A Guide to

Understanding Graphic Arts Densitometry

x·rite

Table of Contents

Transmission Densitometry

The Equation: Density = $\log_{10} 1/T$

Where T = Transmittance
Transmission density is a function of the amount of light which passes through the film.

Black and white transmission densitometers are used for film inspection, as well as scanner and imagesetter calibration and linearization. The basic measurements are Density and Dot Area.

Why measure Density?

Measure D-Min of the film in clear area, to assure there is no fogging.
D-Min is typically .03 D, and not more than .05 D for most films.

Measure D-Max of the exposed (black area) to assure proper exposure and processing. Recommended D-Max is typically 3.8, and 4.0 D and higher for some laser films. Excessive D-Max may reduce resolution, and low D-Max may cause toning in the non-image area on the printing plate.

Apparent Dot Area

The Murray/Davies Dot Area Equation: Apparent Dot Area = $\dfrac{1 - 10^{-(D(t)-D(b))}}{1 - 10^{-(D(s)-D(b))}} \times 100$

Where $D_{(t)}$ = Density of film tint
$D_{(s)}$ = Density of solid, or D-Max
$D_{(b)}$ = Density of film base

The Yule-Nielson Dot Area Equation: Apparent Dot Area = $\dfrac{1 - 10^{-(D(t)-D(b))/n}}{1 - 10^{-(D(s)-D(b))/n}} \times 100$

Where $D_{(t)}$ = Density of film tint
$D_{(s)}$ = Density of solid, or D-Max
$D_{(b)}$ = Density of film base
n = An empirically determined factor

Why measure Dot Area

To verify that screens or film tints are correct and have not changed during duplication. To verify that an intended 50% tint on imagesetter output is in fact 50%?

Today, software programs are available to automate imagesetter calibration and linearization. Modern densitometers can be interfaced directly to a Macintosh or Windows PC, eliminating time consuming and error-prone manual entry of density and dot area values/data.

Reflection Density

The Equation: Density = $\log_{10} 1/R$

Where R = Reflectance
Density is a function of the percentage of light reflected. The table to the right shows the relationship of percent reflectance to Density.

% Reflectance	DENSITY
100%	= 0.0 D
10%	= 1.0 D
1%	= 2.0 D
0.1%	= 3.0 D
0.01%	= 4.0 D

Why measure Density?

In the pressroom, solid patches of each ink printed are measured, and the density values indicate to the press operator whether the amount of ink should be increased or decreased.

v 1.68D	c 1.37D	m 1.44D	y 1.08D

In four-color process printing, it is especially important that the cyan, magenta, and yellow densities are in balance, or the color (hue) of the Red, Green and Blue two-color overprints will shift.

What should my Density values be?

Table 1 shows some typical solid density values for three common printing conditions. If you are just starting to use densitometers, measure a number of samples from two or three similar jobs that ran well. The average densities for each ink color are good starting target densities.

Typical Wet Ink Densities for North America:

	BLACK	CYAN	MAGENTA	YELLOW
SHEET-FED, OFFSET	1.70 D	1.40 D	1.50 D	1.05 D
WEB-OFFSET, Magazine	1.60 D	1.30 D	1.40 D	1.00 D
NON-HEATSET WEB, Newspaper	1.05 D	0.90 D	0.90 D	0.85 D

Table 1: Values are Status-T, Density Absolute (paper included) as reported from GRACoL..

Typical Wet Ink Densities for Europe:

	CYAN	MAGENTA	YELLOW E	BLACK	YELLOW T
HIGH GLOSSY PAPER	1.45	1.40	1.40 E	1.85	1.00 T
COATED PAPER, mat	1.35	1.30	1.30 E	1.75	0.95 T
UNCOATED PAPER, News Print	1.20	1.15	1.20 E	1.55	0.85 T

Table 2: Values are recommended from UGRA / FOGRA with Polarization Filter and E response.

Keep in mind that a printing press naturally varies, and a typical tight tolerance for density is ± .05 D. A good demonstration of the normal variation of the press is to measure the same patch on ten press sheets, pulled at one-minute intervals, then record and plot the density values. This shows how density varies with no adjustments to the press.

