# REQUIREMENTS for SOFT COPY PROOFING

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Abstract: The widespread use of Cathode Ray Tubes (CRTs) as soft copy proofing devices in color electronic imaging systems has raised serious questions as to the appropriate viewing conditions and the necessary colorimetric and tone reproduction characteristics of the color monitors themselves. The effects on image reproduction of the surrounding room illumination on both the optical and the psychophysical characteristics of the displayed picture are discussed. Also, the relevant optical characteristics of CRTs of the type used in modern soft copy proofing systems are presented. These results are compared with the corresponding characteristics of a typical prepress proofing system (3M Matchprint) when viewed under industry standard D5000 viewing conditions. Conditions are derived under which an appropriate match between the soft and hard copy proofs can be achieved.

## The Purpose of the Soft Copy Proof

Before discussing the colorimetric requirements for a soft copy proofing system, it is well worth defining what its role should be in a modern Color Electronic Prepress System (CEPPS). The soft copy proof should give the real-time feedback to the scanner operator that is required to enable him to color correct and otherwise edit the image interactively. The purpose of the soft

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proof is not to eliminate the hard proof, but rather to increase the efficiency of the operation by reducing guesswork and makeovers. This results in a significant savings in both time and materials.

The hard proof remains a necessity for several reasons. First, it becomes part of the contract between the color separator and the buyer of the separations that defines how the final printed product should look. Second, since the films used to expose the hard proof are the same as those used to expose the plates, the hard proof is the only way to evaluate errors in the film writing section of the system. Finally, and perhaps most importantly, the hard proof is the communications link between the color separator and the pressroom. It defines the necessary adjustments that must be made in order to provide the Customer with press sheets that meet his expectations.

Soft proofing is of value only if it provides an accurate representation of the final printed product. To this end, the data processing part of the system must be able to remap colors that are displayable but not printable into the gamut realizable on the printed sheet. Compensations must also be made for differences in viewing conditions of soft and hard proofs due to differences in surrounds, flare, lighting and viewing geometries, and highlight luminances. Some of these factors have been considered in the literature by Bartleson and Breneman (Bartleson and Breneman, 1967), Yule (Yule, 1967), and Hunt (Hunt, 1975). However, relatively little data are available on their applicability to soft copy proofing systems, nor has much attention been paid to problems particular to such systems. It is not the purpose of the present work to elaborate all of the adjustments necessary to achieve agreement between the color display monitor and the hard copy proof, but to define the physical conditions that are required in order to enable a color match.

## The Type of Color Match Required

Hunt (Hunt, 1975, Chapter 11), has defined several "objectives in color reproduction." These include exact, colorimetric, and equivalent, reproductions of color. All of these objectives are defined in terms of the relationships between original scenes and their corresponding reproductions as viewed by the end consumer. In the case of soft and hard copy proof matching, however, both of the images to be matched in appearance are reproductions of the original scene, and it can be assumed that all editorial and aesthetic changes have been made either by the photographer or the scanner operator.

If, when viewed under standard viewing conditions, the hard proof and the soft proof can be made to have the same chromaticity and absolute luminance at all image points, then an exact color match has been achieved. The images will have the same appearance providing that the surround and observer's state of visual adaptation are matched, and that the observer has normal color vision.

If only relative luminances can be made equal, then a colorimetric match between the hard and soft copy proofs may be achievable. Since the maximum luminance of typical CRT monitors is only about 30 footlamberts, it is usually the case that point for point luminance matching between monitor and proof is not possible. Even if the two images can be provided with equivalent surrounds, the perceived tone reproduction will not be the same since the brightness function depends on the absolute highlight luminance as well as the surround (Bartleson and Breneman, 1967). In order that the two images have the same appearance, appropriate remapping of the luminances is necessary so that equal relative brightnesses can be established for all image points. It is also necessary that the chrominance gamut of the monitor exceed that of the hard copy proof at all relative luminances, since, as was noted above, the latter is the reference point.

If it is not possible to provide the same surround conditions for viewing of hard and soft proofs, then equivalent color matches must be provided. In this case additional remapping of the colors must be provided, and the specific adjustments required become more complicated and less well understood.

