Application Note:
MTF, CTF, and Contrast Measurements

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Introduction

Much of the improvement in print quality over the last two decades is the result of improved resolution of digital printers. Most printer manufacturers market their resolution in terms of DPI (dots per inch), but this is misleading. DPI is actually the printer's addressability and this may or may not indicate higher resolution.

Indicators of resolution are MTF (Modulation Transfer Function) or CTF (Contrast Transfer Function). These functions show the ability of the printing system to maintain good black and white contrast on patterns of black and white lines of increasing frequency. This application note explains MTF and CTF and how they are measured using the Personal IAS. MTF and CTF are applicable to almost any printing technology.

Definitions

Contrast Transfer Function (CTF) is the preferred term for printed sample measurements. The term MTF is really more appropriate for optical components characterization.

There are three components in CTF, 1) *contrast*, 2) *transfer*, and 3) *function*. The word *contrast* is the difference in reflectance between black and white lines. The word *transfer* indicates that the contrast is being transferred from the digital file to a print. The word *function* means that the resulting contrast will be dependent on the frequency. Generally, contrast is lower at higher frequencies. The measurement results are displayed in a graph of contrast versus frequency.

There are several definitions of contrast or modulation. Here are some

$$Modulation = \frac{R_{max} - R_{min}}{R_{max} + R_{min}}$$

$$PrintContrast = \frac{R_{max} - R_{min}}{R_{max}}$$

$$EdgeContrast = R_{max} - R_{min}$$

where, R_{max} is the average reflectance in the areas between the lines, and R_{min} is the average reflectance of the lines.

Many people say they are measuring MTF when they are actually measuring CTF. Generally, CTF is the correct measurement for printed materials. When in doubt about what is being measured, ask for the equation being used.

Contrast has a number of standard definitions that are confusing. *Print Contrast* is known as simply "contrast" in ISO-13660 and as "Print Contrast Symbol (PCS)" in ANSI X3.182 barcode standard. *Edge Contrast* is defined in ANSI X3.182 and referred to as the "QEA method" in Personal IAS software.

In summary: MTF is really CTF and for the rest of this article the word Contrast = $R_{max} - R_{min}$.

Setup

To get started in CTF quantification, a test target with a range of frequencies must be created. This must be created in bitmap software (e.g. Photoshop). Vector graphic software like Illustrator should not be used because aliasing may occur during printing. The test target should start with a one-pixel-on/one-pixel-off pattern, continue with a two-pixel-on/two-pixel-off pattern, and so on. The file should be set to print at the resolution of the printer, e.g. 600dpi for a 600dpi printer or 720dpi for a 720dpi printer. In Photoshop this is set under the menu selection **Image|Image Size…**

When printing the target on a color printer, shut off color management, if possible. It might also be helpful to use a "black only" print mode if one is available.

There are a few simple steps involved in setting up for MTF measurement.

1) Use a black "backstop" beneath target to prevent the table color from affecting the measurement.
2) Enter the frequencies of the patterns into the Personal IAS under the **Options|MTF…** menu selection.
3) Select the appropriate color filter under **Options|General…** , e.g. visual density for B&W.

Start the measurement by clicking the MTF button

CTF of B&W Laser Printers

Over the last two decades, laser printer manufacturers have improved the print quality and increased the number of dots per inch (dpi) of their printers. To study the effect of these improvements, a group of three HP LaserJet printers were measured for CTF.

The three printers chosen for this study were

1. HP Series II, introduced 1987, 300dpi

2. HP 5Si, introduced 1995, 600dpi
3. HP 4050, introduced 1999, 1200dpi

A test target was created, printed on each printer, and measured using the Personal IAS. The results of the measurements are shown in Figure 1 and Figure 2.
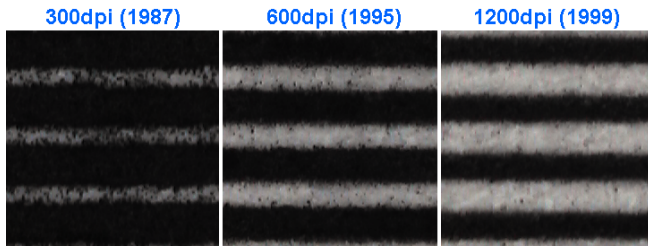

300dpi (1987)   **600dpi (1995)**   **1200dpi (1999)**

Figure 1: 3 cycles/mm patterns on HP LaserJet series II (left), 5si (middle), and 4050(right) (1.2×1.2mm images)

Interpretation of the CTF graph is straightforward. At low frequencies, the contrast will approach the difference between the paper brightness and ink reflectance, usually around 0.7 to 0.8 depending on the paper used. The high frequency is more indicative of the resolution of the printer. Higher resolution printers will have higher contrast.

