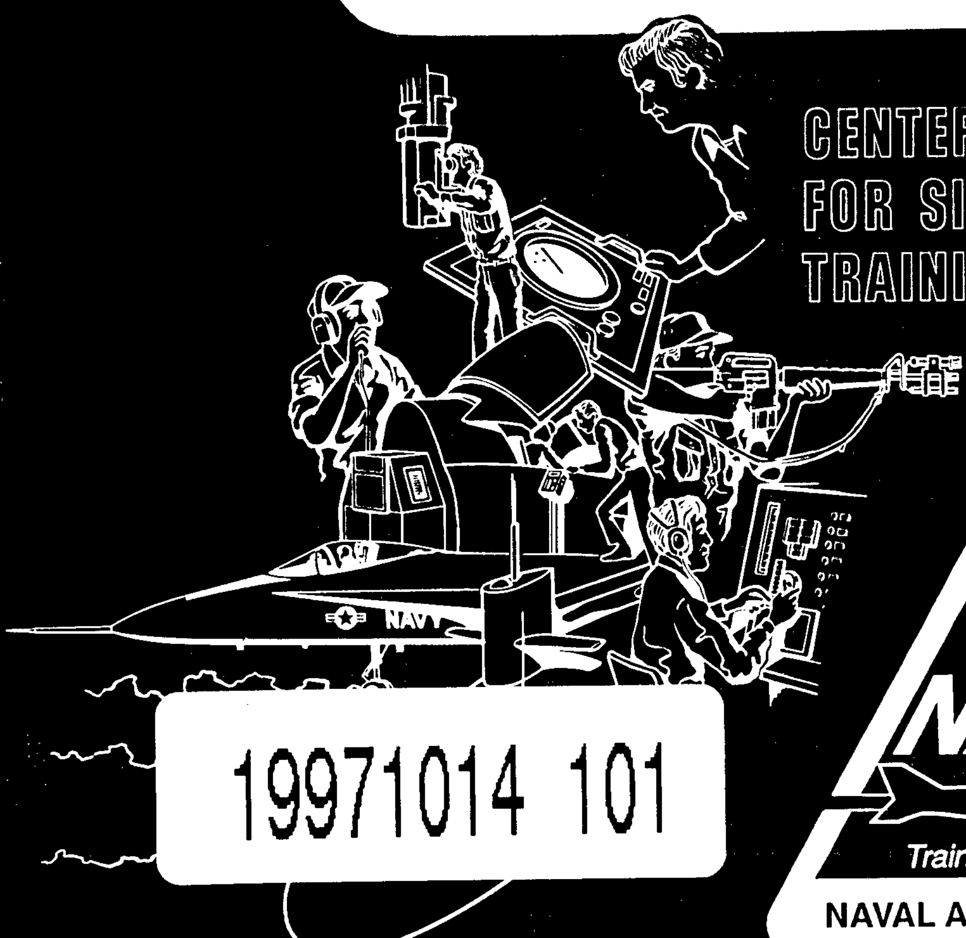
NAVAL AIR WARFARE CENTER
TRAINING SYSTEMS DIVISION
ORLANDO, FLORIDA

TECHNICAL REPORT 97-005

SIMULATING VARIATIONS IN NIGHT SKY IRRADIANCE VIA CRT PROJECTOR CONTROLS

JULY 1997



CENTER OF EXCELLENCE FOR SIMULATION AND TRAINING TECHNOLOGY

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Availability of spectrally correct simultaneous near-IR and visual imagery in night mission capable simulators would improve night vision goggle (NVG) training fidelity. While providing the aided, through-the-goggle view, it can also provide unaided peripheral and under-the-goggle views of the simulated nighttime scene. Within certain constraints, a properly modified CRT projection display can furnish both. In addition, computer automated or manual adjustment of projector contrast and brightness controls could also effectively simulate a range of moon phase and time-of-night conditions.

After gamma mapping an off-the-shelf CRT projector for various combinations of brightness and contrast control settings, the gamma corrected display imagery was used to stimulate an ANVIS. Together, the contrast and brightness controls were used to reduce or increase the projector output to simulate changing nighttime conditions. This report discusses some of the issues, practical constraints and findings of the research investigation.

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EXECUTIVE SUMMARY

INTRODUCTION

Availability of spectrally correct imagery in night mission capable simulators would improve Night Vision Goggle (NVG) training fidelity. Use of this imagery can accurately stimulate NVGs. Within certain constraints, a properly modified CRT projection display can furnish both simultaneous near-IR and visual imagery for stimulation purposes. While providing the aided, through-the-goggle view, this would also provide the unaided peripheral and under-the-goggle views of the simulated nighttime scene. Computer automated or manual adjustment of projector contrast and brightness controls can effectively simulate a range of moon phase and altitude. Some of these concepts can now be demonstrated in the Night Scene Display System test bed. This report is one of a series which discusses some of the issues, practical constraints, and results of our research investigation.

OBJECTIVE AND APPROACH

Energy being emitted by the night sky varies with time of night, moon phase and position, and weather. This report addresses the search for how to provide the variations that occur in night sky irradiance, while also providing spectrally correct nighttime imagery. Of particular interest is the ability to vary a CRT projector's output without affecting the image quality. Since CRT video projectors are inherently nonlinear, and a linear input does not result in a linear brightness output, some form of image gamma compensation must be employed to restore the original image linearity. Changing the simulated night sky energy through the use of CRT projector controls can impose additional nonlinearities, requiring further compensation. Measurements of the display system gamma will allow for display compensation, while maintaining image quality under various projector adjustment conditions.

NIGHT SCENE DISPLAY SYSTEM

The present Night Scene Display System test bed consists of five components: a three CRT video projector, a rear projection screen, a black curtain enclosure, a desktop computer system, and a set of filters. Spectrally equivalent night sky irradiance from the CRT projector is produced by the filter set. This filter set modifies the CRT projector to provide simultaneous visible and near-IR outputs that replicate night sky irradiance levels. Variation in night sky energy are simulated by varying the projector output through adjustment of brightness and contrast controls. Image linearity is maintained throughout the adjustment range by gamma compensation of imagery.

CONCLUSIONS

The contrast control on the Night Scene Display System test bed CRT projector can be used to provide simulated variations in night sky energy levels. Data provided indicates that only a single image gamma compensation is required for certain ranges of control settings in the Night Scene Display System. Over a specific contrast adjustment range, a 3:1 change in output levels can be achieved without additional gamma compensation. Further changes in output level are made through use of additional filters. Other schemes to increase the adjustment range may require the use of real time image gamma compensation.