Fortunately it is a relatively simple matter to provide a surround of almost any chrominance and luminance on the soft copy proof so that colorimetric matching is possible. This is accomplished by writing a border into the image memory around the area actually occupied by the image. Since the printed picture is usually viewed with a border of white paper, it is appropriate to select a border for the soft proof that has chromaticity equal to that of white paper (as illuminated by the D5000 standard) and luminance equal to that of the highlight in the displayed image. Under these conditions a colorimetric match can be achieved if the gamut of chromaticities producible with the display monitor is at least as great as that of the printing process (when viewed under standard viewing conditions) and if the contrast of the monitor is at least that of the reflection proof. It is the purpose of the current research to examine both gamut and contrast as functions of viewing conditions.

## Colorimetric Models of the Hard and Soft Copy Proof

In order to represent the colors on the hard copy proof accurately, it is necessary to have a model of the relationship between ink and color. Data suitable for "calibrating" such a model should be free of extraneous factors such as surround effects, flare due to specular reflections, etc., so that the model can associate inkings with the colors they are intended to produce. On the other hand, since the soft proofing medium (monitor) is intended to match proofs viewed under real-world conditions, its model for color reproduction should take account of those conditions as they apply to both monitor and proof. As noted previously, the monitor should be calibrated and operated under conditions which make it possible to compensate for viewing conditions, as well as differences between the two mediums.

The most successful colorimetric models of halftone printing processes are those based on the work of Neugebauer and include contributions by Hardy and Wurzburg (Hardy and Wurzburg, 1948), Clapper and Yule (Clapper and Yule, 1953), Pobboravsky and Pearson (Pobboravsky and Pearson). In this class of model, the lithographic process is assumed to be an additive one with a multiplicity of effective primary stimuli. The model parameters required include the tristimulus values of the effective primaries, as well as terms which compensate for mechanical and optical dot gain. If the geometry of the illumination is not optimal ($45^{\circ}$ illumination, $0^{\circ}$ collection), then additional parameters will be required to account for differing amounts of specular reflection.

The largest gamut of chromaticities producible, with the four-color lithographic printing process, is defined by the chromaticities of the single process color solids and the three two-color solid overprints when the illumination and viewing geometries are such that no specular component is collected. This is not to say that all of the included chromaticities are producible at all luminances, only that they are producible at some. Inclusion of specular reflections forces the maximum achievable gamut to be reduced since this is equivalent to adding the source illumination to all colors in the image and results in both desaturation and loss of shadow contrast.

The maximum dynamic range of the four-color lithographic process is limited by the density of the darkest printable patch. Barring ink opacity, interlayer reflections, and trapping problems, this would be the 400 percent overprint consisting of solids of each of the three process colors plus black. Due to these effects, the darkest patch is often that consisting of the cyan, magenta, and back solid overprint. Like the chromaticity gamut, the dynamic range can be reduced by specular reflections in real viewing conditions since these rarely approximate the ideal 45:0 degree geometry that is standard for reflection densitometers (ANSI, 1977).

An often used colorimetric model for the CRT is a simple linear summation of the tristimulus values of the red, green, and blue phosphors, each weighted by a factor related to the voltage applied to the appropriate electron gun (Wentworth, 1955, Chapter 6). Since the phosphors themselves emit radiation roughly proportional to the 2.2 power of the applied voltage, a (1/2.2) power law is sometimes applied to the voltages to compensate. This is known as Gamma correction. Since the 2.2 power law is only approximate, and is valid only over part of the monitor's operational range, it is better to measure the response characteristic directly and to compensate exactly. This is easily accomplished by inverting the measured response function and applying the resulting linearization function through a set of look-up tables. It is practicable to invert the function only when the gradient is at least 20 percent, however, and this puts a lower limit on the correctable dynamic range of the CRT.