To put this data into perspective, it is helpful to know that humans cannot perceive frequencies above 10cycle/mm at a 300mm viewing distance (reading distance).
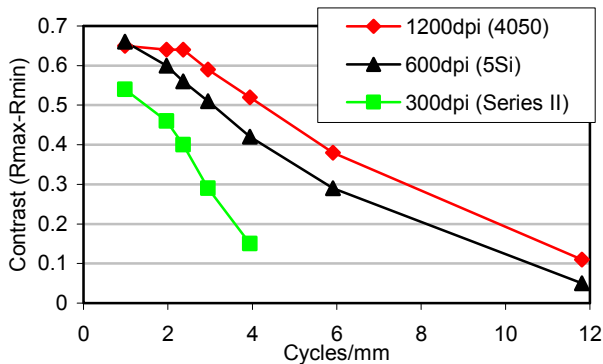

Figure 2: CTF for HP LaserJet printers

The CTF of these printers has clearly improved with the newer generations. The HP 4050 can maintain higher contrast than the HP 5si or the HP Series II printer.

Lower contrast results from 1) printing the black lines too wide and 2) toner splatter darkening the white area.

CTF of Inkjet Printers

Inkjet printers have also improved print quality and resolution over the last two decades. To see this effect, two Epson printers were used to print a CTF test target with seven patches ranging from 14.2 cycles/mm to 1.2 cycles/mm. The printers used were an older Epson 1520 and the newer Epson 900. The key difference between these printers is that the Epson 900 uses smaller drops. Both printers are marketed as 1440dpi. Epson *Photo Quality Ink Jet* paper was used.

The inkjet printers had a difficult time printing the CTF pattern as seen in Figure 3 and Figure 4. The HP LaserJet 4050 laser printer data is also included as a reference.

Clearly, the Epson 900, the newer inkjet printer with the smaller drop size, has higher contrast than the older Epson 1520 printer. The sources of low contrast can be seen in the images. The Epson 1520 has a lot of satellite drops (or misaligned jets) that are darkening the areas intended to be white. In addition, both the Epson 1520 and Epson 900 printed excessively wide black lines. This further darkens the white lines. By comparison, the HP LaserJet sample has almost equal width black and white lines. This equal spacing generates much higher CTF numbers for the laser printer.
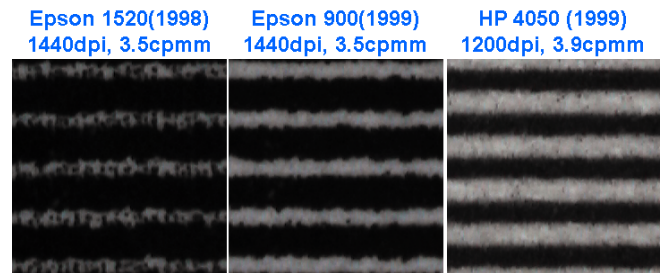

Epson 1520(1998)   **Epson 900(1999)**   **HP 4050 (1999)**
1440dpi, 3.5cpmm   **1440dpi, 3.5cpmm**   **1200dpi, 3.9cpmm**

Figure 3: Two inkjet printers (left) compared with laser printer (right). (1.2×1.2mm images)

One other point worth noting, neither Epson inkjet printer could print a 720dpi one-pixel-on/one-pixel-off (14.2cycle/mm) pattern. The resulting patch looked uniformly gray. So despite a claim of 1440dpi these printers cannot even print a black/white pattern at 720dpi. The 1200dpi laser printer was able to print a 600dpi one-pixel-on/one-pixel-off (11.8cyle/mm) pattern, albeit at low contrast. This data shows the misleading nature of DPI and the importance of instrumental measurement of resolution.
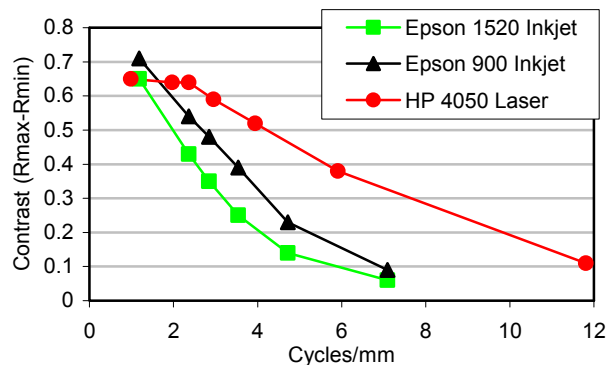

Figure 4: CTF for Inkjet Printers

Hint: Try to align the pattern of lines with the horizontal or vertical axes of the Personal IAS.