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INTRODUCTION

Over the years the United States Navy has made substantial investments in flight simulators. Initially well suited for their original training purposes, changing mission requirements with respect to night operations can require different simulator configurations. More specifically, the simulators must be night mission capable. To meet these requirements new simulators are procured or existing simulators modified for Night Vision Goggle (NVG) use.

There are two major approaches to providing the needed NVG training capability, *simulation* or *stimulation*. The first method, still in a research phase, requires providing simulated NVG imagery to a simulated NVG. A more commonly used second method uses the aviator's actual NVG equipment and stimulates the NVG with NVG compatible near-IR imagery. Although the future may very well lie in the direction of the simulation approach, how does the Navy leverage existing simulator resources and technology while still providing high fidelity night mission training?

One major objective of this Office of Naval Research (ONR) sponsored research has been to search for methods of increasing the fidelity (realism) of the simulated night time imagery that is currently displayed or will be displayed in Navy/Marine Corps NVG capable flight simulators. The premise for this work has been that use of higher fidelity NVG compatible imagery in the simulator will enhance aviator NVG skills and will increase the probability of skill acquisition and retention. The purpose of simulating the ambient night sky is to more skillfully and realistically represent objects that are illuminated, or more correctly *irradiated*, by night sky energy.

Availability of spectrally correct simultaneous near-IR and visual imagery in night mission capable simulators would improve NVG training fidelity. While providing the aided, through-the-goggle view, it also provides unaided peripheral and under-the-goggle views of the simulated nighttime scene. Within certain constraints, a properly modified CRT projection display can provide both. In addition, computer automated or manual adjustment of projector contrast and brightness controls could also effectively simulate a range of moon phase and time-of-night conditions. At a minimum, proper use of the controls requires three things: a detailed knowledge of night sky conditions for a wide range of moon phase and times of night, an understanding of the CRT projector's display characteristics at various control settings, and some form of image compensation.

Some of these concepts can now be demonstrated in the Night Scene Display System test bed. This report is one of a series which discusses some of the issues, practical constraints and results of our research investigation.

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NIGHT SCENE DISPLAY SYSTEM

The present Night Scene Display System test bed consists of five components: a CRT projector, a rear projection screen, an enclosure, a desktop computer system, and a set of optical filters. One of the primary components is a VPH-1272Q Sony CRT projector whose red, green, and blue projection CRT lenses have been filtered to produce a spectrally equivalent, simulated night sky environment [1]. A Dalite Pearlescent front projection screen is effectively used as a rear-projection screen surface. The rear-projection screen surface forms one side of an approximate eight foot by eight foot box enclosure, with ceiling to floor Sunbrella Firesist Black black-out curtains forming the other five sides. By blocking stray reflected visible and near-IR energy, the curtains help to increase screen contrast. A Gateway 166Mhz Pentium computer system with an ATI 3DProTurbo video card produces the video imagery driving the CRT projector.

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SIMULATING VARIATIONS IN NIGHT SKY ENERGY

Figure 1 shows a range of night sky spectral scans obtained at one location during a Florida moonlit night. Examining the data, variations of 3 to 1 in the amount of night sky energy with change in time can be seen. Similar but even more extensive variations on the order of 50 to 1 or greater can be shown for moon phase. If an equivalent spectral output from a CRT projector can be produced by use of filters or other means, variation in night sky energy can be simulated by varying the projector output. This report addresses the search for how to vary a projector's output without affecting the perception of the image contents.

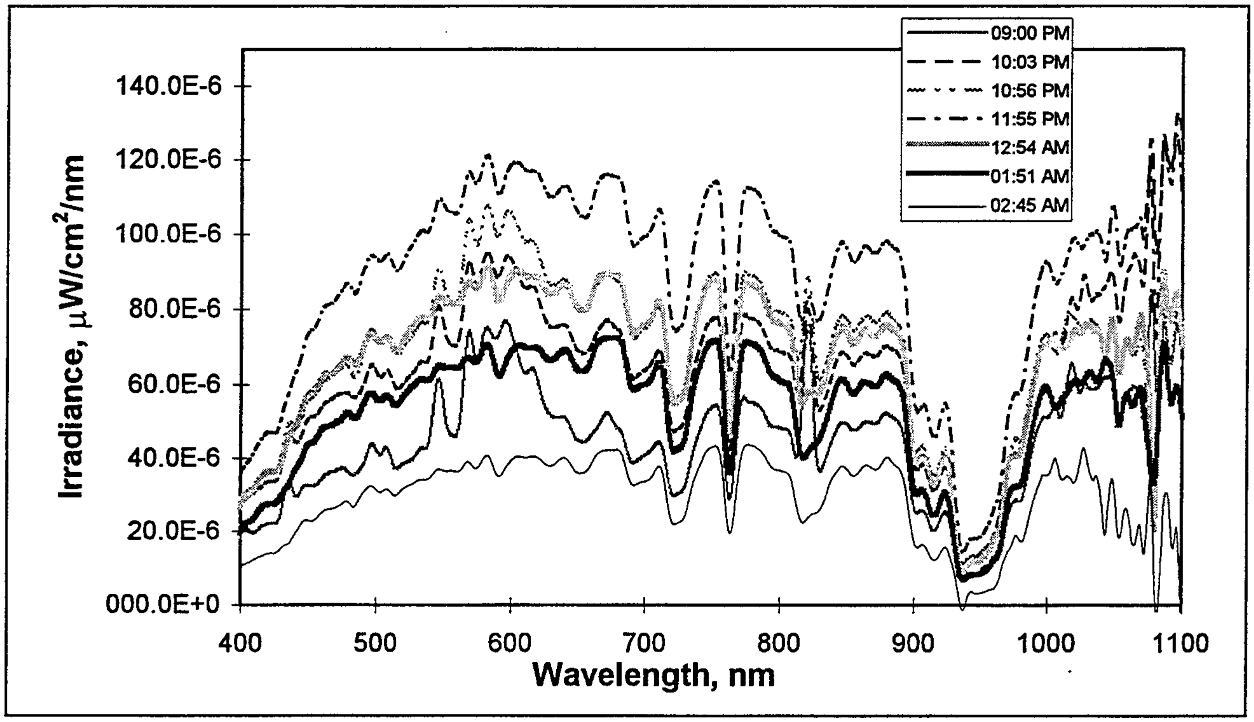


Figure 1. Night Sky Energy Variations With Time

Color Table Remapping

Ignoring any CRT display characteristics for a moment, one way the projector output variation could be achieved is through color table remapping. This would be unacceptable due to the loss of color depth. As an example, consider a computer generated black and white bitmap image with 8 bits of color depth, equating to 256 possible gray level outputs. If a night sky energy variation, on the order of 2 to 1 is simulated by such a scheme, all image gray levels 0 through 255 must be reduced somehow to fit within a range that extends only from 0 through 127. In this instance, levels 255 and 254 both become equivalent to 127. This results in a drop in color depth or color resolution. Now 7 bits represent all the variation that was originally possible with 8 bits. For small variations like that shown in Figure 1, color table remapping may be useful. However, in instances in which the variation is 8 to 1, the number of available levels falls to less than 32 levels, or 4 bits of digital resolution. At some point the remaining color resolution is no longer capable of supporting the intended fidelity of the visual simulation.