Just as specular reflection components reduce the gamut and dynamic range of the hard copy proof, so too do stray light and reflections from the phosphor coating reduce the gamut and dynamic range of the CRT. If the reduction is not so much as to reduce these parameters below that of the proof, then they can be compensated in the data processing system. If there is sufficient stray light to cause the CRT's gamut to be smaller than that of the hard proof or it's dynamic range to be less than that which is printable, then no amount of data processing can yield a monitor/proof appearance match.

The primary source of stray light and surface reflection on the monitor is the ambient lighting in the room. Any characterization of the colorimetry or gray scale response of the monitor must be done under the ambient conditions present during viewing.

## Experimental

The chromaticity gamuts and luminance dynamic ranges of a typical hard proofing material and a soft proofing system were measured under several conditions. 3M Matchprint was used for the hard copy proof, and the model 8101 Electronic Picture Preview and Editing Station from an EIKONIX DESIGNMASTER® 8000 color prepress system was used to generate the soft proof. This system has been described previously (Masia, 1984).

Patches consisting of the three process color solids and the three two-color solid overprints were prepared using the Matchprint proofing system. These were used to measure the color gamut. In addition, a no ink patch was prepared, and also one containing solids of all four inks. These were used to measure the dynamic range of the hard copy proofing system.

Displays of solid red, green, and blue fields were generated using special test software on the DESIGNMASTER Preview and Editing Station. Uniform gray patches were also generated at various intensities in order to characterize the gray scale response of the CRT monitor. Primary testing was performed using a Tektronix 690 SR high-resolution monitor with a 0.43mm pitch shadow mask. The color gamut of an Aydin Controls Model 8835 monitor was also evaluated.

All measurements were made with a Spectra-Pritchard 1980A telephotometer equipped with a set of tristimulus filters for colorimetry and an f/3.5 objective lens. Two different illumination geometries were employed for the measurement of reflection samples, and three different levels of general room illumination were used for the measurement of the self luminous CRT display. The two reflection geometries are referred to as geometry "A" and geometry "B." These are shown in Figures 1 and 2. In both cases industry standard D5000 fluorescent tubes were used to illuminate the samples. In geometry "A" great care was taken to insure that the collected specular component of reflection was minimized by illuminating from about 45 degrees and collecting along the normal to the sample surface. Geometry "A" is very similar to that of a standard reflection densitometer. Geometry "B" is much closer to that found in typical color viewing booths that are made to conform to ANSI PH 2.32 (ANSI, 1972). In fact, the measurements were made by locating the photometer at approximately eye level in front of a Graphic Technology, Inc., Model CVS-1 color viewing booth, and measuring the samples located on the viewing surface.

In the case of the soft copy display, the measurement geometry was as shown in Figure 3. The off axis and light trap configuration was used to eliminate specular reflections from the glass surface of the tube itself. Both chromaticity gamut and gray scale response measurements were made under three different levels of general room illumination. General room illumination was measured at the face of the CRT display with a Gossen illuminance meter. In the case of no, low, and moderate room light the illuminance was 0, 0.3 and 0.5 footcandles respectively.

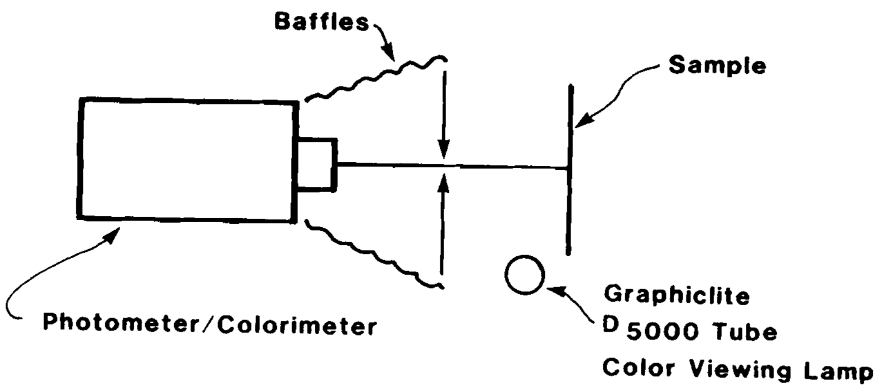


Figure 1. Reflection measurement geometry "A."

