The Lithographic Impact of Microdot Halftone Screening

Dan Blondal*

Keywords: Stochastic, Screening, Printing, Ink, Color, Gamut

Abstract

Imaging advances in very high resolution computer-to-plate technologies have enabled the stable rendering of microdots and pioneered a worldwide increase in printing with frequency modulated (FM) halftone screens. This paper defines various forms of FM, AM and hybrid screening technologies and evaluates their strengths, weaknesses and behavior against the implementation requirements and potential benefit to printing.

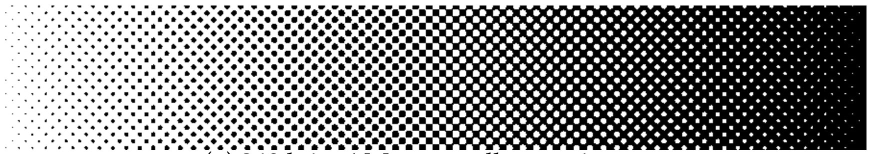
The Halftone

The industry-standard terms *halftone cells* and *screens* are used to describe the organization of dots into deterministic structures in order to simulate a continuous tone rendering on a bi-level output device. Electronically generated halftone dots are constructed with output device pixels, grouped into halftone cells.

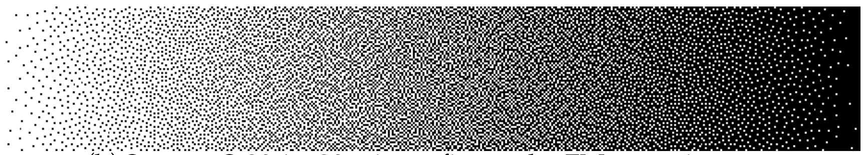
Pixels can be grouped into different dot shapes with the halftone cells organized in a grid like fashion. Tonality is controlled by changing the dot size and this is commonly referred to as conventional AM screening (see Figure 1a). Alternatively, the pixels may be grouped into fixed size microdots and dispersed pseudo-randomly. Tonality is controlled by changing the number of microdots and this is commonly referred to as FM, stochastic, first-order FM or non-periodic screening (see Figure 1b).

In addition, there are two main variations on AM and FM screens that blend the techniques. We refer to the first one as second-order FM, where the tonality of an FM screen is controlled by changing size, shape and frequency of the microdot structure. This is sometimes referred to as second-order FM or Hybrid FM screening (see Figure 1c). The second variation is where the AM screen forms the main part of the tone scale but above and below certain thresholds (typically 1-10% and 90-99%), microdots are avoided and tonality is controlled by varying the number of dots (FM) rather than the size of the dots (AM). This is commonly referred to as Hybrid AM screening (see Figure 1d).

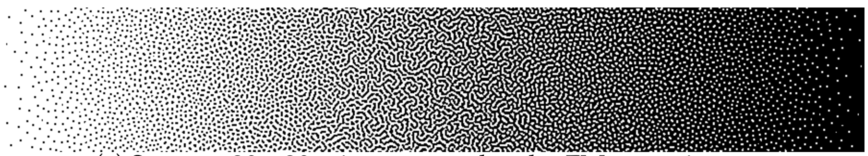
* Creo Incorporated



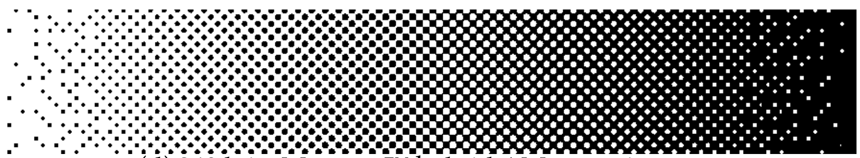
(a) 240 lpi – AM supercell screening



(b) Staccato® 20.1 – 20 micron first-order FM screening



(c) Staccato 20 – 20 micron second-order FM screening



(d) 240 lpi – Maxtone™ hybrid AM screening

Figure 1. AM and FM screens at 12x magnification. (a) Supercell techniques allow high lpi AM screens to be rendered with a full range of graylevels. (b) First-order (stochastic) FM screens are rendered by varying the spacing of equal sized microdots. (c) Second-order FM screens are rendered by varying the spacing and shape of microdot structures. (d) Hybrid AM screening techniques overcome resolution limitations in the print reproduction process with a transition to FM techniques in highlights and shadows.