CRT Projector Controls

The preferred solution is to use the CRT projector brightness and contrast controls to vary the output. If performed properly, no loss of color resolution occurs and the desired linear display characteristics are retained. But to maintain display linearity, nonlinear CRT display characteristics must be determined and accounted for.

NONLINEARITY IN CRT DISPLAYS

CRT displays of any kind are inherently nonlinear [2], which means for a linear video input voltage, there is a non-linear luminance output. The amount of light energy produced by a CRT is a power function of the input video signal. If we consider both the input and output as imagery of some kind then the relationship can be expressed in its simplest form as:

$$\text{OUTPUT IMAGE} = (\text{INPUT IMAGE})^{\gamma} \quad ,$$

where " γ ", or CRT display gamma, typically has a value between 2 and 3. Ideally, γ should have a value of 1, indicating a linear relationship between the input image and the output image.

To be displayed correctly by a CRT display, input imagery must be "gamma corrected" or "gamma compensated" in some manner. An uncompensated image will typically appear too dark. Objects within the scene which would just be visible in the real world will exhibit little or no contrast when displayed and hence, may not be visible at all. An image which has been properly compensated, and where the compensation reverses the effect of the CRT display, will neither be too dark nor too light when viewed.

Imagery is gamma compensated by altering the relationship of its dark to light tones in a mathematically precise manner. In practice, a gamma compensation of $1/\gamma$ is applied to the image before it is displayed, and the effect of the CRT display gamma " γ " is canceled out. This can be shown by the following relationship:

$$\text{OUTPUT IMAGE} = (\text{INPUT IMAGE}^{1/\gamma})^{\gamma}$$

or:

$$\text{OUTPUT IMAGE} = \text{INPUT IMAGE} \quad ,$$

and in a perfect world, the output image is identical to the original input image.

Effects of Brightness and Contrast Control Settings on Gamma

CRTs are not quite so simple. CRT display gamma is highly dependent upon the CRT display brightness and contrast control settings. A CRT display system has a unique display gamma only at a specific setting of the two so called "independent" variables, brightness and contrast.

Also, the functions of the brightness and contrast controls are not universally defined. It is certainly true that in most cases, the purpose of the brightness and contrast controls is to accomplish an image alteration of some kind. Most of the time we don't care about how the resultant image alteration occurred. Usually brightness and contrast are both varied until the display is considered to be at some optimum viewing level. But the "brightness" control is supposed to change the gain of all components within the image, and the "contrast" control is supposed to change the relationships of various component tones within the imagery; our original concept of gamma. On some CRT displays, the role of contrast and brightness are reversed, and altering the contrast actually changes the image gain while brightness directly affects the image gamma.[3]

Adding to the complexity, adjustment of either control, brightness, or contrast, may not produce an independent result. Alteration of one control can produce changes in both output image gain or brightness as well as the output image gamma.

DETERMINATION OF NIGHT SCENE DISPLAY SYSTEM GAMMA

Controls that are potentially useful for simulating night sky energy variation are most probably undefined and do not operate independently of each other; not the best of all possible worlds. Further, if an attempt to change the simulated night sky energy through the use of these controls unintentionally results in alteration of the output image gamma, there must be some form of gamma compensation employed to restore the original image linearity. Some image generation systems may have the capability to compensate in real time, but most, like the one in our test bed, do not. And the correct compensation must be known for each specific control setting. So where does that leave us?

At first, the problem seems intractable; but it is merely difficult, not impossible. The solution lies in finding a combination of control settings resulting in the desired changes in output image brightness without the unwanted changes in output image gamma. Perhaps a more modest but realistic expectation is that only limited but acceptable output image gamma changes will occur during changes in brightness.

This approach requires direct optical measurement and determination of the CRT projector brightness and gamma at various combinations of display control settings. For the CRT projection display in the Night Scene Display System test bed, it requires the development of several special purpose procedures and techniques.

Use of Electronic Slide Show Software to Manage and Display Source Image Bitmaps

During the course of data collection, selecting and displaying bitmap images on a one-at-a-time basis proved to be tedious, time consuming, and error prone. Experimenting with various methods of image display finally led to a rather surprising result. Although Microsoft PowerPoint for Windows 95, Version 7.0 is actually meant for slide show presentations, its versatility and display capabilities made it perfect for examining and measuring CRT display response using a small selection of special purpose bitmapped images. In fact, it was eventually used for all of the experimental test procedures and data gathering described in this report. The gray scale bitmap discussed below and shown in Figure 2, along with many others, was inserted into one of a series of slides in an electronic slide show. This made it relatively easy to change bitmap images and manage experiments by simply changing slides.

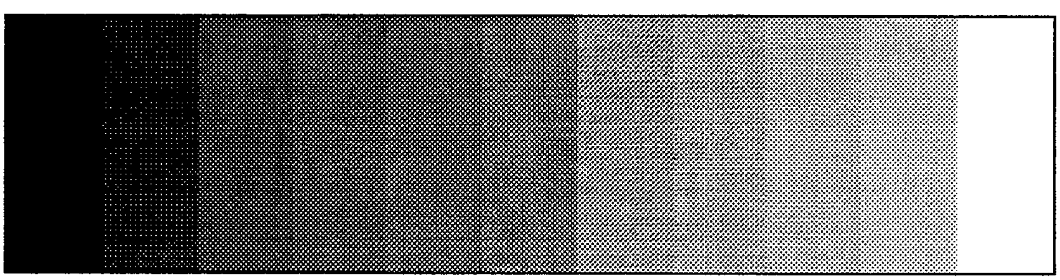


Figure 2. An Eleven Step Gray Scale Bitmap

Since some CRT projector electronics may not be capable of providing the full driving beam current when 100% of the display area is used, the actual area of measurement or test patch was confined to between 5 and 10% of the display area. Also, since the characteristic display brightness does change as a function of radial distance from display center, also known as display brightness rolloff, the area of measurement is confined to the center of the screen. All slides developed for these test and measurement procedures meet these criteria.

The PowerPoint based slides, which are available as a download from the NAWCTSD web site or from the author, contain all the bitmap based test imagery that was used to measure CRT and video card gamma. Realize, of course, there is no guarantee that they will meet anyone's measurement criteria, or even be useful for any particular application.

