A PRACTICAL APPROACH TO GRAY BALANCE AND TONE REPRODUCTION IN PROCESS COLOR

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Abstract

A set of color separations for process color reproduction must be screened to satisfy the gray balance requirement and to produce the correct tone scale. Both of these requirements depend not only on the selection of inks, paper, and plates, but also on press variables which vary from shop to shop, from press to press, and even from job to job. In designing a color reproduction system, all these factors must be taken into consideration.

This paper describes a simplified method of finding the desirable screening curves for correct gray balance and tone reproduction in one operation.

Introduction

The screening operation is an important step of a color reproduction process. It must satisfy two requirements: (1) The dot areas in the yellow, magenta, and cyan printers must be balanced in relation to each other to reproduce each step of a gray scale as a neutral. (2) The tone scale of the original copy must be reproduced within the tonal range of the printed sheet in such a way that the picture has an "optimum" tone reproduction.

The problem of finding the correct shapes of screening curves is greatly complicated by the variability of the color reproduction process. Various sets of process inks having different physical and optical properties are

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selected for various reasons. These inks are printed on dozens or even hundreds of different stocks from various types of plates in various combinations of ink film thicknesses and in various color sequences. The presses used throughout the industry are of different types and designs. Not all pressmen adjust their presses in the same manner. Various individuals may add to their inks some "secret" compounds that result in variable dot gain and trapping conditions. All of these variables will have some effect on the printed color reproduction and, consequently, on the shapes of the desirable screening curves.

A color reproduction system must be based on the color and printing variables that prevail in the shop and on the press that will be printing the job. The simplest way to find these variables is to actually print some kind of test target using the given combination of inks, plates, paper, and press, and thus collect the necessary data.

The RIT Gray Balance Chart

The RIT Gray Balance Chart, shown in Figure 1, is such a test target. It was designed to indicate the desirable screening curves for a given combination of color and press variables. The data provided by this chart can also be used to design a complete color reproduction system.

The chart consists of six blocks of color patches. The first five blocks – the gray balance blocks – are matrix arrangements of the three-color overprints of yellow, magenta, and cyan tints. The dot area of the cyan tint is constant in all patches of each block,* but the magenta tints change from line to line, and the yellow tints change from column to column.

Each circular patch in each block is thus a different combination of yellow, magenta, and cyan tints. When printed in color, one of these patches will approach neutral. To provide a convenient neutral reference, the patches are surrounded by a background of a black tint which greatly simplifies the visual selection of the neutral gray patch.

*The exception is Block No. 1, where the cyan tint in the first column and the first line has a dot area different from other patches for the reasons given in the following paragraphs of this paper.

