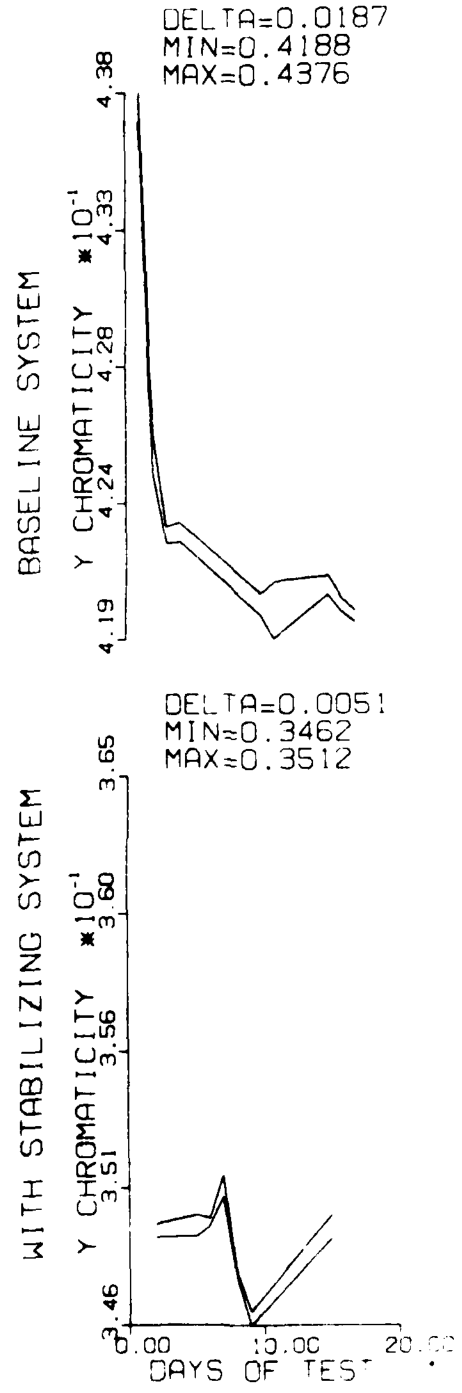


Figure 24. Comparison Using Conrac Monitor of Long-Term Drift in y CIE Chromaticity Coordinate Between Baseline and Compensated Display System.

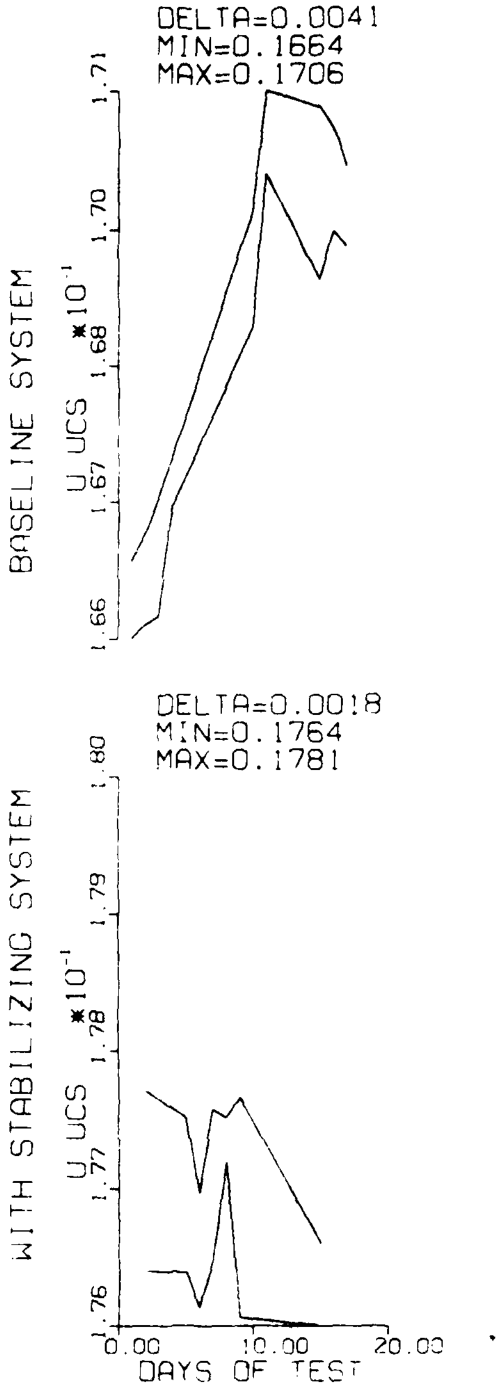


Figure 25. Comparison Using Conrac Monitor of Long-Term Drift in u' CIE UCS Coordinate Between Baseline and Compensated Display System.

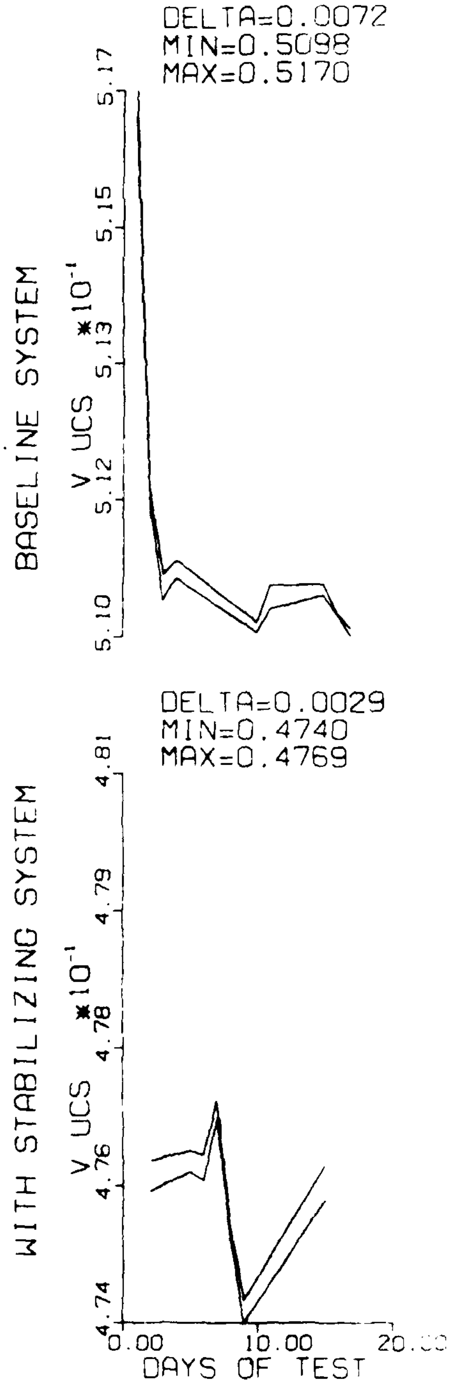


Figure 26. Comparison Using Conrac Monitor of Long-Term Drift in v' CIE UCS Coordinates Between Baseline and Compensated Display System.

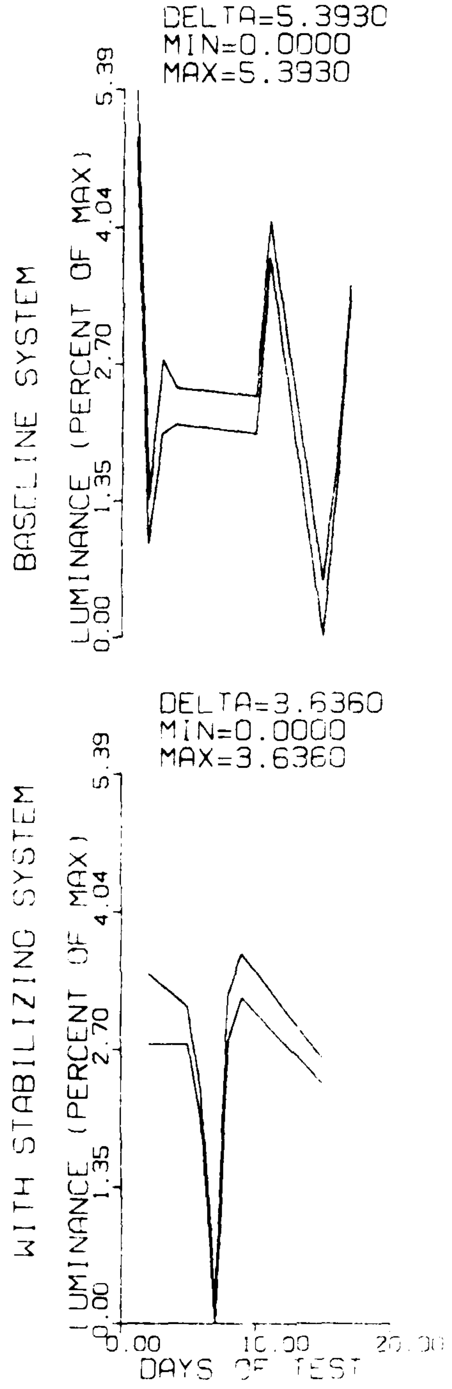


Figure 27. Comparison Using Conrac Monitor of Long-Term Drift in Percent Luminance Change from Maximum Luminance Between Baseline and Compensated System.

TABLE 5. Summary of Long-Term Drift Results:

CONDITION	x	y	u'	v'	Percent Luminance
Aydin Baseline	.0091	.0294	.0058	.0144	8.21
Aydin Stabilized	.0061	.0052	.0037	.0033	2.44
Conrac Baseline	.0076	.0187	.0041	.0072	5.39
Conrac Stabilized	.0045	.0051	.0018	.0029	3.63
Aydin In-Line Baseline	.0047	.0082	.0021	.0032	8.03
Aydin In-Line Stabilized	.0082	.0063	.0051	.0033	2.09

interesting to note that with the exception of the Aydin 8025 y and v' and the Conrac y, the variability of the baseline measurements is not dramatically greater than the measurement system variability of .002 in u' and v'. It is also interesting to note that across all of the monitors the stabilization system produced a significant improvement in the luminance stability. Therefore, if a researcher using an unstabilized system finds large changes in chromaticity over time, he should look at external sources that might cause the changes. These would most probably be in the measurement area. However, the data clearly show that large luminance changes are normal.

Transient Response Results

The Aydin 8025 monitor was then evaluated for its transient response with and without the Feedback Control System. It was discovered during these measurements, conducted with the CRT measurement system described in Section IV, that the transient change was the largest change measured.

Figure 28 shows luminance and cathode current as a function of time. The display was caused to change from a value of 750 bits to 650 bits during the measurement session. The cathode current was measured by taking the voltage drop across a 1000 ohm resistor which was in series with the cathode. No particular care was taken to establish the precise value of the cathode current. The purpose of the measurements was simply to look at the change in cathode current as a function of luminance. The low level of the signal resulted in a low signal-to-noise ratio. Figure 28 shows the error band for luminance and cathode current as a result of the noise. It should be noticed that the cathode current tracks the luminance changes very well. This fact could be used in future systems to effect feedback control without using light detectors in front of the screen.

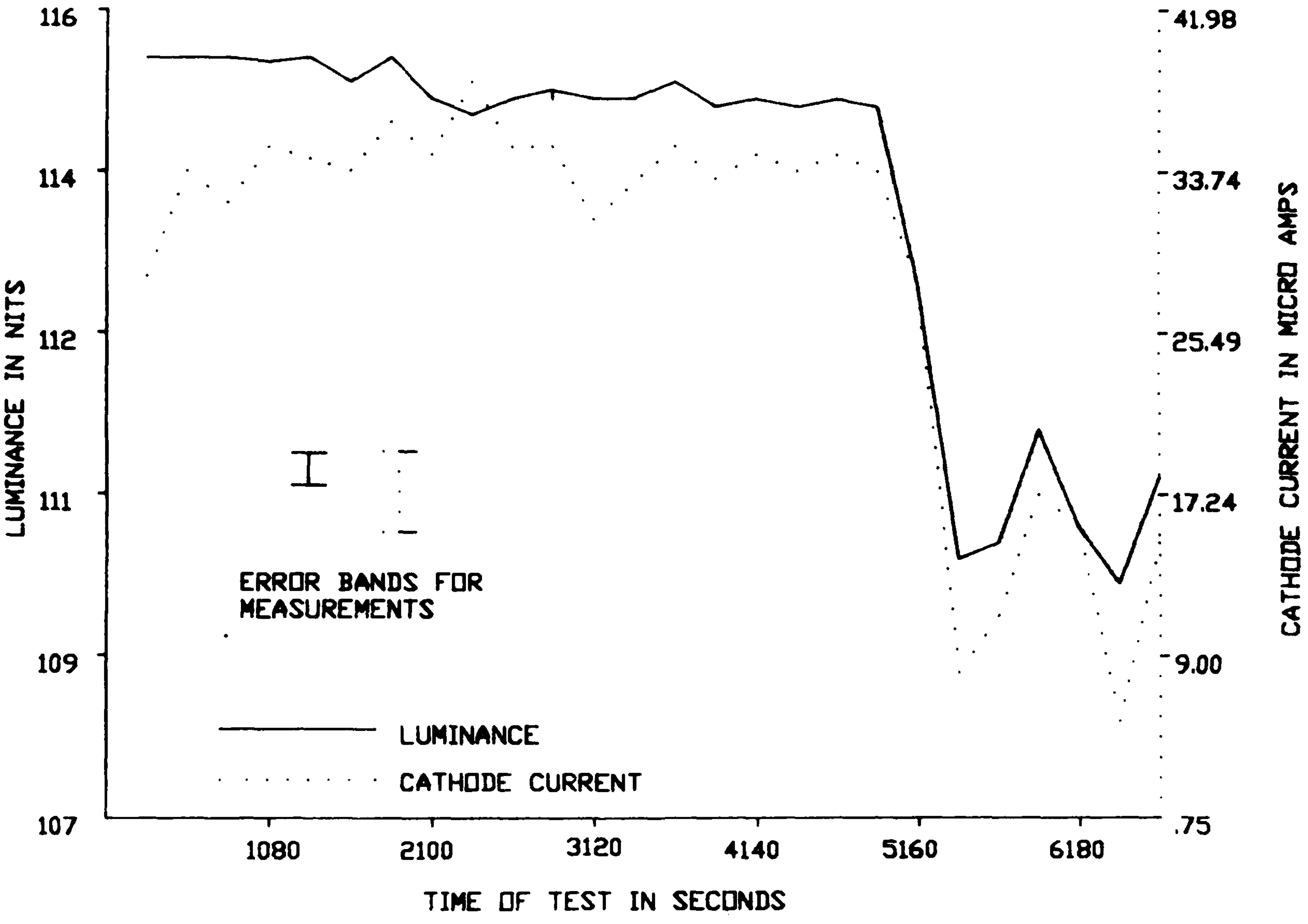


FIGURE 28 - CATHODE CURRENT AND LUMINANCE VS TIME FOR GREEN GUN

In the next test of the Aydin 8025 monitor, the green gun of the CRT was given a zero bit value drive for two hours. The zero bit value produced a dark CRT and the two-hour time period allowed the display to stabilize. The green gun was then changed to 1000 bits and the measurement of luminance as a function of time was started. The test was run for four hours; the results are shown in Figure 29.

The luminance of the CRT starts at 286 nits when the green gun is first given the increased drive, but in approximately 1.5 hours it has fallen to 186 nits. This represents a 35% decrease from the initial value of 286 nits.

Two things should be noticed in Figure 29. First the falling output followed by a small rise is a common response of the cathode of the CRT. The physics behind the curve is beyond the scope of this report. It is sufficient to say that the amplitude of this change is dependent upon the amount of cathode drive. The cathode drive is dependent upon the cathode voltage which is controlled by the video input and the setup of the monitor. If the monitor is set up to give a high luminance output then the effect will be more noticeable. The Aydin 8025 monitor used in this test was set up to give a high output which intensifies the effect. The time to reach a minimum value and the time to rise to a stable value are dependent upon the age of the cathode. The older the tube the longer the two times will be.

The "jitter" seen in Figure 29 and to a greater extent in Figures 30, 31, and 32 is due to a combination of photomultiplier tube noise, line noise, and analog-to-digital converter (ADC) quantization noise. It should be noted that the "jitter" is constant for Figures 29 thru 32. The effect becomes more noticeable due to the different ordinate scales. The photomultiplier tube has a noise level of 10 to

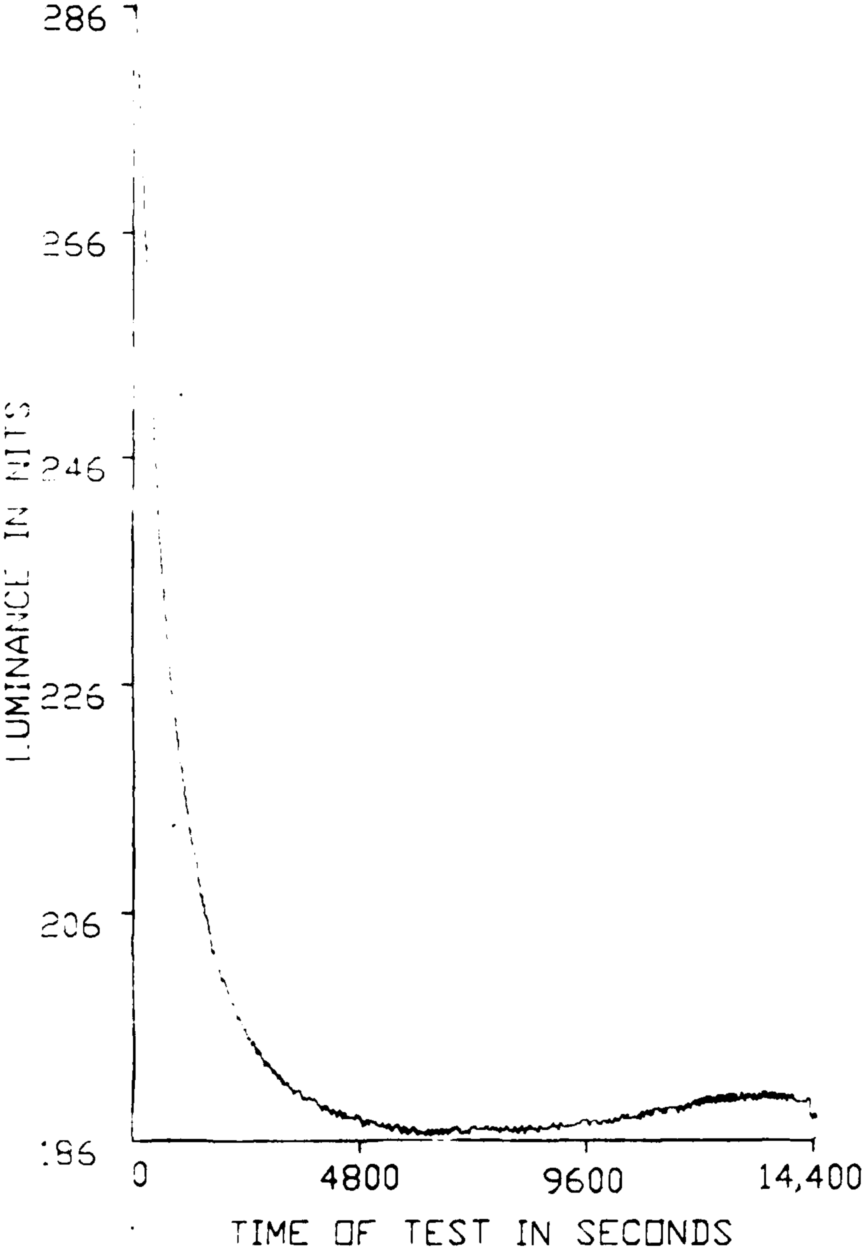


Figure 29. Transient Test of Aydin 8025 Monitor From 0 Bits to 1000 Bits With No Feedback Control Over a 4 Hour Time Period.

25 millivolts depending upon the setting of the high voltage. These levels are based upon the normal high voltage setting for this level of luminance. If the high voltage of the photomultiplier tube is increased beyond these normal values to make the system more sensitive then the noise will increase. The ADC noise arises from the fact that the system may only record discrete digital values. For the transient measurements the system was calibrated to a value of 350 nits, corresponded to 7 volts out of the PMT amplifier. Since the computer system has a 12-bit ADC there are 2.4 millivolts per bit for a 10-volt range. For the 7 volt PMT amplifier range we have .122 nit per bit. As we can see from Figures 29 through 32, this is a very small part of the noise. The line noise for the system is 5 millivolts rms. This translates into a error value of .25 nit rms of line noise. The noise component due to the photomultiplier is between .5 and 1.25 nits and is the largest component of the noise. The output of the photomultiplier tube could be filtered to remove the noise, but this would compromise the response of the system and adversely affect the measurements.

The same test was conducted again, except that the Feedback Control System was used. Figure 30 shows the results of the test with the Feedback Control System in place. The luminance starts at a value of 229 nits and after 2 hours has fallen to a value of 204 nits, which represents an 11% reduction from the initial value.

The test was conducted again in the same manner except the change was from 0 bits to 600 bits. Figure 31 shows the results of the test without the Feedback Control System. The luminance starts at 85.6 nits and ends at 79.2 nits, which represents a 7% decrease from the initial value.

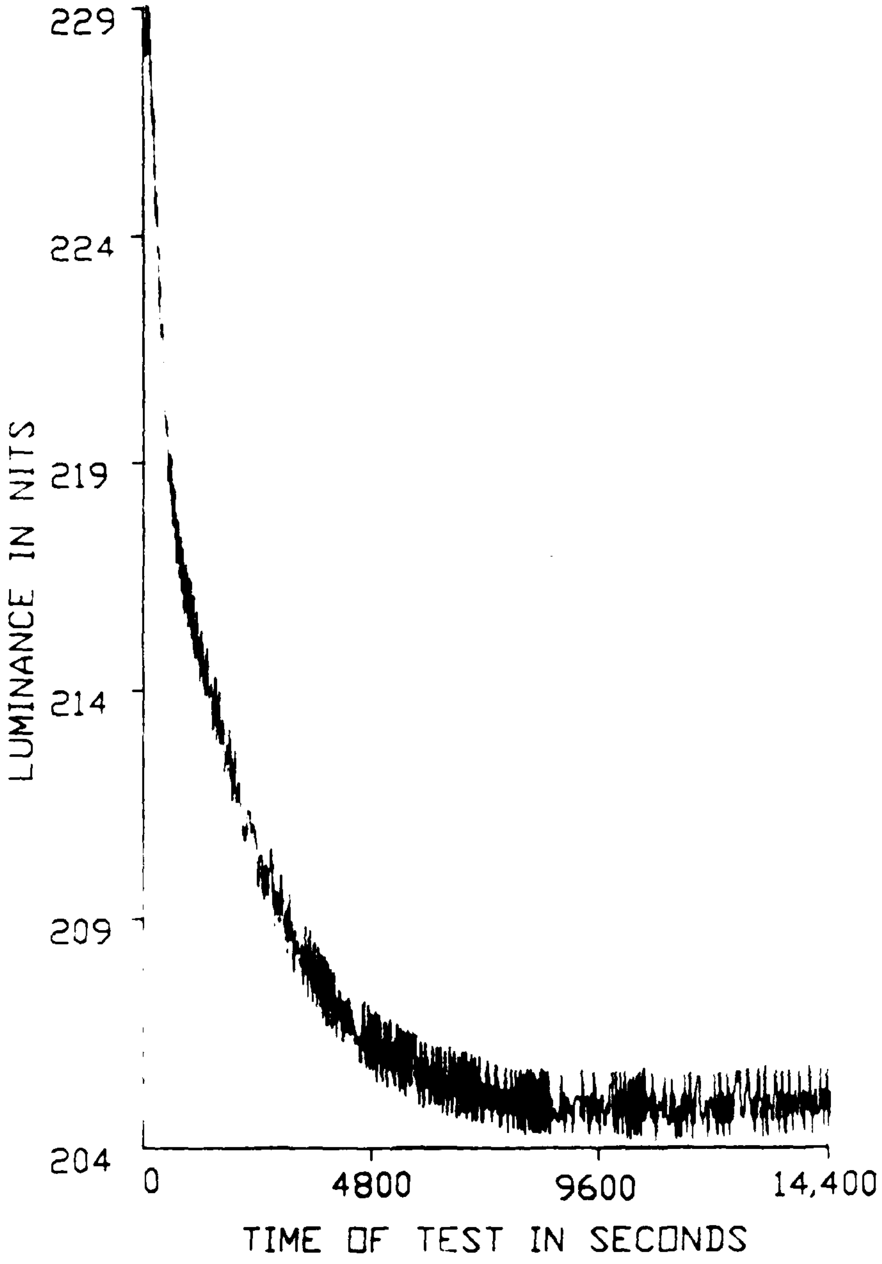


Figure 30. Transient Test of Aydin 8025 Monitor from 0 Bits to 1000 Bits With Feedback Control Over a 4 Hour Time Period.