The FM screens in Figure 1 are categorized into first and second-order FM screens. Visible graininess of the microdot structure varies with each algorithm; however, second-order FM algorithms generally produce smoother renderings. First-order FM algorithms are more susceptible to process variations in prepress and the pressroom and are not as successful as second-order FM screens.

FM screening overcomes a number of the reproduction problems inherent with all AM, Hybrid AM and supercell AM halftone screening. Because there is no longer a halftone screen frequency or angle, FM screens overcome reproduction issues associated with AM screening, such as screening moiré, subject moiré, halftone rosettes, mottled tints and poor detail renderings.

The Halftone and Gray Levels

In older screening engines, the number of pixels in a halftone cell determined the number of tonal steps or graylevels that could be rendered. This was represented by the formula graylevels = $(dpi/lpi)^2+1$. The number of graylevels could only be preserved by lowering the screen ruling (lpi or lcm) or raising the resolution or addressability of the output device (dpi).

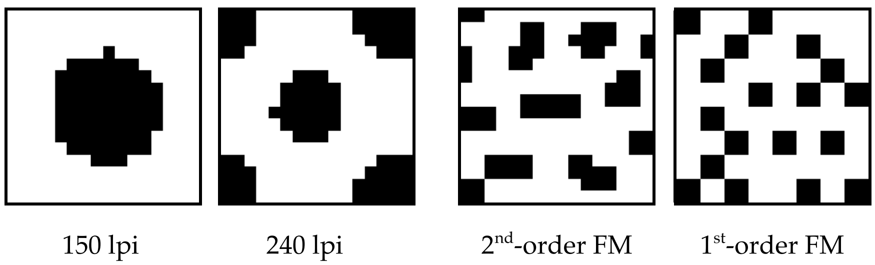


Figure 2. A 16x16 pixel cell can render 256 +1 graylevels, regardless of how the pixels are organized.

With modern screening engines, groups of halftone cells are organized into supercells that generally contain more than 256 pixels. In Figure 2, graylevel limitations are illustrated as the number of pixels in a cell. There is no need to increase resolution for higher screen rulings, and graylevel limitations should no longer be a concern.

The Halftone and Resolution

Although there is no longer a need for increased output resolution to eliminate grayscale limitations or to achieve higher screen frequencies, high-resolution imaging is, in reality, required for process stability.

Modern AM screening standards range between 100 lpi (40 lcm) in newspaper and 175 lpi (70 lcm) in commercial. Supercell screening techniques are used to render accurate angles, rulings and graylevels; paving the way for higher screen rulings. However, in practice, many systems are limited in their ability to deliver high frequency AM screens, because the microdots in the highlights cannot be rendered reliably.

This issue is shared by FM screens, because the microdots are distributed through the tone scale and are typically between 10 and 30 microns (1-4% @ 175 lpi; 1-14% 300 lpi). In film-based printing, it is difficult to render the FM microdots consistently to film, proof and plate. Variations in exposure, media sensitivity and chemistry lead to inconsistent microdot area and consequently could lead to tonal variations outside acceptable print manufacturing tolerances. This is not only true for film-based but also CTP workflows.

In a film-based workflow, this is further compounded by inconsistent microdot transfer to the plate in the exposure frame, requiring 6 to 10 times longer vacuum times to get within acceptable manufacturing tolerances. This proved impractical for all but a few FM zealots.