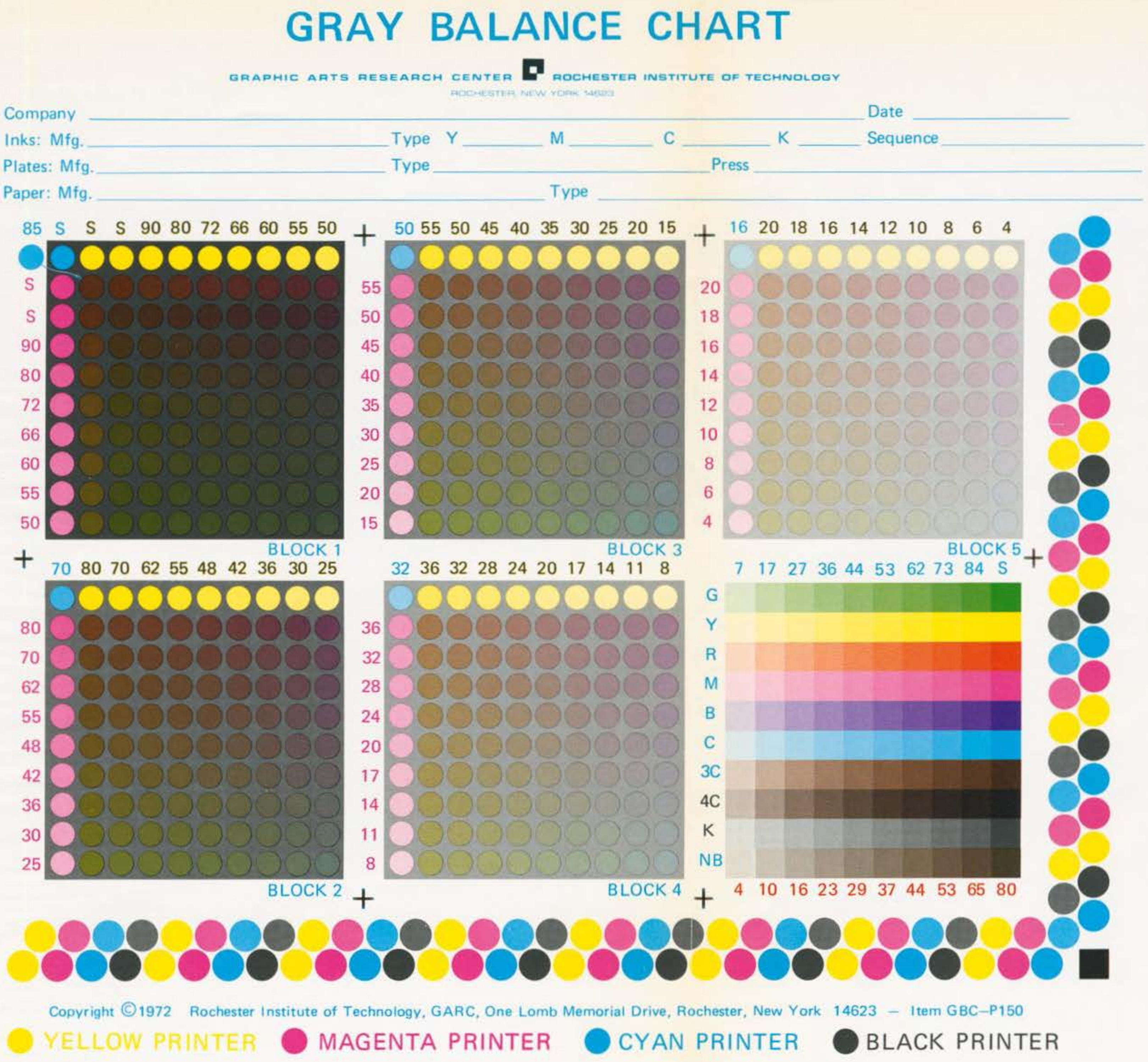

Figure 1. RIT Gray Balance Chart.

This illustration pertains to the paper *A Practical Approach to Gray Balance and Tone Reproduction in Process Color*, pages 78-97.

It would be convenient to select, for the magenta and the yellow, the scale of tints that would have an approximately equal visual difference from step to step when printed on paper. The variability of the tone scale due to various papers, inks, and press conditions makes it impossible to do this for all printing conditions, but one step in this direction was made by reducing the spacing from dot area to dot area in the lighter patches as compared to the darker patches of the chart.

The first line and the first column in each of the gray balance blocks show the components of the three-color patches, printed separately. The numbers printed next to these patches in the respective colors indicate the printing dot area percent in the negative or positive of the chart. For better visibility, the yellow figures are overprinted with black.

Under normal printing conditions, we expect the neutral three-color patches to be composed of the largest cyan dots and the smaller yellow and magenta dots. A block of three-color overprints, starting with equal dots in all three colors and then gradually reducing magenta and yellow dots in crossed directions, should include a combination of dot areas that appears neutral.

To our surprise, we have found that this assumption is not always correct. In one case, for example, we could not find any neutral patches in a chart because all patches looked greenish. To obtain a neutral, the magenta dot had to be larger than the cyan dot. This was an abnormal situation. It was caused by the undertrapping of the magenta ink printed on the third unit of a four-color web offset press. The best remedy, in this case, would be to correct this abnormal situation by changing the color sequence or adjusting the ink tack. In this case, however, the pressman insisted that he has good reasons for not doing so and that this is the printing condition that must be accepted.

To cover similar situations, the scales of yellow and magenta tints in the RIT Gray Balance Chart were extended one step beyond cyan.* This means that the first line of magenta tints and the first column of yellow tints have larger dot areas than cyan. This applies to all blocks except Block No. 1. In this block, the yellow and magenta could not be extended beyond cyan,

*Two steps in Block No. 5.

because cyan in this block is solid. The only way to simulate this situation was to reduce the dot area of the cyan tint. Block No. 1 is the only block where the cyan dot area is *not* constant. In the first line and in the first column of these patches, the cyan was reduced from solid to 85 percent dot area.

Block No. 6, in the lower right corner, is basically a 10-step color reproduction guide consisting of halftone scales of primary colors and scales of two-, three-, and four-color overprints. These scales can be used to calculate the gray balance by other methods, if one wishes to compare the results of the method given in this paper to more elaborate procedures published in previous years (Clapper, 1959; Wulff and Jorgensen, 1964; Pobboravsky, 1966). The color scales can also be used to find such color and printing factors as proportionality, additivity, and trapping of printed inks and to calculate the color correction requirements for a complete color reproduction system.

The dot areas in each step of each color are identical in the first nine scales of the block. These dot areas are marked by the cyan figures above the first (green) scale of the block. In scale No. 10 (marked NB), only the cyan printer has the same dot areas as the other scales. The percentages of yellow and magenta tints indicated in red figures below Block 6 are equal but lower than cyan. They have been adjusted to give, in combination with the cyan tints, a scale of approximately neutral patches. In some cases, this scale will look neutral, but the hue of these patches will, of course, change with the printing conditions. It may look brownish, greenish, bluish, or purplish. Since the normal human eye is quite sensitive to small hue differences in near-neutral colors, this scale is a good indicator of the direction in which the gray balance is shifting during the run. The scale of black tints printed next to the NB scale provides a good reference to check its neutrality.