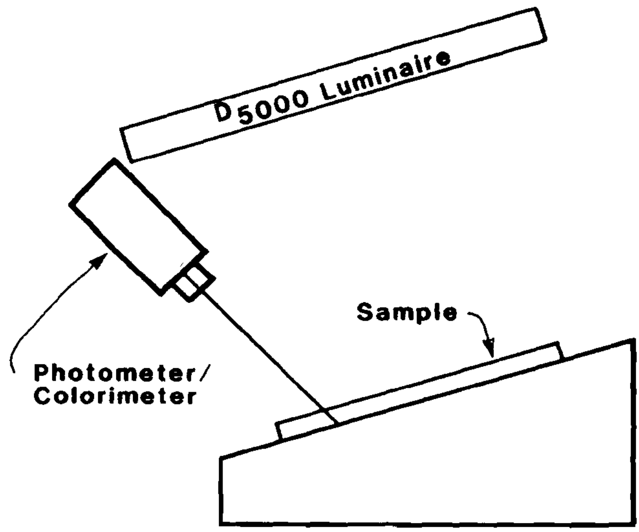


Figure 2. Reflection measurement geometry "B."

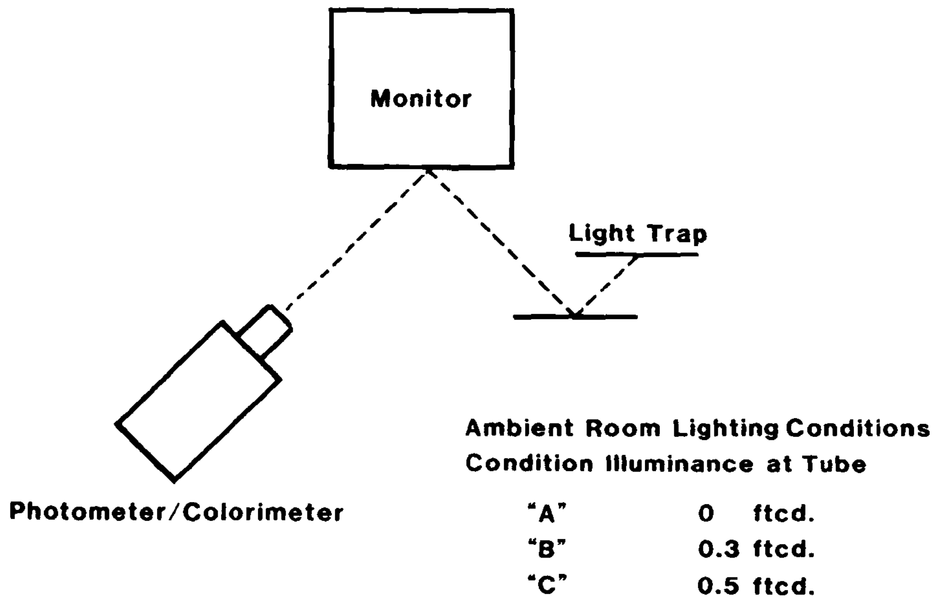


Figure 3. Soft proof measurement geometry.

## Results and Discussion

The chromaticity gamuts of the reflection print material under both the "A" and the "B" measurement geometries are shown in Figure 4. As would be expected, the gamut is reduced by the partial inclusion of the specular component under the "B" condition. The offset of the yellow point is probably due to a slight difference in color between the two sets of illuminating lamps. The maximum possible luminance contrast was calculated as the common logarithm of the ratio of the paper white luminance to that of the 400 percent overprint. These were 1.84 and 1.27 log units for the "A" and "B" geometries respectively. That the dynamic range was reduced by 0.57 log (or density) units when the geometry was changed significantly was not surprising. However, the fact that the use of a "standard" viewing booth produced a 3.7 times increase in the magnitude of the specular component was not expected.