Dot Area/Dot Gain *(Tone Value/Tone Value Increase)*

The Murray/Davies Dot Area Equation:

$$\text{Apparent Dot Area} = \frac{1 - 10^{-(D(t)-D(p))}}{1 - 10^{-(D(s)-D(p))}} \times 100$$

Where: D_t = Density of tint
D_s = Density of solid
D_p = Density of the paper/substrate

The Yule-Nielson Dot Area Equation:

$$\text{Apparent Dot Area} = \frac{1 - 10^{-(D(t)-D(p))/n}}{1 - 10^{-(D(s)-D(p))/n}} \times 100$$

Where: D_t = Density of tint
D_s = Density of solid
D_p = Density of the paper/substrate
n = An empirically determined factor

The Yule-Nielson equation is a modification of the Murray/Davies equation used to estimate the physical dot area. An empirically determined factor "n" is included to calculate an approximation of physical dot area resulting from the use of specific raw materials (ink, paper, substrate, etc.) used in the printing process.

Dot gain is the difference between the apparent dot area measured in the film with a transmission densitometer, and the apparent dot area measured on the printed substrate or proof with a reflection densitometer. Note from the equation that Dot Gain is a function of Density, and compares a tint patch to a solid patch. Dot Gain, as measured and calculated by the densitometer, includes both mechanical gain (growth of the physical half-tone dot) and optical gain (how the dot appears to the human eye, due to the refraction of light on the substrate). Mechanical dot gain is measured using a microscope or magnifier to eliminate the effect of optical dot gain.

Why measure Dot Gain?

Most of the information, or detail, in printed halftone pictures is carried in the tonal, or tinted areas. In the pressroom, measuring dot gain at 25% (highlight), 50% (mid-tone), and 75% (shadow) for each color is a quick indication of tone reproduction quality. In four-color process printing, the balance of dot gain between the three process colors, cyan, magenta and yellow, is critical for gray balance, and for maintaining critical overprint colors such as flesh tones, green grass, and blue sky. For example, excessive magenta dot gain will cause flesh tones to go red. Reducing magenta ink density to compensate might ruin the match of the red car, which is in line. For low key pictures, such as a black cat in a coal mine, excessive dot gain in the shadows will cause plugging and result in a loss of definition and detail. Excessive dot gain in highlights make pastels nearly impossible to reproduce.

What should my Dot Gain values be?

Table 2 shows some typical Dot Gain values for three common printing conditions.

	BLACK	CYAN	MAGENTA	YELLOW
SHEET-FED, OFFSET	22%	20%	20%	18%
WEB-OFFSET, Magazine	26%	22%	22%	20%
NON-HEATSET WEB, Newspaper	32%	30%	30%	28%

Table 2: Values are Status-T, calculated using Murray/Davies Equation measured at 50% film tint.

Apparent Trap

The Preucil Equation: $\% \text{ Apparent Trap} = \dfrac{D_{OP} - D_1}{D_2} \times 100$

Where: D_{OP} = Density of 2-color overprint, minus paper density
D_1 = Density of 1st ink down, minus paper density
D_2 = Density of 2nd ink down, minus paper density

Trap is an indication of the ability, or inability, of a printed ink to accept the next ink printed compared to how well paper accepts that ink. Factors influencing trap include ink film thickness, ink tack and viscosity, ink printing sequence, and the mechanical adjustments on press such as rollers and impression settings.

Because the Apparent Trap formula uses the density values measured with the complementary filter of the second down ink, you must know the printing sequence of the inks. Today's densitometers lead the operator through the necessary sequence of measurements.

READ Paper	READ O.P.	2nd INK	1st INK	y/c 80 T

Why measure Trap?

Poor trapping will result in a hue (color) shift in overprint reds (magenta and yellow), greens (cyan and yellow), and blues (cyan and magenta).

Consider an image with a *red* car on a *green lawn* and a *blue sky*. Poor trapping characteristics will make it difficult to achieve and maintain a color match of both the *blue sky* (cyan and magenta) and *green* grass (cyan and yellow).

What should my Trap values be?