Another quality control device printed below the six blocks and at the right-hand margin of the chart is the double row of circular patches in four primary colors. Each pair of these patches consists of a solid and a 75 percent tint. They can be used to check uniformity of solid ink density and dot gain across the printed sheet. With patches provided in both horizontal and vertical directions, the chart may be oriented on the printing form in either direction.

The Shapes of Halftone Dots

The halftone negatives or positives produced by various types of contact screens or by various lens apertures in front of a crossline screen consist of dots of various shapes. The small dots are usually round, but when they grow from highlights into middle tones, they gradually change their shape. At approximately 50 percent dot area, they usually look like a checkerboard pattern of squares or parallelograms ("elliptical dots"). Sometimes, we may encounter the cushion-shape dots or the dots which retain their circular shape well beyond the 50 percent dot area. This type of dot is found quite frequently in commercially available halftone tints.

The effect of various shapes of halftone dots on the shape of a tone reproduction curve is a well-known phenomenon. To represent a color reproduction process, the dots of a test target must have the same shape as the dots used in the process. And yet, some gray balance charts used in the industry are composed of circular dot tints which are quite different from those produced by contact screens in color reproduction. The data provided by these charts will, in most cases, be misleading.

The contact screens used in the color reproduction process can be divided into two principal groups: square dot screens and elliptical dot screens. The trend is toward the elliptical dot because this type of screen gives a smoother tone reproduction in the middle tones. The RIT Gray Balance Chart is made of elliptical dot, 150 line-per-inch tints. We are also considering the production of this chart in other screen rulings and, possibly, in square-dot tints.

Printing the RIT Gray Balance Chart

The RIT Gray Balance Chart is available in the form of a set of film negatives or positives. To provide useful information, it must be properly printed. The printing must be done under shop conditions. The pressman must realize that the printed chart will be used as a shop printing standard and that he must be able to repeat the printing conditions while running the final job: the same paper, the same inks, and, if possible, the same press.

If the shop is using several presses of the same type, there may be no need to print the chart on each press, provided that one press can simulate the printing conditions of another, especially the dot gain and the trapping.

However, the chart printed on a sheet-fed single color press will probably not represent the printing conditions on a four-color web press.

In practice, it may be impossible to print the chart on each paper that will be used in production, but it should be printed on stock representing each type of paper to be used in production, e.g. coated, uncoated, cast coated, newsprint, etc.

Printing a color picture next to the chart may help the pressman to adjust the press the same way as he does it for production printing. If control bars of a particular type are used in production then these should also be included.

In his book *Principles of Color Reproduction,* John A. C. Yule writes: "It is desirable to adjust the relative strength of magenta and yellow ink so that equal amounts of these two are needed for a gray balance since the halftone positives are then easier to make. This cannot be done, however, with very reddish or bluish magenta inks."

With many sets of inks this can be done, and the RIT Gray Balance Chart is a convenient printing guide for equalizing these two curves. They will be equal when the neutral patch is located on the diagonal between the cyan patch and the opposite corner in each block. If the last of the three primary colors is either yellow or magenta, the pressman may be able to adjust its strength to print the neutral patches on the diagonals of blocks. However, he must keep in mind that changing the strength of the primary colors will also change the hues of the secondary colors (two-color overprints). This complication may limit his options on this point.

If the last printed ink is black, the pressman also has some freedom to adjust its strength to match the surround to the neutral patches in density as well as in neutrality. However, the brightness match is not essential. The neutral background provides a good reference for gray, even if the sample does not match the brightness of the surround. The different colors of various patches will influence our perception of the neutral background so that it may appear to the eye to have a slightly different color in different areas of the block. In the area of the neutral patch, it usually appears neutral.

Various black inks have different hues. We have bluish black inks and brownish black inks. The human eye will usually accept the tints printed in most black inks as neutrals, but if the printer has a choice in selecting the black ink, he should use an ink which is neutral for printing the Gray Balance Chart.

Printing the chart in only three colors, without black, will make it more difficult to find the neutral patches. The three-color chart will be adequate for a three-color process, but in a four-color process it will lack some information useful in finding the correct tone reproduction.

Evaluation of the RIT Gray Balance Chart

The basic feature of the RIT Gray Balance Chart is the simplicity of its evaluation. The gray balance requirements are found by the visual selection of the neutral patches, without measurements.

The difference in the hue of the adjacent patches in the printed chart is usually small. In most cases, it is possible to find in each block a patch which looks close to neutral. If a critical observer is not satisfied with the closest-to-neutral patch that he can find on the chart, he can easily interpolate between two patches.

The chosen neutral three-color patches and the gray background are metameric colors. They will match each other under one light source but not necessarily under a light source having a markedly different spectral composition. The neutral patches should be selected under standard illumination.*

If required, the individual patches can be measured on a small spot colorimeter (Pearson and Yule, 1970) or a densitometer. These measurements may be necessary for statistical evaluation or for variability studies.

*The illumination standard for the appraisal of color quality in the graphic arts industry (PH2.32-1972) was approved by the U. S. Standards Institute January 12, 1972. The color temperature of this illumination standard is 5000 K.