Determination of Video Signal Linearity

It was important to first establish the linearity of the video signal source used to drive the CRT projector display. Provided by a high performance video card in a Windows 95 based system, the current test bed video operates at a color resolution that is 24 bits deep and a pixel resolution of 800 by 600, although from time to time other configurations were successfully used. To determine the response of the video card a special gray scale image was produced and then rendered by the image display software. The resultant red, green and blue video signals were measured on an oscilloscope.

Figure 2 depicts a 24 bit RGB eleven step gray scale bitmap that was developed and eventually used as the image source. The vertical bands are equally spaced with the center band at 50% white and the extreme left and right bands at 0% and 100% respectively.

Observing each of the red, green and blue output video signals separately on an oscilloscope produced results similar to that shown in Figure 3. Uniform, stairstep shaped signals indicate that the video card is producing the desired linear outputs. If not, some cards may allow for minor adjustments in gamma through software and the Windows 95 operating system. Tests to gamma correct nonlinear video cards through this means were not conducted.

CRT Projector Measurement and Test Conditions

Since the output of the video card proved to be linear, then any nonlinearity observed in the output image could be attributed to the CRT projector. As in the video card above, the measurement and eventual determination of the CRT projector gamma would involve separate examination of the component red, green, and blue output images. In general, the results were expected to be similar for each color.

For this test setup it was decided that the CRT projector brightness and contrast controls would not be set past a working control setting of 50. This was done to preserve the lifetime of the CRT, and served to eliminate the need for frequent adjustments to maintain a constant CRT output.

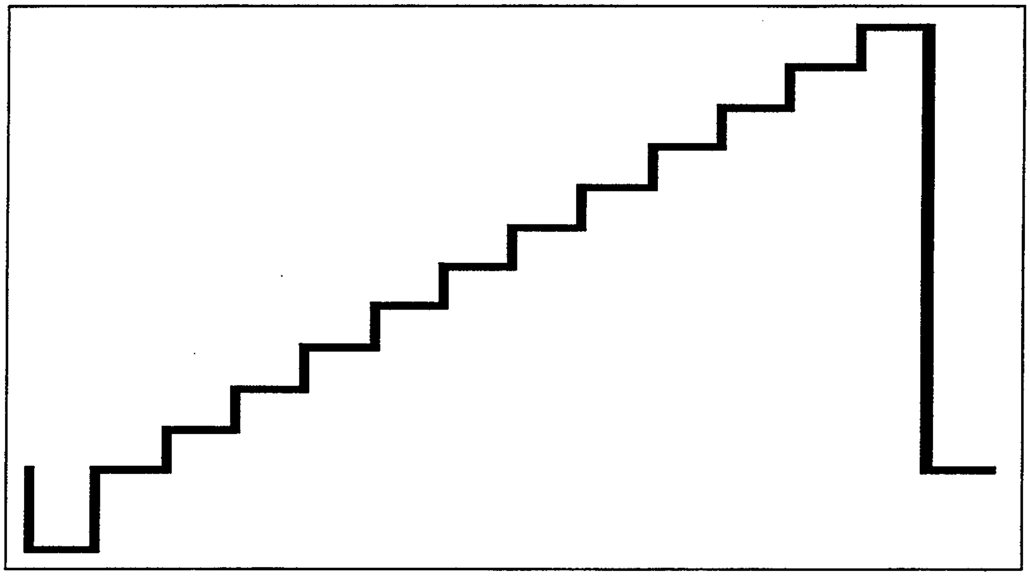


Figure 3. A Linear Video Signal Generated From the Displayed Bitmap in Figure 2.

CRT Projector Brightness and Contrast Control Measurements, Preliminary Data

Analyzing what each of the controls, brightness and contrast, did to the output image required the display of two separate test images, one with a small 100% white square in the center, and one that was at 0% or black. The full screen area surrounding each of the test images was also set at 0%. Using the two slides, a matrix of 36 data points was obtained by measuring the 100% white square output image at various combinations of brightness and contrast settings from 0 to 100. Also obtained were 36 data points at the same brightness and contrast settings of the CRT projector black level, using a 0% white square. Figure 4 shows the 100% white square data arranged as a function of contrast control setting, while Figure 5 shows the same data rearranged as a function of the brightness control setting.

Data in Figure 4 indicate that use of the contrast control results in nonlinear brightness changes in the output image. At first glance, it seems that the use of the contrast control, though it increases output image brightness, performs that task in a way that is not particularly useful to this application. Figure 5 definitely shows output image brightness changing linearly with changes in the brightness control. Other data, specifically the black level shown in Figures 6 and 7 seem to indicate a similar trend.

Good Data, Wrong Conclusion

A preliminary look at the data seemed to indicate that alterations in the brightness control setting, at least those from about 0 to 50, led to linear changes in image output brightness. It appeared that the solution was to simply alter the brightness control to linearly change the output image brightness. It made sense that changing the brightness control would change the image brightness, and that linear image output brightness changes implied a constant CRT projector gamma. However, as the next test results will show, we were completely wrong.