For CTP, the rendering of FM microdots comes down to exposure resolution. Acceptable manufacturing tolerances dictate that dot area vary by no more than ±2% in the midtones. With both visible-light and thermal media (film and plates), the exposure threshold will change with emulsion sensitivity, oven temperatures and processor activity.

Conventional optical resolution is equal to the raster resolution, such as 2400 dpi. Very high optical resolution equal to 4x the raster resolution makes it 9600 dpi. Figure 3 illustrates how very high optical resolution reduces variation at the dot edge (600% less variation as shown later).

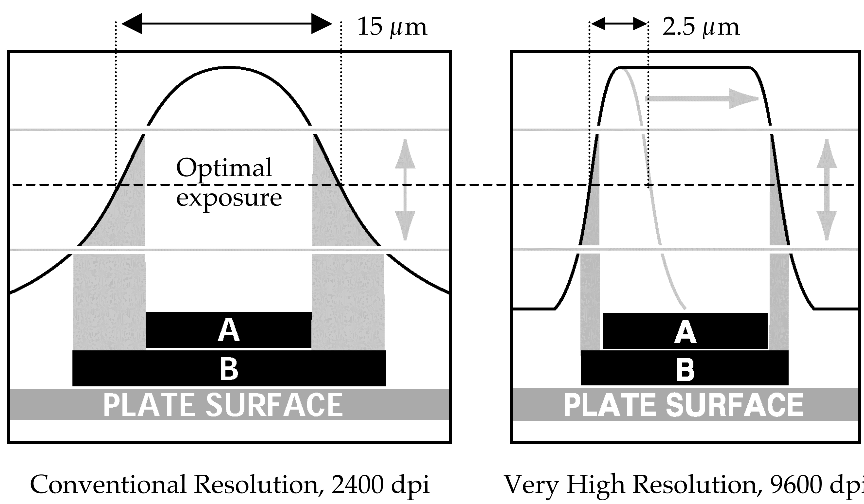


Figure 3. Exposure thresholds for conventional (2400 dpi, Gaussian) and very high (9600 dpi, SQUAREspot®) optical resolutions.

A series of equations were developed to model the impact of optical resolution, dot circumference and dot area on process stability. Equations were derived from simple geometric relationships, resulting in (1) Effective Dot Diameter, (2) Change in Surface Area and (3) Sensitivity to a change in Dot Area (Tint). These equations are used to compare all AM and FM screens with equivalent metrics as shown in Figure 4.

$$D_{eff} = Effective\ \ Dot\ Diameter = 4 \times \frac{\sum area}{\sum perimeter} \tag{1}$$

$$\Delta A_{surf} = \Delta\ Dot\ Surface\ Area = \frac{\partial}{\partial D_{eff}}\left(\frac{\pi D^2}{4}\right) = \frac{2\pi D_{eff}}{4} \tag{2}$$

$$Dot\ Area\ Sensitivity = \frac{2(\Delta A_{surf})(PhysicalDotArea)}{\frac{2\pi D_{eff}}{4}} \tag{3}$$