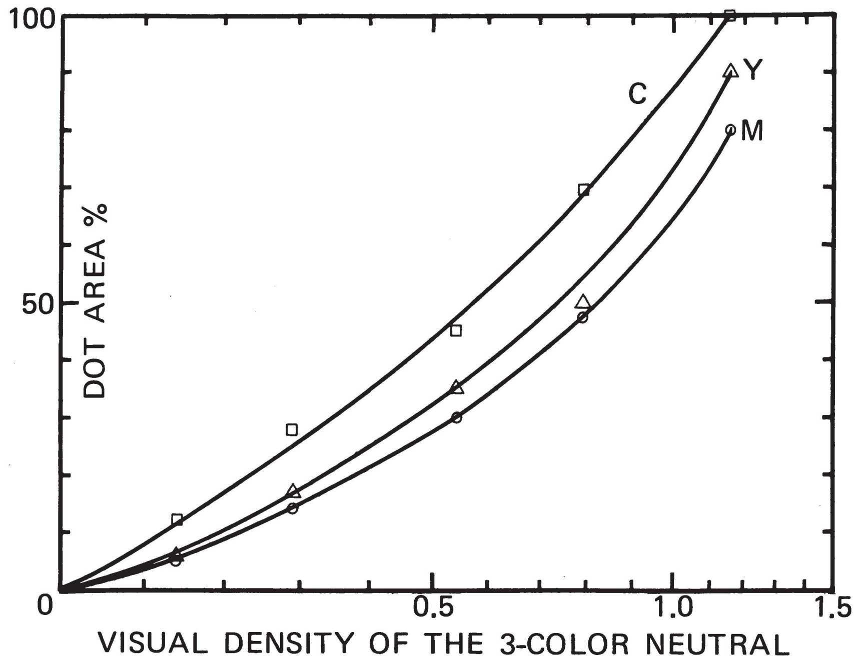

Figure 2. Gray balance curves constructed directly from five neutral patches in the RIT Gray Balance Chart.

When the neutral patches have been selected and their visual densities determined, the dot areas of their components indicated by the printed figure can be used to plot a set of gray balance curves as shown in Figure 2. It should be pointed out that these curves are plotted directly from the chart in terms of dot area vs. neutral density. There is no need to plot neutral density or END against single ink density as Clapper (1959) did. However, these curves can be plotted if desired, using the densities of single-color halftone tints printed separately in each block.

The measurements of the dot areas in the film negatives and positives of the chart were made on a Sargent Welch Densichron Dot Area Meter, Series 3885D. These films were carefully made to minimize the variability between various patches having the same dot area and the differences between the intended and measured dot area. These differences are smaller than the expected variability on the press and between two densitometers. The user should repeat these measurements on the same instrument on which he will measure the final halftone separations, and recalibrate them if necessary.

The Use of the RIT Gray Balance Chart in a Limited Printing Space

Since the space on a printed sheet may be very expensive, we tried to keep the dimensions of the chart as small as possible. With the control patches and the data sheet, the chart measures approximately 7-3/4 x 8-1/2 inches. The six blocks alone, which will provide practically the same information as the complete chart, will fit into a space of only 5-1/4 x 7-1/2 inches. Since even this space may not be available on some flats on which the printer would like to print the chart, it was designed in such a manner that it can be cut in half and still give the most important information on gray balance and tone reproduction.

Of the five blocks that indicate the gray balance at five density levels, Blocks No. 1, 3, and 5 are in the first row. If the lower half of the chart is cut off, only two in-between points on the gray balance curves will be missing. The remaining three points will still show the general shape of these curves. The space required to print the three blocks of the chart is 2-1/2 x 7-1/2 inches.

If the printer knows the approximate expected location of the gray balance patches in the print, the size of the chart can be reduced even further to only five horizontal rows of Blocks 1, 3, and 5, as shown in Figure 3. This strip of patches will include the figures for the dot area percent of magenta, but not of cyan and yellow. These two must be found from the complete chart. The selected five rows must, of course, include the neutral patches. This strip, only 1-1/8 inches deep and 7-1/2 inches long, will give the same information as complete Blocks 1, 3, and 5. It is quite sensitive to changes in press variables and can be used for studies of variability on the press. Experience may show that it is possible to reduce the depth of this strip to less than five rows. It would then be narrower than one inch.

Tone Reproduction

Adjusting the dot areas of yellow, magenta, and cyan separations for reproducing the scale of neutrals as neutrals, satisfies only one requirement of correct screening. Another important requirement which must also be satisfied is that of the correct tone scale.

