Paper: The Fifth Color

Paper, an analog variable in the digitized color world, is the reflecting surface for ink, affects hue in the highlights, impacts shadows, controls color gamut size, and is anything but a predictable commodity.

BY TRISH WALES

Paper is integral to print whether the marking technology is inkjet, toner, offset, gravure, flexo or crayons. Although a given paper brand's attributes may be consistent, paper characteristics are not standardized. There is variation in attributes between mills as well as variation around an attribute property from a given mill. Paper is considered a commodity but its properties are a long way from standardized.

Today's image reproduction workflow is almost completely digitized.

- Analog film is extinct, photographers have learned to deal with digital cameras.
- Design is almost exclusively executed on a computer using Adobe or Quark products, also digital.
- Separation of RGB files to CMYK for output is based on a variety of algorithms in prepress.
- Plates are CTP and digital information is sent to modern presses for presetting ink keys.
- Press controls measure color and adjust inking accordingly, applying digital measurements to an analog process.

Paper manufacture is an analog process. It starts with a natures' variation and continues in an elaborate and sophisticated workflow that converts trees into paper. Describing the finished product requires more than a single test result. Paper properties are measured and measurements averaged to provide one number with a range of possible values. Any measured property has an average value, not a single number, and a range of values that describe the property. Variation is a fundamental concept in an analog process and that variation must be understood by all who use paper (and ink) to display their message.

Imagery output on paper is strongly influenced by the substrate and the substrate is critical to color management. It is the reflecting surface for ink, a major contributor to hue in the highlight tones through its whiteness, and contributor in the shadows with its impact on trap. It is the fifth color in a four-color process printing system, a controller of color gamut size and anything but a predictable commodity.

Color Management and Paper

Color management is a current and still emerging technology, frequently talked about, not always understood, and advancing at a rapid pace. There is an alphabet soup of buzzwords—CMM [color management module], ICC [International Color Consortium], L*a*b* [a color space] and such terms as rendering intents, device link profiles and the list goes on. Color management is not plug-and-play yet; many clients are still dissatisfied with the quality of their four-color process jobs but it is approaching the world of science.

From prepress, where it was arguably born, upstream to the photographer and downstream to the printer and suppliers, color management gurus are identifying critical variables. Standards groups are trying to establish specifications that are realistic and spur suppliers to provide measurable and predictable products. Paper is part of the equation.

Measuring Details: Some Basic Definitions

Color is precisely defined in a three dimensional system devised by the CIE in 1932. The L*a*b* color

space is a mathematical computation based on this measurement system and is the language of choice for color management from design through prepress and now into the pressroom. Color values are a calculation from a measurement that describes the fundamental components of color relative to human vision. The L* value represents lightness, a* the red-green component and b* the yellow-blue component.

Measuring L*a*b* has several facets. Since a fundamental tenant of color management is measurement, and measurement requires carefully controlled variables, there are just a few important definitions to digest.

A first variable is light wavelength. In case you have not seen a rainbow lately, let me remind you that light can be separated into wavelengths that are associated with a color in the visible light range. We see visible light and the color associated with visible light wavelength. Other wavelengths of light exist. We are interested in those short wavelengths

Light is divided into wavelengths,
Some we can see and other wavelengths we cannot

called ultraviolet, the same ones that cause sunburns and skin cancers.

A second variable and one under much scrutiny is illuminants. Illuminants are well-defined light sources that describe the emitting light's strength at selected wavelengths. Illuminants are special light bulbs and they have names. D50 is the standard illuminant for Graphic Arts. D65 is the standard illuminant in the paper industry.