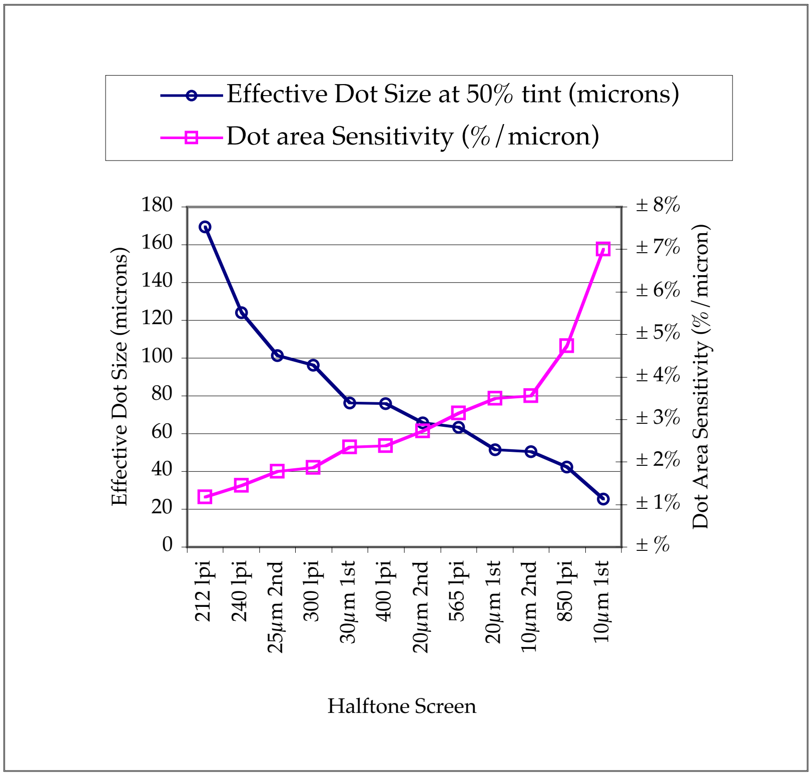


Figure 4. Effective Dot Diameter and Dot Area Sensitivity for various AM and FM screens.

Process variations from plate sensitivity and development were then simulated in a test by varying laser exposure by ±10%. Figure 5 shows the measured changes in dot area for multiple screens on different plate types.

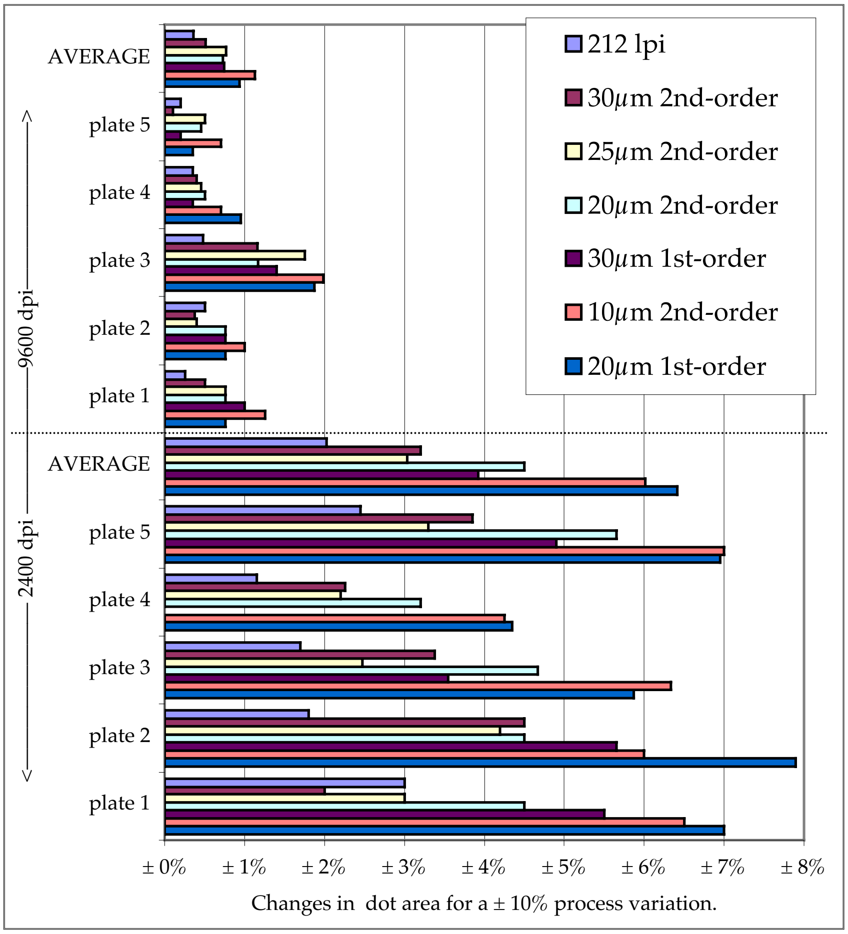


Figure 5. Changes in physical dot area for a ± 10% process variation. Results measured on five plate types for seven screens and two CTP imaging resolutions (2400 dpi Gaussian & 9600 dpi SQUAREspot.)