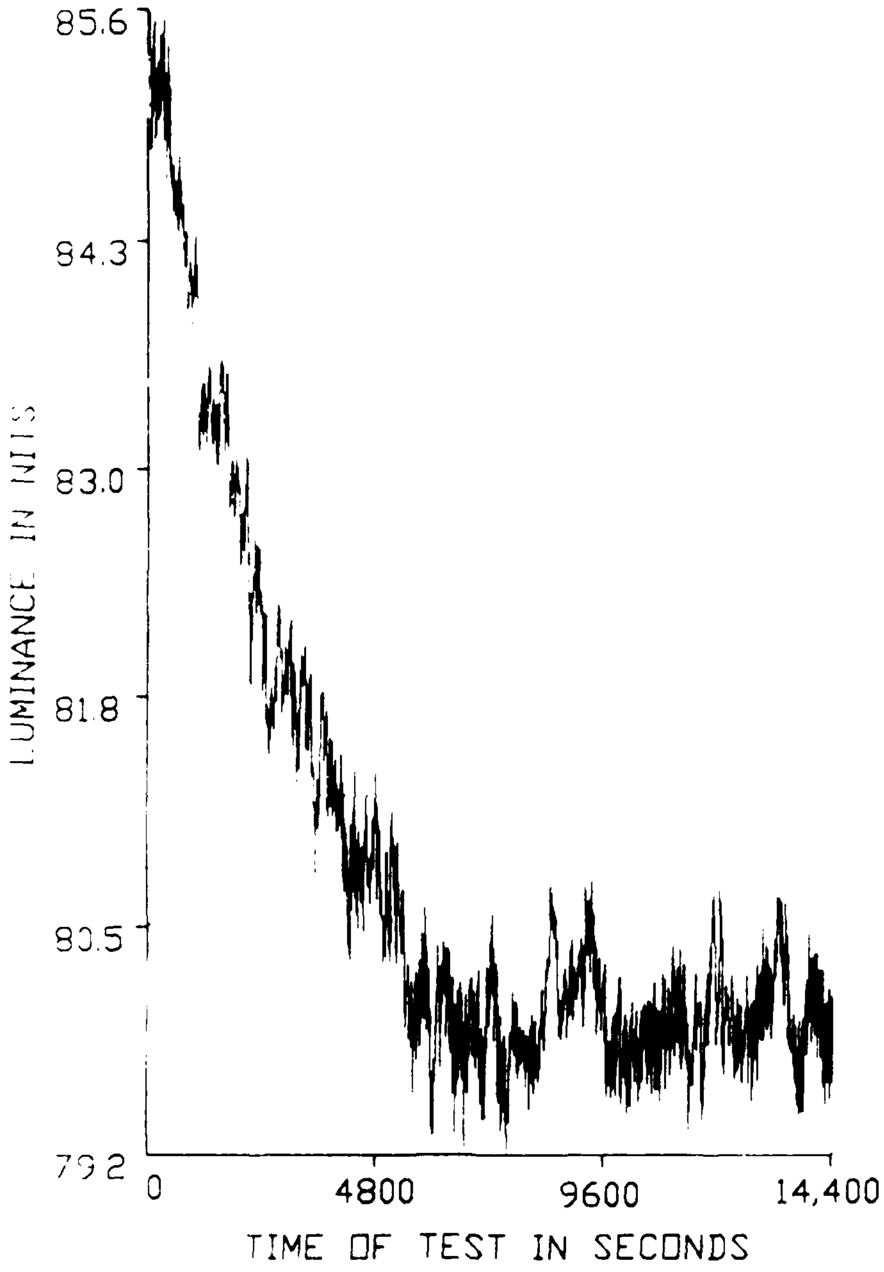


Figure 31. Transient Test of Aydin 8025 Monitor from 0 Bits to 600 Bits With No Feedback Control Over a 4 Hour Time Period.

The test from 0 bits to 600 bits was conducted with the Feedback Control System in place. Figure 32 shows the results of the test. The display changes range from 69.5 to 68.4 nits, or a 1.6% difference. It is not clear why the luminance increases in Figure 32.

In both cases, it is clear that the Feedback Control System had a very positive and beneficial effect on the transient response of the system. The result leads to the conclusion that the basic idea of stabilization via an external means can make the computer controlled display system a better research tool. The technique needs some further work and refinement, but it is fundamentally sound.

After completing the tests described above and in the preceding sections, the stabilization system was delivered to AAMRL and demonstrated using their computer display system. During the demonstration, it became clear that the device would have to be modified if it was to be useful to AAMRL. They sometimes reduce the green- and red-gun gains on their monitors so as to enhance colorimetric resolution. This means that the luminances seen by the stabilization system's silicon detectors can be lower than was anticipated when the stabilization circuitry was designed, resulting in a need for greater gain. VPI & SU therefore offered to modify the circuitry to eliminate this problem. The circuit description of the resulting second-generation stabilization system is contained in Appendix D. Tests of the revised system show that its performance is comparable with the original version. Therefore, the discussion of these test results has also been deferred to Appendix D.

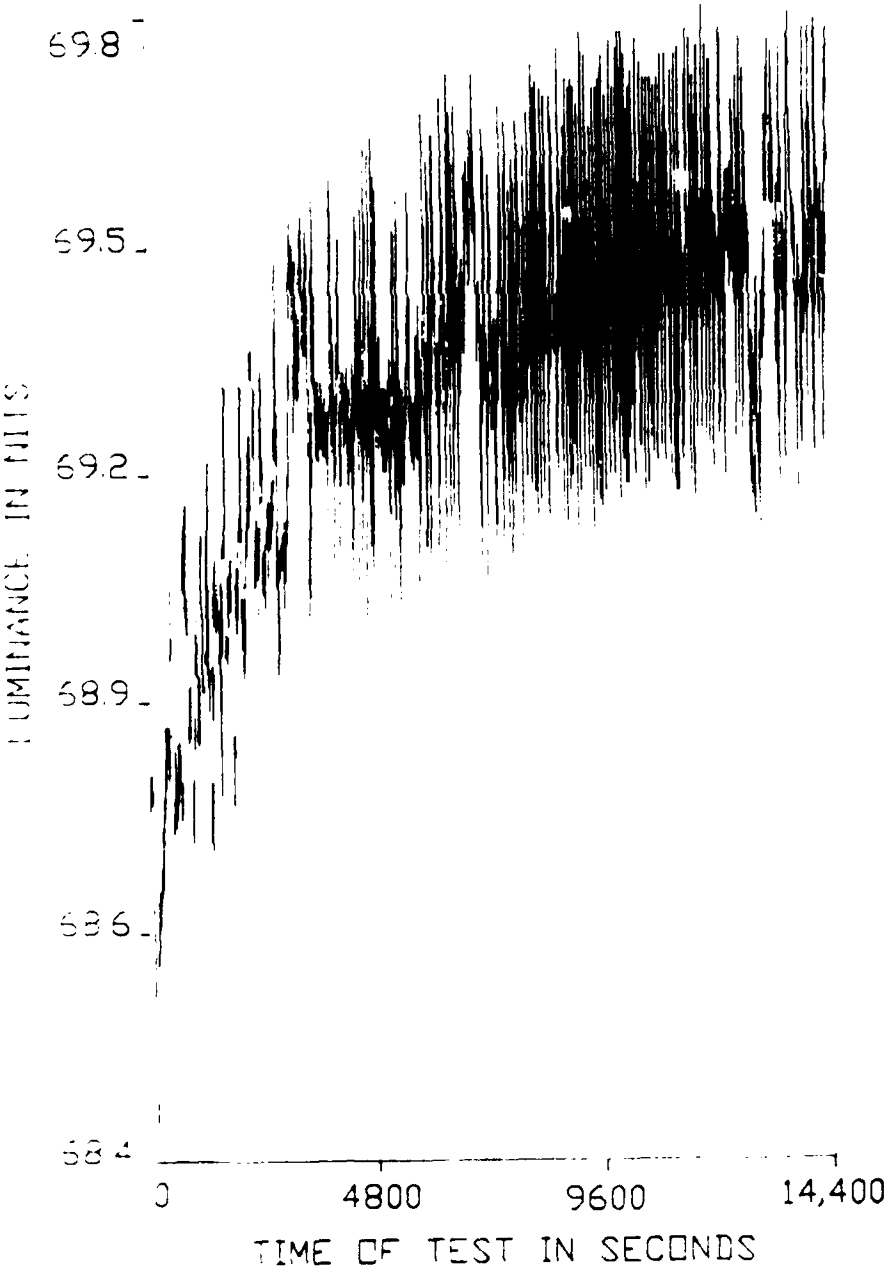


Figure 32. Transient Test of Aydin 8025 Monitor From 0 Bits to 600 Bits With Feedback Control System Over a 4 Hour Time Period.

VIII. CONCLUSIONS AND RECOMMENDATIONS

One may conclude from this work that the idea of obtaining a more stable display monitor by providing external control of the video signal is entirely feasible. In both transient conditions and in 12 out of 15 long-term drift conditions (Table 5), the Stability System improved performance. In all cases, it improved the luminance stability of the system. Perhaps the most important result is that the stability system had a pronounced affect on the transient response of the monitor. This response was the largest of the temporal non-uniformities and was reduced significantly by the stabilization system.

As with any research project, knowledge is one of the most important and beneficial results of the work. The knowledge gained in this work has shown the areas that need to be improved for the computer display to render more stable and uniform color stimuli. The spatial nonuniformity findings showed that one must take care to measure the area of the display in which the stimulus is to be presented. The work also showed that the transient response may very well affect the measurements and experimental stimuli, and should not be ignored. The knowledge also points the way to further work in improving the computer display system.

The goal of any subsequent research should be to provide research scientists with the most stable and uniform display system possible based upon the research completed to date. As in any research, the quality and sensitivity of the equipment are directly proportional to the effects which can be detected. Since the human visual system is a most complex image processing system, an increase in the capabilities of the research equipment will allow the exploration of more subtle vision phenomena.

DISPLAY CHARACTERIZATION

One area of potential improvement is the display characterization. Characterization of the display by means of spectroradiometric measurements can be very time consuming. It is hard to imagine a CRT-based display system that would be so stable that it would not require periodic characterization updates. Realizing that luminance measurements can be made relatively quickly, however, the time required for the characterization can be minimized by first making a set of spectral measurements of the phosphor at enough different intensities to account for any measurement system and display system changes. The spectra would be normalized and permanently stored in the computer system. When the time occurs for the characterization to be made, a luminance measurement can be made at every bit value, the stored spectra scaled by this value, and the appropriate tristimulus values calculated and stored. This approach would give a more accurate characterization since every bit value could be represented, instead of a small sample. This method would also be much quicker than performing complete spectroradimetric measurements every time, even with every bit being measured.

SPATIAL NONUNIFORMITY

As shown in this report, one of the largest areas of display change is the change with location on the surface of the display. If the nonuniformity pattern is linear with intensity, then the image processing system can be used to store an inverse map of the display surface changes. This inverse can then be multiplied with the image to reduce the change across the display. Ultimately one would like to incorporate a system within the monitor that would compensate for the nonuniform display surface. There are several possible techniques that might be used for this correction if the monitor can be modified. Since semiconductor memory is so inexpensive, the display characteristics could be measured and then stored in the display. This could be done for one or more levels of intensity and any other variables such as convergence, focus, astigmatism, and linearity. The location and intensity could then be used as the address for the memory and the memories' values could be used to change the monitor. If the monitor cannot be modified, as in this work, then the image itself can be modified in either real time via image processing or by preprocessing the images.

CATHODE SAMPLING

Another very important area for likely improvement in the feedback system would be to use cathode sampling to determine the intensity of the display rather than to use the silicon light detectors. The use of silicon detectors requires that they be placed upon the display surface, which masks a nontrivial portion of the display as well as placing an obtrusive structure between the observer and the display. The silicon detector also requires the display to be operated in a light-stable environment to prevent interactions with the ambient light. Care was taken in the construction of the holders of the detectors because a small amount of ambient light entering the silicon detector will be mistaken for a change in the display. Whenever the Feedback Control System receives a change in the light intensity, it causes the display to change in order to keep the light intensity constant. For example, in one case, the high intensity room lights were turned on and the stabilization system caused the display to go dark when in fact it should have had a moderate intensity display.

A cathode sampling system would eliminate these problems. This system would not have light detectors at the face of the CRT, but would sample the cathode current directly. This

approach would require at most three lines of the display which would contain the reference levels, thus giving a larger area for the experimental stimulus. This small area could be masked off so it would not disturb the viewer. A block diagram of such system is shown in Figure 33.
The cathode current would be sampled in much the same manner as it was for the display measurements. A voltage signal that is proportional to the cathode current would then be sent to the high voltage isolation circuits. This circuit would isolate the rest of the system from the cathode voltage, which is often in the range of 50 to 100 volts. The cathode current signal would then be conditioned, including adjustment of the bandwidth and gain to be compatible with the rest of the system. The conditioning circuit would most probably contain a Sample/Hold circuit.

An intelligent controller would be the heart of the system and would in all probability contain a microprocessor. The intelligent controller would sample three different intensity levels from each of the three color channels. These low, mid, and high intensity signals would be used by the intelligent controller to compute not only the offset change, but the gain change as well. The intelligent controller then would send the appropriate signals to the video signal modifying circuit to modify the gain as well as the offset. This system should make the display as stable as possible.

The above mentioned system, along with an area uniformity correction system, is the next logical step toward the best possible research display.

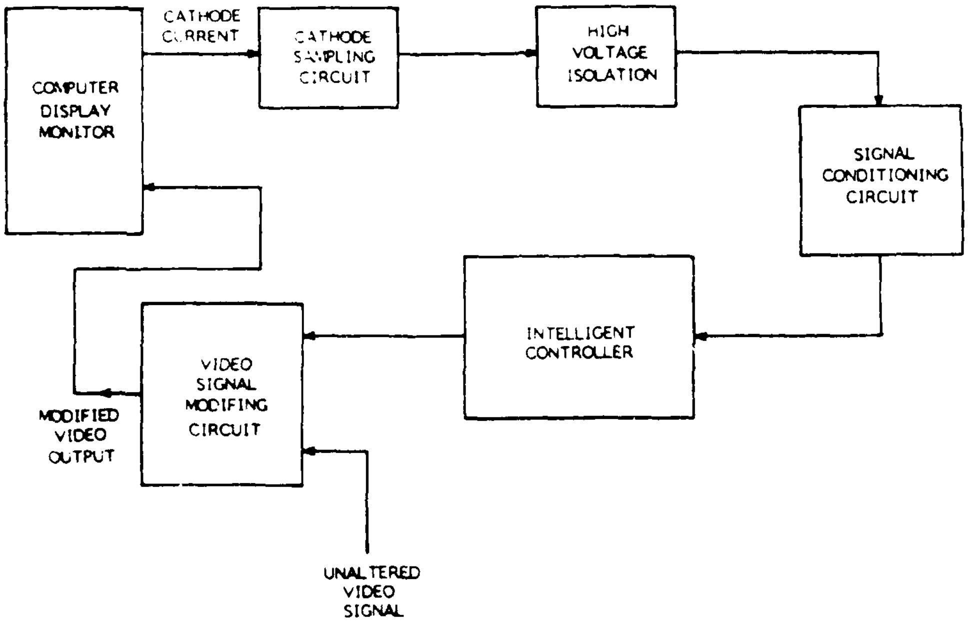


Figure 33. Block Diagram of Cathode Sampling System.

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Farley, W. W. and Gutmann, J. C. Digital image processing systems and an approach to the display of colors of specified chrominance. Arlington, Virginia: Office of Naval Research, HFL-80-2/ONR-80-2, August 1980.

Wyszecki, G. and Stiles, W. Color Science: Concepts and Methods Quantitative Data and Formulae. John Wiley, 1982

APPENDIX A

PHOSPHOR STABILITY AS A FUNCTION OF INTENSITY

To investigate phosphor stability as a function of intensity, a series of measurements was made of the Aydin 8025 delta gun monitor's green gun, at different intensity levels. Three spectral measurements were made of the monitor with an input bit level of 300, 400, 600, 800, and 1000 bits. Table 6 shows a summary of the results. The table is followed by each of the measured spectra.

Table 6 shows the mean and standard deviation of CIE x and y chromaticities, u' and v' UCS chromaticities, and luminance for each bit level. The numbers in parentheses under each of the mean values indicate the difference of the mean from the mean at 1000 bits.

It should be noted that at 600 bits (45.01 nits) the u' and v' means differ from their values at 1000 bits by no more than .0003. This difference is at the limit of the measuring system's resolution and therefore these measurements may be regarded as identical. The difference of the mean values of u' and v' at 400 bits (11.67 nits) is a full order of magnitude higher. The difference at 300 bits (3.43 nits) has approximately doubled to .00577. These values are significant and must be investigated further. If one looks at the spectra for 1000 bits (Figure 34), 800 bits (Figure 37), and 600 bits (Figure 40) it can be seen that whereas the scales of the intensity axis have changed the shape of the curves are very similar. This result is consistent with the values reported in Table 6. If one then compares the spectra for 600 bits (Figure 40), 400 bits (Figure 43), and 300 bits (Figure 46) one finds that as the luminance value decreases the shape of the spectrum changes. This is most noticeable at the lower intensity values found at the blue and red ends of the spectrum change. These low intensity values seem to show a higher "noise" level and are of a proportionally larger value. It is our belief that this is caused by the measurement system's inherent noise, as described earlier in the report. However, a definitive answer to the question of whether the changes are a result of the measurement system or a result of changes in the phosphor will have to wait for a more sensitive measurement system.

Bit Value	s for u'	$\bar{x}$ for u'	s for v'	$\bar{x}$ for v'	s for x	$\bar{x}$ for x	s for y	$\bar{x}$ for y	$\bar{x}$ for Luminance	s for Luminance
1000	.00021	.13550 (.00000)	.00002	.55709 (.00000)	.00037	.31273 (.00000)	.00024	.57155 (.00000)	131.32	0.085
800	.00004	.13574 (-.00024)	.00009	.55780 (-.00071)	.00011	.31409 (-.00136)	.00029	.57361 (-.00206)	86.26	1.575
600	.00015	.13640 (-.00090)	.00005	.55726 (-.00017)	.00025	.31589 (-.00316)	.00023	.57460 (-.00305)	45.01	0.476
400	.00002	.13875 (-.00325)	.00009	.55860 (-.00151)	.00009	.32062 (-.00789)	.00031	.57369 (-.00214)	11.67	0.190
300	.00037	.14127 (-.00577)	.00021	.55902 (-.00193)	.00088	.32572 (-.01299)	.00052	.57286 (.04295)	3.43	0.06

TABLE 6. Mean and Standard Deviation for a Set of Three Spectral Measurements of the Green Phosphor at Several Different Bit Values. (Note: Numbers in Parentheses Indicate Difference from Bit Value of 1000).