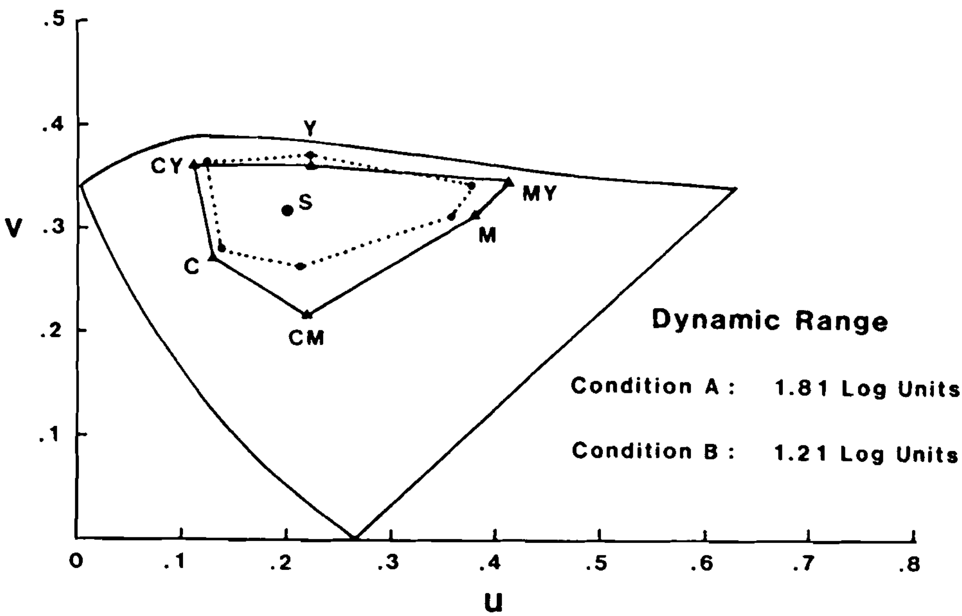


Figure 4. Chromaticity gamut of hard proof under two illumination conditions.

Gray scale response for the Tektronix 690 SR monitor driven with equal red, green, and blue command values are shown in Figure 5 for all three illumination conditions. The individual color contrast and brightness controls were adjusted to give a chrominance of (0.209,0.326) in 1961 CIE UCS u,v units at both the full scale signal level and at 7.5 percent of full scale. This chrominance corresponds to that of standard King James white paper stock when illuminated with the ANSI D5000 standard illuminant. The overall brightness controls were adjusted to produce a 100:1 (2.0 log units) luminance range over the 7.5 to 100 percent input range.

