DESIGN CRITERIA FOR AN INPUT COLOR SCANNER EVALUATION TEST OBJECT

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Abstract: The need for a color test object that guides the basic color correction adjustments of the electronic color separation scanner provides the starting point for this paper. The scope of this need, including differences in original photographic color materials, different process ink colorants and differences in the red, green, and blue responses of the various color scanners will be identified as variables. A three-element test object evolved from a detailed analysis of this need: A "selective" neutral scale based on visual perception step-to-step differences, a neutral scale plus corresponding C-M-Y-R-G-B dye scales, and a set of 120 color patches (10 variations in lightness and saturation at 12 different hues) which cover the color space of the color material. The engineering of these elements, using colorimetric mapping to CIELAB L*a*b* aims for each element, and the conversion of these into dye density, color material aims will be discussed.

Introduction

A common problem in graphic arts is the task of making a colored sample in a reproduction "match" a colored sample in the original under some specified illuminant. By "match" we mean that the colored samples look the same to an observer with normal color vision. In fact, the spectral curves of the colored samples will most likely not be identical because the dyes or inks in the original and reproduction are rarely identical. Thus under one set of viewing conditions, the colored samples appear to match, but under another set of viewing conditions, the colored samples will not match. These two colored samples are termed a "metameric pair" and they exhibit "metamerism" (Billmeyer, 1981). The important principle here is that two objects which appear to be the same under one viewing condition do not appear to be the same under another viewing condition because their spectral curves are different. If the spectral curves were identical, the colored patches would be a "nonmetameric" pair or an "invariant" pair and would match under all viewing conditions.

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There is another form of metamerism, termed "observer metamerism" (Billmeyer, 1981), in which two colored objects which appear to match to one observer do not match for another observer. In the broadest interpretation of this definition, one observer could be a human and the other observer could be an instrument, such as a densitometer or a color scanner. It is easy to forget about observer metamerism and think that if two objects look the same, they will measure the same, or, conversely, if they measure the same, they must look the same. In fact, with objects made of different colorants, as is the case in samples used in the graphic arts industry, observer metamerism will be very common if one of the observers is an instrument. As above, if the two colored samples have the same spectral curves, they will match to all observers, whether human or instrumental.

In the usual case where the original is a photographic image and the reproduction will be made with a set of printing inks, it may be possible to obtain an exact color match, but the spectral curves will be different, so the probability of observer metamerism between a human observer and an instrument is very high. In this case, the use of a known test object made from the same photographic material as the materials that will be scanned can be used to guide the operator in making the basic color correction adjustments to an electronic color separation scanner. This paper describes the design and specification of such a color test object.

Requirements of the Test Object

If the test object is to be useful, it must meet the following criteria:

1) The test object must be made from the same photographic material as the objects that will be scanned. The reason for this is that if both the test object and the object to be scanned are from the same photographic material, they will have the same colorants. Two colored areas which match will then have the same spectral curves and the two areas will be a nonmetameric pair. The result is that if they look the same, they will measure the same; if they look different, they will measure different.

2) The test object must have a neutral scale. The neutral scale will be a selective neutral scale because it will be made up of the cyan, magenta, and yellow dyes in the pho-

tographic material. In this way the metamerism problems noted above can be avoided.

3) The test object must have a set of colored patches:

a) that cover the color gamut (Hunt, 1987) of the photographic material,

b) that provide a guide for making the color correction adjustments on the electronic color separation scanner,

c) that include a number of the more important and more common hues, and

d) that are arranged in an orderly pattern to facilitate automated evaluation of predetermined values stored in a look-up table.

Design of the Test Chart

The chart we have designed meets all of the criteria listed above.

1) The charts we are making will be generated on photographic materials - the same photographic materials that are used in making original images and that are commonly scanned in the graphic arts industry. Due to the different colorants in different photographic materials there must be a different chart for each photographic product.

2) Our test chart has two neutral scales, one perpendicular to the other. Each neutral scale covers densities from white to black in increments that are visually equal. It should be noted that equal visual increments are not the same as equal density increments (see below).