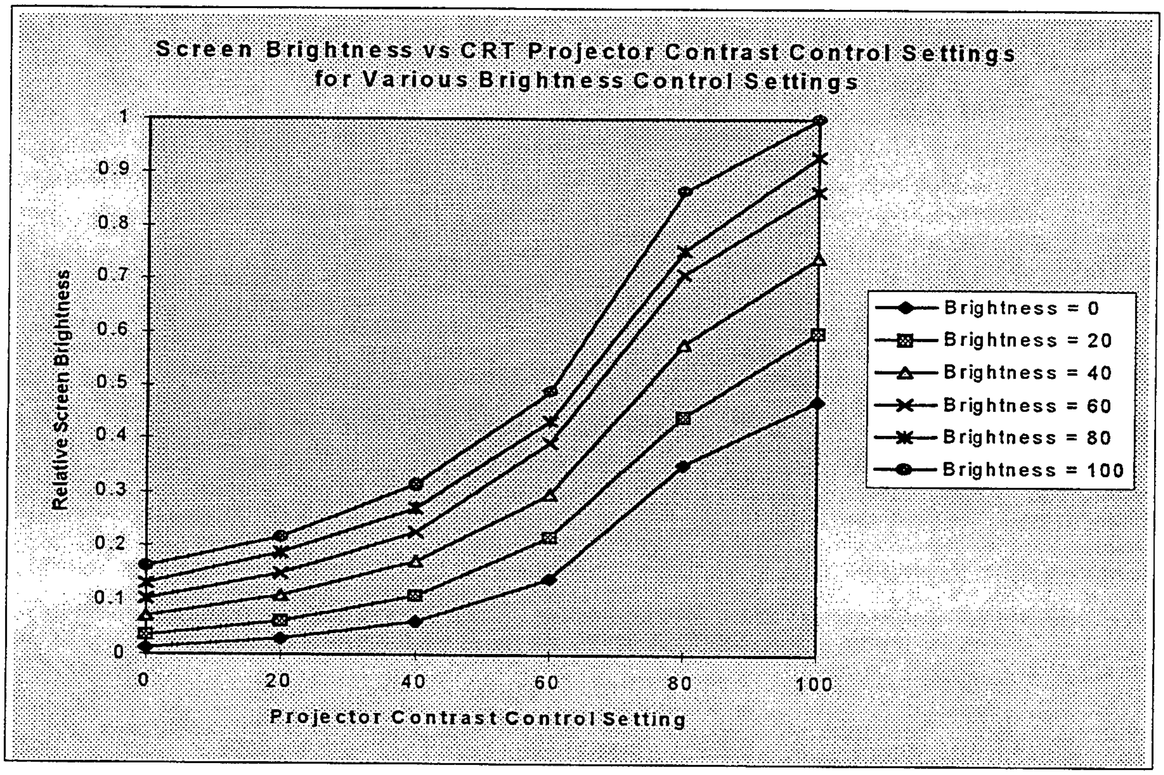


Figure 4. Output Screen Brightness Versus Contrast Control Setting

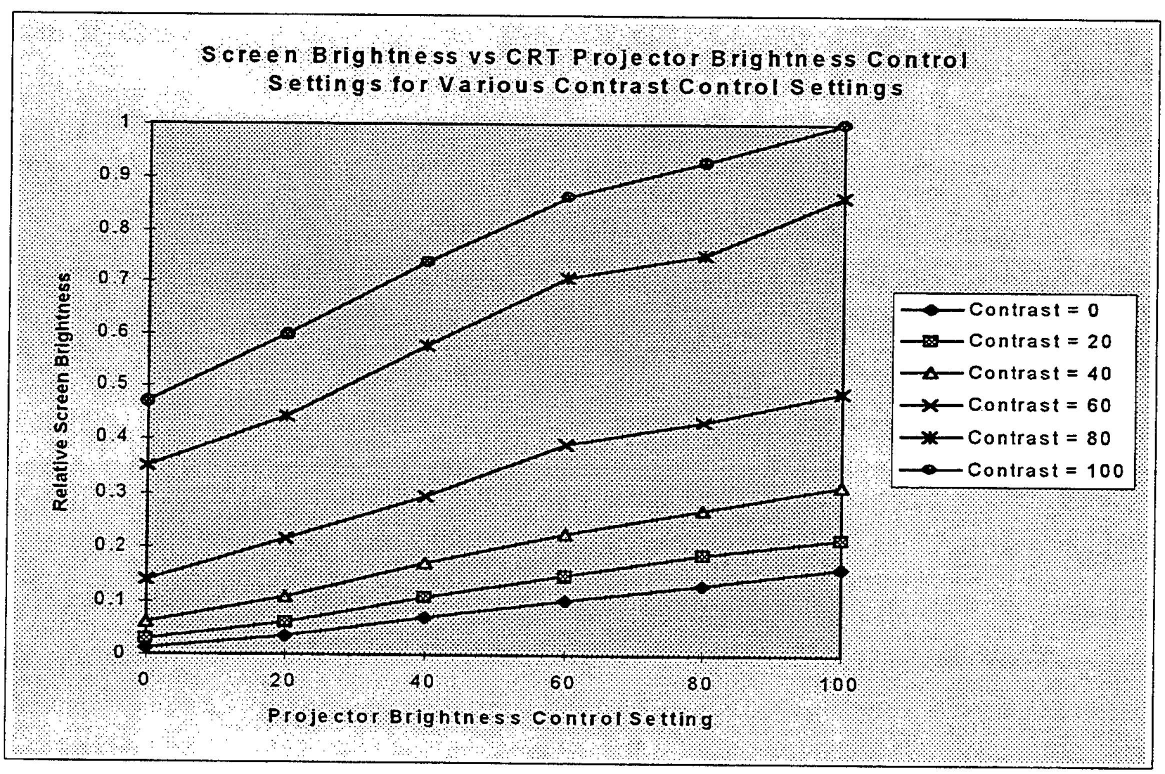


Figure 5. Output Screen Brightness Versus Brightness Control Setting

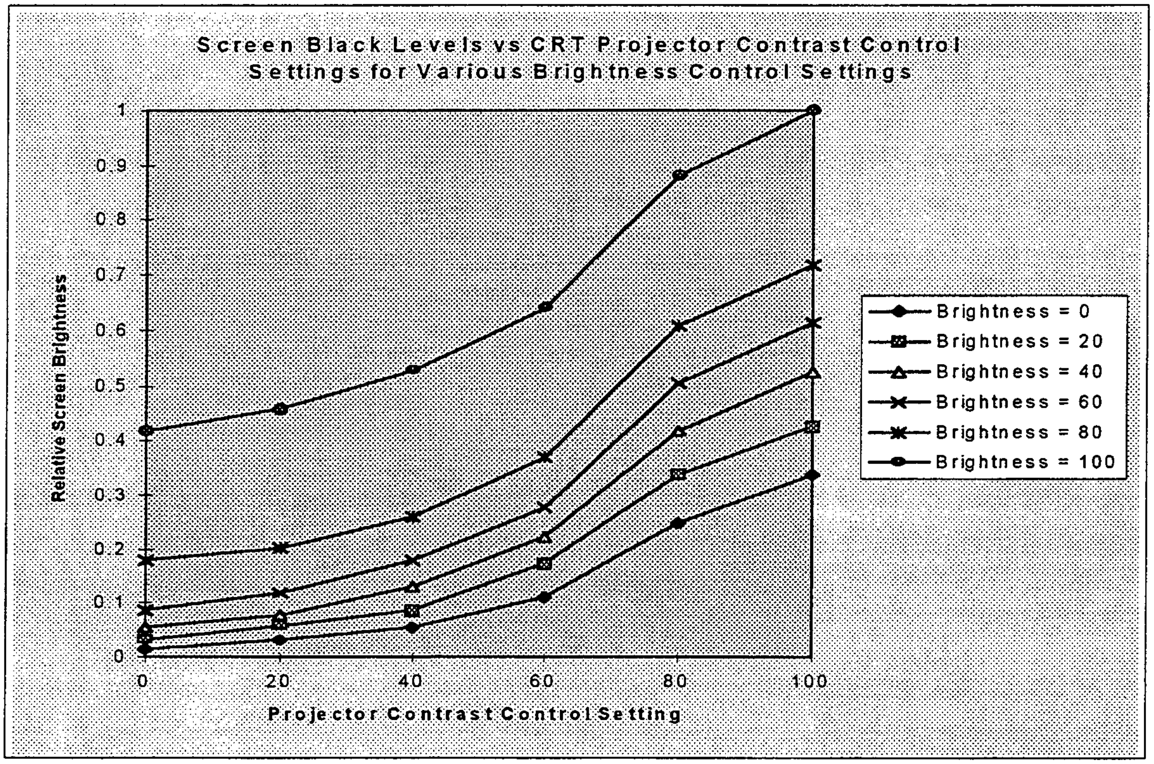


Figure 6. Screen Black Level Output Versus Brightness Control Setting

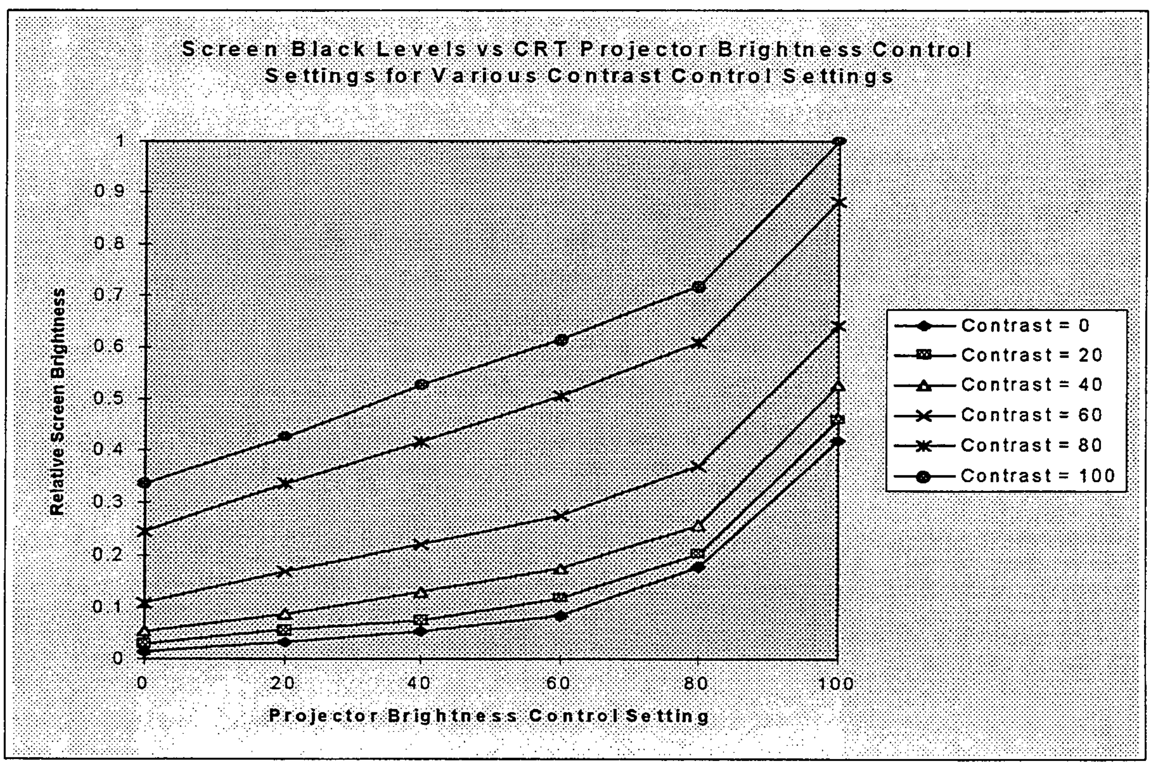


Figure 7. Screen Black Level Output Versus Contrast Control Setting

CRT Projector Gamma Measurement, Preliminary Data and Analysis

Under the assumption that adjusting the brightness control had no affect on the CRT display gamma, a single CRT display gamma was sought for the gamma compensation process. Again, the previously discussed electronic slide show format was used. This time the slides consisted of three image sequences. Each red, green, and blue color sequence consisted of nine increasing color intensities of 0% , 12.5%, 25%, 37.5%, 50%, 67.5%, 75%, 87.5%, and 100%.

