MEASUREMENT AND CONTROL OF COLOR OPACITY

Philip J. Schoepke*

ABSTRACT

Ink companies supply to the printing industry a variety of colors with various opacity levels, yet seldom do we see opacity specifications for both standard and non-standard inks. With so many variables (paper stock, light source, dot overlap, etc.) complicating color printing, control of all color properties, including opaqueness, becomes vital. Errors in color opacity are often mistaken as trapping and density problems. Our industry must put controls on color opacity, especially between press and proof, in order to add consistency to an interactive process.

The importance of color opaqueness and its control is described and method of measurement introduced. Specific examples are discussed which show significant color error due to differences in color opacity when overlapping halftone and solid color areas, with primary emphasis on applications to color proofing.

INTRODUCTION

In the printing reproduction of an image, a continuous tone image must be made to "look" the same as the original to an observer. Since a press cannot print continuous tone images, we must convert the image to a collection of dots and, by making the dots small, fool an observers eye into thinking the image is continuous. In addition to making the dots small to create an optical illusion, color overlapping is a vital tool used to create colors needed to reproduce the original.

A hard-copy proof is commonly used to predict press performance. Color and image characteristics must exactly match between press and proof if the proof is to be optimally utilized. For most applications, color is defined only by density-hue-grayness, spectral curve, position in color space, etc., and not by its opacity. Ink companies keep tight control on color opacity, yet similar awareness is absent in the printing industry.

* Polaroid Graphics Imaging, Inc.

Because of the extensive use of color overprinting in the printing industry, changes in color hiding power can cause color differences which are noticeable to the eye. With today's variety of inks and proofing colors, it is necessary to keep a control on the opacity of color.

This paper seeks to prove that a match is a match only if matched for opacity. Methods of measuring opacity with a densitometer or spectrophotometer are presented. Hypothetical and practical examples are given which demonstrate how errors in opacity can be mistaken for trapping differences. Furthermore, opacity errors resulting in large color differences of overprints are introduced.

Polaroid Proofing System toners, film, and receptor film were used to make all samples for experimentation, except where ink samples are specified.

OPACITY DUE TO COLOR REFLECTION

A transparent color is one which acts as a filtering device. Wavelenghts of light are either selectively filtered or allowed to transfer beneath. A color which reflects any incident light, preventing such light from transferring below, is partially opaque. Higher amounts of light reflection by a color results in greater levels of opacity.

Throughout the paper, the term "opacity" refers only to the characteristic of a color to reflect some or all wavelenghts of light instead of allowing that light to transfer beyond the color to a reflecting medium such as paper.

MEASUREMENT OF OPACITY

Color opacity can be measured by either a densitometer or spectrophotometer, although a spectrophotometer gives more consistent results. In either case, a color must be coated on both white and black surfaces.

With a densitometer, the dominant densities are used in the following formula:

$$\text{reflectance ratio} = 10E(-D_d + D_l),$$

where D_d is the dominant density of the color on the dark substrate and D_l is the density on the light substrate.

This ratio represents the reflectance of the color on top of a light absorbing background compared to the total reflectance of the package on a white background. The higher the number, the more opaque the color. This formula has the drawback that it only takes into account the reflectance in the region of the dominant color.

A more complete determination of color opacity can be made using a spectrophotometer or colorimeter. The Applied Color Systems Spectro-Sensor models calculate a "contrast ratio" (CR from hereafter), which is simply Y_d, the tristimulus value of the color over the dark substrate divided by Y_l, the tristimulus value over the light substrate, or