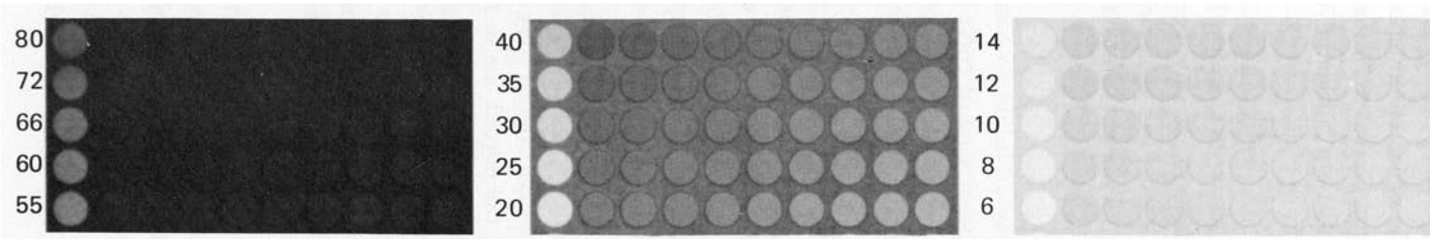

Figure 3. A miniaturized RIT Gray Balance Chart.

If the density range of the copy does not exceed that of the printed sheet, the printer may try to get a facsimile reproduction. Usually, however, the tonal scale of the copy must be compressed to fit the lower density range of the printed sheet in such a way that an "optimum" tone reproduction is achieved.

It is not the subject of this paper to investigate what kind of compression will give an optimum reproduction. It may be necessary to use a different curve for reflection copy than for a transparency. Also, an overexposed transparency will require a different tone reproduction than an underexposed transparency.

The printer often does not pay attention to tone reproduction, but when he does, he may not be sure what kind of curve he should follow. A good way to start doing something about this is to follow one of the curves that gives a satisfactory tone reproduction for an average copy.

A series of such curves, preprinted on graph paper, is shown in Figure 4. These curves were suggested by J. A. C. Yule in his paper: "Plotting Tone Reproduction Curves" (Yule, 1968). The series starts with the straight-line facsimile reproduction followed by curves giving a satisfactory tone reproduction for average copy at various degrees of tone compression.

Tone Reproduction for Three-Color Printing

The selection of a desirable tone reproduction curve depends on the density range to which all densities of the original copy must be compressed on the printed sheet. For example, the dotted line in Figure 4 is an "optimum" tone reproduction curve compressing the density range of 2.0 in the original copy to a density range of 1.2 on the printed sheet. For a copy having a smaller density range, a curve with less tone compression can be selected, as is shown in the same figure where the solid line represents a desirable tone reproduction curve that will compress the lower original density range of 1.5 to 1.2.

After selecting a desirable tone reproduction curve, we can construct the required halftone curves for yellow, magenta, and cyan separations from data supplied by the printed RIT Gray Balance Chart.