Using the three image sequences, measurements were made to find the individual gamma value for each of the three CRTs. Measurements were made of each of the 27 color intensities at a single projector contrast and brightness setting of 50. Only the CRT being measured was allowed to illuminate the screen, with the two others blocked. From this data a CRT projector gamma for each color output was determined.

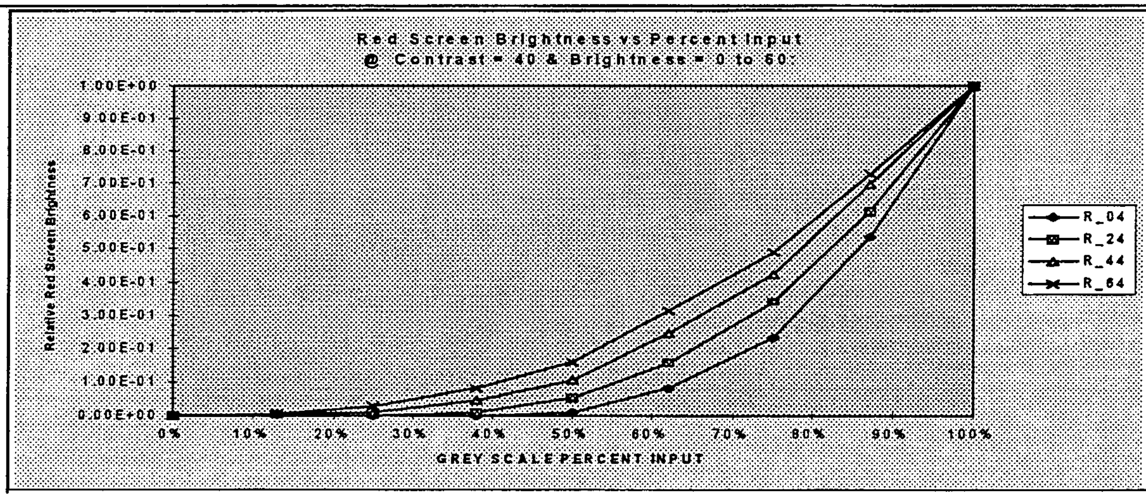
Later, a gamma compensated gray scale image using an averaged gamma value, was displayed by the CRT projector. Compensated for the CRT projector brightness and contrast setting of 50, the output image brightness was measured at a brightness and contrast setting of 50. As expected, the image was found to be correctly compensated by measuring the gray scale brightness values. After adjusting the projector brightness control to reduce the image intensity, the gray scale values were reexamined. They did not match predicted values. Instruments and cabling were rechecked, but no changes occurred. The data was then reexamined.