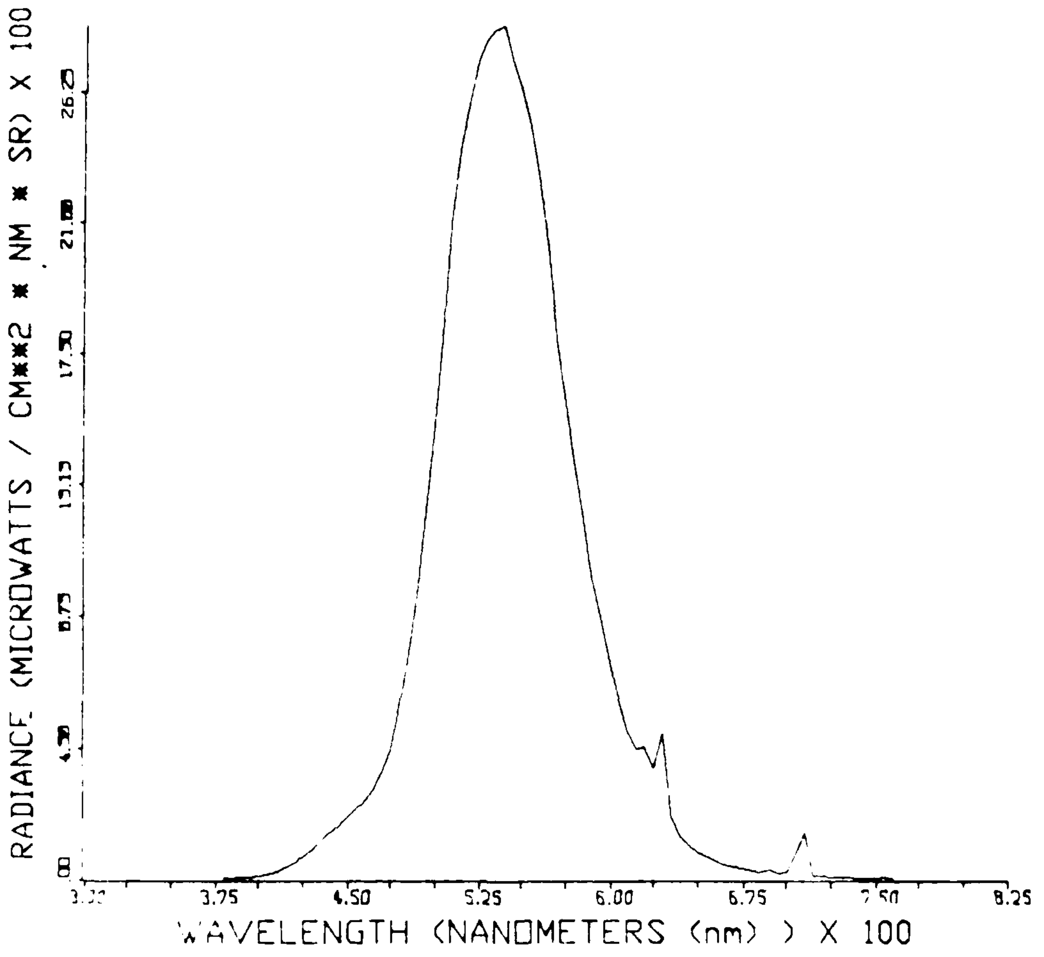

Figure 34. Measurement of Green Gun at 1000 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

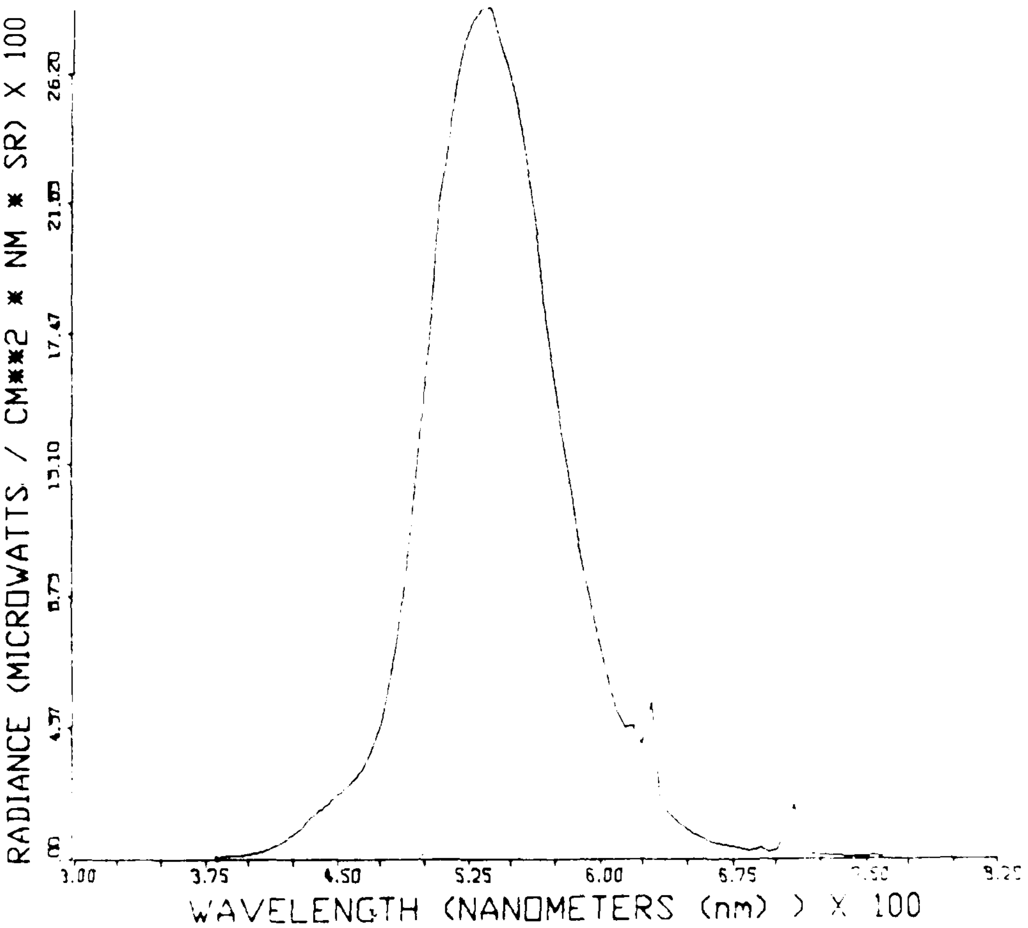

Figure 35. Measurement of Green Gun at 1000 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

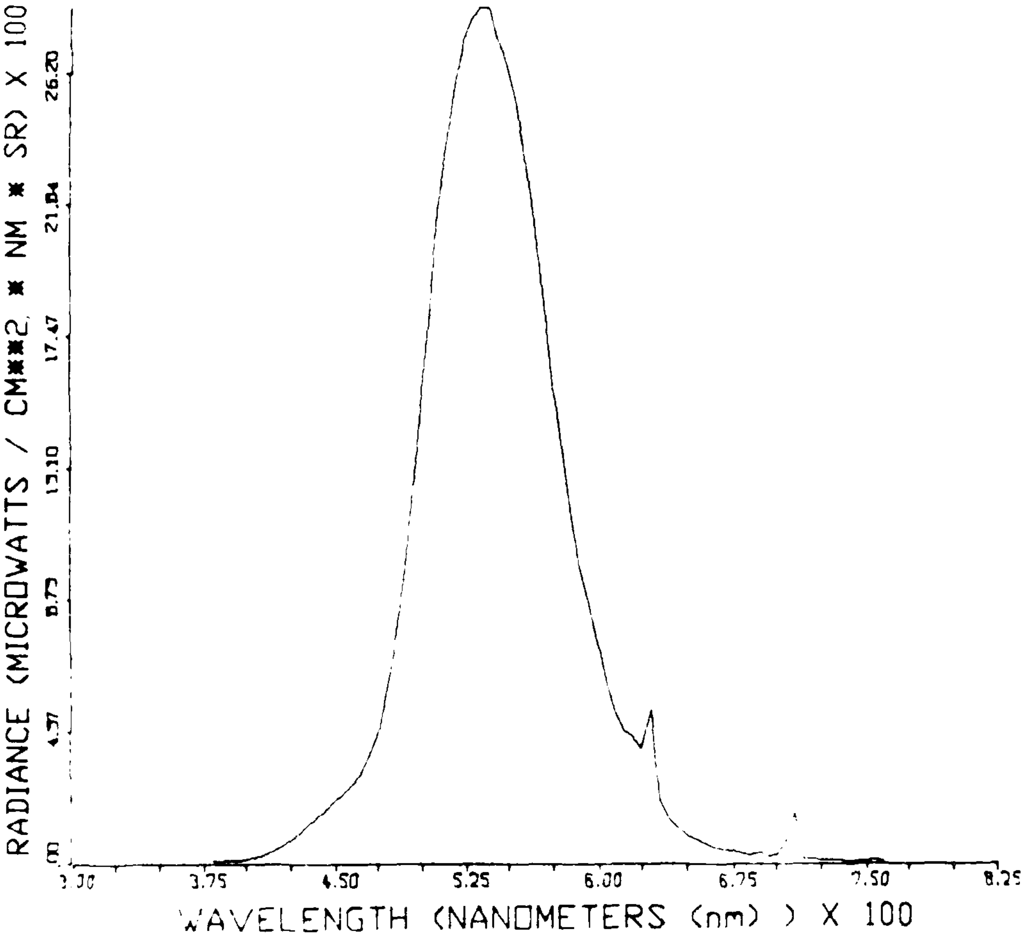

Figure 36. Measurement of Green Gun at 1000 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

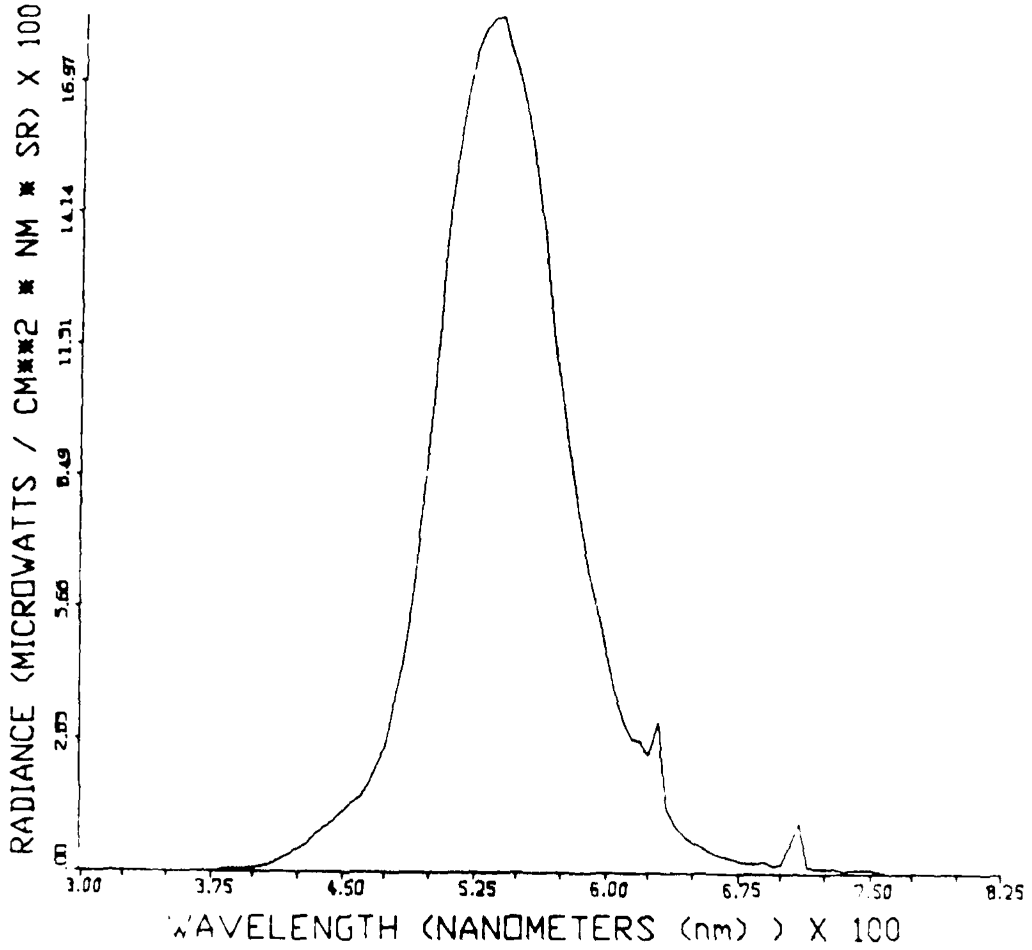

Figure 37. Measurement of Green Gun at 800 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

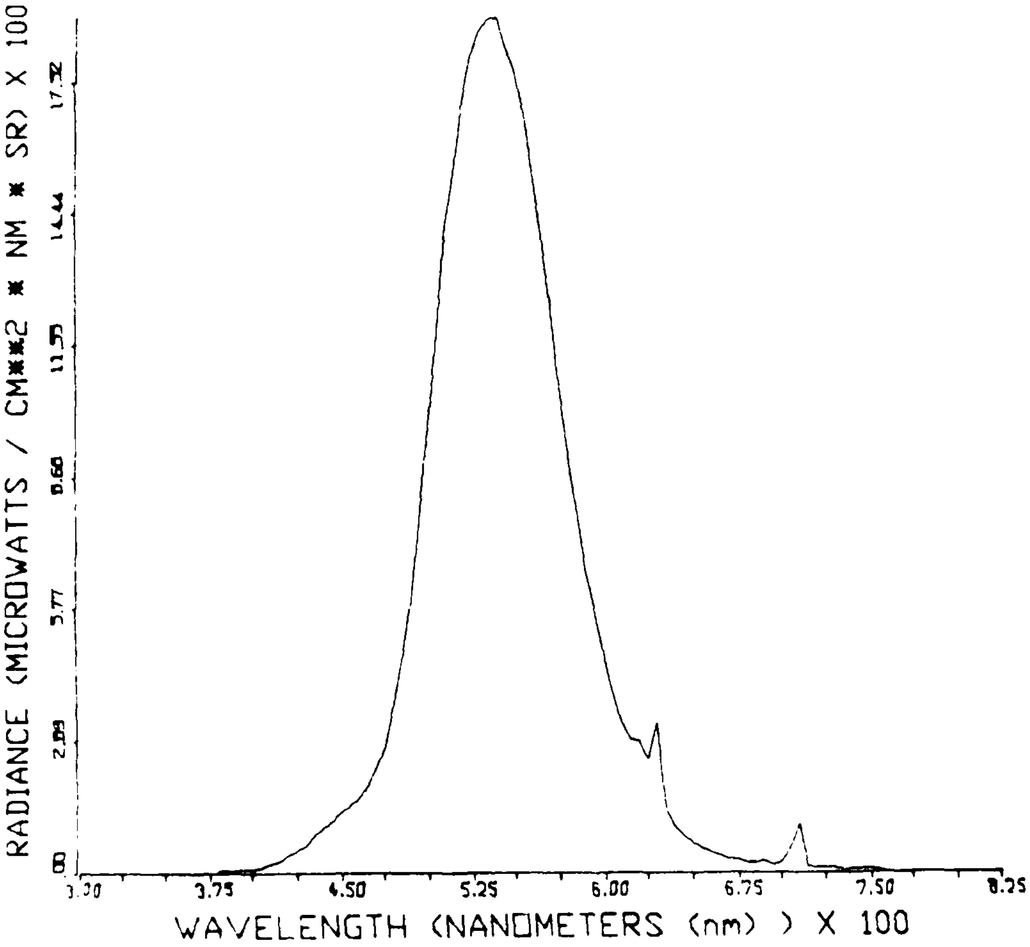

Figure 38. Measurement of Green Gun at 800 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

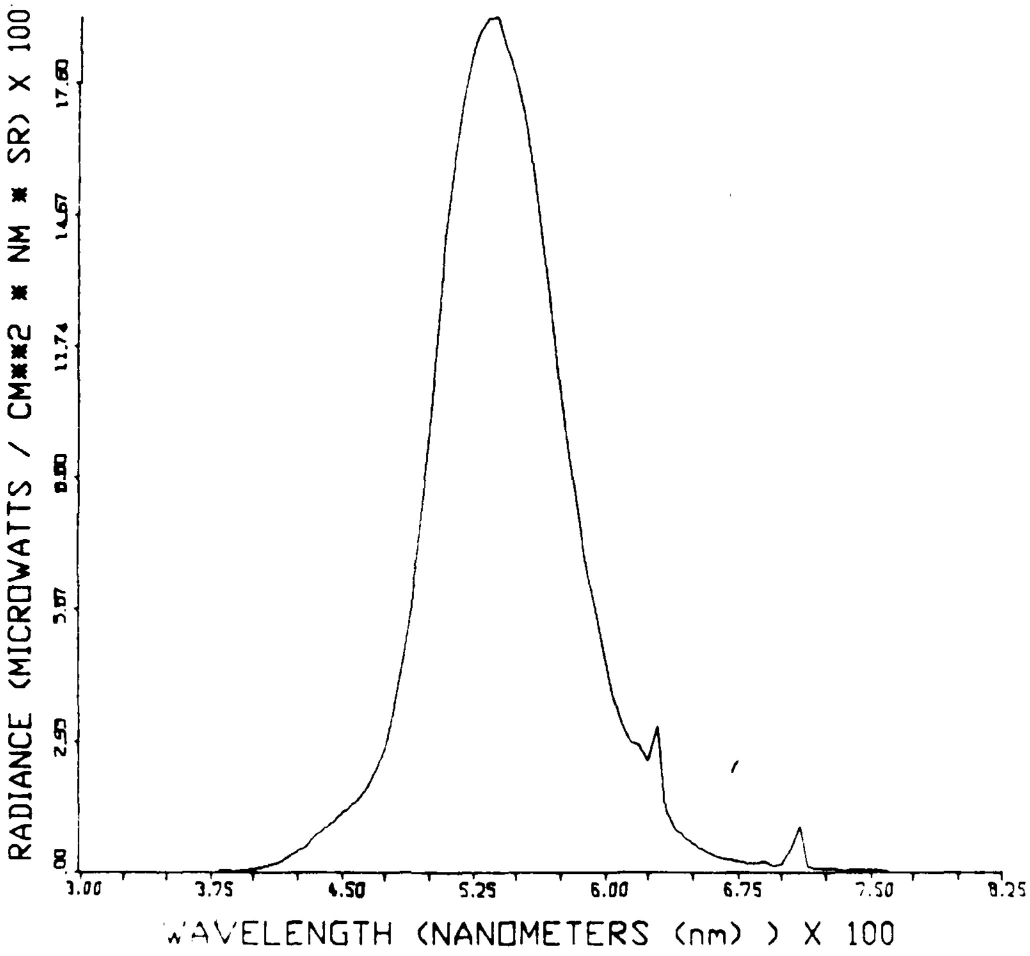

Figure 39. Measurement of Green Gun at 800 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

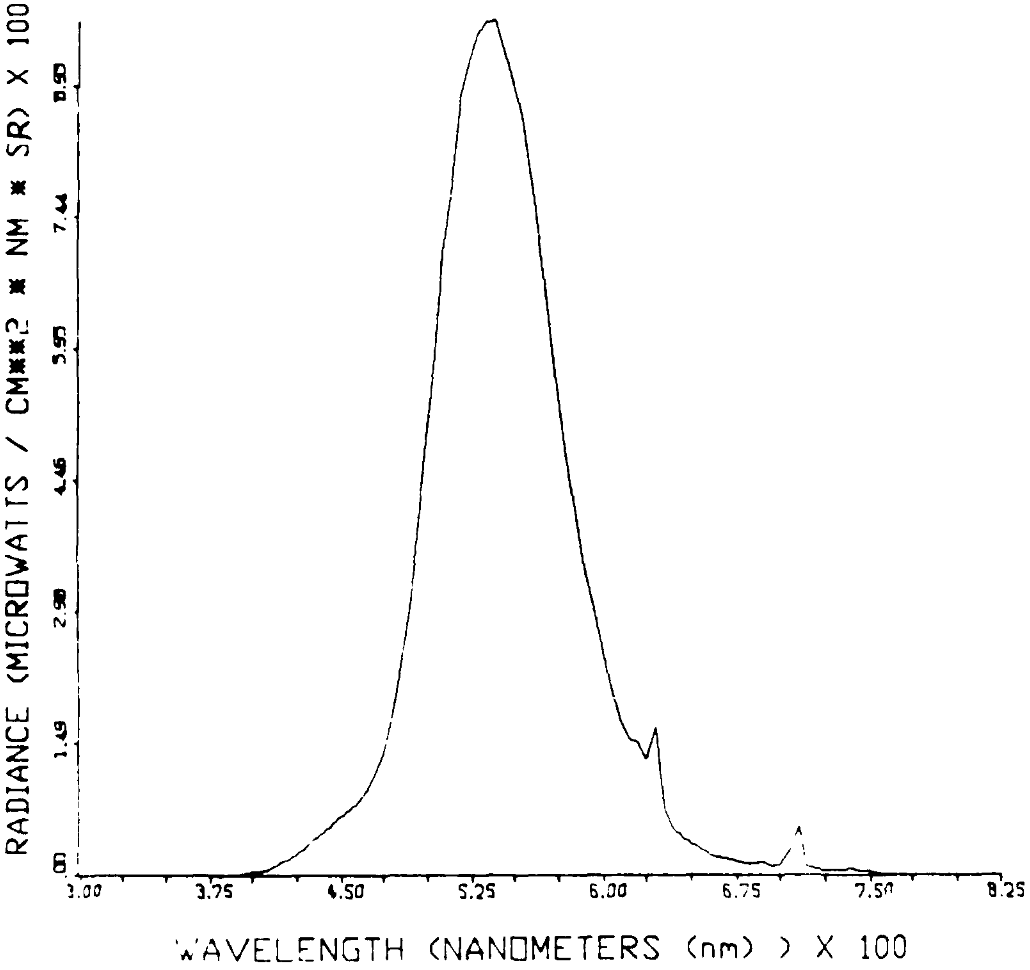

Figure 40. Measurement of Green Gun at 600 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

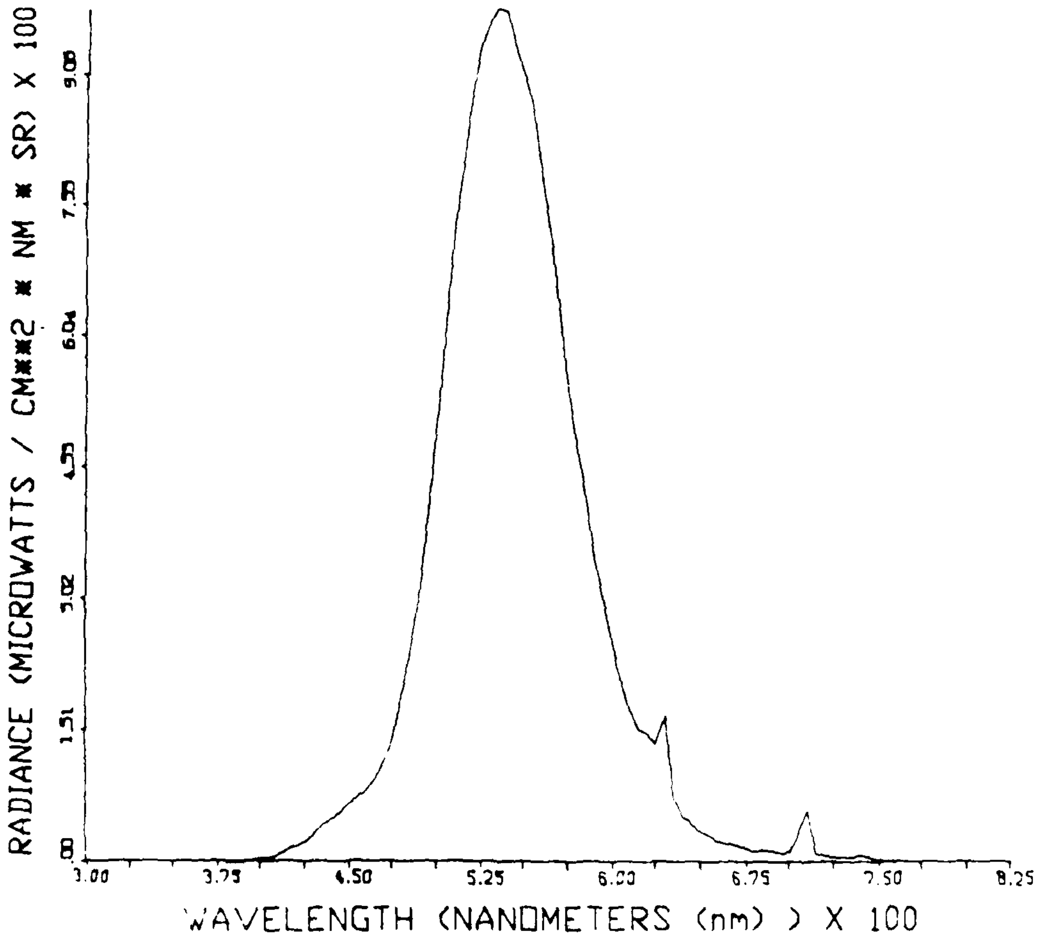

Figure 41. Measurement of Green Gun at 600 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