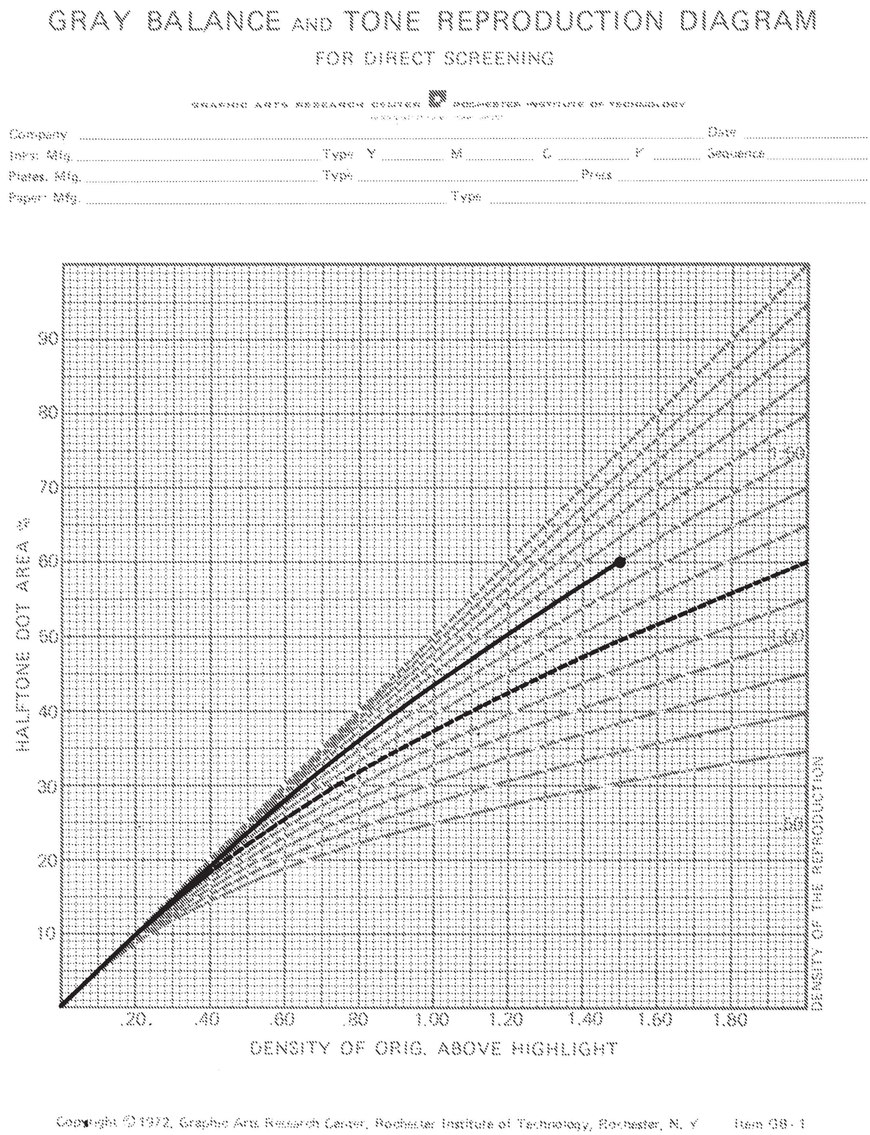

Figure 4. A tone reproduction diagram with preprinted tone reproduction curves for various degrees of tone compression. The dotted line is an "optimum" tone reproduction curve selected to compress the original copy density range of 2.0 to the density range of 1.2 on a printed sheet. The solid line is a similar curve for a copy having a smaller density range.

Each of the five neutral density patches in the chart has a certain visual density that can be measured on a reflection densitometer through an appropriate filter such as the Kodak Wratten Filter No. 106. Since the cyan in the neutral patch of Block No. 1 is solid, this patch represents the highest neutral density that can be reproduced in the given process with the three primary colors. It is the density of the upper end of the selected tone reproduction curve. The densities of the remaining four neutral patches in Blocks 2, 3, 4, and 5 can be likewise located and marked on this curve as is shown in Figure 5.

A tone reproduction curve shows how the densities of the original copy should be reproduced in the press sheet. But the cameraman is interested in the dot areas that will give those densities, and this information can be found from the printed Gray Balance Chart which shows the combinations of yellow, magenta, and cyan tints in neutral patches. All we have to do is to mark these dot areas on the diagram and to plot the curves that will show the required dot sizes in each density step of the picture. A set of halftone separations following these curves (Figure 5) will be balanced to reproduce a neutral density scale as a neutral and, at the same time, will give the desirable tone reproduction.

At first, this diagram may be a little confusing because it is actually a combination of two diagrams, each plotted in different units. The abscissa in both diagrams is the same: density of the original copy above its highlights. That is to say, the highlight density is subtracted from all the original densities before plotting them on the graph. But the ordinates are different. The tone reproduction curves are plotted in densities and the halftone curves — in percent dot area. The graph paper is calibrated in both units.

A diagram like one shown in Figure 5 is very useful to the cameraman. It can be easily applied to existing color reproduction methods. For example, if a shop is using Kodak A, M, and B patches, they can be included in the copy and marked on the diagram. The diagram will show to which dot areas these patches should be screened in individual color separations. It should be remembered that, for plotting, the highlight density is subtracted from the densities of those patches as well as from other original densities.

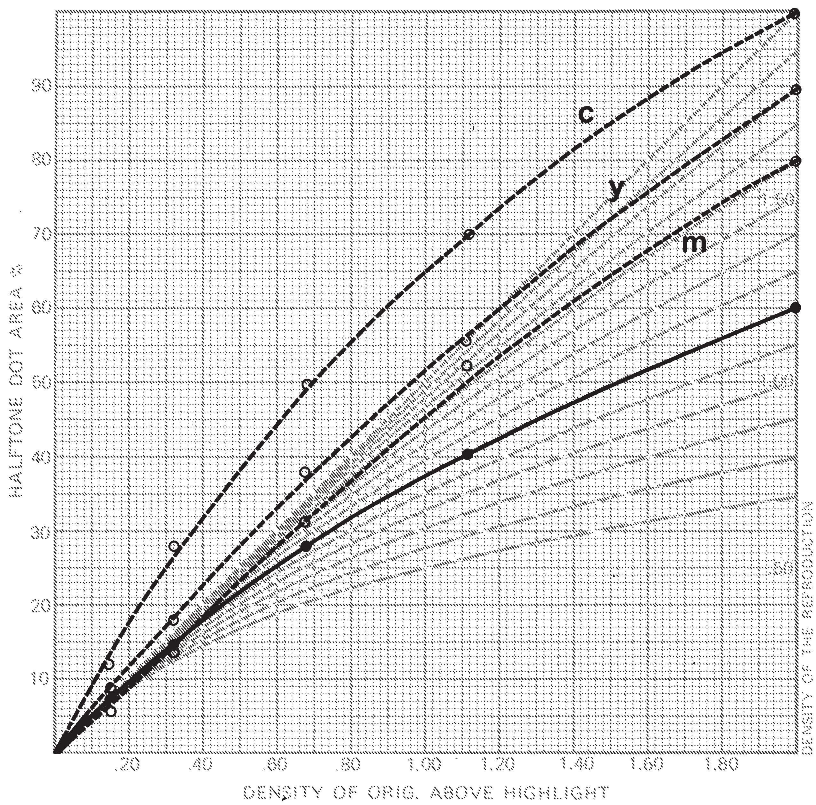

Figure 5. Construction of a set of halftone curves for three primary colors. A desirable tone reproduction curve is indicated by the solid line. Each of the five neutral patches in a printed RIT Gray Balance Chart is marked on this curve and then separated into three dot areas. Corresponding points are then joined to give the three upper dot area vs. original density curves.