The results from Figure 5 were used in equations (1), (2) and (3) to determine that the average change in effective dot diameter is ±1.734 microns at 2400 dpi (0.151 micron standard deviation) and ±0.313 microns at 9600 dpi (0.058 micron standard deviation). The resulting variations in physical dot area are charted in Figure 6, where conventional resolutions (2400 dpi) generate 600% more variation than very high optical resolutions (9600 dpi).

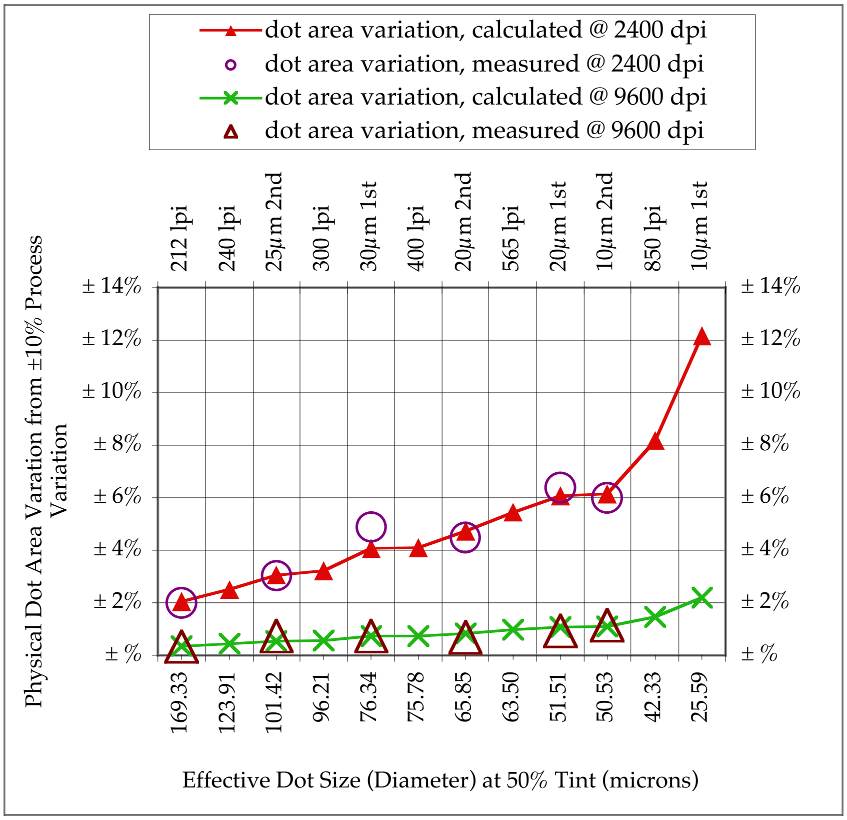


Figure 6. Dot area variations caused by ± 10% change in process sensitivity vs. AM, FM and Effective Dot Size.

Devices with conventional optical resolutions can still be used to render FM microdots; however, regular laser power calibration and linearization may be required to compensate for day-to-day variations in plate sensitivity and development conditions. Using coarser FM screens will also reduce the magnitude of variation.

Rendering reliable microdots requires very high optical resolution at the time of exposure, or a fanatical degree of device linearization and processor maintenance. Lower resolution plates (offset and flexo) may also hinder results because they are not able to render microdots reliably and clip the tonal reproduction range.

Hybrid AM screening algorithms (as illustrated in Figure 1d) get around this problem by avoiding the use of microdots and using larger printable dots controlled with FM techniques below the problematic threshold.