Table 3 shows some typical Apparent Trap values for three common printing conditions. These values are for a print sequence of cyan-magenta-yellow with black ink laid down first or last.

	RED	GREEN	BLUE
SHEET-FED, OFFSET	70	80	75
WEB-OFFSET, Magazine	70	87	72
NON-HEATSET WEB, Newspaper	50	89	50

Table 3: Status-T, calculated using the Preucil formula.

Print Contrast

The Equation: $$\% \text{ Print Contrast} = \frac{D_s - D_t}{D_s} \times 100$$

Where: D_s = Density of solid
D_t = Density of tint (typically 75%)

Print Contrast indicates the degree to which shadow detail is maintained or kept open.

Why measure Print Contrast?

Print Contrast is a good indication of print quality because shadow detail carries important information in many images. Print Contrast values correlate well to the subjective evaluations of print quality, such as “flat” (low Print Contrast values) versus “jumps off the page” (high Print Contrast values).

Compared to mid-tone Dot Gain values, which change with ink film thickness and therefore Density, high Print Contrast values require both high density and sharp printing to maintain shadow detail. It is often used as a guide for maintaining proper ink/water balance. Today's densitometers lead the operator through the necessary sequence of measurements.

Solid	Tint	cyan 36 PC

What should my Print Contrast values be?

Table 4 shows some typical Print Contrast values for three common printing conditions.

	BLACK	CYAN	MAGENTA	YELLOW
SHEET-FED, OFFSET	43	38	38	33
WEB-OFFSET, Magazine	38	45	35	30
NON-HEATSET WEB, Newspaper	16	13	12	15

Table 4: Print Contrast values are Status-T, measured at a 75% film tint.

Hue Error & Percent Grayness

The Equations: $\% \text{ Hue Error} = \frac{M - L}{H - L} \times 100$ $\% \text{ Grayness} = \frac{L}{H} \times 100$

Where: L = Low density value
M = Middle density value
H = High density value

This equation is used when measuring all three color density values on a single patch. Example: Measure a solid yellow patch using the DEN ALL feature on your X-Rite densitometer. A single measurement yields three values:

yellow= 1.06D	magenta= .12D	cyan=.06D
(high)	(middle)	(low)

$$\% \text{ Hue Error} = \frac{.12 - .06}{1.06 - .06} \times 100 = 6\% \qquad \% \text{ Grayness} = \frac{.06}{1.06} \times 100 = 6\%$$

Hue is how we describe the color of an object, or printed area, such as red, green, or cyan. Hue Error does not indicate an “error” or problem but rather the variation from a theoretically perfect or ideal cyan, magenta, or yellow. For example, a printed solid patch of cyan has some magenta and yellow.

Grayness indicates the gray component of a color. Consider a perfect Yellow, then add a small amount of Black to it. The Hue (color) does not change but the *Grayness* increases.

Why measure Hue Error and Grayness?

Measuring *Hue Error* and *Grayness* indicates whether colors of proofs, inks, and inks printed on paper are consistent from day to day or throughout the press run. These values are also useful for testing incoming ink and paper. *Hue Error* values from two-color overprints (red, green, blue) can also be used as another indication of proper ink trap.

What should my Hue Error and Grayness values be?

Table 5 shows some typical *Hue Error* and *Grayness* values for three common printing conditions.

	Cyan		Magenta		Yellow	
	HUE	GRAY	HUE	GRAY	HUE	GRAY
SHEET-FED, OFFSET	20	14	46	14	5	6
WEB-OFFSET, Magazine	21	21	50	18	6	15
NON-HEATSET WEB, Newspaper	28	42	58	34	10	25

Table 5: Values are Status-T, paper included.

Glossary

ANSI, American National Standards Institute, Inc. is the U.S. standards body which verifies requirements for due process, consensus, and other criteria for approval met by standards developers.

ANSI PH2.17: American National Standard, Density Measurement – Geometric Conditions for Reflection Density.

ANSI PH2.18: American National Standard, density measurement – spectral conditions. This standard defines the Status responses for densitometers, such as Status T, and Status A.

ANSI PH2.19: American National Standard, conditions for diffuse and doubly diffuse transmission measurements (transmission density). This standard defines the Geometric and Spectral Conditions for transmission densitometers.