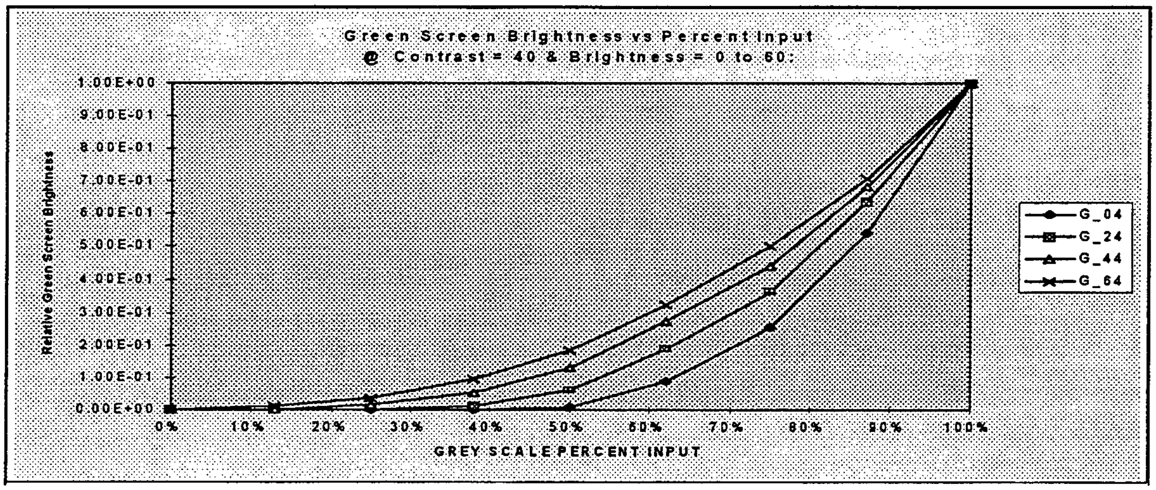
It seems so obvious now, but during the course of data gathering and experimentation we had formed an erroneous conclusion...that the gamma was constant for changes in the CRT projector brightness control. Acting on that presumption, a single gamma had been determined which could supposedly be used to compensate the output image for any brightness setting between 0 and 50. While earlier measurements of maximum image output at maximum image input indicated a linear relationship, that did not prove that the gamma itself was constant. The problem was that only the two endpoints of the gray scale had been measured, and the middle points had been neglected.

CRT Projector Gamma Measurement, Final Data and Analysis

During the subsequent round of data gathering, measurements were made for each of the nine red, green, and blue color intensities at a contrast control setting of 40 while varying the brightness control between 0 and 60. Then data was collected for a constant brightness control setting of 40 while varying the contrast control between 0 and 60. As extensive as it was, this collection was still not all encompassing, but it did cover the areas of interest.

Final test results are presented in Figures 8 and 9. Figure 8 shows the relative variation in output image (screen) brightness plotted as a function of input image intensity for each red, green, and blue video CRT. Four sets of data appear for each color. Data sets were generated by keeping a constant projector contrast control setting of 40 and varying the brightness control from 0 to 60 in four increments, 0, 20, 40, and 60. Legends at the side are decoded this way: the letter represents the color (R is red etc.) and the two following digits represent the 10's digit





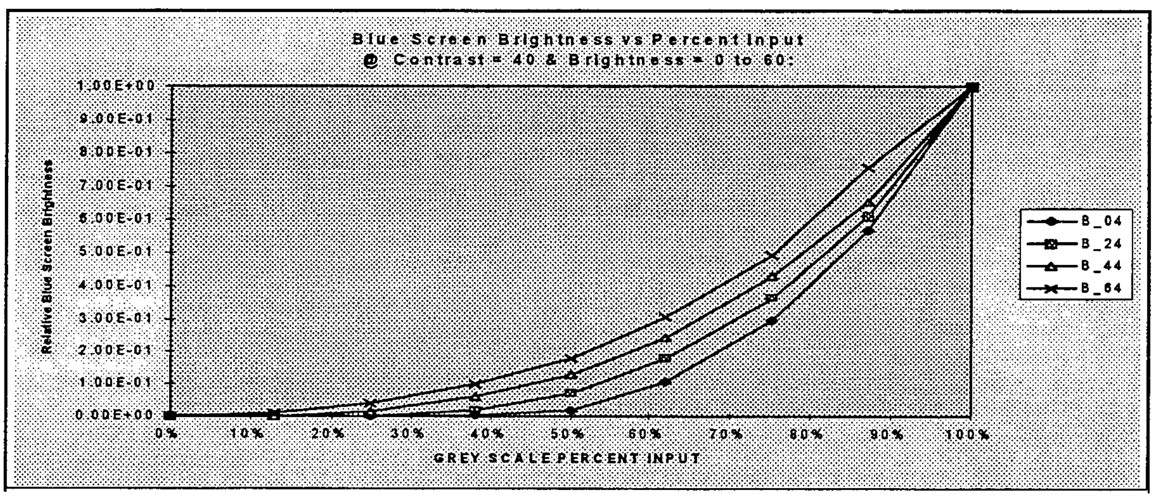


Figure 8. Screen Brightness Versus Percent Input at Varied Brightness Control Settings