Because the hybrid dots are constrained to fit within the AM grid, the renderings are not as smooth as a true FM screen. This can compromise the uniformity of the screen, generating visibly grainy and structured highlights. The uniformity and smoothness of Hybrid AM screens will differ with each vendor's algorithms, making some highlights structures and transitions more visible than others.

In flexography, this is an acceptable compromise, because it recovers a large percentage of the tonal range; however, this is generally not required with CTP offset devices, unless laser spot resolution and/or plate resolution restricts the rendering of microdots.

The Halftone and Dot Gain

A certain amount of dot gain is intrinsic to the lithographic reproduction process. There is both physical and optical growth of all dots and microdots.

Physical growth is a function of ink film thickness and ink rheology as well as lithographic resistance from water, blanket pressure, and paper texture. Physical and optical growth is related to the perimeter and area of the dot in a manner similar to equations 1, 2 and 3. The sum of optical and physical gain is commonly referred to as effective dot gain or tonal value increase.

For conventional AM screens, physical gain accounts for about a third of the gain; optical gain accounts for the remaining two thirds. For FM screens, optical gain plays a larger role because of the smaller Effective Dot Diameter; leading to tonal values that are between 10% and 20% darker than AM screens for the same physical dot area on plate as AM dots.

FM screens, therefore, require tonal compensation curves to re-align tonality with desired standards and targets.

Lithographic Behavior of Microdots

Lithographic behavior of screens is most influenced by the organization of the dots and the physical size of the dots themselves.

FM screening is still considered an emerging technology. It entails significant change to the printing mindset and has been subject to a very healthy dose of scrutiny over the years. It is well understood that FM screening eliminates screening moiré, screening rosettes and delivers photographic quality while boosting fidelity and detail in the reproduction of images.

However, as FM screening has grown in popularity, a number of lithographic characteristics have been discovered that are not shared with traditional AM screens. The lithographic behavior and rendering properties of FM screens are best understood by the Effective Dot Diameter (equation 1) of the microdot structure.

Finer dot structures tend to have smaller Effective Dot Diameters, which has the following effects: (1) Fine image detail is rendered more effectively. (2) Physical dot area is more sensitive to process variations. (3) Optical gain is greater. (4) Color gamut is larger, (5) Ink mileage is greater. (6) Midtone values on press are less sensitive to solid density changes. (7) Ink dries faster. (8) Lithographic performance problems may be exacerbated.

With so many different types of AM and FM screens, one cannot evaluate screens solely on the rulings, frequencies or dot size. One must also consider the smoothness and quality of a photographic rendering. The integrity of the underlying dot pattern governs dot distribution, irregularities, continuity and directionality. Consequently, this impacts the visual level of grain, mottle, moiré and tone jumps. This paper does not explore methods of evaluating the qualitative properties of screening.

Color Gamut

One of the lesser known but most compelling behaviors of FM screens is that they render a larger gamut and a greater number of colors than AM screens. Although this phenomenon has been documented before (see publications by Rosenburg, Tritta, Gustavson and Anderson), this paper explores the impact that optical dot gain has on gamut.

Color gamut is a three-dimensional volumetric space bounded by the one and two color builds between 0%, 100% and black. FM's increased color gamut cannot be observed in the projection onto the a* b* plane, because screening does not impact solids. The gamut behavior must be viewed as screen tints or Luminance vs. Chroma.

Gamut is measurably larger for FM screening in both presswork (Figure 7) and digital laminate proofs (Figure 8). 100% of the color donor is transferred in the Spectrum Digital Halftone Proofing system, pointing to the optical gain properties of FM microdots as a mechanism for increased gamut. The increased gamut in the presswork is larger than in the proofs, indicating that ink film thickness and other lithographic behavior is also playing a role. In some of the presswork, the chroma is measurably lower in the AM solids. This is believed to result from the effects of emulsification and ink film thickness and has been noted for future investigation.