$$CR = Y_d / Y_l.$$

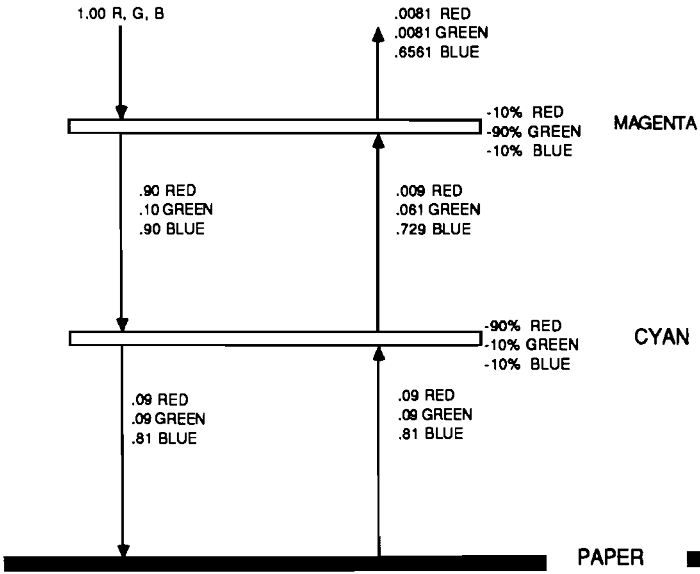
The Y tristimulus value is basically an estimation of a sample's lightness based on the entire color spectrum. A high Y tristimulus value indicates a light or low density color.

HYPOTHETICAL OVERPRINT

Trapping is the phenomena by which inks show different strengths when applied on top of other inks as opposed to directly on paper stock. The resulting color of the overprint is different than what is expected. Many variables affect trapping such as ink rollers, porous paper stock, ink viscosity, etc. Since the proofing system available has none of these variables which can cause trapping, the only reason for trapping differences would be the opacity of colors used.

In this example, two magentas are made to look the same but have different opacities. In one case, the color is purely transparent while the other sample reflects 0.5% of all incident light. Both magentas have the same spectral curve when analyzed as single colors over a reflecting substrate. If both of these colors are printed over the same cyan, the resultant overprints can be analyzed. Both examples are depicted on Figures 1 and 2.

Figure 1. Transparent Magenta Over Cyan.

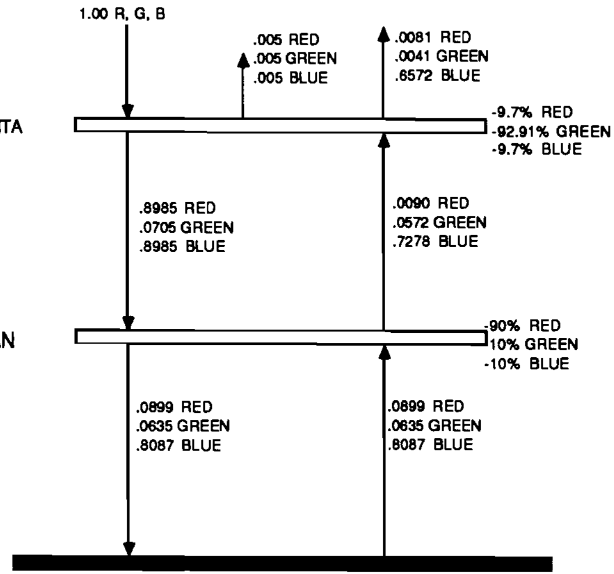


DENSITIES: 2.09 CYAN
2.09 MAGENTA
.18 YELLOW

HUE ERROR=100
GRAYNESS=9

$$\text{BLUE TRAPPING}=\frac{2.09-.09}{2.00}=1.00 \text{ OR PERFECT TRAPPING}$$

Figure 2. Opaque Magenta Over Cyan.