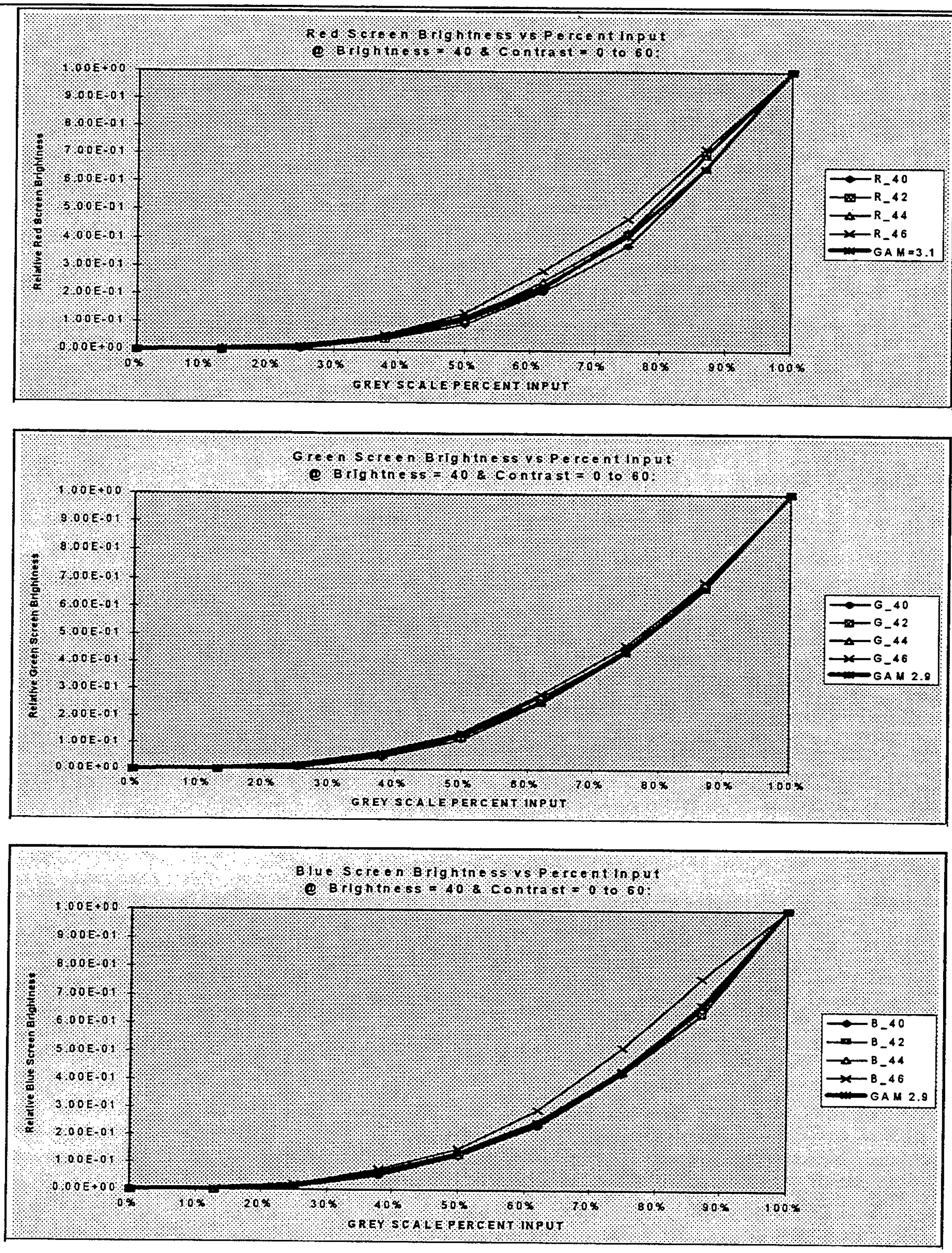


Figure 9. Screen Brightness Versus Percent Input at Varied Contrast Control Settings

of the brightness and the contrast setting (R_24 is the legend for the red CRT with brightness at 20 and contrast at 40). Data for all three CRTs show that gamma decreases as the CRT projector brightness control is increased. This finding explains why the test image output did not match the predicted values discussed earlier. Evidently the gamma was not stable for changes in the brightness control.

Fortunately, the results shown in Figure 9 are completely different. Again, as in Figure 8, relative variation in output image brightness is plotted as a function of input image intensity for the red, green, and blue video CRTs, with four sets of data appearing for each color. This time, however, the data sets were generated by keeping a constant projector brightness control setting of 40 and varying the contrast control in four increments, 0, 20, 40, and 60. Legends are decoded in the same manner. Data collected for all video channels indicate that gamma is relatively stable for increasing projector contrast control settings. This is precisely the opposite result that was expected from the preliminary data.

There is a fifth data set shown in Figure 9 for each of the three video CRTs indicating an "average" gamma for that CRT. All three averages are surprisingly close, with the red and green CRTs indicating a gamma of about 2.9 and the blue indicating a gamma of 3.1. Note also that both blue and red CRT gamma begin to diverge from the average at the higher contrast control setting of 60. Therefore, it appears that altering this CRT projector contrast control will serve our present purposes at projector contrast settings of 40 and below and perhaps even at 60 if we can tolerate a small change in gamma at higher output levels.

By looking first at Figure 4 and then comparing the results of Figure 9, it seems that there is sufficient evidence to show that the contrast control on our Night Scene Display System test bed CRT projector can be used to provide output image brightness changes on the order of three to one, and can do so without any significant changes in output image gamma.

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CONCLUSIONS

In the interest of maintaining image quality, the use of the projector controls to change the output image levels would be the preferred method of simulating changes in night scene irradiance. At present, meeting the long term objective of eight to one or better control of output image brightness at a constant gamma is possible only with use of additional neutral density filters to reduce CRT output. The primary objective of demonstrating time of night effects on the order of three to one that was depicted in Figure 1 is certainly feasible using the present Night Scene Display System. It is also possible that additional adjustments to the projector would have extended the range available to us, but no attempt was made to change factory setup or specifications.

While not discussed specifically in this report, it seems feasible to implement a system where a carefully chosen combinational range of individual contrast and brightness control settings could achieve output image brightness changes on the order of 50 to 1 or better. Since the gamma corrections required for these settings will, in all probability not be identical, one must then rely on the ability of the image generator to make the gamma corrections in real time.

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APPENDIX A

SOME LESSONS LEARNED

From several initial mistakes certain working procedures evolved, and it might be instructive at this point to mention a few.

To reduce quantization effects when assigning gray levels, create the gray-scale bitmap images using 24 bit bitmaps (8 bits, 256 levels, per color). When displaying the bitmap gray scales, make sure the display is operating in 24 bit mode.

The best measurement environment is a darkened room, one where the only source of illumination is the display itself. However, a low level of ambient illumination is okay as long as the level is known and subtracted from all readings.

Lock the position of the measurement device relative to the display image, ie. at the display center, and ensure that the measurement field is fully within the gray scale area of interest.

Prior to measurements, ensure that the display and measurement device are warmed up and stable.

Since video displays are composed of sequential frames with less than 100% duty cycles, ensure that data sample exposures are on the order of three to eight video frame times. This will help to reduce sample to sample deviations due to vertical blanking periods.

Resist replacing component parts of the system between data collection intervals. If you do, make note of it. While being on a learning curve, sometimes long intervals would pass between periods of frantic data collection. In one instance the lull lasted several weeks. During that period, a video splitter was replaced and the act of replacement eventually forgotten. The video gain of the new splitter turned out to be slightly different than the previous one. It took several days to figure out the "data problem."

Above all, never alter video resolution or fiddle with projector focus or location. It is so tempting to make that "minor tweak" just to make things a little better.

To reduce data collection time considerably, plan ahead so that similar data sets can be obtained in one sitting.

Reduce or eliminate visitors. If a knob or instrument can be turned or moved, someone will do it.

Make sure that all video cables are secure and the connectors tight. It's really disheartening after a long tedious data collection period to see the output brightness jump when video cables are accidentally jiggled.

And last, in a brief acknowledgment of Murphy, realize the probability of a data file being misplaced or deleted is in direct proportion to it's importance.

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