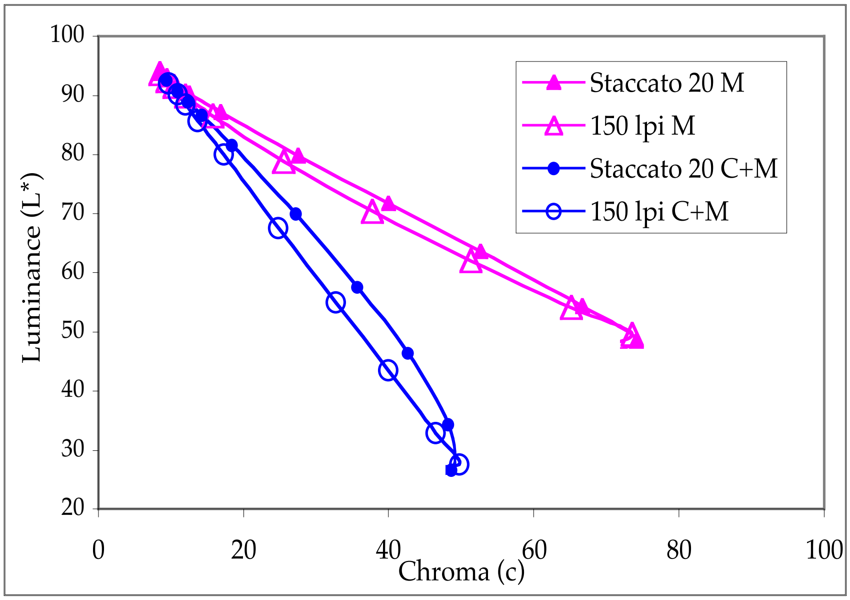


Figure 7. Offset Presswork; Chroma vs. Luminance for FM and AM.

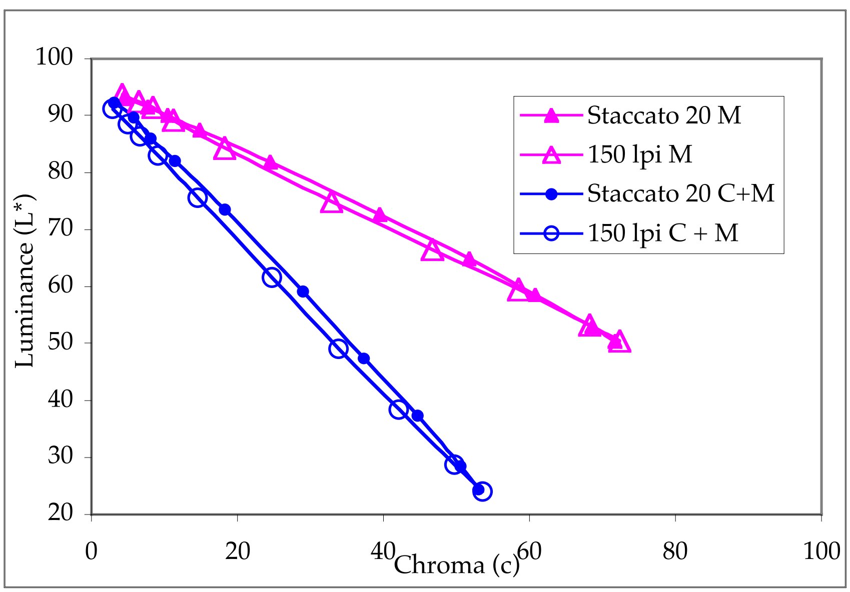


Figure 8. Spectrum Digital Halftone Proof; Chroma vs. Luminance measured from FM and AM.

In Figure 9, some light just inside and outside the perimeter of the dot passes through the ink film only once, RB_1. The apparent ink film is halved. Light striking the middle of larger dots passes through the ink film twice, RB_2.