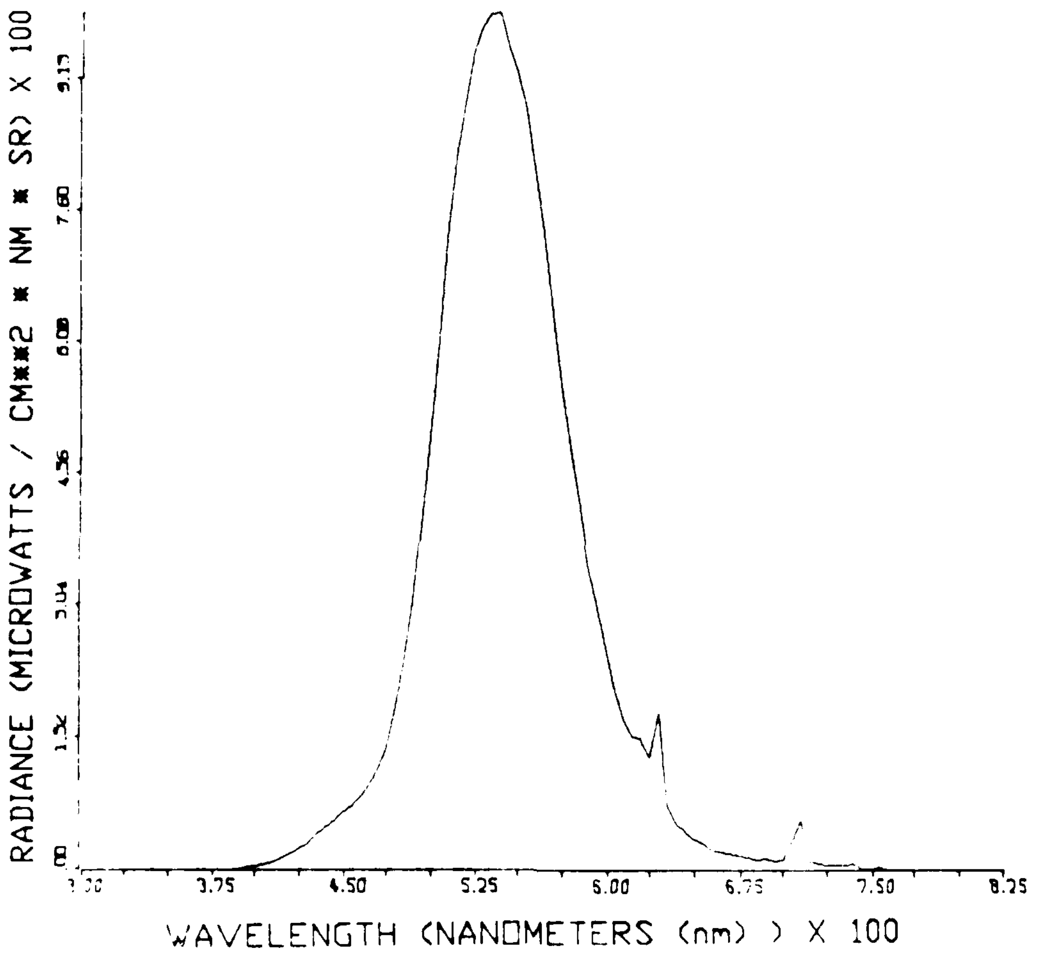

Figure 42. Measurement of Green Gun at 600 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

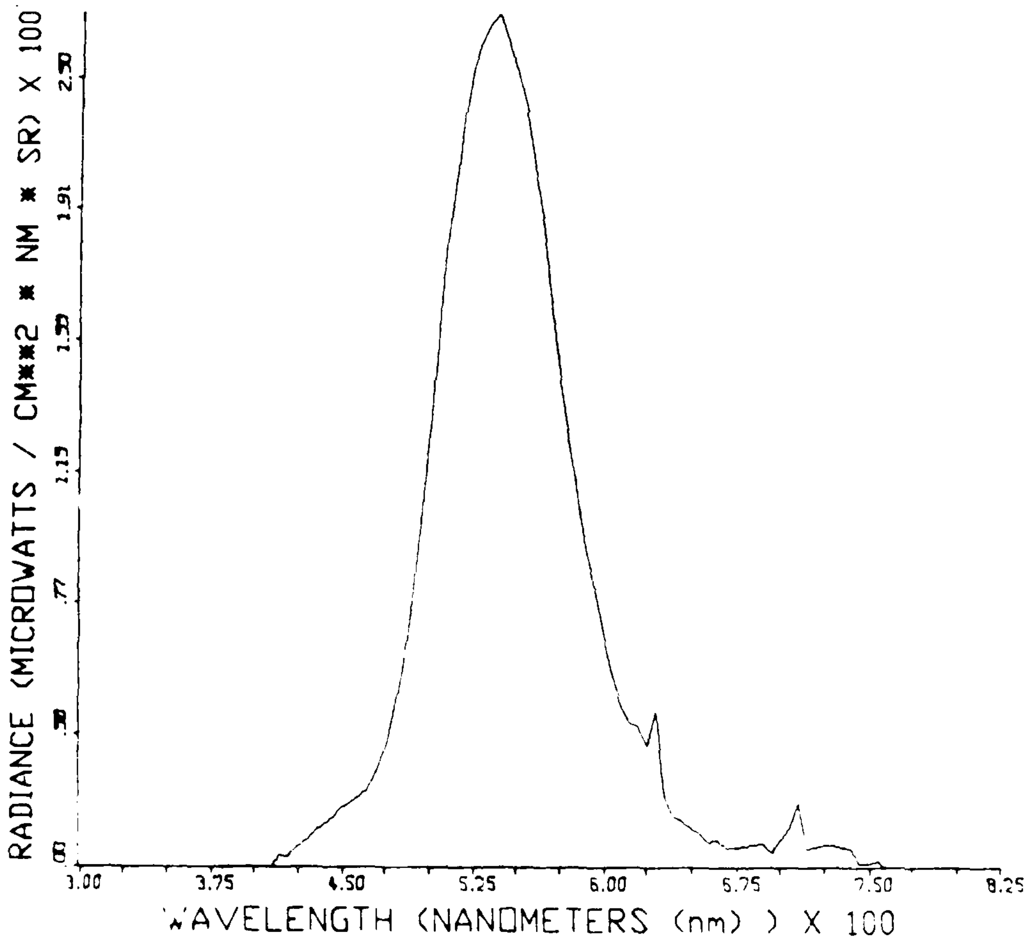

Figure 43. Measurement of Green Gun at 400 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

AD-A191 922 DESIGN AND TESTING OF A LUMINANCE AND CHROMINANCE 2/2
STABILIZATION SYSTEM FO..(U) VIRGINIA POLYTECHNIC INST
AND STATE UNIV BLACKSBURG HUMAN FAC.. W W FARLEY
UNCLASSIFIED JUL 87 VPI/HFL-86-1 AAMRL-TR-87-027 F/G 12/6 NL

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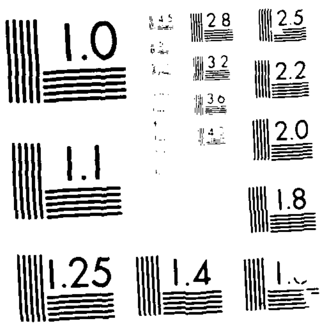


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

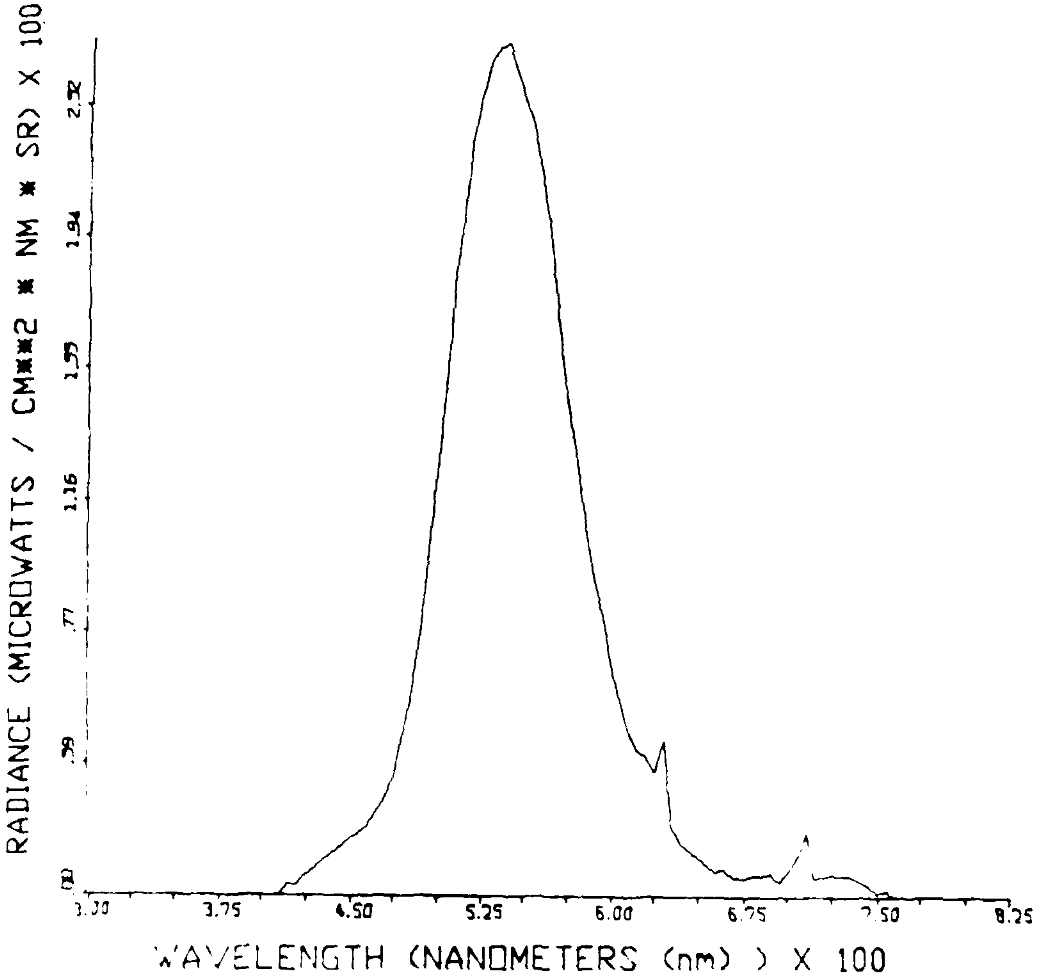


Figure 44. Measurement of Green Gun at 400 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

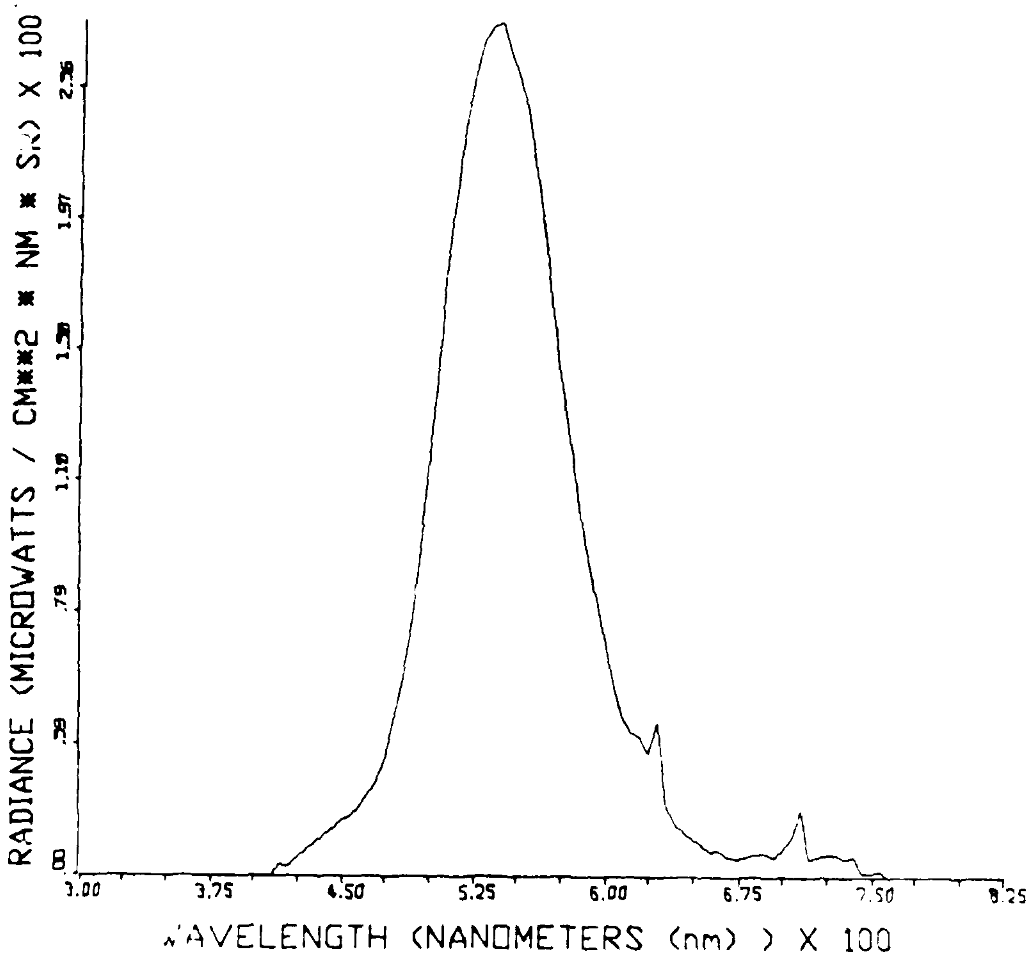


Figure 45. Measurement of Green Gun at 400 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

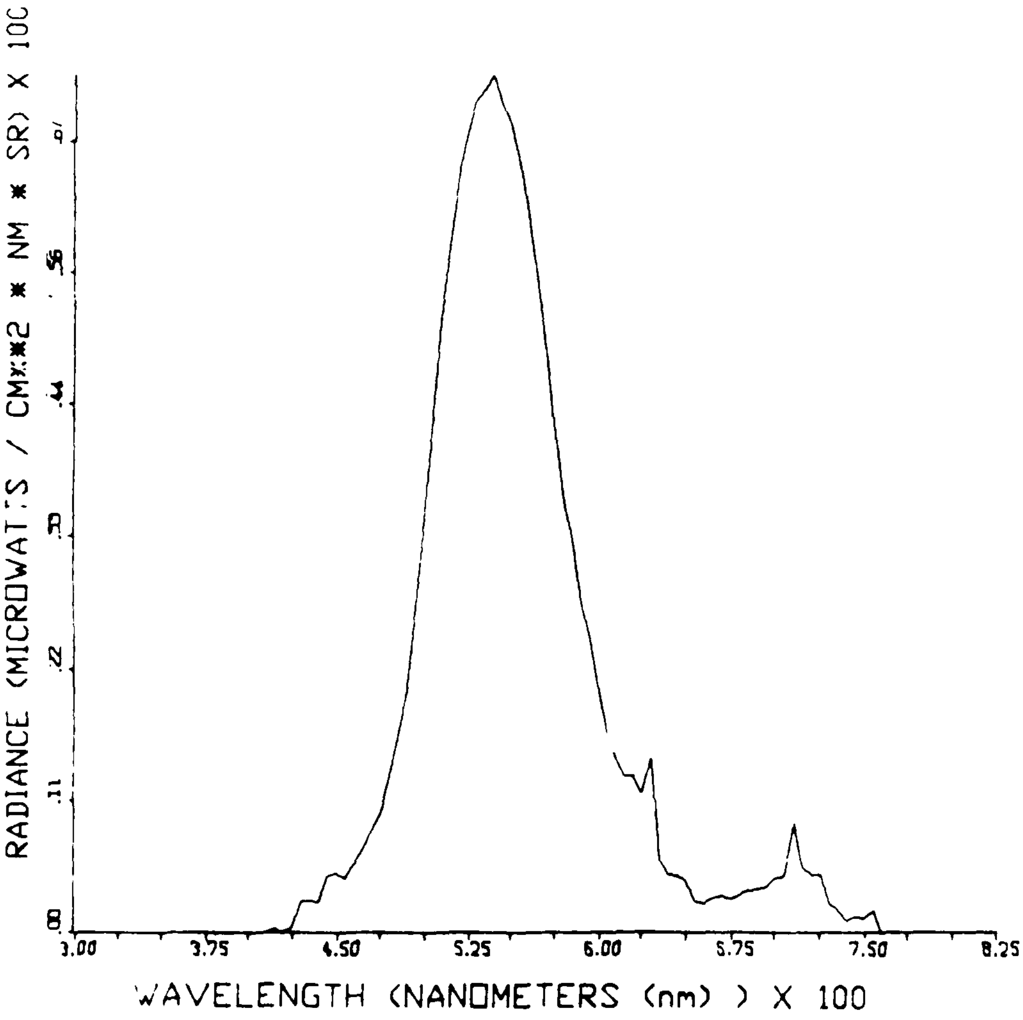


Figure 46. Measurement of Green Gun at 300 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

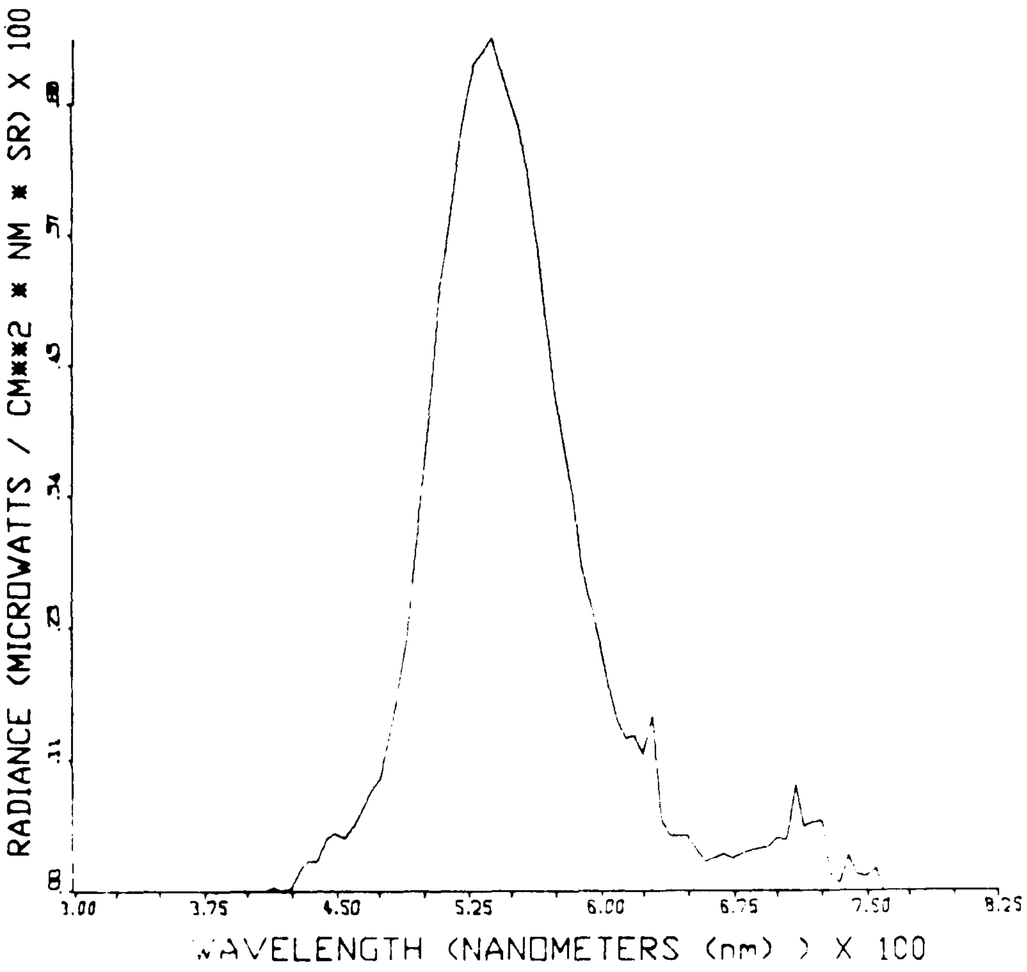


Figure 47. Measurement of Green Gun at 300 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

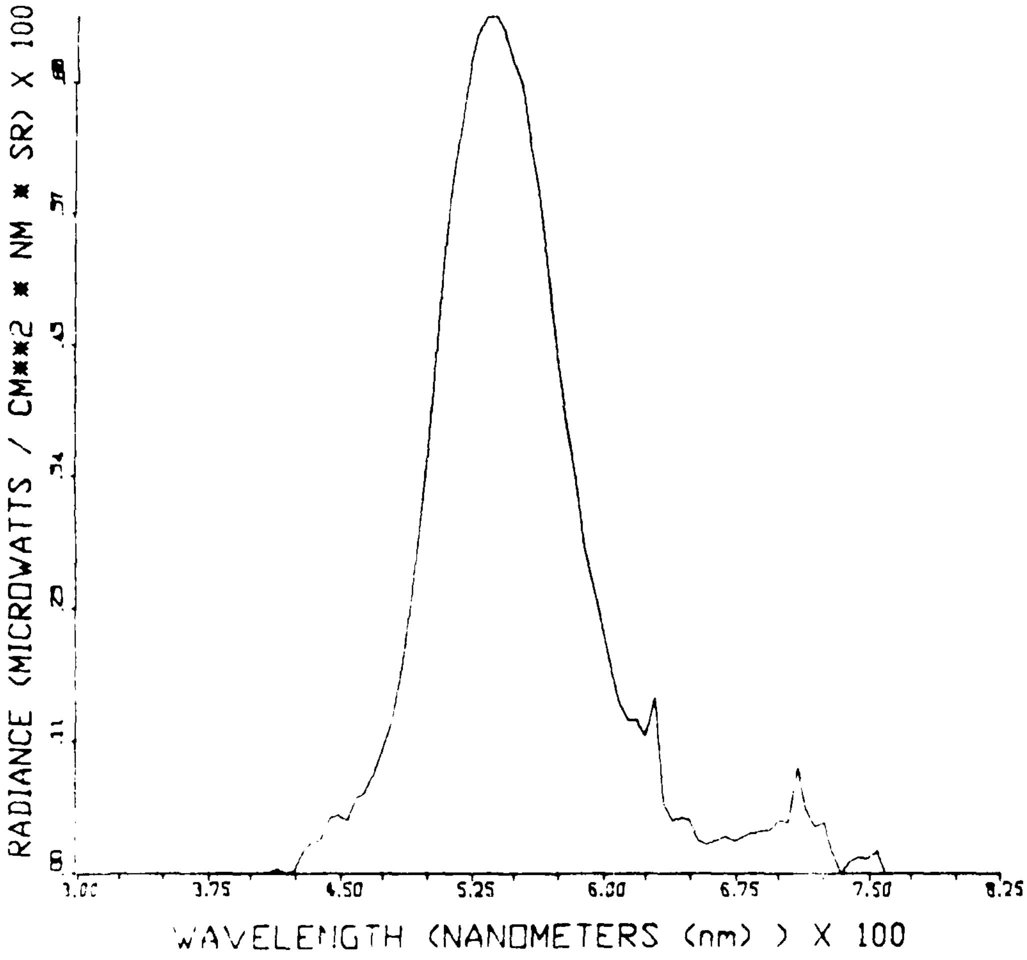


Figure 48. Measurement of Green Gun at 300 Bits for the Evaluation of Phosphor Stability as a Function of Intensity.