Tone Reproduction for Four-Color Printing

In a four-color process, the black printer adds to the three-color neutral scale some density that will increase the density range in the printed sheet so that less tone compression will be needed. This problem is complicated further by the difference between various black printers that vary in the maximum size of the shadow dot.

The simplest way to find the maximum four-color density in the printed sheet would be to overprint the darkest neutral three-color combination with various tints of black and to measure the patch having the same amount of black as the darkest area in the black printer. However, in the absence of such a scale the square patch at the lower right corner of the chart, next to the circular color control patches, can be used. This patch is an overprint of solid black and the darkest step of the NB scale (solid cyan, 80 percent yellow and magenta). If the composition of the darkest three-color neutral in a color reproduction process is not much different from this combination, and if the black printer scale includes the solid, the measured density of this patch may be used to select a desirable tone reproduction curve. If the darkest tint in a black printer is less than solid, the maximum neutral density will be intermediate between this patch and the darkest three-color neutral.

A desirable tone reproduction curve selected to match a measured or estimated maximum four-color density is shown in Figure 6. This four-color scale consists of two neutral components: the three-color scale and the black. The maximum density of the three-color scale will be the same as the density of the three-color patch in Block 1. This density is marked on the tone reproduction diagram (Figure 6). The curved line drawn between this point and approximately the center* of the four-color curve will form the shoulder of the three-color tone reproduction curve that should be followed.

Finding the desirable halftone curves and following them in a direct-screen color process are two different things. The cameraman must find the

*More accurately, the point at which the three-color curve should begin to depart from the desired tone reproduction curve should be the point at which the black printer image will begin.

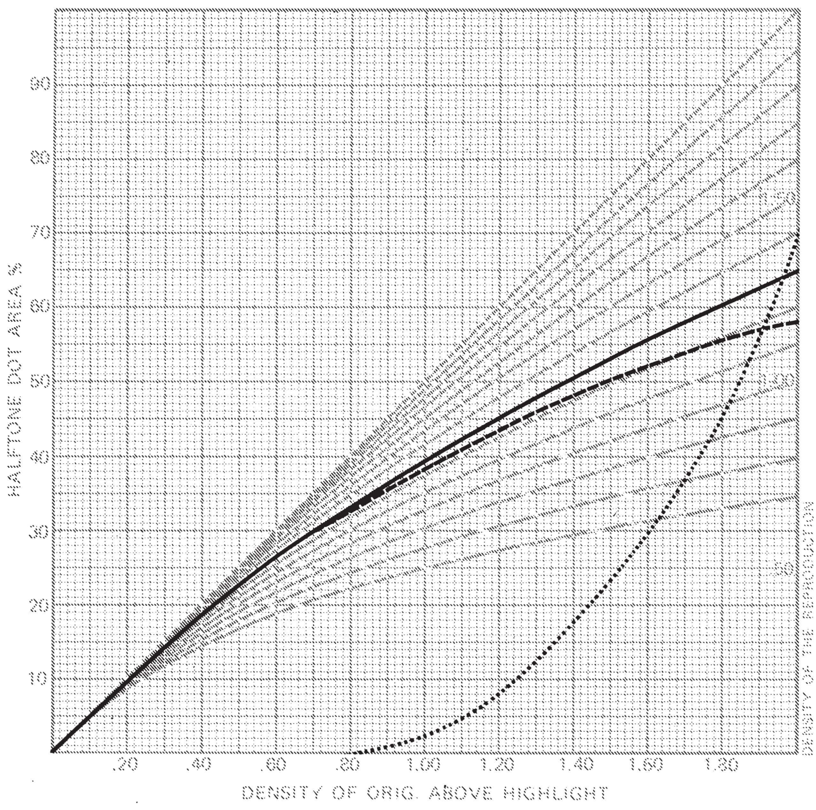

Figure 6. Constructing a three-color tone reproduction curve (dashed line) from a four-color curve. The dotted line indicates the halftone curve of an arbitrary skeleton black printer having the maximum dot area of 70 percent.

way to approach these curves by selecting the correct type of contact screen and by adjusting the ratio of main, bump, and flash exposures. It is relatively easy to increase the highlight contrast by increasing the bump exposure, but it is not easy to go in the other direction. If the highlight contrast is still too high, even after eliminating the bump exposure, a different type of contact screen giving a lower contrast in the highlights must be found. This is sometimes difficult to do while making the direct screen separations for newsprint.