3) Our test chart has a variety of color patches:

a) There are cyan, magenta, yellow, red, green, and blue scales that meet the criterion that in each of the patches in these pure color scales the amount of each dye present, if the dye is present, will be the same as the amount of that dye in the corresponding patch of the neutral scale. These scales, including the neutral scales, are the most important scales to use in making the color correction adjustments on the electronic color separation scanner.

b) In addition there are 120 color patches that cover the color gamut of the photographic material. There are 12 additional color patches that cover the gamut of typical flesh tones. These 132 patches are most useful in checking that the color correction adjustments have been made properly and that colors in the original will be reproduced properly.

c) Because the color patches have been laid out in a regular pattern and because the chart itself includes some fiducial marks to aid in alignment, this chart can be set on a scanner, automatically scanned, and the results compared with a table of stored values.

d) Because the dyes in different photographic materials are different, the color gamuts will be different. It is, therefore, necessary to make a number of charts, one for each photographic material, and each of the charts will be different. The following description of how to specify the color patches for a chart and how to do the calculations needed to make the chart are general and do not apply to any specific chart. The techniques to calculate and make a specific chart are identical; all that would change would be the spectral dye curves and the density-log E curves for each product.

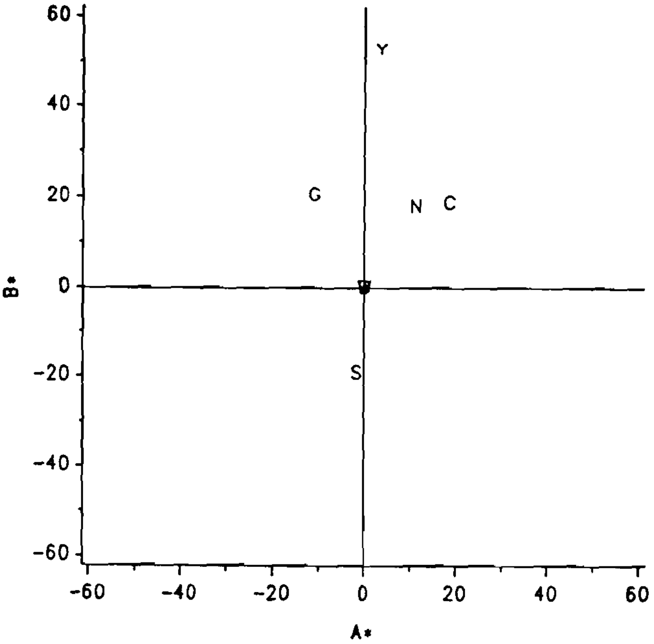
Specification of the Color Patches

Out of all of the color spaces that could be used to graph the dye gamut of a system, we have chosen to use the CIELAB L*a*b* system (CIE, 1978, 1986). In this space, L* represents lightness (white to black) and the a*b* coordinates indicate the hue information. Two advantages of the CIELAB L*a*b* space are that equal distances are approximately equal color differences and that straight lines radiating out from the L* axis are approximately constant hue. We made use of these two properties in designing the test chart.

The three-dimensional CIELAB L*a*b* space is usually represented by a number of two-dimensional plots. One of the plots represents what you would see if you looked straight down the L* axis - in this case you see all of the points plotted on the a*-b* plane with no information about the L* value of the points (Figure 1). This gives accurate hue information, but without the lightness information. To understand the most common second plot, it is necessary to define chroma, c*:

