H46: Measurement of Print

Measurement of print

The colour parameters XYZ or L*a*b* are not related in a simple way to the characteristics of the half-tone image. Densitometry refers to the measurement process used to describe the print “density” characteristics of images produced by the four-colour printing process.

Reflection density is widely used for quality and process control within the graphic arts industry. Once the half-tone characteristics of a visually acceptable print is established, densitometry offers a way of assessing the properties of a print using parameters that are directly related to the half-tone process. The information from the instrument can be used to monitor the production process so that corrections and adjustments of the press can be made in order to maintain acceptable reproduction.

The methods and terms used here follow the practice of the Committee for Graphic Arts Technologies Standards (CGATS).

Printed colour

Printed layers are usually semi-transparent which means that the incident light can interacted with the material in a number of ways, as is illustrated in Figure 1. The light could be reflected light by the air to coating boundary or it could be scattered by the pigment particles within the ink layer. It could also be transmitted through the layer, reflected by the substrate and then transmitted, back out of the system.

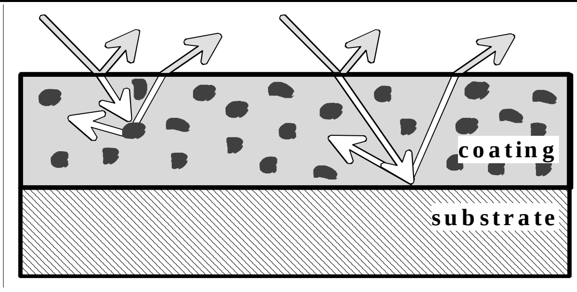


Figure 1: Light reflection by a semi-transparent layer

It is helpful to understand the way which the dot-areas of a half-tone pattern are related to the amounts of light in the red wavelength band (R), green wavelength band (G) and the blue wavelength band (B) that are reflected by each area of the print.

Colour mosaic

In the case of half-tone printing, only eight different coloured dots are produced. Typical colour separation values (amounts of light in the red, green and blue wavelength bands) for each type of dot relative to those of the white substrate are shown in Table 1.

Table 1: Reflectance values of single print and overprints of the process colours

Dot Type (i)	Dot Colour	% Red, r(i)	% Green, g(i)	% Blue, b(i)
1	White	100.0	100.0	100.0
2	Cyan	5.38	39.54	63.35
3	Yellow	97.77	88.86	10.95
4	Magenta	88.75	8.14	39.01
5	Red	86.91	6.74	2.94
6	Green	5.27	33.39	7.35
7	Blue	4.88	3.53	23.89
8	Black	4.78	2.66	1.95

All the colours available in the printed image are formed by changing the area occupied by of each type of dot in the mosaic of dots in a localised area of the print. The area of a single dot is so small that there will be several hundred even in the smallest part of the image that the eye can resolve. The colour seen by the eye in each part of the image arises from the blending of the light reflected by the mosaic of dots. Each type of dot will contribute a proportion of light from the red, green and blue bands of the spectrum and the net effect is determined by the sum of these contributions.

Densitometer: c y m k

The densitometer is the workhorse instrument of the printed colour reproduction industry. Each step of the production can be monitored by the values recorded by the densitometer. The principle of the reflectance densitometer is shown in Figure 2.

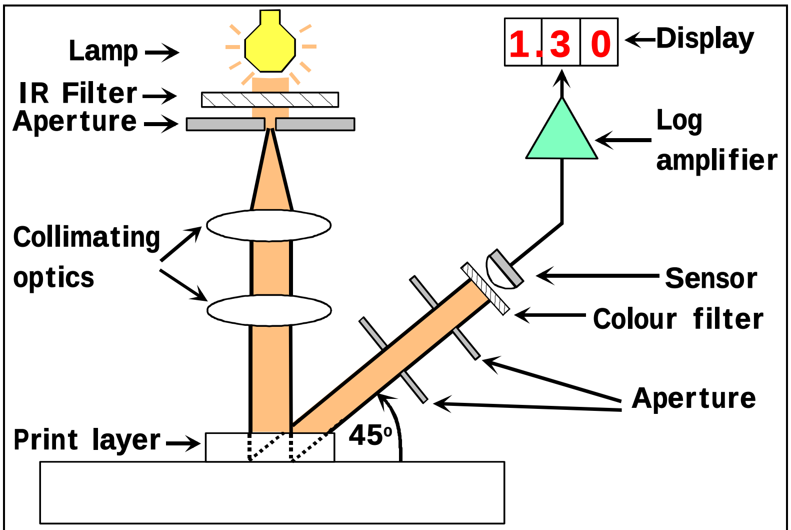


Figure 2: The 0/45 optical arrangement of a densitometer

Light from a tungsten filament lamp that simulates the CIE type A illumination is collimated into a parallel beam of rays and shone onto a small, well-defined, area of the printed surface. Light reflected by the printed surface is collected at an angle of 45° to the surface, as defined by a pair of apertures.