DENSITIES: 2.04 MAGENTA
1.88 CYAN
.18 YELLOW

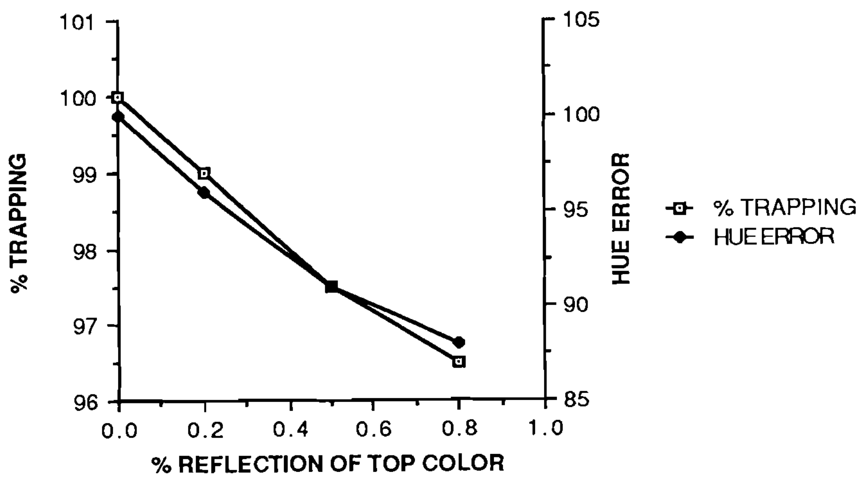
HUE ERROR=91
GRAYNESS=9

$$\text{BLUE TRAPPING}=\frac{2.04-.09}{2.00}=97.5\% \text{ TRAPPING}$$

It is assumed that the paper base is a perfect reflector and that any reflection on the underside of the magenta has a negligible effect on the color. Both samples receive the same amount of red, green, and blue light and the resultant light emitted is shown in the figures. Since density is the negative log of the reflectance for each color, densities, hue errors, and trapping can be calculated.

For the transparent magenta overprint, a pure blue hue and perfect trapping are attained. The opaque magenta reflects some of the light that the cyan layer would see, thereby producing an overprint which is slightly more magenta in hue. Also, the resulting trapping performance is reduced by using a magenta which is not as transparent. Hypothetical overprints using magentas reflecting 0.2% and 0.8% of incoming light were also calculated and results appear on Figure 3. Notice that as the opacity of the top color increases, the apparent trapping decreases.

FIGURE 3. EFFECT OF COLOR REFLECTION ON MAGENTA/CYAN OVERPRINT



PRACTICAL EXAMPLES OF OVERPRINTS

In an effort to demonstrate that trapping decreases with increasing opacity of the top layer, six color samples were made: two magentas, two cyans, and two yellows. For each color, a "transparent" and "opaque" sample was made, both possessing the same spectral curve. Spectral curves of the resulting colors can be found in the Appendix. The contrast ratios appear below in Table 1.

Table 1. Contrast Ratios of Transparent and Opaque Samples.

Color	Transparent CR	Opaque CR
Cyan	20.22	36.29
Magenta	26.90	37.83
Yellow	10.63	24.62

Each color was coated over opaque and transparent samples of the other two colors, resulting in 24 different overprints. The resulting trapping values are shown below. Subscript "o" is used to indicate the opaque sample while "t" represents the transparent color.

Table 2. Trapping of Overprints Using Transparent and Opaque Colors.

Color Below	Color On Top: C_o	C_t	M_o	M_t	Y_o	Y_t
C_o	x	x	79.8	88.0	96.4	95.6
C_t	x	x	79.2	85.4	96.2	97.4
M_o	94.2	93.8	x	x	15.6	76.0
M_t	92.0	95.8	x	x	19.6	81.0
Y_o	99.6	100.0	99.8	100.2	x	x
Y_t	98.2	97..4	98.8	99.0	x	x

According to Table 2, differences in opacity of the bottom color have no effect on trapping. However, the top color has an impact on the trapping results of the package. The densitometer's uncertainty of +/- 3 units of trapping leaves magenta over cyan and yellow over magenta trapping differences as significant in this data. In these cases, especially when yellow is placed over magenta, trapping decreases as opacity increases. Since densitometers only measure small sections of the spectral curve, the choice of colors may have created a selective impact on trapping differences. The choice of more balanced spectral curves may affect the trapping numbers equally between overprint colors. The data shows, however, how in practical examples opacity differences can be mistaken for trapping problems.

COLOR DIFFERENCES CAUSED BY OPACITY

Trapping errors are a concern because they explain the reason for color differences compared to a perfect system. Sometimes, because of hue shifts and a densitometer's lack of sensitivity to detect them, color differences occur even though trapping numbers are similar. Since color is what is most important, how it is affected by opacity differences must be studied.