$$c* = \sqrt{a*^2 + b*^2}$$

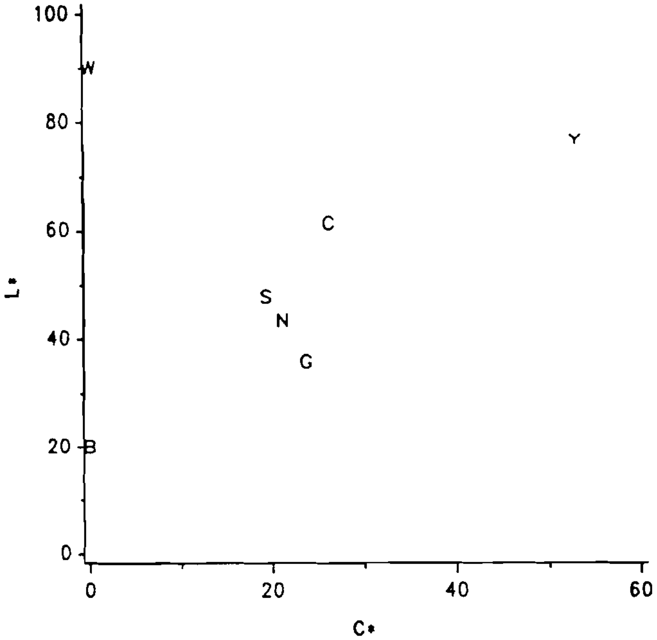
Figure 1. A*-B* Diagram
showing Several Common Colors



W=White, B=Black, Y=Banana Peel, G=Grass, S=Sky
N=Black Skin, C=Caucasian Skin

Chroma is the distance of any point from the L* axis. With the specification of chroma only, however, the specific a* and b* values have been lost, so the hue information has been lost (the hue information comes from the a*-b* diagram, Figure 1). The plot of L*-c* provides a convenient second graph, Figure 2, to represent CIELAB L*a*b* space. This plot gives the lightness information that was missing on the a*-b* graph. Another technique occasionally used is a slice along the L* axis at some specified hue angle. The axes are again L*-c*, but only colors at the specified hue angle are plotted. This will then show all of the colors at that hue angle that a system will produce, Figures 3 and 4. This type of graph is the most useful for depicting the color gamut of a system at a particular hue angle.

Figure 2. L*-C* Diagram
showing Several Common Colors



W=White, B=Black, Y=Banana Peel, G=Grass, S=Sky
N=Black Skin, C=Caucasian Skin

Figure 3. L*-C* Diagram
showing the Dye Gamut for a Red Hue Angle

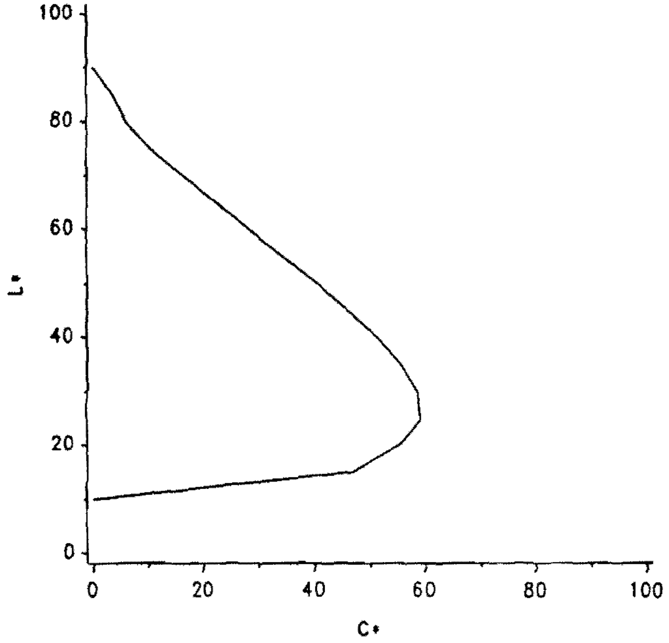
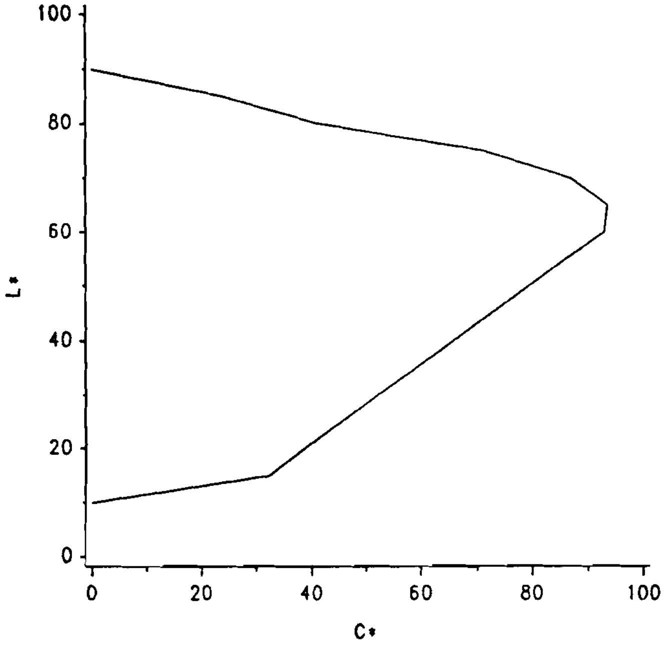