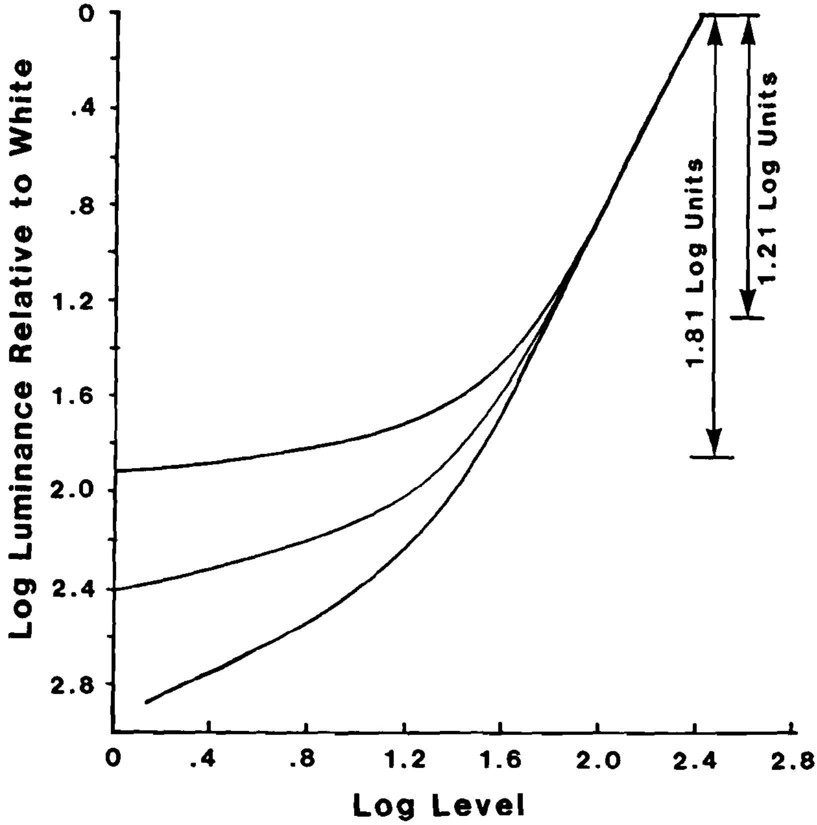


Figure 5. Gray scale response functions of Tektronix 690SR color monitor.

The gray scale response functions are typical of those for optical systems with stray light or flare components and are in close agreement with results presented by Wentworth (Wentworth, 1955). The upper parts of all three of the curves show the power law behavior (as evidenced by the straight line on the log-log plot) with gamma of about 2.1 to 2.2 that is typical of these devices. Even with no room illumination however, there is a significant departure from the power law behavior when the luminance falls to about 0.01 of full scale at a command level of about 12 IRE units. When the room light is increased, the point at which this departure occurs and the total dynamic range of the monitor decrease very rapidly. Shown on the side of the figure are the log luminance, or density ranges of the reflection print material under the two viewing geometries. If the hard proof is to be viewed under condition "B" with an effective density range of only 1.21, then it matters little which of the three illumination levels are chosen since, over this range, all three behave nearly identically. If viewing conditions similar to condition "A" are employed, however, then the high ambient room lighting condition is at the limit of applicability, and the 0.3 footcandle level is probably a more realistic upper limit.

Results of the chromaticity measurements, at each of the three illumination levels, are shown in Figure 6 for the Tektronix monitor. Chrominances outside of the triangle connecting the red, green, and blue points are not displayable with this device. The desaturation due to the addition of stray light is to be expected, since this is equivalent to adding white light to each of the three primaries. Also plotted in the 1961 CIE u,v diagram are the chromaticity coordinates of the solid ink patches for the reflection prints. Note that there is a range of very saturated cyans and greens that are printable, but not displayable, though this range of colors is reduced dramatically when typical (geometry "B") viewing conditions are employed. Reducing the room illumination does little in the way of improving the situation for cyans and greens. In some cases a narrow range of very saturated yellows is not displayable either. All of the printable reds and magentas are displayable on the soft copy monitor for the illumination levels tested. The high room light level is about the highest one would want to use without bringing about problems in these regions of the color space.