APPENDIX B

EXTERNAL DISPLAY SYSTEM PROBLEMS AND SOLUTIONS

One of the more important findings of this work is that the typical CRT color monitor is not as unstable as was originally thought. If large temporal changes are found, then one should look elsewhere for the problem. Several sources of temporal instability were found in this work. The better displays have good power supplies, but large power line fluctuations will challenge even the best supplies when such small display differences are important. It is recommended that a power line conditioner be used for research-quality CRT displays. The conditioner should also be used for the computer if possible.

Another issue encountered in this work is the ground loop problem between image generation and display. Ground loops are especially common when the image generator is run from one building power circuit and the display is run from another. In this situation, the grounds may be at a slightly different potential. This will result in a ground current flowing between the two grounds if they are connected. To minimize this problem in the Human Factors Engineering Laboratory, the power line controller and the displays are connected to the same circuit on the building power system. In general, it is best to have the image generator and display as close together as possible; however, this is not always practical when conducting human performance studies.

A problem with the use of our spectroradiometric measurement system was also encountered during this effort and some discussion might prove useful to other experimenters. The spectroradiometric measurement system used in the work is similar to many other systems in that the intensity of the light is measured by a photomultiplier tube (PMT). The response of a PMT and the radiometer to which it is connected is often quite fast, on the order of 1 to 10 microseconds. This means that the analog output of such a system can contain several peaks for each CRT display field as the beam passes under the measurement device. This signal intensity is converted via an ADC to a digital value. However, the ADC sampling of the probe is not usually synchronized with the movement of the display beam. This means that care must be taken that the light collecting system sees the same amount of light on each sample. Our solution to this problem in the Human Factors Engineering Laboratory system was to sample at 1000 Hz for 100 ms to assure that an integer number of fields (i.e., 6) would be seen.

There still exists the possibility of an interaction between the measurement system and the display because of the slow ADC sampling rate compared to the speed at which the beam moves under the light collection device. An electronic filter was used between the output of the radiometer and the ADC system to eliminate this problem. The time constant of the filter was set at 100 ms so that there is no possible interaction between the two systems.

In summary, no matter what system is used, care must be exercised in the measurement of the spectrum to assure that the difference one measures is due to the display and not to the measuring process itself.

APPENDIX C

DETAILED DESCRIPTION OF THE VERSION I FEEDBACK CONTROL SYSTEM

The Feedback Control System can be divided into three basic circuits: the Light Sampling Circuit, the Blanking Buffer Amplifier Circuit, and the Video Circuit. A block diagram of the Feedback Control System is shown in Figure 49. The Video Circuit is basically a video switch. It switches between the original video signal and the DC value provided by the Light Sampling Circuit during the blanking interval of the video signal. By changing the level of the video signal during the blanking interval, the video circuit modifies the black reference, thereby changing the offset of the display.

The Blanking Buffer Amplifier has as its input the video blanking signal, which is amplified and level shifted such that it will cause the Video Circuit to switch at the proper time. The Light Sampling Circuit uses a Silicon Detector placed at the reference area of the CRT and amplifying circuitry to provide a feedback voltage to be used by the Video Circuit. This voltage is used by the video circuit to determine the proper change in the video signal level during the blanking interval. As outlined earlier, the change in the blanking level causes the black reference to change. The change in the black reference changes the offset value. This change tends to cause the reference area of the CRT to move back to the original intensity.

The Light Sampling Circuit will be considered in detail first. Since all three color channels are the same, only one is described here. Figure 50 shows the light sampling circuit. The Silicon Detector is connected to the inverting input of operational amplifier U1. There is no series input resistor, which means the detector sees the virtual ground of the operational amplifier in the feedback configuration.

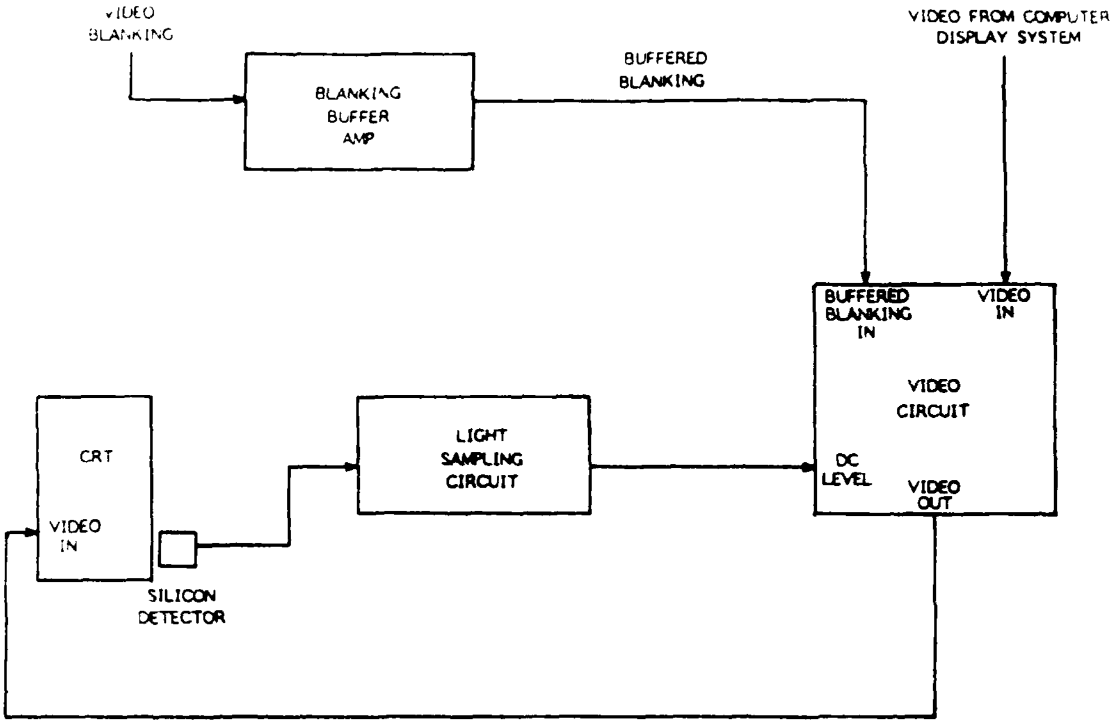
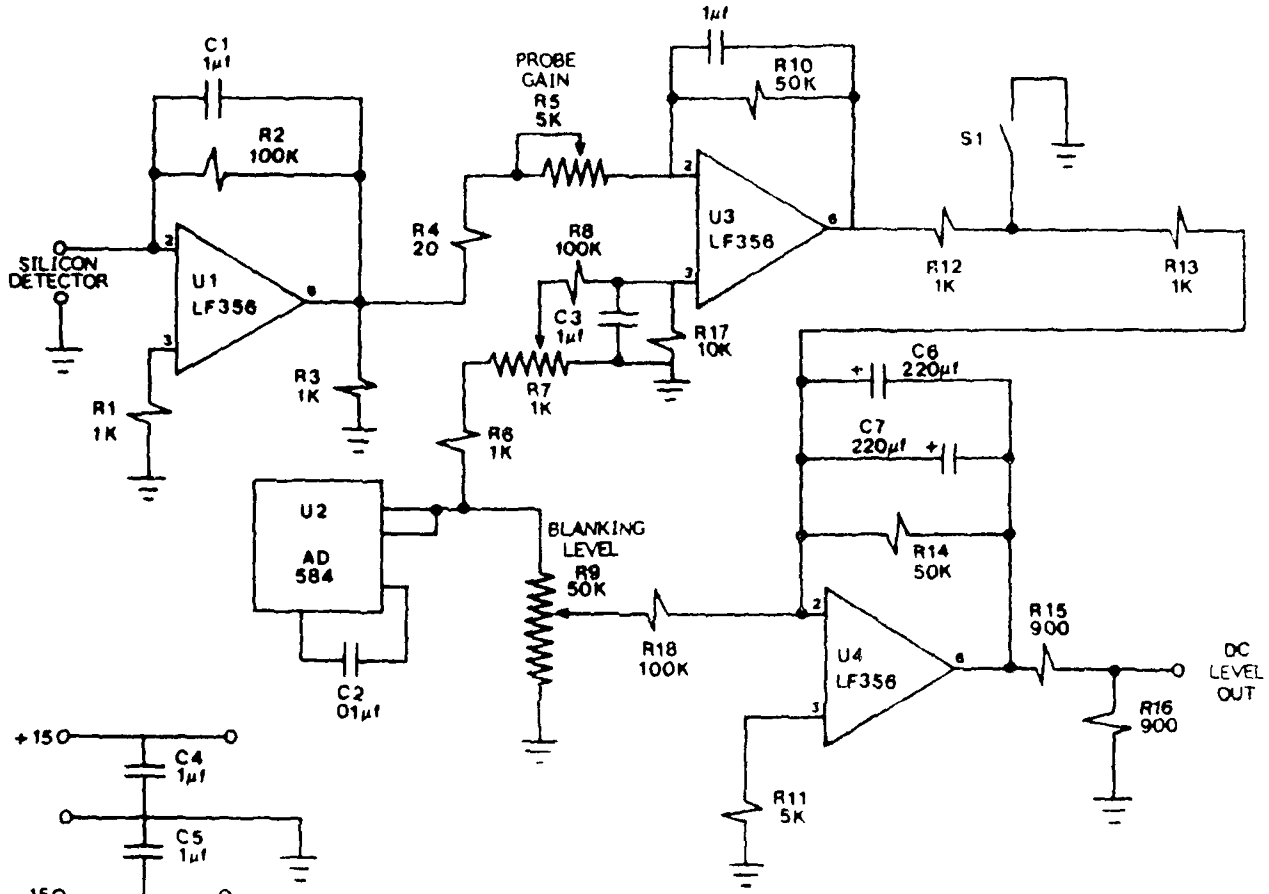


Figure 42. Block Diagram of Feedback Control System.



NOTE: PIN 7 CONNECTED TO +15 VOLTS AND PIN 4 CONNECTED TO -15 VOLTS OF ALL LF356

Figure 50. Light Sampling Circuit.

This configuration is used so that the Silcon Detector, which is a photodiode, may be operated as a photovoltaic detector. This is done because there is no need for the high-frequency response of a photoconductive device (see EG&G Application Note D3011C-8) and the photovoltaic mode has less noise.

The Silicon Detector sees a circular portion of the CRT screen that is approximately 0.25 inch in diameter, which results in the electron beam passing under the detector about six times every 16.667 ms. This geometry results in a set of six pulses, each approximately 50 microseconds apart, every 16.667 ms.

This timing presents a problem for the feedback system. The resulting signal from the silicon detector must be filtered to eliminate the transient nature of the signal. The filtering, however, averages the signal, which results in a signal of about 5 mV for a display value of 50 nits. This signal is quite small for a DC voltage and is the limiting factor of the system.

Operational amplifier U1 provides some filtering as well as serving as the input buffer for the silicon detector. Operational amplifier U3 serves as an additional filter for the light intensity signal as well as providing an adjustable gain. Operational Amplifier U3 also is used as a summing amplifier. The amplified signal from the detector is summed with a reference voltage from U2 via the voltage divider provided by R6 and R7.

The voltage reference is an Analog Devices AD584 which has a very stable output voltage with time and temperature. The two signals, light intensity and voltage reference, are adjusted during the initial set-up to give a value of zero volts at the output of U3. By causing the output of U3 to be zero initially, any change in the intensity of the signal will result directly in an error signal. This is a very desirable situation in a Feedback Control System because an error voltage is not needed for the system to operate. If the system is designed such that an error signal is always needed, then the error signal cannot be independently controlled, which limits the performance of the system.

The error signal from U3 goes to operational amplifier U4, where it is further amplified and filtered in U4. The initial value for the blanking reference voltage is applied to the summing input of U4 from the ultra-stable voltage source U2 via R9 and R18. The variable resistor R9 is used to adjust the blanking level during set-up.

The output voltage of U4 is divided by R15 and R16 and becomes the DC LEVEL OUT. The voltage divider provided by R15 and R16 was placed in the circuit to allow for additional filtering of the output of the DC LEVEL, if needed, thus preventing an additional printed circuit board fabrication cycle. No such filtering was needed, however.

The Video Circuit is shown in Figure 51. It can be divided into three parts: the input/output buffers, the video switch, and the power supply filters. At the center of the video circuit and the feedback control system itself is the video switch, the MC1445. This device has the capability of switching from one video source to another in a very short time, 20 ns. The MC1445 is used to switch from the original input signal, which is applied to pins 4 and 5, to the DC LEVEL supplied by the light sampling circuit, which is applied to pins 3 and 2. This switching is controlled by the BUFFERED BLANKING signal applied to pin 1 of the MC1445. The BUFFERED BLANKING signal will cause the MC1445 to pass the original video signal at pins 4 and 5 during the video interval shown previously in Figure 9.

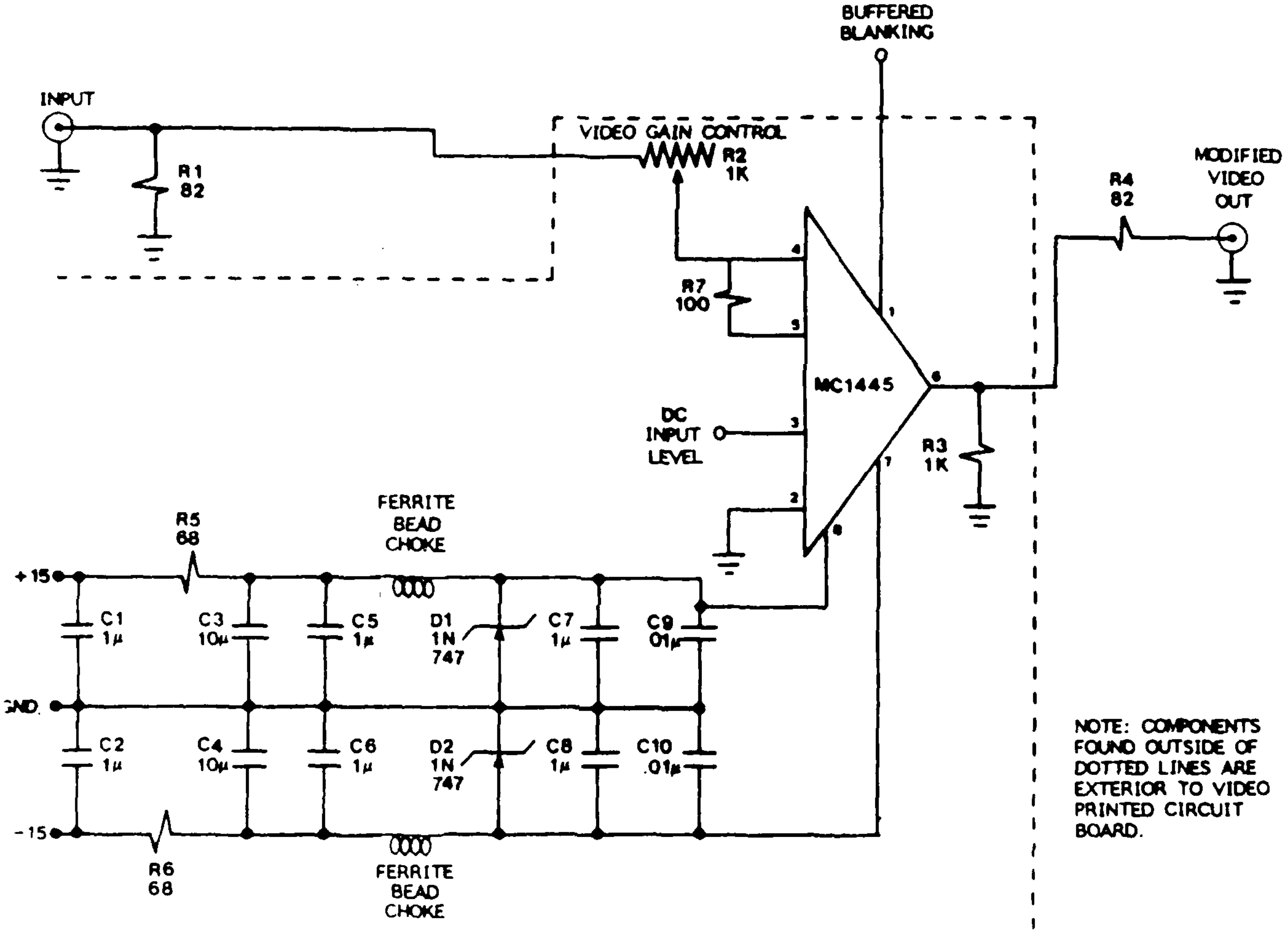


Figure 51. Video Circuit.

During the blanking interval the BUFFERED BLANKING signal will cause the MC1445 to pass the DC LEVEL signal and thus effect the desired feedback control. The resistor R1 serves as the input buffer by matching the 75-ohm video transmission line and the Feedback Control System's video input. The resistor R4 serves the same function for the video output of the Feedback Control System.

The power supply filter and conditioning circuit serve two functions. The filter section of the circuit isolates the video signal from any noise on the power supply circuit. The voltage conditioning circuit drops the +15 volt and -15 volt power busses to +9 volts and -9 volts. The filter might be described as a "belt-and-suspenders" design due to its conservative nature. However, it has been our experience that power supply spikes that are in sync with the 60-Hz power line frequency can be seen on the display even when they are less than a millivolt.

Since the +15 volt and the -15 volt filters are identical, only the +15 volt circuit will be described. Capacitor C1 provides the initial filtering of the power line. Resistor R5 provides for the voltage drop of 6 volts needed to reduce the 15 volts to the 9 volts required by the MC1445. Capacitors C3 and C5 give an additional low impedance path to ground for any noise, ripple, or transients. The use of two capacitors in parallel allows for a much wider filter frequency band than could be achieved by a single capacitor, especially due to the inductive nature of electrolytic capacitors at higher frequencies. The ferrite bead choke serves as a high impedance to the high frequency components of noise spikes.

The diode D1 is a 1N747, which is a 9.1 volt Zener diode used to provide the MC1445 with the necessary 9 volt power supply voltage. The diode conducts current sufficient to maintain

9.1 volts across itself with the voltage difference between the 9.1 volts and the 15-volt power supply dropped across resistor R5.

Capacitors C7 and C9 provide filtering for the very high frequency components of any noise spike that might be on the power line. This filtering system has worked very well in the video circuit and has become a standard for our video circuits.

The Blanking Buffer Amplifier is shown in Figure 52. The system Blanking signal is applied to the non-inverting input of the Operational Amplifier U1 via resistor R5. Resistor R6 is used to match the 75-ohm transmission line to the Blanking Buffer Amplifier. Resistor R4 is selected to provide a gain of two to assure that the MC1445 video switch is turned completely on. The resistor R1 provides a variable DC voltage input to U1 via R2. Resistor R1 is adjusted such that the output value of the Blanking Buffer Amplifier is at zero volts. If it is not at zero volts, the MC1445 video switch will not turn completely off. During setup, the voltage is usually set to a slightly negative value to assure good turn off.

The first thing that must be done before the Feedback Control System can be used is that the adjustments must be set for proper system operation. This procedure is not very complicated if done in the proper order. The following procedure should be followed for each color channel. No special color order is required.

The Computer Display System should be programmed such that there are red, green, and blue reference color areas on the CRT. In our system, the reference areas were at the bottom of the display and approximately 3 inches by 2 inches. Care should be taken when reducing the size of the reference area

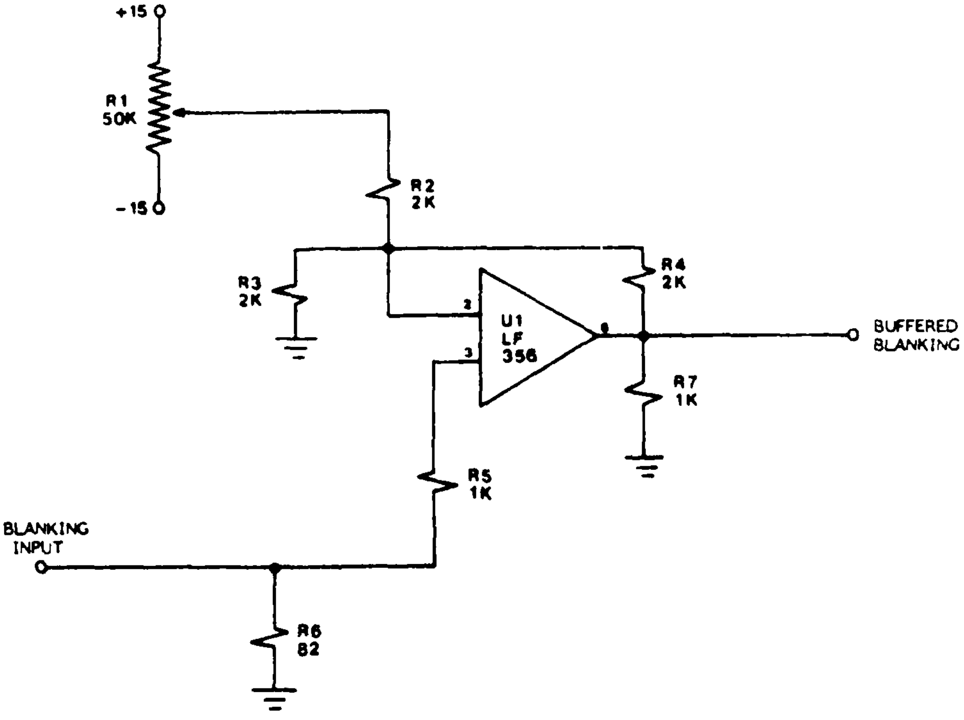


Figure 52. Blanking Buffer Amplifier.

to assure that no stray light enters the detector. Some type of apparatus is needed to hold the detectors in the correct position. The color channel that is being set up should have its video output looped through a scope with at least 50-MHz bandwidth.

The Video Circuit is set up first. Switch S1 on the Light Sampling Circuit is closed, thus opening the feedback path. At this point, it is helpful to have the Computer Display System display an 8 or 10 step gray scale of vertical bars. The output video amplitude should be adjusted, via R2 on the Video Circuit, to give a uniform gray step scale. Care should be taken to adjust R2 so that the video is not greater than 600 mV. Setting the output video at a higher level will cause the MC1445 to be nonlinear and overheat. One need not be concerned about the blanking interval at this time because it will be adjusted during the Light Sampling Circuit set-up.