Figure 4. L*-C* Diagram
showing the Dye Gamut for a Yellow Hue Angle



With this color space, we can now define our color patches for the chart:

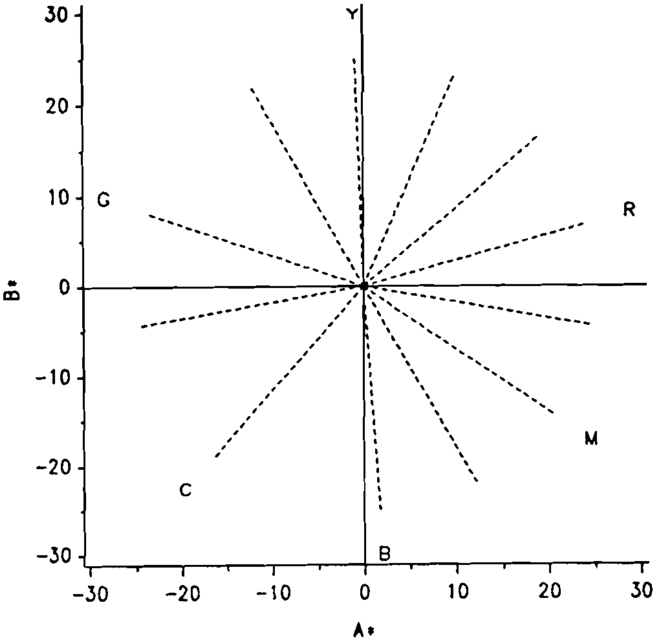
1) The neutral scale has equal visual intervals, which in CIELAB color space means equal intervals in L*. The range in densities is from white to black. For this scale to be neutral, a* = 0 and b* = 0.

2) The cyan, magenta, yellow, red, green, and blue scales are defined as the same amount of dye in each patch as the corresponding neutral patch, if that dye is present in the color patch. For instance, in the neutral patch, which has a visual density of 1.0, there is 1.0 amount of cyan dye, 1.0 amount of magenta dye, and 1.0 amount of yellow dye (dye amounts are in arbitrary units). The corresponding yellow patch has 1.0 amount of yellow dye and no cyan or magenta dye. Because of the unwanted blue absorptions of the cyan and magenta dyes, the blue density of the yellow patch will be lower than the blue density of the

corresponding neutral patch, but the amount of yellow dye is the same.

3) We wanted the 120 other color patches to cover color space: 12 hue lines with 10 patches on each hue line. The hue lines are laid out in Figure 5. From this diagram you can see that we have included more hue lines, and thus more colors, in the more important yellow-orange-red-purple-blue part of color space. In order to understand the 10 patches chosen at each hue, it is necessary to understand the dye gamut of a photographic material in CIELAB L*a*b* space.

Figure 5. Twelve Hues chosen for the Chart



The common hues yellow (Y), red (R), magenta (M), blue (B), cyan (C), and green (G) are labeled.