Illuminants are defined and calibrated light sources

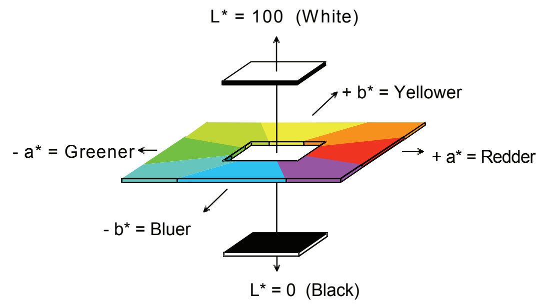
Light Source	Illuminant	Color Temperature
Midday Sun	D65	6500 Kelvin
Average Daylight	D50	5000 Kelvin
Indoor Lighting	C	6774 Kelvin
Incandescent	A	2856 Kelvin

Other considerations involved in quantifying color include incident light and viewing angles.

The last measurement detail to understand is the spectrophotometer. This is a device that measures the amount of light reflected at selected wavelengths and translates those measurements into various scales describing color, brightness, whiteness, and opacity. It is not the densitometer found in the typical pressroom but an instrument that translates color into well defined numbers that enables us to talk about color in more scientific terms. A spectrophotometer, often called a spectrometer, separates light into its component wavelengths and provides information about how much light is reflected at each wavelength.

Color, of course, is the name of the game. Color measurements are the vehicle to communicate information. Paper has color and is also described using the L*a*b* color space. The mills call it shade.

Scientific descriptors of color are not verbal. Color management has moved the language of color into the measured L*a*b* color space. This is the language of color measurement, the basis of ICC profiles, and the interpreter of color between the different devices in the workflow.

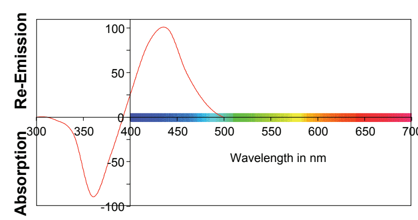


*The L*a*b* Color space defines color using three dimensions*

Optical Brighteners: Color Matching Nemesis

With those quick definitions behind us, let's move to understand how new trends in paper are affecting color measurement and therefore color reproduction.

Today's print designers demand high "bright," blue white papers at a competitive price. In response, many paper companies add optical brighteners to their papers. These chemicals absorb light in the ultraviolet region of the spectrum and emit light in the blue region of the visible spectrum.



Optical brighteners absorb invisible ultraviolet light and emit blue light

Viewed in light that has an ultraviolet component, the papers appear bright and blue. They have an apparent expanded gamut. However, the printed hues will mutate, or change color depending on the light source. This effect is called metamerism and drives a need for light booths and an understanding of the viewing conditions when color matching or judging color. Simply put, printed hues shift, particularly in the highlight tones, when papers contain optical brighteners.

If paper contains optical brighteners, color matching must be done in reference light conditions. When proofing on job stock that contains optical brighteners, it is important to critically examine both separations and curve effectiveness in the cyan containing highlight areas. The cyan/yellow color balance is hardest to achieve with these papers.

Even proofing papers contain optical brighteners. Creating profiles on these papers requires interpretation and tweaking if the press papers have a different level of optical brighteners or if the press papers have no optical brighteners.

Finally, optically brightened papers lose their fluorescence over time especially if exposed to light. The paper yellows. Print hues shift. Once printed, there is no recovery of the original paper whiteness so this should be kept in mind when a job reprints. Trying to match a first printing several months after completion is almost impossible. New proofs are a minimum requirement.

Why Can't I Just Measure the OBA Effect and Compensate?

The effect of optical brighteners changes with the intensity of the ultraviolet light illuminating the paper. Intense UV light, think midday sun, results in bluer appearing paper. The same paper viewed on a cloudy day would appear less blue (or more yellow). And any image, even a color-managed image, with significant white space will show some level of similar hue shifting.

Now to the measuring illuminant. When papers contain optical brighteners, the measuring illuminant must be precisely calibrated through both the UV and visible wavelengths. More UV light in the illuminant will make the paper appear bluer and measure differently than if the illuminant has less UV light. D50 illuminants found in pressroom measuring instruments do not accurately reproduce the UV component of the D50 light source. You cannot rely on the L*a*b* values when papers contain significant levels of optical brighteners. White point compensation moves away from science back to art. You will most likely recognize the presence of optical brighteners in the highlights and skin tones because they will be casted either blue or yellow.