The spectral character of the 45° light is analysed using optical filters to determine the amounts of light in four bands of wavelengths; red, green, blue and visual. National and International Standards establish the characteristics of the filters or weighting functions.

The densitometry standards allow the positions of illumination and collection to be reversed to provide an alternative design for the instrument. In the 45/0 arrangement light is shone onto the print surface at 45° to the surface and the reflected light is collected normal to the surface.

R: Reflectance factor

In all cases the reflectance factor is defined as the ratio of the amount of filtered (or weighted) light detected from the sample relative to the amount of filtered (or weighted) light detected from a perfect white diffuser measured under the same conditions. In normal use the term “reflectance” is used rather than “reflectance factor”.

- $\mathbf{R}_v$ Visual filter reflectance: the reflectance for spectral analysis by the filter that transmits across all visible wavelengths.
- $\mathbf{R}_r$ Red filter reflectance: the reflectance for spectral analysis by the filter that transmits in the red wavelength band.
- $\mathbf{R}_g$ Green filter reflectance: the reflectance for spectral analysis by the filter that transmits in the green wavelength band.
- $\mathbf{R}_b$ Blue filter reflectance: the reflectance for spectral analysis by the filter that transmits in the blue wavelength band.

D: Optical density

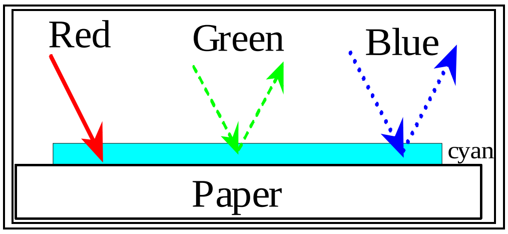
The optical density, also known as the reflection density, is a measure of the light absorbing property of a material, so that higher density values indicate that more light is being absorbed. The values of R and D over the range 0 to 3 are given in Table 2. It is determined from the logarithm of the reciprocal of the reflectance.

Table 2: Reflectance and density values

D	% R	D	% R
0.00	100.0	1.50	3.16
0.25	56.2	1.75	1.78
0.50	31.6	2.00	1.00
0.75	17.8	2.25	0.562
1.00	10.0	2.50	0.316
1.25	5.62	2.75	0.178

Equation 1 $$D = \log_{10}\left(\frac{1}{R}\right)$$

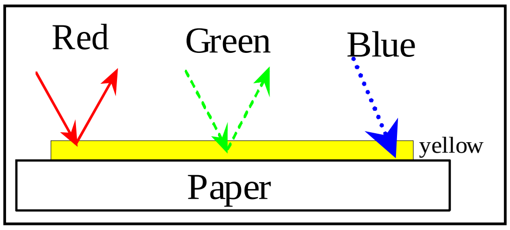
C or red-filter density: D_R



The cyan ink layer transmits blue and green light and absorbs red light. It follows that the cyan density unit depends on the fraction of red light reflected by the surface.

$$c = \log_{10}\left(\frac{1}{R_r}\right)$$

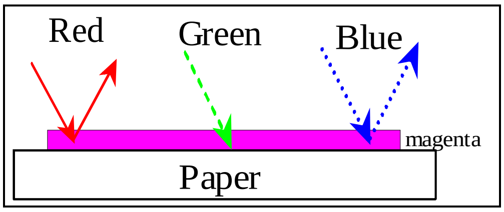
Y value or blue-filter density D_B



The yellow ink layer transmits red and green light and absorbs blue light. It follows that the yellow density unit depends on the fraction of blue light reflected by the surface.

$$y = \log_{10}\left(\frac{1}{R_b}\right)$$

M value or green-filter density D_G

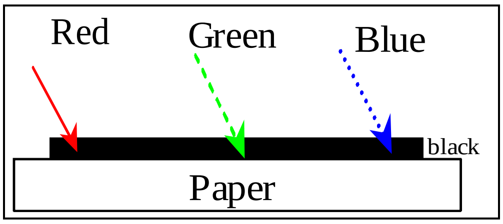


The magenta ink layer transmits red and blue light and absorbs green light. It follows that the magenta density unit depends on the fraction of green light reflected by the surface.

$$m = \log_{10}\left(\frac{1}{R_g}\right)$$

K value or visual-filter density: D_V

The black ink layer transmits absorbs throughout the spectrum. It follows that the black ink density unit depends on the fraction reflected by the surface, irrespective of wavelength. $k = \log_{10}\left(\frac{1}{R_v}\right)$



Typical values

Typical optical density values for a solid print are given in Table 3. They are the UGRA/FOGRA recommended values for measurements made under Status E filter response.