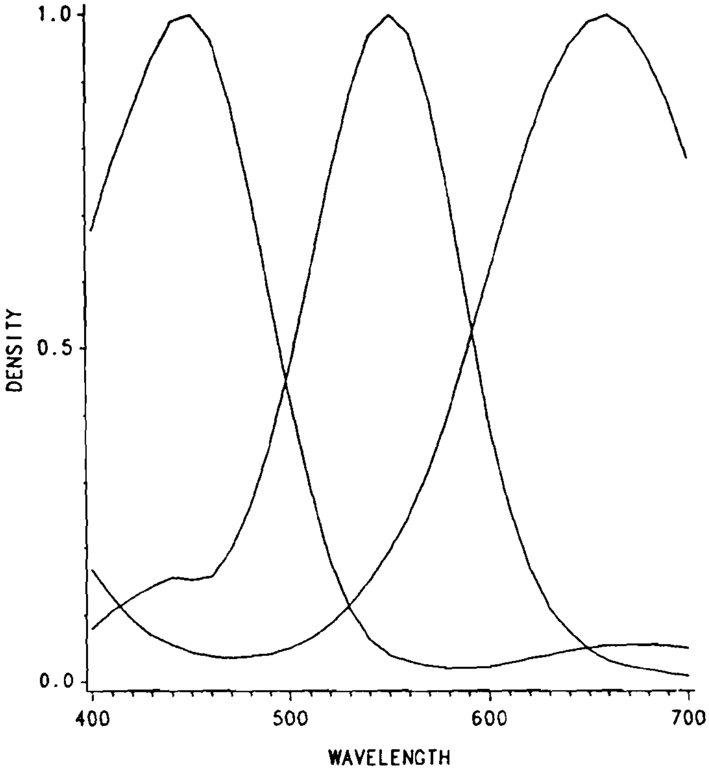
Calculation of Color Patch Aims

The objective in choosing the color patches is to represent the dye gamut of the photographic material with a limited number of color patches. There are two methods to determine the dye gamut of a photographic material: by direct measurement and by calculation.

In the direct measurement method, a material is given a series of exposures, it is processed, and the resulting color patches are read and plotted in a color space (Gordon, 1987). Although this is probably the most accurate technique because the actual material is being tested in the same way a person would use the material, only the original exposures can be accurately controlled. The resulting colors cannot be controlled. So if you wanted to generate a series of possible colors at a given hue angle, you could not do it; the best that could be done would be to generate a series of colors close to that hue angle. By interpolation between the measured colors, a reasonable estimate of the dye gamut at the desired hue angle could be made. This technique would have been time-consuming for us because of the number of color patches that must be exposed, processed, and measured.