The Light Sampling Circuit is set up in the following manner. The Computer Display System is left with the gray scale display used in setting up the Video Circuit. Switch S1 is left in the closed position leaving the feedback path open. The BLANKING LEVEL adjustment at R9 is adjusted to cause the video signal to have a shape as close to the original video shape as possible. With our image processor, the blanking interval was at the same level as the black bar of the gray scale. Therefore, the output of the Feedback Control System was set to give a zero volt level during the blanking interval. It was found helpful in our system to have the first bar of the gray scale a black bar because it made matching the two parts of the video signal easier.

The Computer Display System is then made to display the reference areas. The PROBE GAIN, R5, is set for the desired closed-loop gain. In our system, this was an interactive process. The adjustments were made and the system performance was checked. This was repeated until the desired point was reached. The trade-offs here may be found in great detail in any text on control theory. In summary, it may be said that increasing the loop gain reduces the tracking error at the expense of instability and oscillations.

In the system originally delivered to the Air Force, the PROBE GAIN was set to give the smallest tracking error possible with a small amount of overshoot and oscillation; that is, the system is slightly underdamped. After the PROBE GAIN is set, the output of U3 is made to be zero volts by adjusting R7. Switch S1 is then opened and any change in the light on the reference area of the display will be reflected as an error voltage at the output of U3. This error voltage is then summed with the original blanking level, causing a change in the DC LEVEL OUT. This change in the DC LEVEL OUT causes the video circuit to modify the blanking interval level, which causes the reference area of the display to move back to the desired intensity.

FEEDBACK CONTROL SYSTEM PARTS LIST

VIDEO CIRCUIT

Resistors

R1	82 ohm 500 mW	Allen-Bradley, TRW, Ohmite	$0.04
R2	1k ohm 10/t potentiometer	Allen-Bradley, Bourns	3.88
R3	1k ohm 250 mW	Allen-Bradley, TRW, Ohmite	0.04
R4	82 ohm 500 mW	same	0.04
R5	68 ohm 500 mW	same	0.04
R6	68 ohm 500 mW	same	0.04
R7	100 ohm 250 mW	same	0.04

Capacitors

C1	1 microfarade 25 volt	CDE, Central Lab	1.88
C2	1 microfarade 25 volt	same	1.88
C3	10 microfarade 25 volt	Mallory, CDE, Sprague	1.70
C4	10 microfarade 25 volt	same	1.70
C5	1 microfarade 25 volt	CDE, Central Lab	1.88
C6	1 microfarade 25 volt	same	1.88
C7	1 microfarade 25 volt	same	1.88
C8	1 microfarade 25 volt	same	1.88
C9	.01 microfarade 25 volt	same	0.20
C10	.01 microfarade 25 volt	same	0.20

Integrated Circuits

U1 MC1445 Video Switch Motorola	3.01
Printed Circuit Board, VPI & SU	100.00
TOTAL COST OF EACH VIDEO CIRCUIT BOARD	**122.21**

LIGHT SAMPLING CIRCUIT

Resistors

R1	1K ohm 400 mW	Allen-Bradley, TRW, Ohmite	0.04
R2	100K ohm 500 mW	same	0.04
R3	1K ohm 500 mW	same	0.04
R4	20 ohm 500 mW	same	0.04
R5	5K ohm potentiometer	Allen-Bradley, Bourns	3.88
R6	1K ohm 500 mW	Allen-Bradley, TRW, Ohmite	0.04
R7	1K ohm potentiometer	Allen-Bradley, Bourns	3.88
R8	1K ohm 500 mW	Allen-Bradley, TRW, Ohmite	0.04
R9	50K ohm potentiometer	Allen-Bradley, Bourns	3.88
R10	50K ohm 500 mW	Allen-Bradley, TRW, Ohmite	0.04
R11	5K ohm 500 mW	same	0.04
R12	1K ohm 500 mW	same	0.04
R13	1K ohm 500 mW	same	0.04
R14	50K ohm 500 mW	same	0.04
R15	900 ohm 500 mW	same	0.04
R16	900 ohm 500 mW	same	0.04
R17	10K ohm 500 mW	same	0.04

Capacitors

C1	1 microfarade 25 volts	CDE, Central Lab	1.88
C2	0.01 microfarade 25 volts	same	0.20
C3	1 microfarade 25 volts	same	1.88
C4	0.1 microfarade 25 volts	same	1.88
C5	1 microfarade 25 volts	same	1.88
C6	220 microfarade 25 volts	Mallory, CDE, Sprague	1.70
C7	220 microfarade 25 volts	same	1.70

Integrated Circuits

U1	LF356 Motorola	1.60
U2	AD584 Analog Devices	21.80
U3	LF356 Motorola	1.60
U4	LF356 Motorola	1.60
Printed Circuit Board	VPI & SU	100.00

TOTAL COST OF EACH LIGHT SAMPLING CIRCUIT	**149.92**

BLANKING BUFFER AMPLIFIER CIRCUIT

Resistors

R1	50K potentiometer	Allen-Bradley, Bourns	3.88
R2	2K ohm 500 mW	Allen-Bradley, TRW, Ohmite	0.04
R3	2K ohm 500 mW	same	0.04
R4	2K ohm 500 mW	same	0.04
R5	1K ohm 500 mW	same	0.04
R6	82 ohm 500 mW	same	0.04
R7	1K ohm 500 mW	same	0.04

Integrated Circuits

U1	LF356 Motorola	0.04

TOTAL COST OF BLANKING BUFFER AMPLIFIER CIRCUIT	5.72
TOTAL COST PER CHANNEL	277.85
TOTAL COST OF THREE-CHANNEL FEEDBACK CONTROL SYSTEM	833.55

APPENDIX D

INTRODUCTION

When the first version of the stabilization system was delivered to the Air Force it was clear that their system would be degraded without a full 1.0 volt video signal to the display. We requested additional time to modify the Video Circuit to give the increased drive. The Air Force agreed to a no cost extension of the project to allow for the redesign and construction of the Video Circuit.

During this extension an idea for a better Light-Sampling Circuit was conceived. This new circuit was breadboarded and tested with the old Video Circuit. The preliminary test indicated that the new circuit was superior to the old circuit. While the Video Circuit boards were being fabricated, three wire-wrap boards with the new Light-Sampling Circuit design were made.

The basic operation of Version 2 and Version 1 are the same. The error signal taken from the reference area of the display is used to set the black level of the video signal. If the reference area changes its intensity, then the stabilization system changes the black level to compensate for the change. For a more detailed discussion of the feedback system see Appendix C.

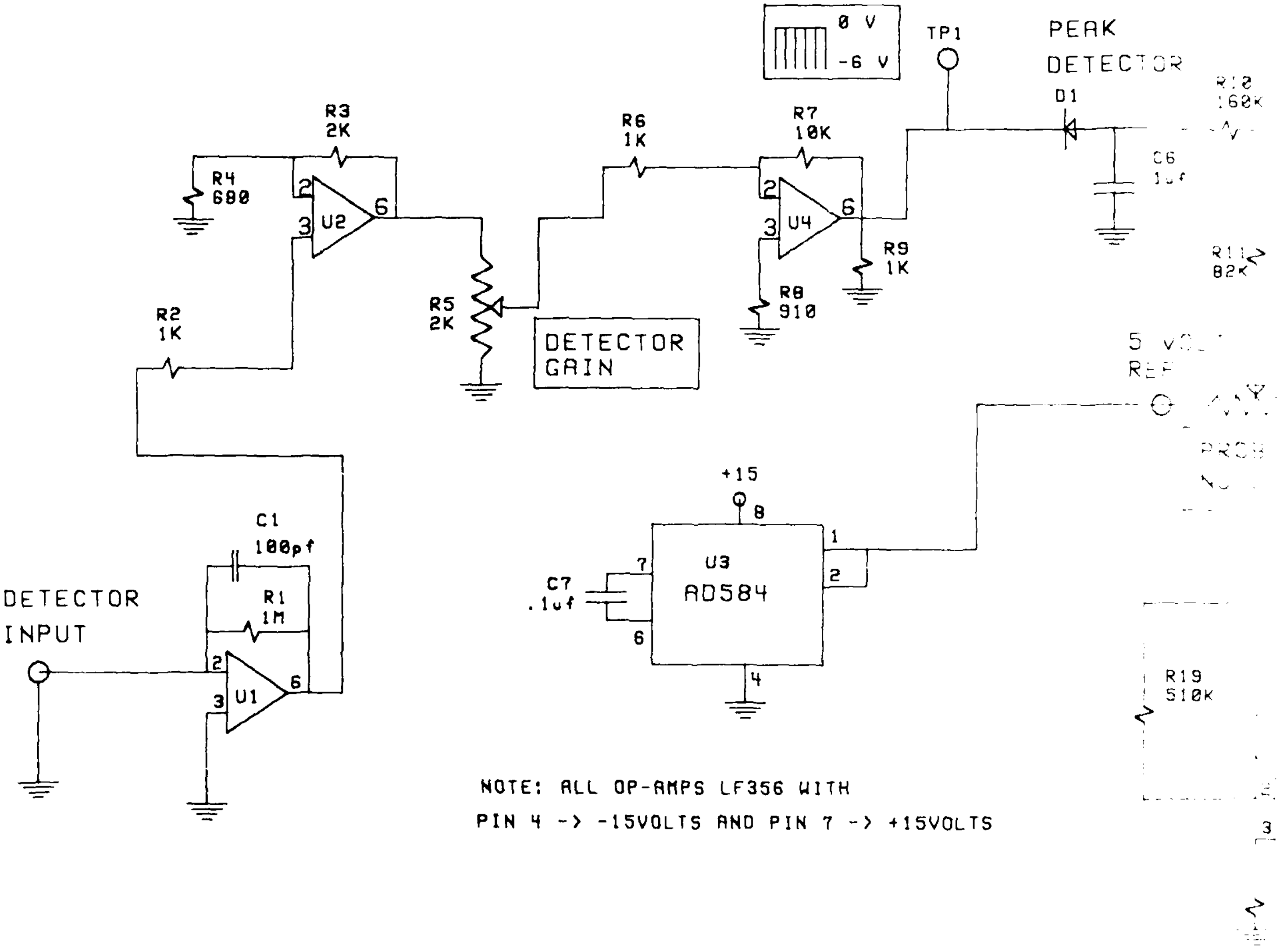
VERSION 1 LIGHT SAMPLING CIRCUIT

It was noted in the discussion of the Version 1 Light-Sampling Circuit design that one of the problems resulted from the fact that the detector would see only four to eight lines of the display field. This caused the output of the silicon detector to be four to eight pulses of current each 16.6 milliseconds. The pulses were of such a short duration, 1.25 microseconds, and occurred only every 16.6 milliseconds, the mean or DC level of the signal was on the order of 5 to 10 millivolts. This low signal level meant that the noise of the system was of the same magnitude as the signal. Since the circuit was DC coupled the drift of the amplifiers was also a concern. Thus, the small detector signal compromised the feedback design by requiring large amplifier gains, large filtering, and a high intensity value for the reference areas.

The detector design used in Version 1 is similar to detectors that would be used to measure intensity or, if provided with the proper filter, luminance. Since the detector must measure light that is constant, the detector must be DC coupled. The detectors used in the stabilization system will only look at the CRT screen and therefore will only see a time varying signal. This means that the detector amplifier may be AC coupled, thus reducing the effect of drift and noise. By using the Version 2 detector circuit the reference areas may be more than an order of magnitude lower than the Version 1 design. This greatly increases the potential range of display stimuli and simplifies display set up.

VERSION 2 LIGHT SAMPLING CIRCUIT

Figure 53 shows the circuit diagram for the Light Sampling Circuit used in Version 2 of the Stability System. The output of the silicon detector is connected to the inverting input of amplifier U1. No series resistor is used which causes the detector to see a virtual ground at U1 because of the negative feedback configuration of the amplifier. This configuration is used so that the silicon detector, which is a photodiode, may be operated as a photovoltaic detector. This is done because there is no need for the high-frequency response of a photoconductive device and the photovoltaic mode has less noise (see EG&G Application Note D3011c-8). Resistor R1 provides the negative feedback path for amplifier



NOTE: ALL OP-AMPS LF356 WITH
PIN 4 -> -15VOLTS AND PIN 7 -> +15VOLTS

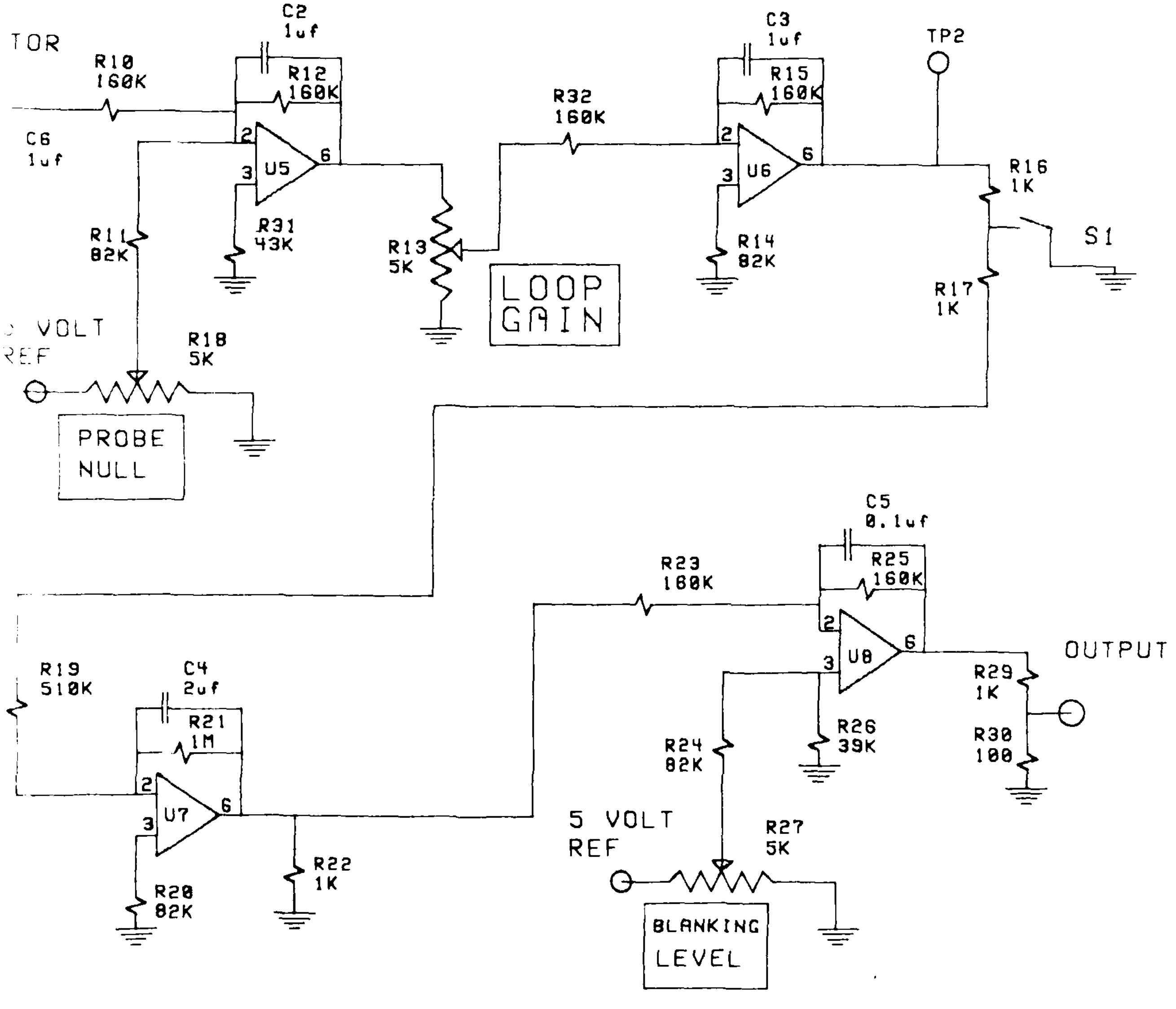


FIGURE 53 - VERSION 2 LIGHT SAMPLING CIRCUIT

U1. The current to voltage gain is set by R1 which is one of the more critical components of the system. Therefore, R1 is a precision (0.1%) resistor with a low change in resistance with temperature. Capacitor C1 reduces the chance of U1 breaking into oscillation . The output of U1 is sent to the amplifier U2 which provides for a gain of two. The output of U2 is sent to resistor R5 which is used to adjust the detector gain. This provides for the system operating over a wide range of monitor setup conditions. The signal then is sent to amplifier U4 which has a gain of 10. The diagram shown above U4 in Figure 53 shows the signal waveform as found at its output which is TP1. Note that the signal is a series of pulses 16.66 milliseconds apart. The individual pulses of the beam passing under the detector are filtered by C1 and the low bandwidth nature of the LF356 amplifiers.

The signal next is sent to the peak detector which is comprised of diode D1 and capacitor C6. The peak detector is the major difference between the Version 1 Light Sampling Circuit and the Version 2 Light Sampling Circuit. Rather than simply filtering the signal diode, D1 conducts during the negative going portion of the detector signal thus charging capacitor C6. When the signal starts to go in a positive direction D1 stops conducting and C6 starts to discharge through resistor R10. The time constant of C6 and R10 is 160 milliseconds, which is an order of magnitude greater than the pulse rate of the detector signal at TP1. This means that the voltage at C6 stays at approximately -6 volts with a small amount of ripple. This relatively large signal makes the effect of amplifier noise and drift less of a factor in the circuit performance. The large signal also means that the intensity of the reference area may be lowered.

The peak detected signal is then filtered by U5. Amplifier U5 also provides for the zeroing of the detector voltage via the application of the reference voltage which is summed with the detector voltage at U5. Resistor R18 provides the adjustable reference voltage and resistor R11 provides the series input resistor to the summing junction of U5. The output of U5 is sent to resistor R13 which provides for the adjustment of the feedback loop's gain by voltage dividing the U3 signal output before it is sent to U6. Amplifier U6 filters the signal ripple. The output of U6 goes to two resistors R16 and R17. The point between these two resistors is connected to switch S1 which is grounded. This arrangement is to allow for the feedback loop to be opened via the closing of S1. This provides a way of adjusting the stability system which will be described later.

The signal is sent to U7 next. Amplifier/filter U7 provides a gain of two and U7's time constant sets the feedback loop's time constant. This is because the other filters are primarily for the filtering of the ripple voltage found on the detected signal. The time constant at U7 is 2 seconds and is so much longer than the other filter time constants that it sets the system time constant. If any changes are to be made to the system time constant they should be made at U7. It should be noted that any change in system time constant should be accompanied by a change in the system gain. For example, if the system time constant was to be changed to 4 seconds from 2 seconds then the system gain should be doubled. This is most easily accompanied by changing the value of R19. The signal from U7 is sent to U8 where it is summed with a reference voltage to adjust the system's blank level. This adjustment is realized via resistors R27 and R24. The output of U8 is divided by a factor of 10 via resistors R29 and R30. This output signal is sent to Channel 1 of the video switch where it is switched on during the blanking interval to provide the black level reference of the video signal.

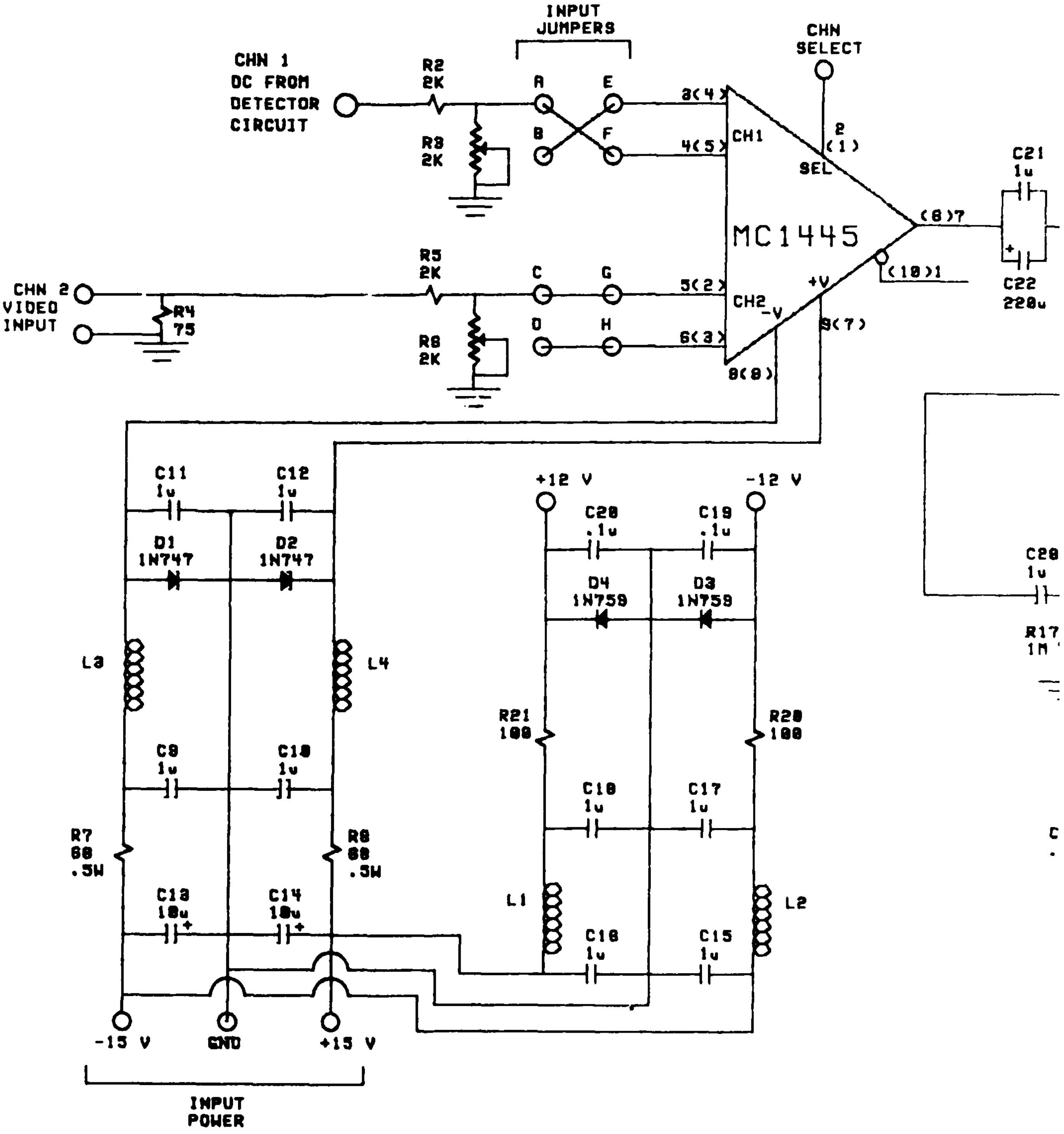
VERSION 2 VIDEO CIRCUIT

The Version 2 Video Circuit is basically the same as the Version 1 circuit. The major difference is that the Version 2 circuit will drive a 75 or 50 ohm transmission line at a level of 2.0 volts peak to peak whereas the Version 1 circuit will drive a 75 ohm transmission line at .7 volt peak to peak.