Apparent Dot Area (Tone Value): The percent dot area, as measured and calculated with a graphic arts densitometer, using the Murray/Davies equation.

Apparent Dot Gain (Tone Value Increase): In graphic arts, the difference between Apparent Dot Area of the films, as measured with transmission densitometer, and the Apparent Dot Area of the proof or printed sheet, as measured with a reflection densitometer.

Backing Material: The material placed directly under, or behind, a sample when measured. ANSI/ISO 5/4 - ANSI PH2.17 specifies a black backing be used to reduce measurement variability, especially when paper is printed on both sides.

CIE, Commission International de l'Eclairage: Translated as the International Commission on Illumination, the main international organization concerned with color and color measurement.

Color: A sensory, visual experience, characterized by the attributes of Hue, Lightness and Chroma.

Colorimeter: A photo-electric device that measures reflectance, has an instrument response known as the standard observer, as defined by CIE, and calculates and displays colorimetric data such as *CIE L*a*b**, and CIE L*C*h°.

Densitometer: A photo-electric device that measures transmitted or reflected light to calculate and display density values. The density values are used to adjust exposures for photographic applications and ink levels when printing. (See Reflection Densitometer and Transmission Densitometer)

GRACoL: General Requirements for Applications in Commercial Offset Lithography

Hue: The attribute of color perception by which an object is judged to Red, Blue, Green, Purple, etc.

ISO: International Organization for Standardization, ISO is the international standards body.

Process Colors: The standard printing ink set for process printing. Graphic Arts process colors are:
Cyan: Absorbs red light, and transmits green and blue.
Magenta: Absorbs green light and transmits blue and red.
Yellow: Absorbs blue light, and transmits red and green.
Black: Absorbs blue, red, and green light. Used for type, and to add weight to 4-color images.

Reflection Densitometer: An instrument that measures the amount of incident light that is reflected from the surface of a substrate, such as ink on paper.

Saturation (aka Chroma): The attribute of color perception that expresses the degree of departure from gray of the same lightness.

SNAP: Specifications for Non-heatset Advertising Printing.

SPC: Statistical Process Control.

Spectrodensitometer: A spectrally-based densitometer that combines the functions of a spectrophotometer, colorimeter and densitometer.

Spectrophotometer: An instrument that measures light at many points on the visual spectrum which results in a curve.

Status A: ANSI PH2.18, densitometer response. This is the accepted standard for reflection densitometers for measuring photographic color print.

Status E: A densitometer response which is the accepted standard in Europe for color reflection densitometers.

Status I: A densitometer response commonly referred to as narrow band or interference-type response.

Status T: Wide band color reflection densitometer response which is the accepted standard in the United States for color reflection densitometers.

SWOP™: Specifications for Web Offset Publications.

Transmission Densitometer: An instrument that measures the amount of light that is transmitted through film from a known light source. Graphic arts transmission densitometers are programmed to calculate Density and Dot Area of half-tone film.

Tristimulus: Of or relating to values giving the amounts of the three colored lights, or receptors, Red, Green and Blue.

Instrument Types

Transmission Densitometer

Measures light transmitted through film and calculates Density and Dot Area.

These measurements are needed for inspecting films, checking accuracy of dupes, and for calibration and linearization of imagesetters and scanners.

Color Reflection Spectrodensitometer

These spectral-based instruments measure reflected light, and calculate Density, Dot Gain, Trap, and Print Contrast values from color bars.

Auto-Scanning Densitometer and Spectrodensitometer

Scanning densitometer or spectrophotometer system for automatic measurement, data collection and analysis. Rapid measurement allows press-side SPC (Statistical Process Control).

Solutions For All Color Needs

X-Rite offers a complete array of solutions for all your color control needs. This includes devices that calibrate monitors, color copiers and printers, and instruments to profile devices for color management, color productivity, and quality control software and ink formulation systems.

xrite.com

ISO 9001 Certified

3100 44th Street SW, Grandville, MI 49418 (616) 534-7663 (800) 248-9748 FAX (616) 534-8960

L7-093 (12/03) Printed in U.S.A.