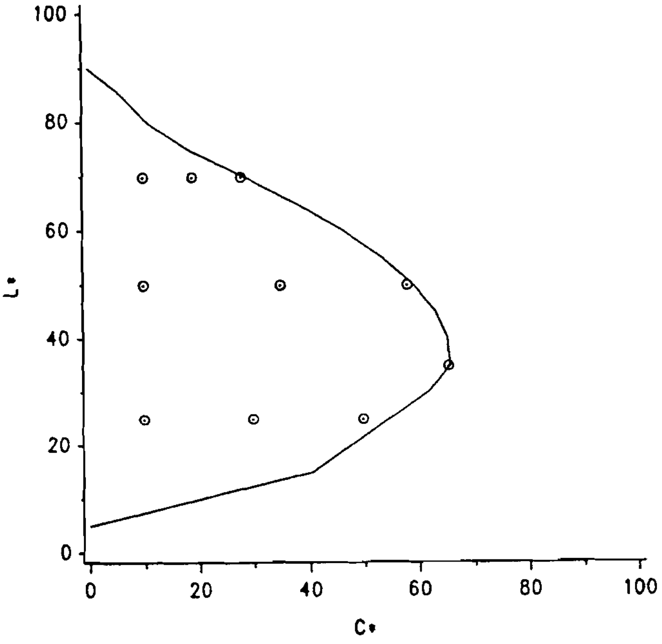
We chose to calculate the dye gamut because we found that method both easier in general and easier to determine the dye gamut at the exact hue angles that we desired. The calculation of the dye gamut of any photographic material is an iterative process (Ohta, 1986). The starting point is the set of measured spectral dye curves (Sant, 1961) for the cyan, magenta, and yellow dyes of the specific photographic product. An example of the general curve shape of such a set of dyes is presented in Figure 6. The object in a color gamut calculation is to find the maximum c* that can be reached with the amounts of each dye above some minimum value and below some maximum value at a given L* and a given hue angle, hab. The full gamut is found by varying the target L* and hab values. Because we had already determined which hues we wanted in our target, it was not necessary for us to do all of the calculations at all hab, only at those 12 hab values we wanted. The scheme to do this is as follows. At any L* and hue angle, assume a c*. From this can be calculated a set of L*a*b* coordinates, which can be converted into tristimulus values. With the tristimulus values and the spectral dye curves, we calculated the dye amounts and then the transmission spectrum needed to match the tristimulus values (Ohta, 1971, 1972a, 1972b). From the transmission spectrum we can also calculate the Status A densities, if they are needed. This set of calculations is repeated at different c* values until we find the maximum c* consistent with the above restriction that the dye amounts must be greater than some minimum value and less than some maximum value. This set of calculations is then repeated at another L* value until the entire gamut for that hue angle is calculated. The results of those calculations at two hue angles are shown in Figures 3 and 4.

Figure 6. Spectral Dye Curves



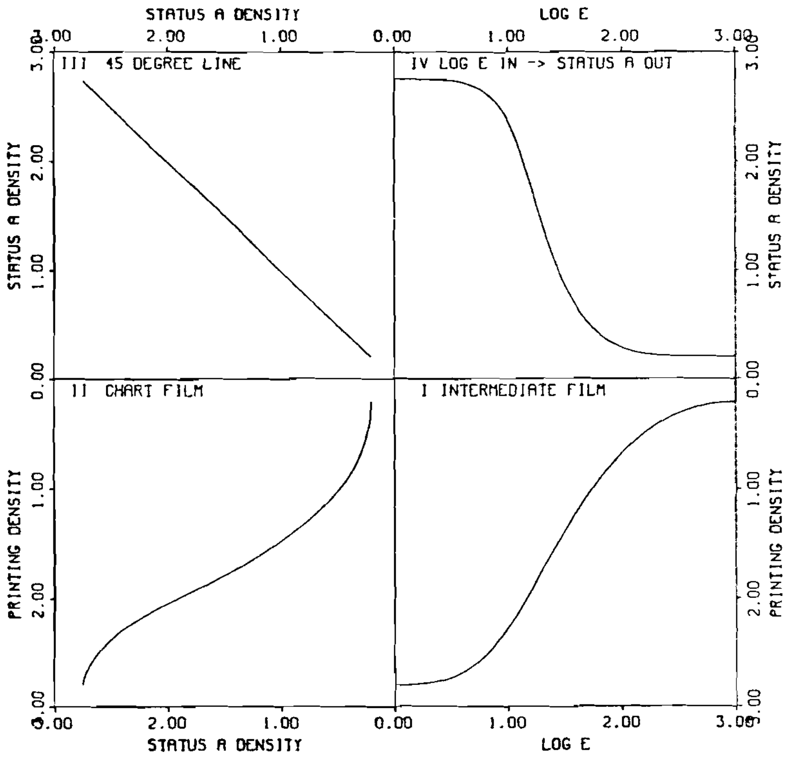
The choice of which 10 color patches represent the color gamut at each hue angle is rather arbitrary. Because each photographic material has a unique set of dyes, the plots of dye gamut will be different for each material, so the choice of patches to use will be different. Figure 7 shows possible points to use for one hue angle for the dye set of our previous calculations. The first patch we chose was the patch at the L* value giving the greatest c* value. For yellow hues, this is a relatively high L*; for blue hues, this is a relatively low L*. Then we chose three L* values (a moderately low, a middle, and a moderately high value) and three c* values (the maximum c* possible at that L*, a low value, and a value between the low and maximum values). The result is that the 10 patches, all defined by their CIELAB L*a*b* coordinates, represent quite well the range of colors, at a particular hue, that a photographic material can generate. With the CIELAB L*a*b* coordinates for these 10 patches, we were able to repeat the above sequence of calculations. We could calculate the spectral curves of these color patches, and from the spectral curves we could calculate the Status A densities of the patches. In this way we had a set of Status A densities that we could measure to determine when we had produced the desired color patches.