Figure 54 shows the Version 2 Video Circuit. It consists of four basic parts: the switching circuit, the buffer amplifier, the line driver, and the power filter/ regulator. The switching circuit consists of a MC1445 video integrated circuit. This integrated circuit receives two video signals on input Channel 1 and Channel 2. The channel which arrives at the output is controlled by the channel select input found at Pin 1. The video from the image display system is presented to input Channel 2 via resistors R5 and R6. The DC voltage from the detector board is presented to input Channel 1 via resistors R2 and R3. The channel select is driven by the Blanking Buffer Amplifier as described in Appendix C.

The buffer amplifier consists of transistors Q1 and Q2 along with their associated components. The buffer amplifier is connected to the video switch via capacitors C21 and C22, which provide for DC isolation between the buffer amplifier and the MC1445 video switch. The buffer amplifier is needed because the MC1445 output distorts when driven much above 700 millivolts. The buffer amplifier provides a gain of approximately 4. The emitter of Q2 has a peaking circuit to help to flatten the frequency response in the 20 MHz range.

A LH0033CG integrated circuit line driver was chosen to provide for the output. The LH0033 has a high input impedance and good output drive capacity. The output of the LH0033 drives R18 and R19. As can be seen from Figure 54 the


INPUT JUMPERS
CHN SELECT
CHN 1 DC FROM DETECTOR CIRCUIT
R2 2K
R3 2K
A
B
E
F
3(4)
4(5)
CH1
2 (1)
SEL
MC1445
(8)7
(10)1
C21 1u
C22 220u
CHN 2 VIDEO INPUT
R4 75
R5 2K
R6 2K
C
D
G
H
5(2)
6(3)
CH2
-V
+V
8(8)
9(7)
C11 1u
C12 1u
D1 1N747
D2 1N747
L3
L4
C9 1u
C10 1u
R7 68 .5W
R8 68 .5W
C13 10u
C14 10u
-15 V
GND
+15 V
INPUT POWER
+12 V
-12 V
C20 .1u
C19 .1u
D4 1N759
D3 1N759
R21 100
R20 100
C18 1u
C17 1u
L1
L2
C16 1u
C15 1u
C20 1u
R17 1M
C

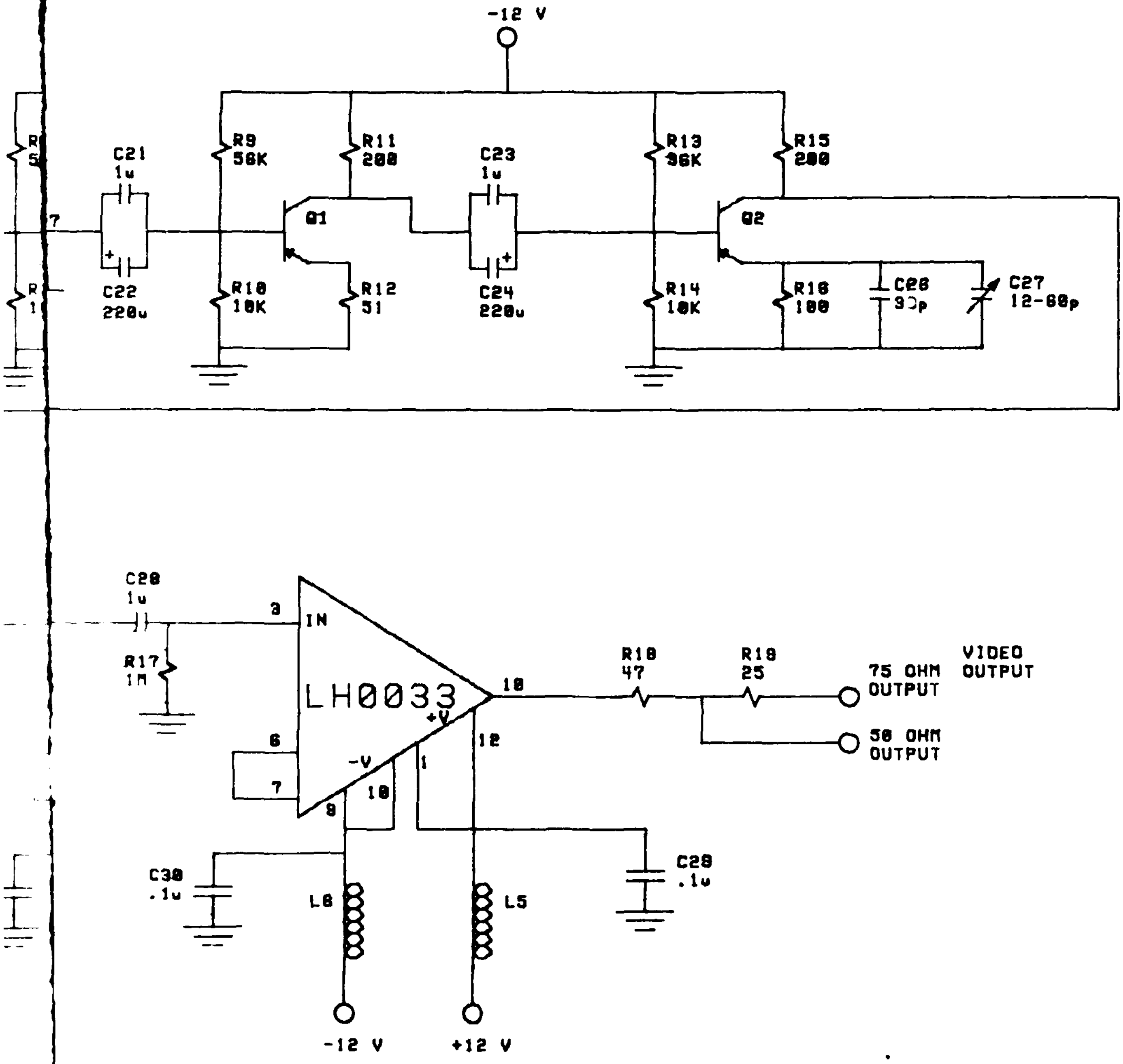


FIGURE 34 - VERSION 2 VIDEO CIRCUIT

connection between R18 and R19 is brought out to provide a 50 ohm output drive. The 75 ohm output is provided by the additional series resistor R19. The video switch is configured for 75 ohm output, but if a 50 ohm output is required, the output cable need only be moved to the 50 ohm pin. It should be noted that the circuit should not be used to drive 50 and 75 ohm lines simultaneously.

The power filter/regulator provides the proper voltages for the transistors MC1445 and the LH0033. This curcuit also provides for isolation of the video circuitry from the system power. It is essential that the video circuitry be isolated from all external noise sources, especially sources that are in sync with the power line frequency. This is because the display field rate is at or very close to the power frequency of 60 Hz. This results in the synchronized noise being stationary on the display screen. The stationary noise is easy for the human to observe because of the integrating nature of the visual system. A positive and negative 9.2 volts is provided for the MC1445. A negative 12 volts is provided for the transistors Q1 and Q2. A positive and negative 12 volts is provided for the LH0033.

Since the positive and negative filter/regulator circuits are identical, only the positive filter/regulation will be described. The positive 15 volts is initially filtered by capacitors C14 and C16. The two capacitors are used in parallel to provide a low impedance path to ground for the noise signals over a wider range of frequencies than could be realized by a single capacitor. Resistor R8 has two functions. First, it provides for the DC voltage drop needed by the voltage regulation circuit which will be described later. It also provides a voltage drop for any noise signal. The capacitor C10 enhances this effect by providing a low impedance path to ground for the time varying noise signal. Inductor L4 is a ferromagnetic balun device which provides a high impedance for the time varying noise signal. With capacitor C12 providing another low impedance path to ground for the noise, the filter is complete and has extremely good noise rejection. Diode D2 is a reference diode with a reference voltage of 9.1 volts. If the voltage rises above 9.1 volts the diode starts to conduct and the excess voltage is dropped across resistor R8.

The 15 volt power supply voltage is also provided to inductor L1 which is identical to L4 and serves the same function of providing a high impedance to the time varying noise signal. Capacitor C18 provides a low impedance path to ground for the noise signal and enhances the effect of L1. Resistor R21 provides the series impedance for the 12 volt regulator and for the noise filter. Capacitor C20 provides another low impedance path to ground for the noise signal, thus enhancing the effect of R21. Diode D4 is a reference diode with a reference voltage of 12 volts. When the voltage at D4 rises above the 12 volts the diode conducts and the excess voltage is dropped across the series resistor R21.

Alignment of the Version 2 Stabilization System

The alignment of the stabilization system may be divided into two parts, the video alignment and the feedback alignment. The video alignment must be completed before the feedback alignment may be started. Since the three channels are identical only one will be described here. The following process must be completed for each of the channels before the system can be used. The following equipment is required to align the stability system:

1. Digital voltmeter
2. Oscilloscope with bandwidth in excess of 70MHz
3. Image processor software for generation of gray step pattern

4. Image processor software for generation of reference areas
5. BNC "T" and terminator

Video Alignment

The channel under test should be removed from the monitor. The BNC "T" is connected to one of the oscilloscope vertical amplifiers. The terminator and the video output signal from the image processor should be connected to the other two ports of the BNC "T". A gray step pattern with at least eight steps should then be sent over the video output to the channel. The step pattern should cover the entire range of the image processor. This will typically be either 1.0 volts or 700 millivolts peak to peak. The signal steps should be adjusted with the variable gain control of the scope's vertical amplifier to cover some even number of vertical divisions. The output of the image processor should then be disconnected from the scope and connected to the input of the stability system. The output of the stability system is then connected to the same vertical amplifier. The image processor blanking signal should not be connected at this time. Switch S1 is turned on, thus opening the feedback loop. The stability system is turned on and allowed to warm up for 10 minutes. Resistor R6 is adjusted to give the same output as before by matching the step response signal to the divisions on the scope that were set in the previous step. The video gain of the Video Circuit is now set to unity. The blanking signal from the image processing system is now connected to the stability system. A large change in the blanking level may be noticed. The blanking level, resistor R27, on the Light Sampling Circuit should be used to bring the blanking interval level back to its original position. The Channel 1 gain should be set to its maximum value by adjusting R3 fully counterclockwise.

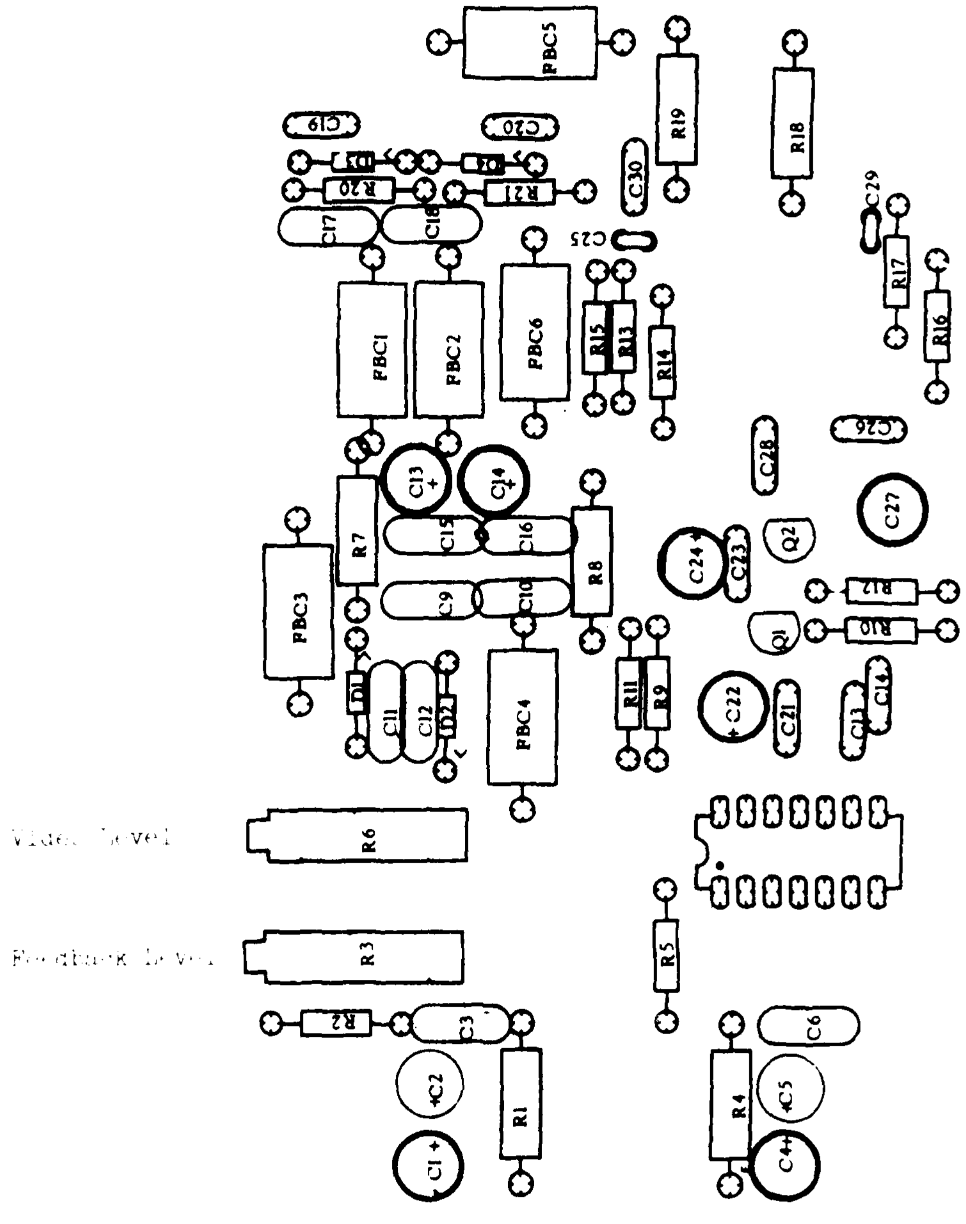


Figure 55. Component Layout for Video Circuit Board.

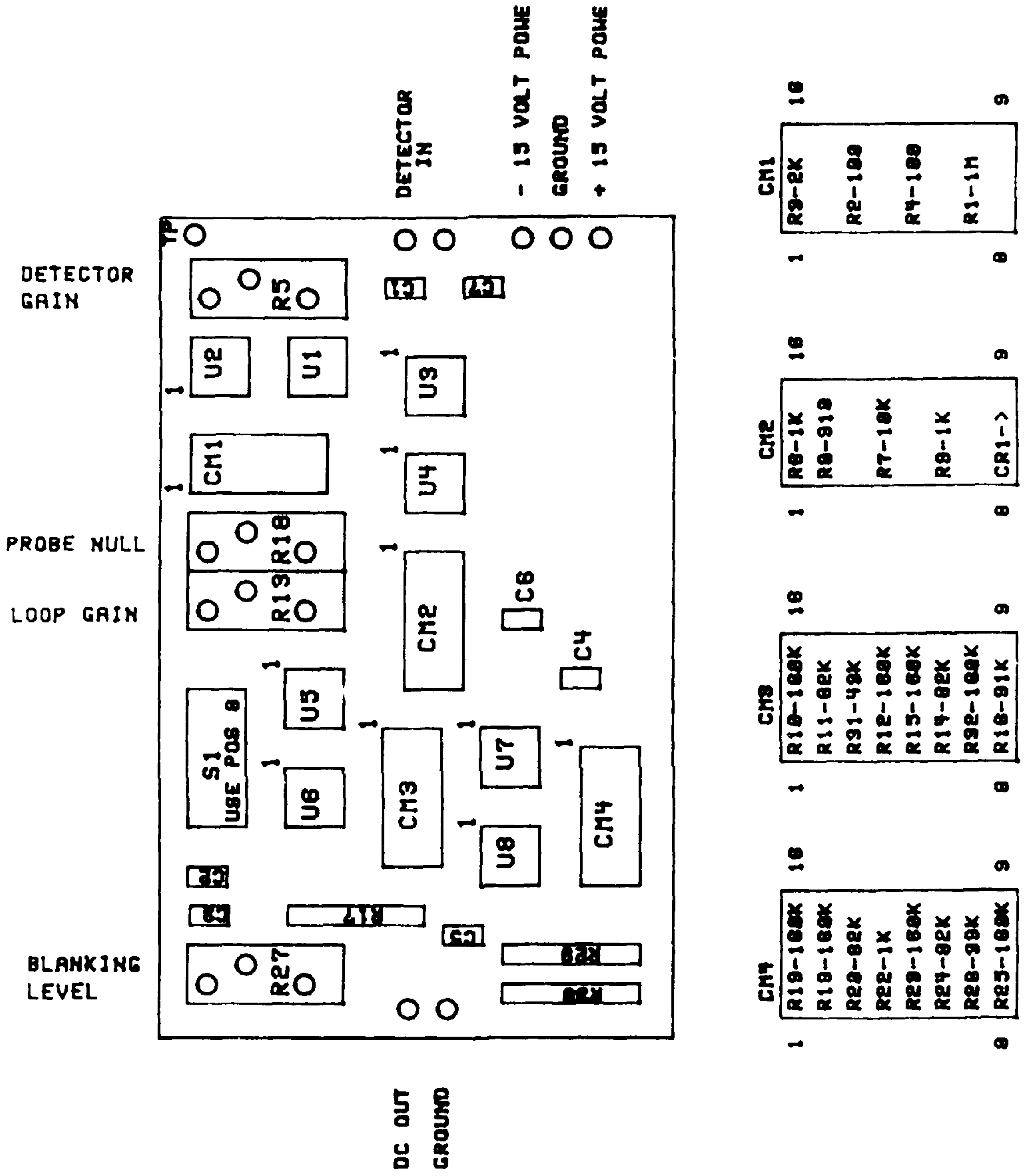


Figure 56. Component Layout for Light Sampling Circuit Board

The above adjustments should be made to each of the three channels before going on to the alignment of the Light Circuit.

ALIGNMENT OF THE LIGHT SAMPLING CIRCUIT

With switch S1 still in the "on" state, the reference area pattern should be displayed. The output of the stability system should be connected to the respective monitor inputs. The silicon detectors should be placed such that they are viewing their appropriate reference areas and such that they will not have to be moved. Any movement of the detectors will in all probability change the alignment due to the spatial nonuniformity of the display. The scope's vertical amplifier should be connected to test point TP1 which is found adjacent to R5. Resistor R5 is used to set the level of the pulses at TP1 to a value of -6 volts. The pulses should start very close to zero volts. If they do not start at zero volts then either the stability system has failed or there is ambient light entering the detector. A voltmeter is then connected to test point TP2 which is the BNC connector adjacent to the detector input. The Probe Null pot R18 is used to bring the value at TP2 to a level of zero volts DC. Switch S1 should now be opened. If the system starts to oscillate, close S1 and reduce the gain by three to four turns. Repeat this procedure until the system does not oscillate. With switch S1 still open increase the system gain by one half of a turn. Wait one minute and increase the gain by another half turn. Continue the increase in gain until the system begins to oscillate. At the point when the system just starts to oscillate decrease the gain by 2 turns. Repeat this procedure for each of the three monitor channels.

It should be noted that the oscillations may very well reach an amplitude of three volts peak to peak. Be sure to check the monitor specifications to make sure that the monitor will not be damaged by this large a signal. If a three-volt signal is too large then level clipping diodes should be used to protect the monitor during the adjustments.

Notes and Special Considerations for the Stability System

The system should be operated in a completely dark room if possible. If this is not possible then the room lights should be kept as low and constant as possible and not be pointed at the display screen.

As mentioned above there is a possibility of signals with a peak-to-peak value of three volts arriving at the output of the stability system. This is not a problem with any of the monitors in our Laboratory, but the manual for any monitor to be connected to the stability system should be consulted before the alignment procedure is started.

Due to printed circuit board layout considerations the level controls on the video circuit operate such that a counter-clockwise turn increases the gain.

The stability system is provided with a switch that may be used to connect the ground found at the power cord to the ground of the system. It is recommended that the switch be left open unless there is some safety code or reason for grounding the stability system to the power input ground.