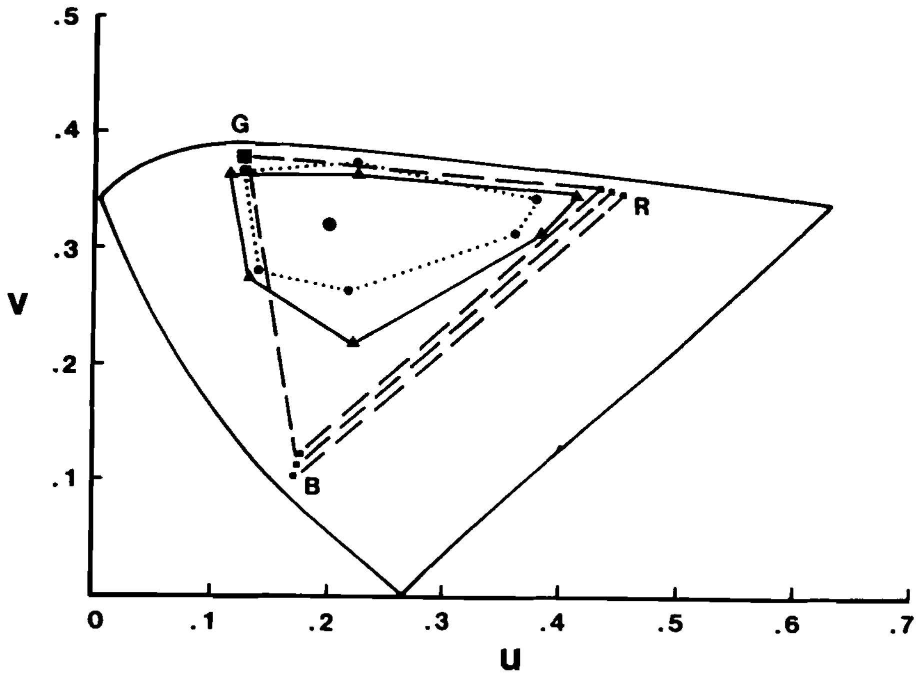


Figure 6. Chromaticity diagram showing locations of effective primaries for Tektronix 690 SR monitor.

Recently several new picture tubes have been introduced to the market that employ special dark glasses and thin film coatings to reduce the sensitivity to ambient illumination and increase the saturation of the effective green phosphor. A chromaticity plot of the primaries employed with one of these tubes is shown in Figure 7, again with the gamut of the reflection proofing system superimposed. No significant desaturation of the phosphors was observed when the illumination level was changed between the 0, 0.3 and 0.5 footcandle levels. The increase in saturation of the green phosphor is sufficient to render all but the most saturated cyans displayable. Additional testing of this tube is now underway.

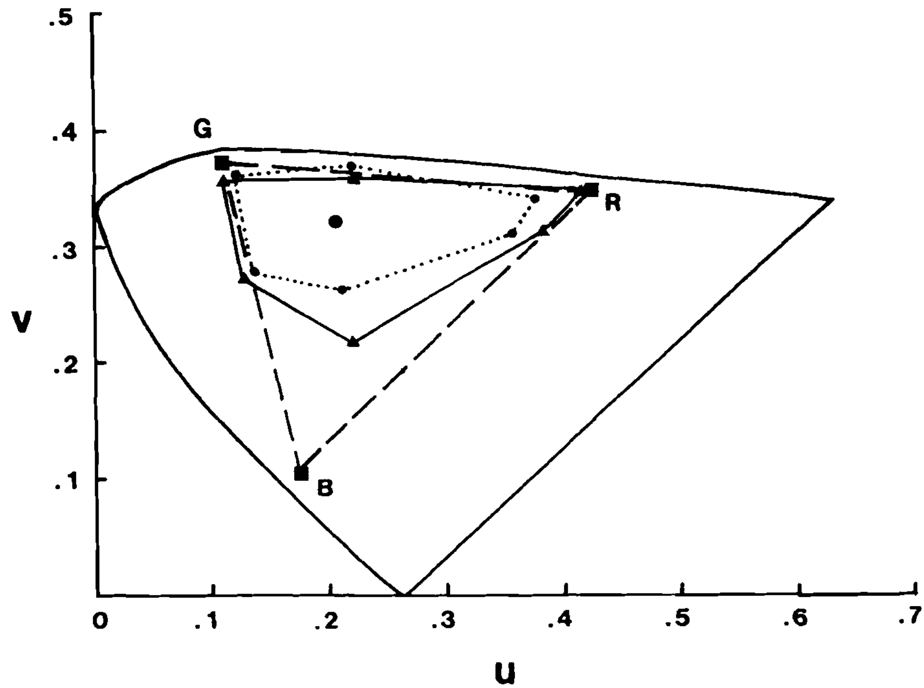


Figure 7. Chromaticity diagram showing locations of primaries for Ayden Controls monitor.

## Conclusions

In conclusion, it has been found that soft copy proofing can be used effectively if the following conditions are met:

1. The operating environment of the color monitor should be such that the illuminance at the face of the monitor be less than approximately 0.5 footcandles. The color temperature of the illumination is also important. For example, it is not

possible to achieve color balance in the shadows on the Tektronix 690 SR monitor described previously if the color of the unexcited faceplate is redder than .2176, .3320 (1961 u,v).

2. If the conditions in 1 are met, the gamut and contrast displayable on the properly adjusted monitor will exceed that on a reflection proof viewed under fairly typical conditions and it will be possible to remap the colors in the display memory to represent their appearance in the hard proof.

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