In evaluating the screened color separations, it must be remembered that the tints in the RIT Gray Balance Chart consist of hard dots with the minimum amount of fringe and the dots in the first generation halftones are soft. Since the measurements of the soft dot halftones on a regular densitometer will produce misleading results (Archer, 1966), they must be measured on a special instrument that ignores the fringe, such as the Sargent Welch Dot Area Meter SS100. It is a good practice to contact the original halftones to a set of hard dot positives or dupes and to use them for dot area measurements and for making the plates.

Tone Reproduction in Continuous-Tone Color Separation Negatives and Positives

The diagram shown in Figures 4, 5, and 6 was designed for use with the direct screen system in which the screening process is adjusted to approach the desirable halftone curves by shooting the halftones directly from the masked copy.

In an indirect screen system, it is convenient to keep the screening procedure constant and to adjust the tone reproduction in the continuous tone stage of the process. To find the shape of the tone reproduction curves in the continuous-tone color separations we use the Jones-type diagram shown in Figure 7.

The first quadrant is the tone reproduction diagram shown in the previous figures. Quadrant 2 shows the relationship between the continuous-tone densities and the dot areas produced by these densities in the halftone. From these two diagrams, a set of curves with the required tone reproduction for the continuous tone separations can be constructed by the known method (Jones, 1920) in quadrant 3.

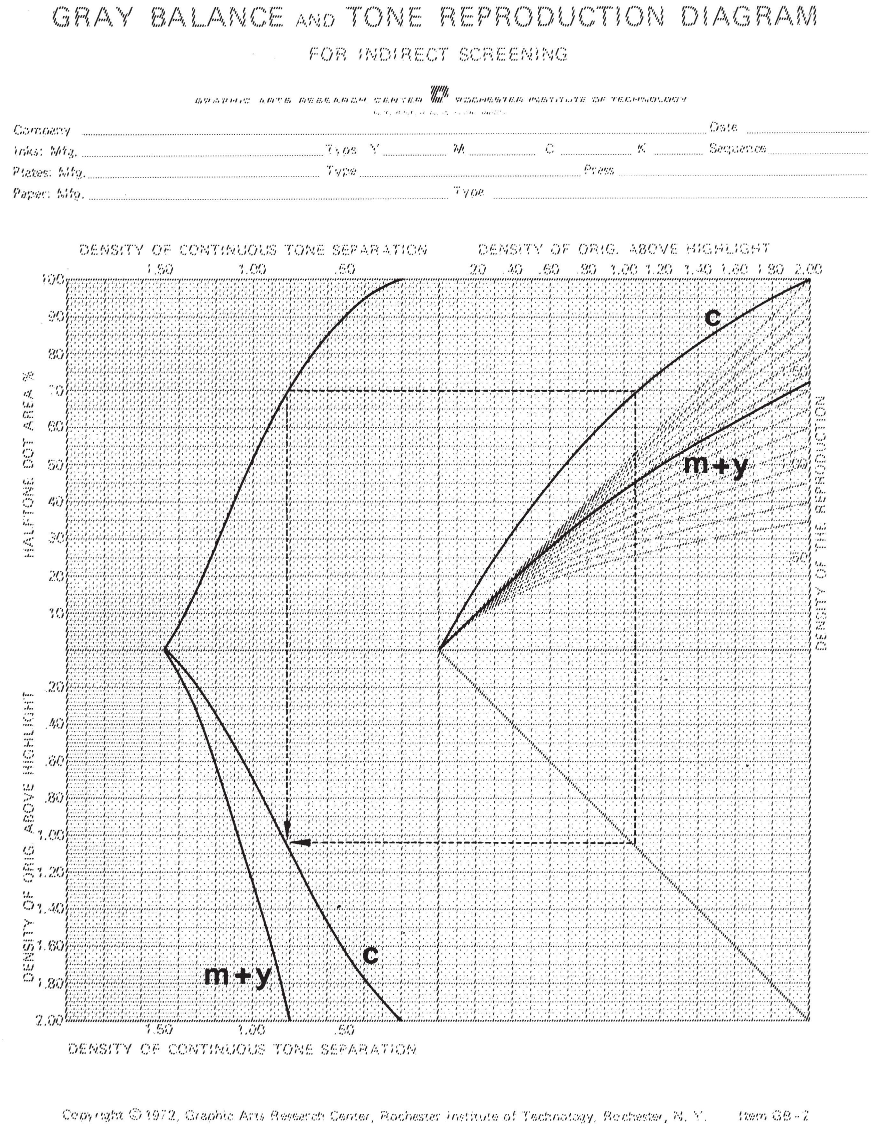

Figure 7. A Jones-type diagram used to construct required curves for continuous-tone separations.

Summary

The method of finding the desirable halftone curves for a color reproduction process, presented in this paper, is based on the RIT Gray Balance Chart, which has a compact design. This chart is printed under shop conditions and thus automatically takes into account the variables of the printing process. The five neutral three-color combinations of halftone tints on a printed chart selected visually under standard illumination give five points on a pre-determined tone reproduction curve, and these are used to construct a set of halftone curves that are balanced for the reproduction of neutrals and for the correct tone scale.

Because of its simplicity, this method can be used in individual shops by semi-skilled personnel.

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