Figure 7. L*-C* Diagram
showing the Patches for a Green Color



Because we wanted to make more than one final chart, we decided to make a chart on an intermediate film such that when the intermediate film is printed onto the final film, the chart on the final film would meet our aims. The calculations for what exposures are needed to make this intermediate chart are best explained by the use of a Jones diagram (Carroll, 1980), Figure 8. It is possible to plot all three colors in each quadrant, but for ease in seeing how to do the calculations, I have plotted only one color. In practice this set of calculations would need to be repeated three times, once for each of the three primary colors. In quadrant I is plotted the printing density - log E curve for the intermediate film. In this case the printing density of this intermediate film is the printing density onto the final film under the conditions which we use for the printing. In quadrant II is plotted the Status A density - printing density curve of the final film, the film which will have the test chart. In quadrant III is plotted a 45 degree line that reflects the Status A densities from Quadrant II to Quadrant IV. In Quadrant IV are plotted the Status A densities of the final film vs the log exposures given to the intermediate film. This curve in Quadrant IV can be thought of as our calibration curve. We can specify the chart color patches by the Status A densities of each patch. From the specified Status A density and the curve in Quadrant IV, the exposure to the intermediate film can be determined. This calculation of log exposure to the intermediate film is repeated for each color patch to build up the entire color chart.

Figure 8. Jones Diagram



Once the intermediate film has been made, we can make, by normal printing techniques, any number of final charts.

We think that the use of these charts will make the set-up of scanners significantly easier and will improve the quality of prints from a variety of film and paper inputs.

Literature Cited

Billmeyer, F. W. and Saltzman, M.
1981. "Principles of color technology" (John Wiley & Sons, New York), 2nd ed., 21 pp.

Carroll, B. H., Higgins, G. C., and James, T. H.
1980. "Introduction to photographic theory," (John Wiley & Sons, New York), 55 pp.

Commission Internationale de l'Eclairage
1978. "Recommendations on uniform color spaces, color-difference equations, psychometric color terms, supplement no. 2 to CIE publication no. 15, colorimetry," (Bureau Central de la CIE, Paris).

1986. "Colorimetry, 2nd ed., publication CIE no. 15.2 (TC-1.3)," (Bureau Central de la CIE, Paris).

Gordon, J., Holub, R., and Poe, R.
1987. "On the rendition of unprintable hues," 1987 TAGA Proceedings, pp. 186-195.

Hunt, R. W. G.,
1987. "The reproduction of colour in photography, printing, and television," (Fountain Press, England), 4th ed., 92 pp.

Ohta, N.
1986. "The color gamut obtainable by the combination of subtractive color dyes," J. Imaging Science, vol. 30, no. 1, pp. 9-12.

1971. "Fast computing of color matching by means of matrix representation. Part I. Transmission-type colorant," Applied Optics, vol. 10, no. 9, pp. 2183-2187.

1972a. "Fast computing of color matching by means of matrix manipulation, II. Reflection-type color print," J. Opt. Soc. Am., vol. 62, no. 1, pp. 129-136.

1972b. "Metameric color matching in subtractive color photography," Photo. Sci. Eng., vol. 16, no. 2, pp. 136-143.

Sant, A.
1961. "Equivalent dyes for color films with incorporated color couplers," Photo. Sci. Eng., vol. 5, no. 3, pp. 181-184.