Brightness, A Marginal Metric

Paper brightness is a measurement developed many years ago to judge the effectiveness of removing lignin (yellow) from pulp (a shade of white). Brightness quantifies the amount of bluish light reflected from the paper surface at a single wavelength. Brightness values are readily available since paper is typically sold based on this measurement. Color reproduction is affected by all wavelengths of light reflected by paper, not just the blue wavelength used in the brightness measurement.

Brightness is not a useful measurement to predict color reproduction or color gamut. Paper hue is the critical attribute. Papers of differing hues can have the same brightness. You need the L*a*b* of paper to predict image appearance.

Even proofing papers contain optical brighteners. Creating profiles on these papers requires interpretation and tweaking if the press papers have a different level or no optical brighteners.

U.S. papers use a Tappi standard test for Brightness while the rest of the world uses an ISO standard test. The two measurements do not correlate. Brighter papers do reflect more light but the numerical comparison requires that you know the test method. Some papers have high brightness measurements but low reflectance at other wavelengths. Some papers have high Brightness only if there is an ultraviolet light component present in the measuring illuminant. Brightness is an indicator but does not accurately predict the range of colors printable on paper. Ask for L*a*b*.

What About Whiteness?

Recently, whiteness values are appearing as a way to better characterize paper. In fact, it is a visually significant indicator. Of all the optical paper measurements available, whiteness is a good predictor of how "white" the paper is. It is not helpful for color management purposes other than as a predictor of the presence of optical brighteners.

A group of industry experts on an IDEAlliance sponsored team, visually ranked 60 samples of unprinted coated and uncoated papers to evaluate the effectiveness of available optical measurements. In separate evaluations, samples were ordered by Brightness, then L* luminance, and then Whiteness. Only the Whiteness ranking provided visual order. This value is not useful in color management tools but is valuable for aiding content creators in understanding their canvas.

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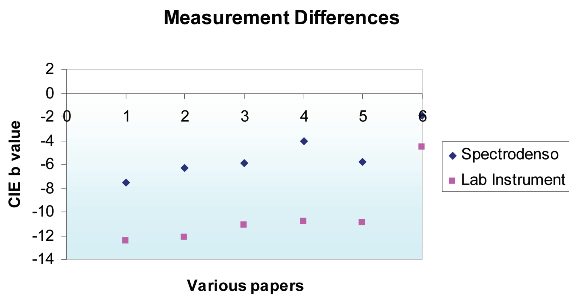

There are actually multiple whiteness measurements, most are based on the L*a*b* color space. To compare whiteness values, you must know which measurement system is used.

By definition, whiteness quantifies the amount of light reflected across all wavelengths. It is theoretically an improvement over brightness but the results are enhanced if the paper is bluish in color. Higher whiteness papers are bluer! In L*a*b* terminology, they have a more negative b* value.

There is yet another whiteness scale that has recently appeared. A new British whiteness scale called Mako Whiteness reduces whiteness to a 1 to 10 scale.

The more prevalent yardsticks for whiteness of paper have scales from about 50 to 150. Whiteness values above about 100 usually indicate the presence of optical brighteners and papers above 120 require careful control of proofing calibration and lighting conditions.

Different whiteness scales exist but basically all reward bluer shades whether blueness comes from dyes or optical brighteners.

Paper Hue Competes with Ink

White papers are not RGB 255,255,255. Paper companies control the shade of their papers by adding dyes and other chemicals to affect appearance. More dyes, less reflection, more color compensation. The paper owns some of the color space so detail that requires paper's hue cannot be reproduced. The recent trends toward blue white papers have resulted in more and more dyes in the paper and further deviations from neutral. Some of today's papers are equivalent to a 5 percent cyan screen.