At this juncture, the densitometer will be abandoned in favor of the Applied Color Systems Spectro Sensor spectrophotometer for results more indicative of what the human eye would conclude. This spectrophotometer uses the visible spectrum to calculate tristimulus values and CIEL*A*B* numbers for any color analyzed. Comparisons to a standard can be made and a DE*, or overall color difference is calculated. A DE* of greater than 1.00 is accepted as noticeable, although a slight difference is apparent in neutral colors at DE* levels above 0.50.

Samples were made to allow comparisons between transparent and opaque colors as top layers of overprints. For each overprint, the bottom layer consisted of a solid, transparent color while the top layer consisted of a 10%, 25%, 40%, 70%, 90%, or solid dot, 150-line screen. A total of 72 samples were made for analysis.

Each pair of overprints of the same color and % dot screen was analyzed using the overprint with the transparent color on top as the standard and the opaque color on top as the batch. DE* color differences were calculated for each pair and are tabulated in the Appendix and plotted in Figure 4.

FIGURE 4. COLOR DIFFERENCES OF OVERPRINTS

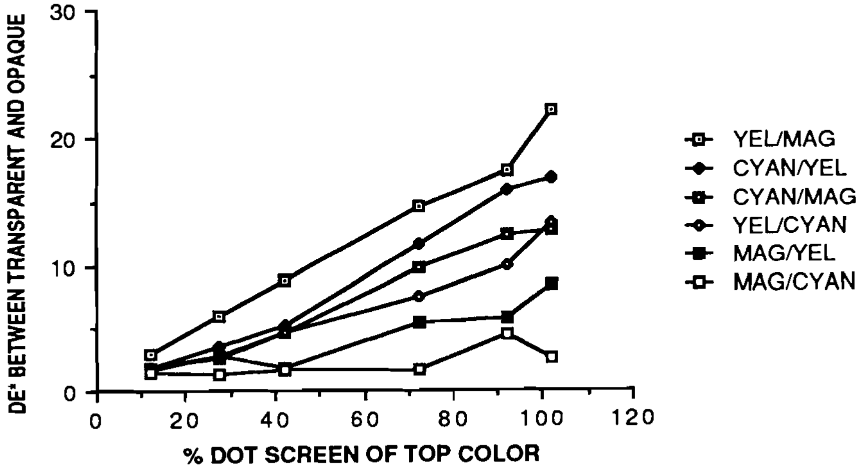


Figure 4 shows that color differences of overprints increase as opacity and dot percent increase. The largest differences are noticed with solid overprints, but more apparent is that the majority of color differences exceed 1.00 even at the 10% dot overprint level. Considering that the spectral curves of the pure colors are identical, these color differences are staggering.

APPLICATION TO PRINTING INKS

Thusfar all the data presented has been gathered using the Polaroid Proofing System. Findings already presented can be used to quantify possible differences found between a printed sheet and a proof. Using samples of printing inks, the effect of opacity differences between press and proof can be predicted.

Two sets of widely accepted printing inks were measured for contrast ratio using the Applied Color System Spectro Sensor and resulting data is shown in Table 3.

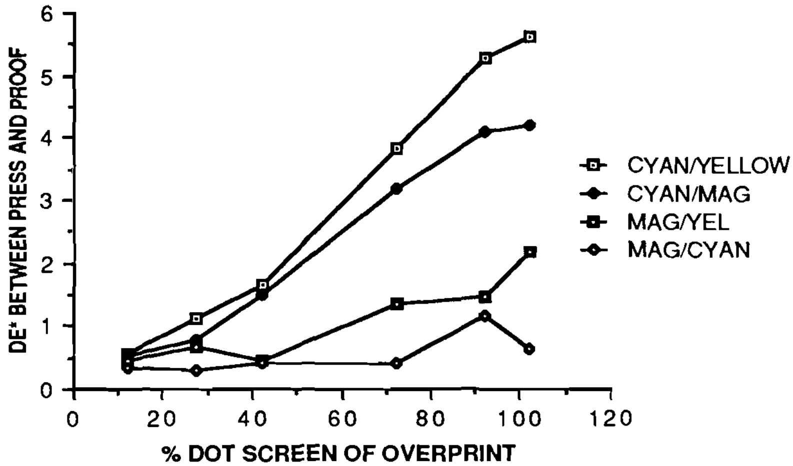
Table 3. Contrast Ratios (CR) of Inks and Color Samples

Color Sample	Trans. Color	Ink Set#1	Ink Set#2	Opaque
Cyan	20.22	25.66	14.94	36.29
Magenta	26.90	29.76	25.21	37.83
Yellow	10.63	10.38	9.89	24.62

The two inks tested showed very different opacities, which demonstrates the variability of printing ink transparency commonly found in the industry.