The density values will naturally vary slightly during a print run, a typical range of variation when operating to a close tolerance is ±0.05D units

Table 3: Example solid ink densities (Europe Status E)

Type of substrate	Type of ink Black Dv or k	 Cyan Dr or c	 Magenta Dg or m	 Yellow Db or y
Glossy paper	1.85	1.45	1.40	1.40
Coated paper, mat	1.75	1.35	1.30	1.30
Uncoated paper newsprint	1.55	1.20	1.15	1.20

Analysis filter characteristics

Densitometers use optical filters with a transmission characteristic similar to the filters used in the colour separation process of printing plate production. There are two major types of response in common use for reflection densitometry, Status T (USA) and Status E (Europe). It is important that the Status response of the densitometer is included in any specification or report of density values.

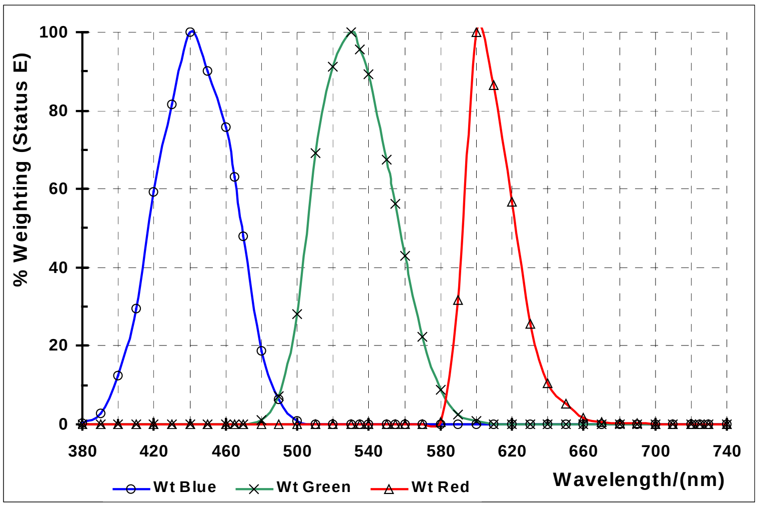


Figure 3: Spectral characteristics of the Status E filters (Europe)

Status E

Status E is generally accepted in the UK and Europe as the Wide Band Graphic arts filter response characteristics, see Figure 3. It has the advantage over the USA based Status T response in that the c y m density values of prints from a balanced set of process inks are similar in value. A balanced set of inks will print a neutral, achromatic colour for overprints of cyan magenta and yellow.

Status T

Status T is generally accepted in North America as the Wide Band Graphic Arts filter response characteristics. The green and red transmitting filters match the response of the Status E filters, however the blue transmitting filter (y density) has a peak transmittance at a longer wavelength than Status E and, on average, gives lower values of density. The differences between the two sets of blue filter responses are shown in Figure 4.

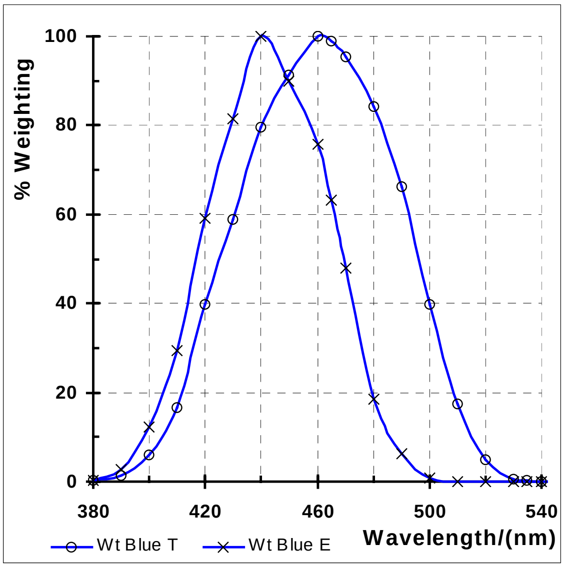


Figure 4: Blue filter response for Status T and E

Polarisation filter

It is generally agreed that polarisation filters can give less difference between the density values of a wet and a dried printed sheet. However the use of polarisation filters in a densitometer is controversial since the effect is not always consistent, there is the possibility of distortion of the spectral response and there are no published standards for the use of polarisation filters.