These papers appear white, crisp and sharp without ink and dots but need color correcting when they are printed. If imagery requires a low level of cyan, the fine detail will have to be achieved with other ink hue combinations or with a neutral black. The use of black reduces reflectance so achieving a smooth tone gradation in the "cyan tone" provided by the paper is difficult.

The Color of White Paper:

Paper shade, or white point, is the key attribute of paper and is measured using L*a*b* based on CIE XYZ. Described by these three values, color management applications calculate complex color interpretations to characterize paper and predict paper's effect on color reproduction. Adobe Creative Suite, the designer application used by about 80 percent of the market, allows the selection of paper using this metric. RIPs, raster image processors, used for high-end color separations and processing, use this metric, and spectrophotometers that measure this attribute are now available for the pressroom. ICC profiles convert hardware measurements through the L*a*b* color space.

The paper industry measures shade and will usually provide the information upon request. Request this data and calculate the Delta E difference between the press paper and your proofing paper to predict color reproduction issues.

The metrology, or test parameters, for shade must be understood in order to compare L*a*b* information. D50 is the graphic arts illuminant but not all D50 illuminants have the proper spectral curve. Laboratory instruments with UV containing light sources (such as Xenon) do not correlate well with handheld graphic arts instruments that typically use a tungsten light source. When optical brighteners are present in paper, the differences are significant.

Measuring equipment manufacturers are working on upgrades and new approaches to this dilemma.

Smooth, Glossy Papers Reproduce Best Dots

Paper gloss is related to surface roughness and therefore affects color reproduction. Light of all wavelengths is reflected from the surface of paper. How it is reflected defines both its gloss and dot gain characteristics. The more light is scattered, the greater the dot gain of the ink printed on the surface. If the paper is glossy and smooth, it scatters less light and there is less dot gain. Light is reflected almost like a mirror (specular reflection). Matte, dull and uncoated papers scatter more light resulting in more dot gain. Also, these papers require more ink to achieve a given density further increasing the dot gain.

One curve for all paper surfaces leads to less than optimum color.

Gloss papers reproduce the finest detail and generally have the lowest dot gain. However, dot gain is not the same on all gloss papers, even those in the same grade category. Dot gain on a premium sheet from one manufacturer may differ by as much as 5 percent from another manufacturer's premium sheet. The same is true for other paper categories.

Papers from different manufacturers absorb ink and fountain solution differently. There is not a standard for surface roughness, ink absorptivity or fountain solution absorptivity within the paper classification scheme. For the most accurate color, press profiles should be made on the chosen stock for a particular job. One curve for all gloss papers is not sufficient for critical color work. Matte and uncoated papers are even more variable.

Optimal Paper for Color Reproduction

The best color reproduction will occur on:

- Bright papers with uniform spectral reflection;
- Papers that are smooth and glossy;
- Papers that are neutral in shade; and
- Papers that exhibit minimal fluorescence.

Here's where the variation enters the equation. All of these product attributes will have a range of values that describe the attribute. Analog processes have variation and this is accepted. The best papers will have the least variation.

Finally, a discussion of opacity or show through of paper is relevant. There is a trend toward lighter basis weight papers that are more cost effective to produce and mail. A downside is that lighter basis weight papers typically have more show through than heavier papers. Sharp outlines and heavy ink coverage imagery may appear on the reverse side. A light colored screen will appear to change color non-uniformly, the result of the back side ink color. Lines of type may be hard to read.

Requesting opacity information and its variation helps predict this important attribute affecting color reproduction. Although higher basis weight papers tend to have more opacity, this is an expensive property to build into a sheet of paper and there is a broad range of opacities available at a given basis weight.

Color Science Emerges

Science requires us to move to new levels of precision in our language and understand the meaning of the terms that characterize our craft. We have measurements. They are a step in the right direction. The reference conditions of measurements of paper attributes must be understood and so must the variation in each of these attributes. Test conditions must be specified when information is provided. Find the appropriate metrics, gather the targets or average values and understand the variation about those average values to understand your paper selection. IPA