Using these contrast ratios, the inks can be compared to the proofing colors to predict the error obtained through differences in opacity. Ink set #1 was chosen since, for the cyan and magenta inks, the contrast ratios fell within the limits of our transparent and opaque proofing samples. Assuming a linear relationship between contrast ratio and DE* color difference and spectral curve similarity, color differences were calculated and plotted in Figure 5.

FIGURE 5. COLOR DIFFERENCES BETWEEN PRESS AND PROOF OVERPRINTS



Since both yellows had comparable contrast ratios, so curves for yellow over any other color do not appear in Figure 5. If the colors used in a proof have the opacities of the transparent samples in Table 3, the proof and press sheet would differ in color by up to 5.5 DE* units in solid overprint areas. If more than 100% trapping occurs, i.e.-cyan over magenta over yellow, the resulting DE* would be even greater.

Because of these opacity differences between ink and proofing colors, darker areas of proofs such as backgrounds and dark objects are virtually impossible to match between proof and press.

CONCLUSIONS

In summarizing what is presented in this paper, the most important point is that differences in color opacity lead to differences in color in overprinted areas, especially in background areas of printed and proofed images. Also, these differences may be mistaken for trapping problems. As a result, a color match is only a match if matched for opacity, and this becomes crucial in overprint areas.

Large differences exist between ink opacities or hiding power which will affect color on a printed sheet. Differences in opacity between colors on press and proof leads to uncorrectable color differences, especially in background areas.

RECOMMENDATIONS

Color problems associated with opacity must be recognized if such problems are to be cured. Opacity should be controlled at all levels of graphic arts, including printing and proofing. Standards for color opacity are needed to lessen the shortfalls of color proofing, which will in turn save wasted time in the proofing segment of the printing process.

Opacity flexibility in both proof and press colors would make it possible to adjust for opacity differences.

APPENDIX

COLOR DIFFERENCES BETWEEN OVERPRINTS OF TRANSPARENT AND OPAQUE PROOFING COLORS

% DOT SCREEN OF OVERPRINT COLOR	COLOR UNDERNEATH		
	CYAN	MAGENTA	YELLOW
100% CYAN	----	12.00	16.14
90%	----	11.68	15.12
70%	----	8.91	10.86
40%	----	4.01	4.41
25%	----	1.86	2.83
10%	----	1.08	1.18
100% MAGENTA	1.85	----	7.77
90%	3.84	----	4.98
70%	1.03	----	0.99
40%	0.99	----	1.03
25%	0.54	----	2.00
10%	0.67	----	1.14
100% YELLOW	12.58	21.46	----
90%	9.26	16.76	----
70%	6.82	13.91	----
40%	3.88	7.97	----
25%	2.04	5.29	----
10%	1.01	2.20	----

COLOR DIFFERENCES BETWEEN OVERPRINTS OF TRANSPARENT PROOFING COLOR AND INK SET #1

% DOT SCREEN OF OVERPRINT COLOR	COLOR UNDERNEATH		
	CYAN	MAGENTA	YELLOW
100% CYAN	----	4.06	5.46
90%	----	3.95	5.12
70%	----	3.02	3.68
40%	----	1.36	1.49
25%	----	0.63	0.96
10%	----	0.37	0.40
100% MAGENTA	0.48	----	2.03
90%	1.00	----	1.30
70%	0.27	----	1.20
40%	0.26	----	0.30
25%	0.14	----	0.52
10%	0.18	----	0.30

SPECTRAL CURVES OF TRANSPARENT AND OPAQUE COLOR SAMPLES