Print control strips

It is difficult to isolate areas on a printed image that are suitable for use in printing process control, as a result a test strip is often printed in an area that is normally hidden or discarded in the final product. The control stripe has a series of test areas whose density values can be used in the control of various aspects of the printing process. The size of the test areas should be larger than the aperture of the densitometer.

A typical general-purpose process control strip or colour bar may include the following elements.

- Solids of each of the process colours and paper (cyan, magenta, yellow, black, paper).

The solids are used to determine solid ink density, a parameter that is used in all the tone value calculations.
The density of paper is subtracted from all other density readings to provide the relative optical density values that are used in the other calculations.

- Three-quartertone, midtone and quartertone tints of the process colours (cyan, magenta, yellow, black). The tone values are used to determine the dot gain in the shadow, midtone and highlight areas of the print.
- Two-colour overprint solids (cyan + yellow, magenta + yellow, and cyan + magenta). The two colour overprints allow the determination of trapping.
- Grey-balanced three colour overprint (cyan + magenta + yellow), solid, three-quartertone tint, midtone tint and quartertone tint.
  The solid three colour overprint is used to assess the grey balance
- Where spot colours or additional colours are used then solids and tonal tints of these colours should be included.

Greyness and hue error

Definition

Greyness and hue error and are measures of the non-ideal nature of the ink-substrate combination, the values are used as quality control tests and are applied to incoming ink or paper/board and during a production run.

Greyness: Characterizes the relative achromatic content of a print made with a process-ink.

Hue error: The hue error characterises the amount of unwanted absorption of a print made with process-ink.

If the values vary during a production run, then it is an indication of contamination of the printing plates or the ink.

Explanation

The density values of a solid process-ink patch can be thought of as the sum of three contributions.

(greyness)+ (hue error) + (ideal process-ink)

The greyness contribution adds equally to each density value. The hue error contribution adds to just one of the density values. Consider a yellow solid patch with the values:

Solid print density yellow = 1.48D, magenta = 0.17D, cyan =0.08D

This is equivalent to the sum of the following contributions:

Greyness contribution yellow = 0.08D, magenta = 0.08D, cyan = 0.08D
Hue error contribution yellow = 0.00D, magenta = 0.09D, cyan = 0.00D
Ideal ink contribution yellow = 1.40D, magenta = 0.00D, cyan = 0.00D

Method

The measurements are made on the solid patch of the cyan, yellow or magenta ink. The solid ink patch is measured and the c, y and m density values units of the patch are noted. The values are examined and sorted into the highest (H), the middle (M) and the lowest (L).

Equation 2 **Greyness is given by** $$\%\text{Greyness} = \frac{L}{H} \times 100$$

Equation 3 **Hue Error is given by** $$\%\text{Hue Error} = \frac{M - L}{H - L} \times 100$$

The values obtained refer to the properties of the printed patch, so it is not necessary to take into account the density of the unprinted substrate.

Example: The yellow solid patch is measured and the values:

yellow = 1.48D (high), magenta = 0.17D (middle), cyan =.08D (low)

are obtained,

$$\%\text{Greyness} = \frac{0.08}{1.48} = 5.4 \qquad \text{Hue Error} = \frac{0.17 - 0.08}{1.48 - 0.08} \times 100 = 13.2$$

Table 4 shows Example values that are expected for different types of print process.

Table 4: Example hue error and greyness values for process inks.

Type of substrate and print method	Cyan		Magenta		Yellow	
	Hue	Grey	Hue	Grey	Hue	Grey
Glossy, sheet offset	20	14	46	14	5	6
Glossy, web offset	21	21	50	18	6	15
Web newsprint	28	42	58	34	10	25

It should be remembered that lower values of hue error and greyness represent a process-ink with properties closer to the ideal.

Tone value, apparent dot area (A%),

The apparent tone value is on a printed sheet is often different from that intended in the image file or on the plate. There are two reasons for the change in apparent area.
Physical dot gain described the change in the printed dot size due to the action of the transfer process of the ink from the plate to the substrate and spreading out (wicking) of the ink into the substrate.
Optical dot gain describes the apparent increase in dot size arising from the scattering and refraction of light within the print layer and substrate.

Definition

The tone values or dot area of a print is the percentage of the surface that appears to be covered by dots from single process-ink, ignoring light scattering in the print substrate and other optical phenomena.

Method

The apparent area is determined using the Murray-Davies equation. Three density values are needed.

The density of the unprinted substrate D_0

The density of the 100% (solid) patch D_s

The density of the # #% (tint) patch D_t

Equation 4
$$A(\%) = \frac{1-10^{-(D_t-D_0)}}{1-10^{-(D_s-D_0)}} \times 100$$

The appropriate c or y or m density values are used in the equation according to the colour of the ink under test.