LIGHT SAMPLING CIRCUIT VERSION 2 PARTS LIST

Resistors

R1	1M ohm	0.1% tolerance, 50ppm/°C, Corning Glass Works	$1.00
R2	1K ohm	500 mW Allen-Bradley, TRW, Ohmite	0.04
R3	2K ohm	same	0.04
R4	680 ohm	same	0.04
R5	2K ohm	10/t potentiometer Bourns	3.88
R6	1K ohm	250 mW Allen-Bradley, TRW, Ohmite	0.04
R7	10K ohm	same	0.04
R8	910 ohm	same	0.04
R9	1K ohm	same	0.04
R10	160K ohm	same	0.04
R11	82K ohm	same	0.04
R12	160K ohm	same	0.04
R13	5K ohm	10/t potentiometer Bourns	3.88
R14	82K ohm	250 mW Allen-Bradely, TRW, Ohmite	0.04
R15	160K ohm	same	0.04
R16	1K ohm	same	0.04
R17	1K ohm	same	0.04
R18	5K ohm	10/t potentiometer Bourns	3.88
R19	510K ohm	250 mW Allen-Bradley, TRW, Ohmite	0.04
R20	82M ohm	same	0.04
R21	1M ohm	same	0.04
R22	1K ohm	same	0.04
R23	160K ohm	same	0.04
R24	82K ohm	same	0.04
R25	160K ohm	same	0.04
R26	39K ohm	same	0.04
R27	5K ohm	10/t potentiometer Bourns	3.88
R29	1K ohm	250 mW Allen-Bradley, TRW, Ohmite	0.04
R30	100K ohm	same	0.04
R31	160K ohm	same	0.04
			17.52

Capacitors

C1	100pf	CDE, Central Lab, Sprague	0.20
C2	1uf	same	1.00
C3	1uf	same	1.00
C4	2uf	same	2.00
C5	.1uf	same	0.20
C6	1uf	same	1.00
C7	.1uf	same	0.20
			9.60

Semiconductors

U1	LF356	National Semiconductor	1.85
U2	LF356	same	1.85
U3	AD584	Analog Devices	21.80
U4	LF356	National Semiconductor	1.85

U5	LF356	National Semiconductor	1.85
U6	LF356	same	1.85
U7	LF356	same	1.85
U8	LF356	same	1.85
Board and Sockets			4.00
TOTAL COST OF VERSION 2 LIGHT SAMPLING CIRCUIT			**65.87**

VIDEO CIRCUIT VERSION 2 PARTS LIST

Resistors

R2	2K ohm	250 mW Allen-Bradley, TRW, Ohmite	$0.04
R3	2K ohm	10/t potentiometer Bourns	3.88
R4	75 ohm	500 mW Allen-Bradley, TRW, Ohmite	0.04
R5	2K ohm	250 mW Allen-Bradley, TRW, Ohmite	0.04
R6	2K ohm	10/t potentiometer Bourns	3.88
R7	68 ohm	500 mW Allen-Bradley, TRW, Ohmite	0.04
R8	68 ohm	same	0.04
R9	56K ohm	250 mW Allen-Bradley, TRW, Ohmite	0.04
R10	10K ohm	same	0.04
R11	200 ohm	same	0.04
R12	51 ohm	same	0.04
R13	36K ohm	same	0.04
R14	10K ohm	same	0.04
R15	200 ohm	same	0.04
R16	100 ohm	same	0.04
R17	1M ohm	same	0.04
R18	47 ohm	same	0.04
R19	25 ohm	same	0.04
			8.40

Capacitors

C9	1uf	CDE, Central Lab, Mallory, Sprague	1.00
C10	1uf	same	1.00
C11	1uf	same	1.00
C12	1uf	same	1.00
C13	10uf	same	1.70
C14	10uf	same	1.70
C15	1uf	same	1.00
C16	1uf	same	1.00
C17	1uf	same	1.00
C18	1uf	same	1.00
C19	.1uf	same	0.20
C20	.1uf	same	0.20
C21	220uf	same	1.70
C22	1uf	same	1.00
C23	1uf	same	1.00
C24	220uf	same	1.70
C26	33pf	same	0.20
C27	12-60pf,	Sprague	1.48
C28	1uf	CDE, Central Lab, Mallory, Sprague	1.00
C29	.1uf	same	0.20
C30	.1uf	same	0.20
			28.68

Inductors

L1	Balun	Fair-Rite Products Corporation	0.75
L2	Balun	same	0.75
L3	Balun	same	0.75

L4 Balun Fair-Rite Products Corporation	0.75
L5 Balun same	0.75
L6 Balun same	0.75
Semiconductors	
MC1445 Motorola	3.01
LH0033CG National Semiconductor	21.50
Q1 MPS6518 Motorola	0.50
Q2 MPS6518 Motorola	0.50
D1 1N747A Texas Instruments	0.30
D2 1N747A same	0.30
D3 1N759A same	0.30
D4 1N759A same	0.30
Printed Circuit Board	100.00
TOTAL COST OF VERSION 2 VIDEO CIRCUIT	159.89
TOTAL COST PER CHANNEL	225.76
Power Supply	60.00
TOTAL COST FOR THREE CHANNELS	737.28

METHOD FOR TESTING THE VERSION 2 STABILIZATION SYSTEM

The method of testing the Version 2 Stabilization System was much the same as the original tests. The luminances of the three guns were set up to conform with the display used by the Air Force. Thus, the red, green, and blue luminances for a value of 600 bits were 16.9, 12.9, and 6.8, respectively. This is a somewhat nonstandard set-up in that the green gun output is lowered and the red and blue outputs are increased. This configuration allowed for better utilization of the color space for research done at the AAMRL at Wright-Patterson. The stabilization system was adjusted as described in the next section. After adjustment a screen of 600 bits, approximately 600 millivolts, was displayed. The system was left in this configuration for two weeks. Each day the display was measured. The measurements consisted of five spectral scans taken in succession. The room temperature was recorded for each measurement session.

RESULTS OF VERSION 2 LONG-TERM DRIFT MEASUREMENTS

The results of the Version 2 measurements are shown in Figures 57 through 61. As indicated above, each day five measurements of the spectrum were made. Figure 57 contains two curves. The top curve plots the largest of the five measured CIE x chromaticity coordinates that were obtained each day and the bottom curve plots the smallest. Thus, the two curves represent the range of values obtained from each day's measurements. Similarly, Figures 58-61 show the measurements of the CIE y, u', and v' chromaticity coordinates and the percentage of luminance deviation, respectively. The percentage of luminance deviation was calculated with respect to the maximum luminance observed in all of the measurements. The maximum and minimum value for the entire test is annotated as well as the difference between the maximum and minimum, which is labeled as Delta. Table 7 gives a summary of the results and compares the

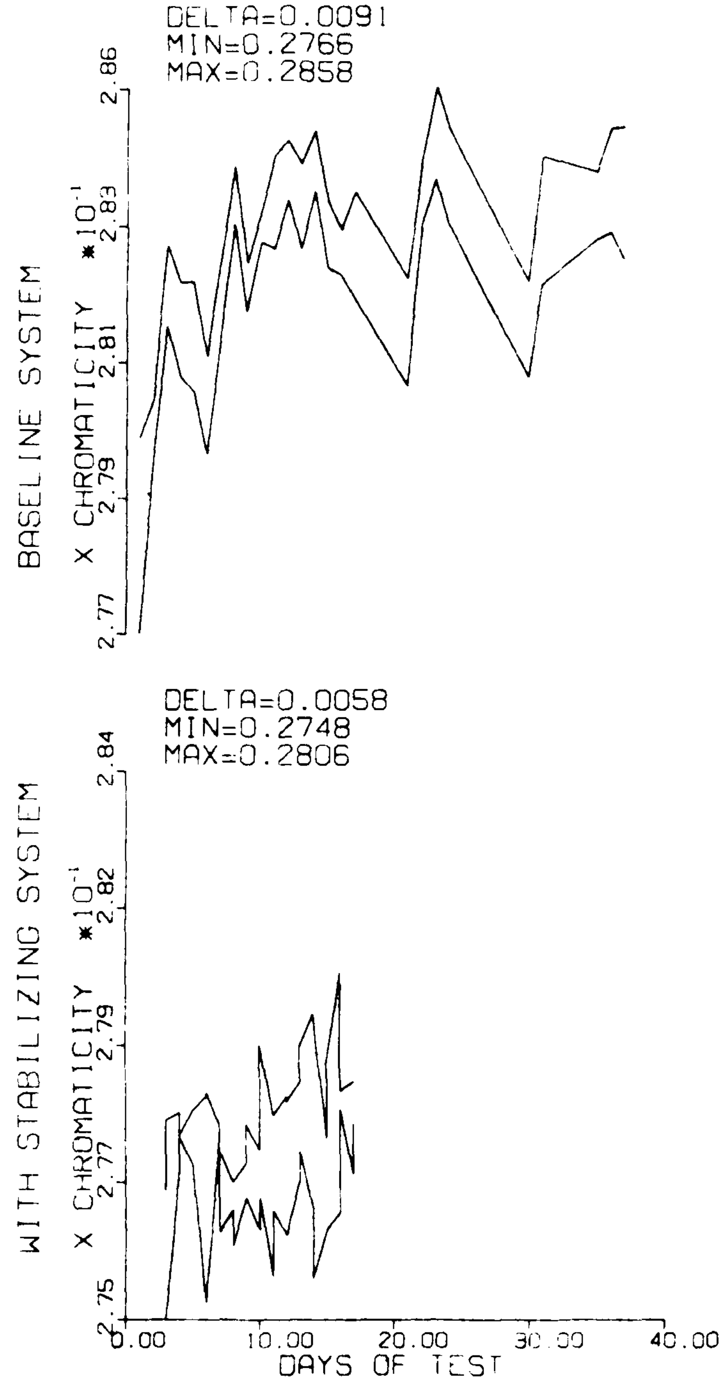


Figure 57. Comparison Using Aydin 8025 Delta Gun Monitor of Long-Term Drift in x CIE Chromaticity Coordinate Between Baseline and Compensated Display System (Version 2).

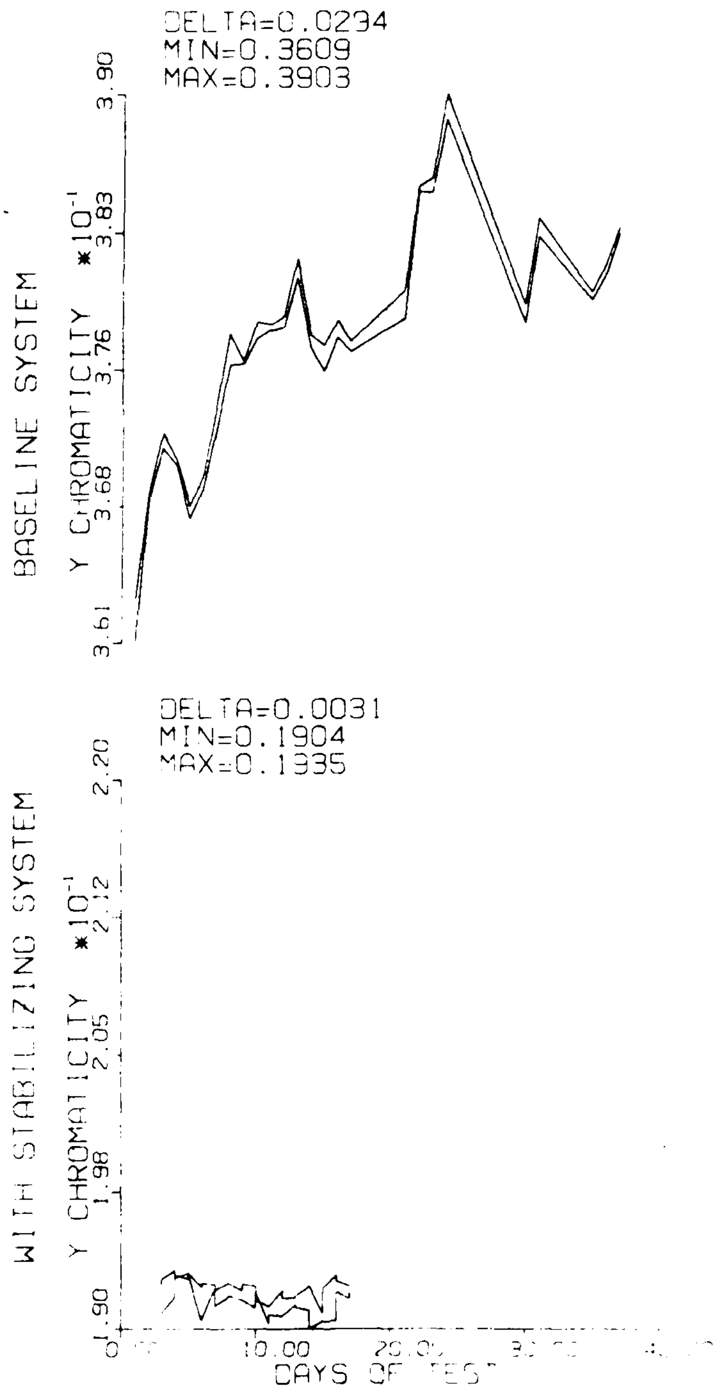


Figure 58. Comparison Using Aydin 8025 Delta Gun Monitor of Long-Term Drift in y CIE Chromaticity Coordinates Between Baseline and Compensated Display System (Version 2).

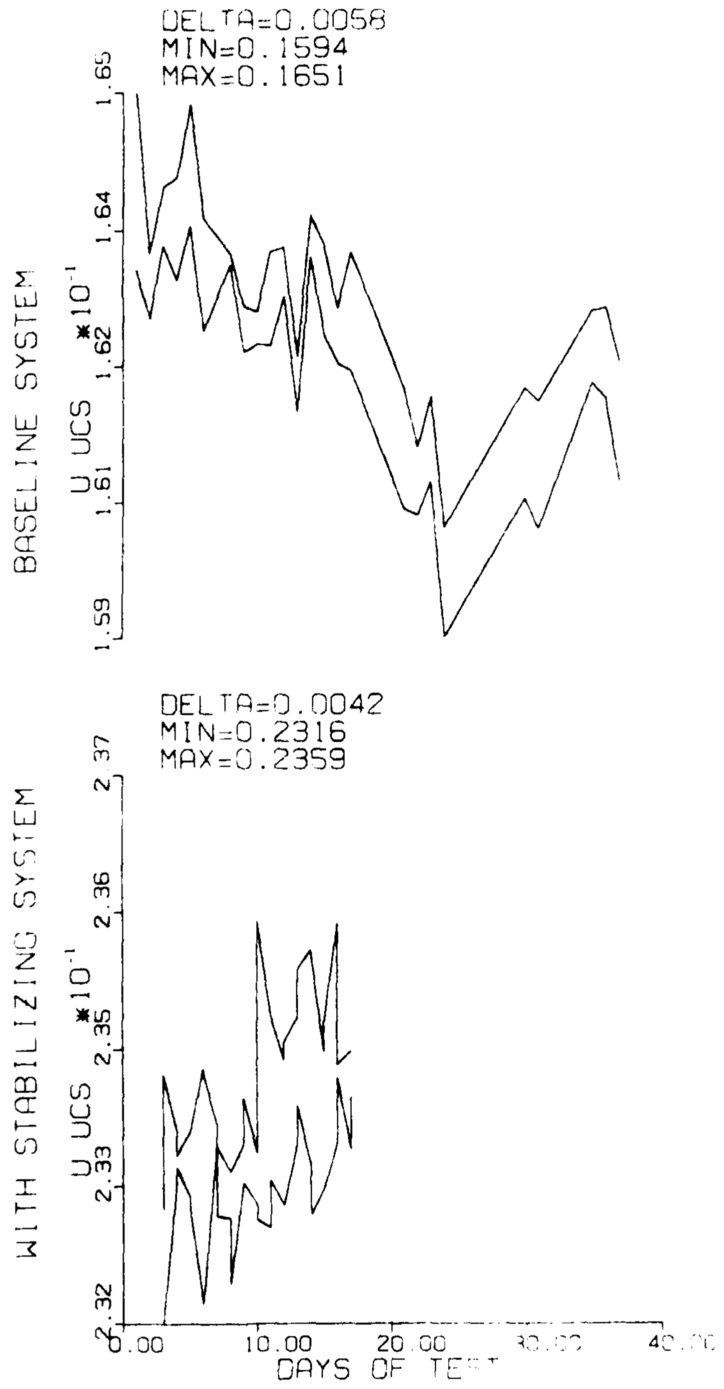


Figure 59. Comparison Using Aydin 8025 Delta Gun Monitor of Long-Term Drift in u' CIE UCS Coordinate Between Baseline and Compensated Display System (Version 2).

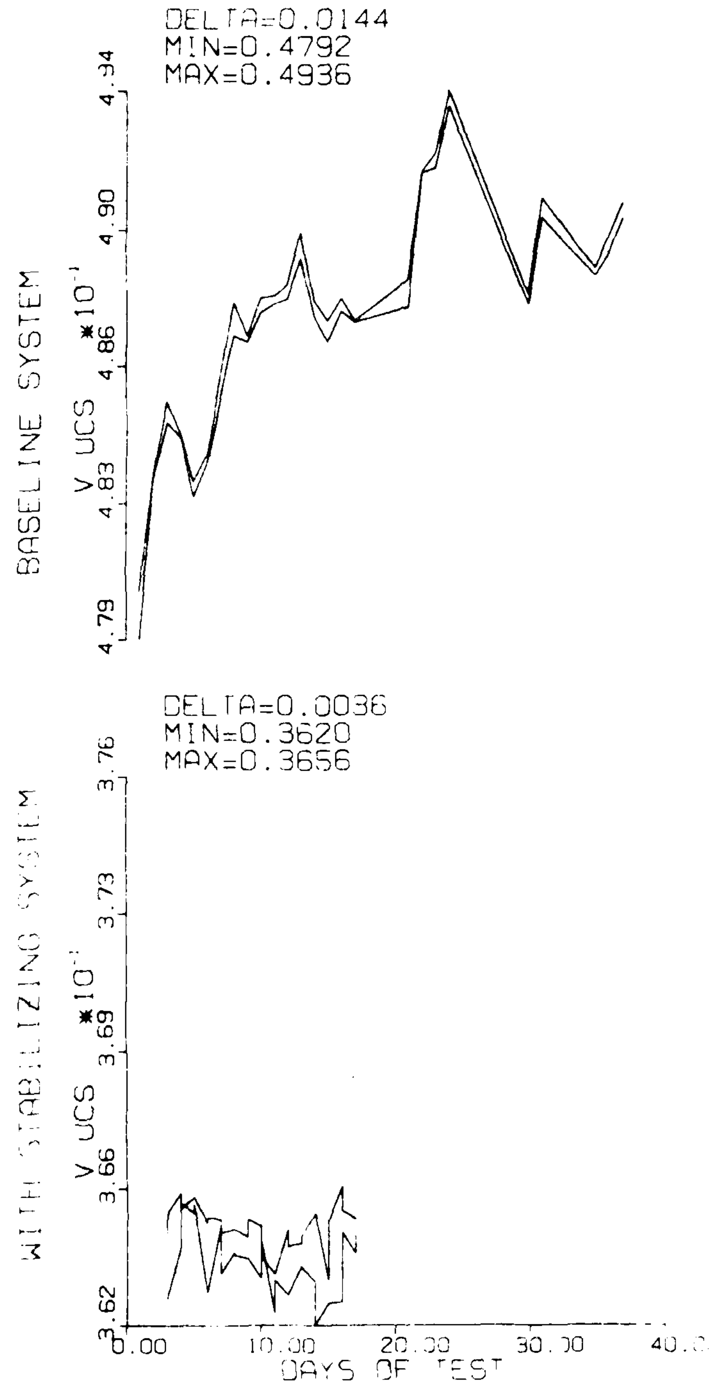


Figure 60. Comparison Using Aydin 8025 Delta Gun Monitor of Long-Term Drift in v' CIE UCS Coordinate Between Baseline and Compensated Display System (Version 2).

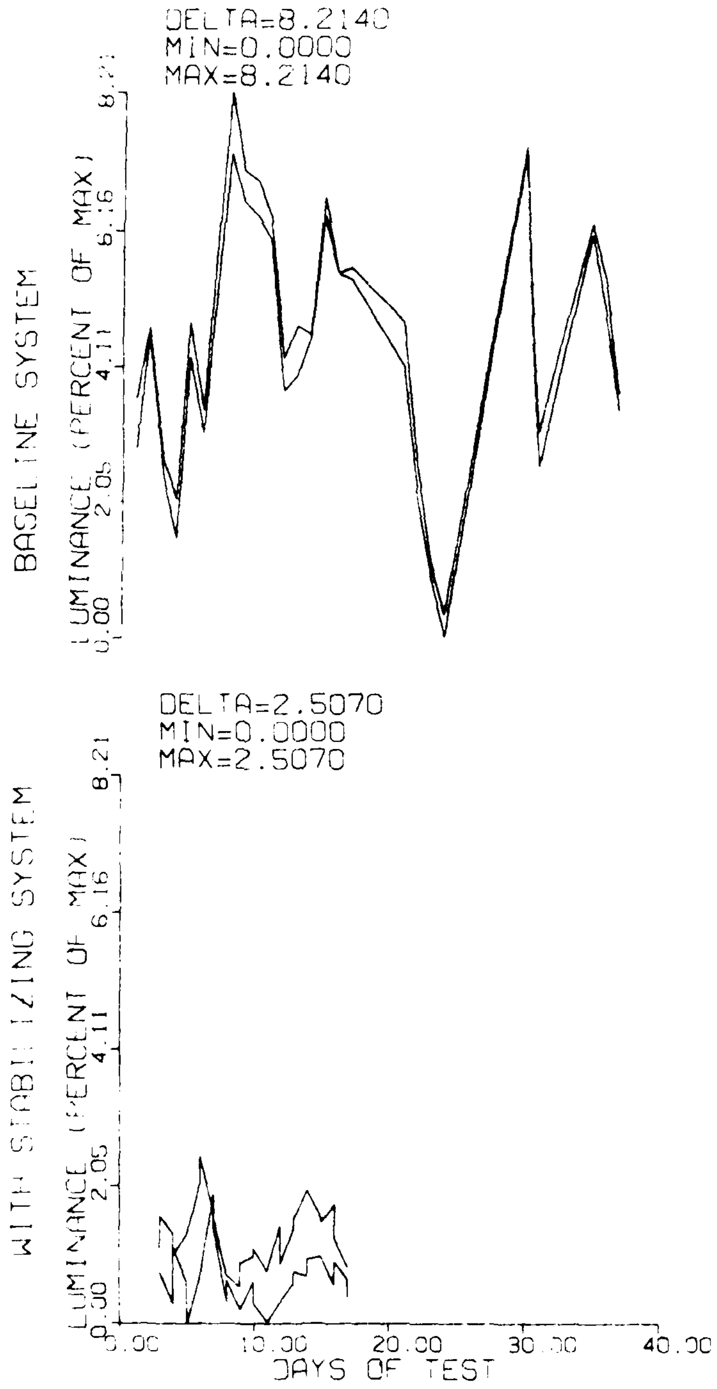


Figure 61. Comparison Using Aydin 8025 Delta Percent Difference from the Maximum Luminance Value Between Baseline and Compensated System.

TABLE 7. Comparison of Aydin 8025 Delta Gun Monitor of Long-Term Drift in x and y CIE Chromaticity Coordinates, and Percent Luminance Change from the Maximum Luminance Between the Baseline System, Version 1 Stability System, and the Version 2 Stability System CIE (Max-Min).

SYSTEM	x	y	u'	v'	%Luminance
Baseline	.0091	.0294	.0058	.0144	8.2140
Version 1	.0061	.0052	.0037	.0033	2.439
Version 2	.0058	.0031	.0042	.0036	2.507

results from the Version 1 Stability System to the Version 2 Stability System.

When comparing the Version 1 system and the Version 2 system several differences between the two systems should be noted. The Version 1 system has a time constant of 22 seconds compared to a 2 second time constant for the Version 2 system. The closed loop gain of the Version 1 system was 11 times greater than the Version 2 system. This means that the Version 1 system should have had an error margin 11 times smaller than the Version 2 system. All other factors being equal the Version 1 system should be 11 times more stable than the Version 2 system. The price for the better error tracking is the long time constant which compromises the transient response of the system. The improved detector circuit in the Version 2 system allowed for the lower time constant. If the time constant can be increased without compromising the experimental stimuli, then the necessary change can easily be made to the detector circuit as described in the Light Detector Circuit description. The other major difference between the two systems is the luminance that the two displays were driven at during the experiment. In the Version 1 system setup the display had to be run at approximately 90 nits for a 600 bit output in the white display measurement location to provide enough signal for the silicon detectors. This high level was used to allow for the use of smaller detectors. In the Version 2 system the display was driven at approximately 57 nits for a 600 bit output in the white display measurement location. This lower level of drive would not have been possible in the Version 1 system.

Surprisingly, despite the differences between the Version 1 system and the Version 2 system there is little difference in their overall performance. Both of the systems are a significant improvement over the baseline system which indicates that the basic idea of stabilizing the display via a feedback system is valid. As discussed earlier, the repeatability of the measurement system is only about .002 in u' and v'. The u' and v' values are very close to the resolution of the measurement system which indicates that differences between the Version 1 and Version 2 system may be difficult to separate from the measurement error. The value of .0144 in v' for the baseline system is very significant and the improvement obtained by using the stability system is significant over the two-week time period. The temperature was measured during the Version 2 system test and ranged from 70.1 to 73.0°F. This temperature change is thought to be insignificant. However, evaluation of the effect of temperature on the stability system was performed.

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