Tone value increase, dot gain (TVI %)

Definition

The tone value increase is the difference in tone value between any two steps in the printing process. Modern definitions include electronic data and measured values on any media.

A statement of the tone value increase should include a statement of steps in the printing process that are being compared. For example:

electronic file to printed sheet; printing plate to printed sheet.

Explanation

The TVI or dot gain value gives a measure of the likely tonal quality of the print. The tonal balance of the print depends on the dot gains of the inks being similar, which is critical for grey balance, and for maintaining critical overprint colours such as flesh tones, green grass and blue sky.

The screen areas of the test patches are picked to correspond to three characteristic tonal regions of an image, highlight (25%), midtone (50%) and shadow(75%). Excessive dot gain in highlights make pastels nearly impossible to reproduce. Excessive dot gain in the shadows will cause loss of detail in these areas of the image.
Example: A 72% tone value (Equation 4) from a 50% input film printing tone value is reported as 22% TVI.

Table 5: Example dot gain values for the midtone (50%) screen dot-area.

Substrate and print method	Black	Cyan	Magenta	Yellow
Glossy, sheet offset	22	20	20	18
Glossy, web offset	24	22	22	20
Web newsprint	34	33	30	28

Print contrast

Definition
The print contrast is the ratio of the difference in density between the solid area and the shadow tint area to the density of the solid, expressed as a percentage. This indicates the printing system's capability to hold image detail in the shadow tone region.

Explanation
The shadow detail carries important information in many images, subjective evaluation such as “flat” or “jumps off the page” indicate a low or a high print contrast value. As a result, the % print contrast is determined using the shadow (80% or 75%) screen dot-area patch.

Method
The appropriate c or y or m density values are used in the equation according to the colour of the ink under test. Since the values refer to the quality of a print, no correction is made for the density of the unprinted substrate.

Two measurements are needed

The density of the solid patch D_s
The density of the tint patch D_t

The print contrast is determined from

Equation 5 $$\%\text{Print contrast} = \frac{D_s - D_t}{D_s} \times 100$$

Example
Table 6: Example of print contrast values for process-inks.

Substrate and print method	Black	Cyan	Magenta	Yellow
Glossy, sheet offset	40	36	36	30
Glossy, web offset	36	31	31	28
Web newsprint	24	22	22	18

Ink trapping

The four process-inks are printed in sequence, with black printed either first or last, then cyan, followed by magenta and then yellow. The inks are formulated to with a graduation in tack according to the sequence of application by the press. This ensures that an ink will adhere to the previous ink layer that was printed rather than lifting it from the paper.

An ink printed on top of another ink in a multi-colour press may not achieve the same density as when printed directly onto bare paper or board. One explanation for this is that the second-down ink does not transfer as efficiently to ink on paper as it does to paper alone. Factors influencing trap include ink film thickness, ink tack and viscosity, printing sequence and the mechanical adjustments on the press such as rollers and impression settings.

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

Definition

Ink trapping is the relative transfer of an ink onto previously deposited ink(s) as compared to the transfer of the same ink onto the bare paper/substrate.

Method

Ink trapping compares the density of the overprinted ink layers with that of the same ink layer printed directly onto the substrate. The appropriate c or y or m density values are used in the equation according to the top colour of the overprint.

Identify the top colour, or second ink laid down, of the two-colour overprint target to be measured. When taking measurements for this patch, use the filter for the top colour. For example, for a green overprint made by printing yellow over cyan, a yellow density (blue optical) filter is used.

Perform the following measurements using the filter for the top colour:

- Measure the density of the solid patch of the two-colour overprint. ***Record this value as D_{op}***
- Measure the density of the solid patch of the first laid down colour (for the yellow on cyan example this would be the cyan solid patch). ***Record this value as D_1***
- Measure the density of the solid patch of the second laid down colour (for the yellow on cyan example, this would be the yellow solid patch). ***Record this value as D_2***
- Measure the density of the unprinted substrate ***Record this value as D_0***

The apparent trapping of the top colour ink on the ink first laid down is given by the Preucil quation:

$$\%\text{Apparent trap} = \frac{D_{op} - D_1}{D_2 - D_0} \times 100$$

Example

Table 7: Example ink trapping values for wet on wet application of process inks.

Over print hue	**Red**	**Green**	**Blue**
Print order	M then Y	C then Y	C then M
Trapping of	Y on M	Y on C	M on C
Glossy, sheet offset	70	80	75
Glossy, web offset	65	75	70
Web newsprint	55	65	60