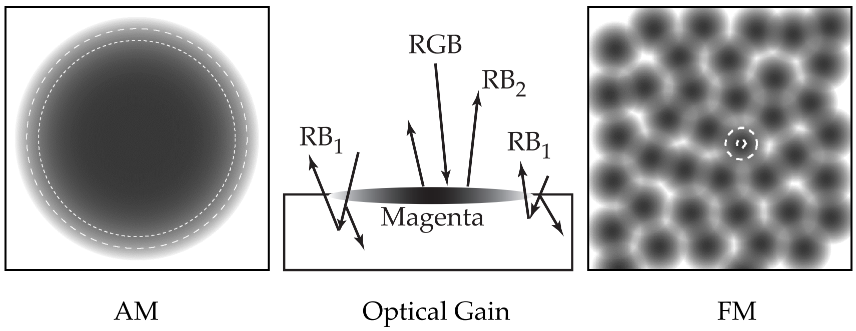


Figure 9. AM and FM optical dot gain.

Optical dot gain darkens the rendering but also filters out a greater percentage of the contaminating light. In Figure 10, the impact of ink film thickness is explored by plotting the amount of cyan, magenta and yellow reflected from continuous tone magenta ink films. Note that as the continuous film of ink is reduced, the ratio of cyan and yellow contamination is reduced. Therefore, microdots see less visual discoloration partly because the middle of the dot is smaller, and a greater percentage of light is filtered through the ink film just once.

In the section on Ink Mileage, it is demonstrated that overall ink film thickness may be reduced by as much as 33% for FM presswork. Using the relationship established for magenta ink in Figure 10, the ratio of cyan and yellow to magenta micro density is reduced by approximately 10%. Therefore, the reduced ink film with FM microdots also contributes to the enlarged gamut.

In Figure 11, the cyan, magenta and yellow densities of a magenta tone scale were measured for AM and FM screens. The screens were treated with densitometric compensation curves to align the FM and AM magenta densities. Note that the resulting cyan and yellow densities are lower for the FM screens.

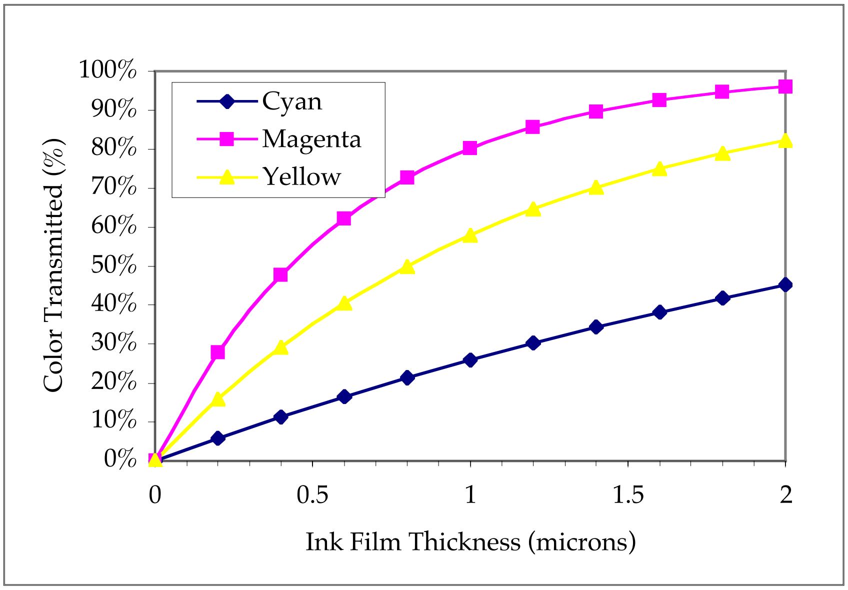


Figure 10. Color contamination as it relates to ink film thickness. Percentages of cyan, magenta and yellow color on a magenta ink films. Solid magenta densities were measured to be c0.26, m1.41 and y0.75.

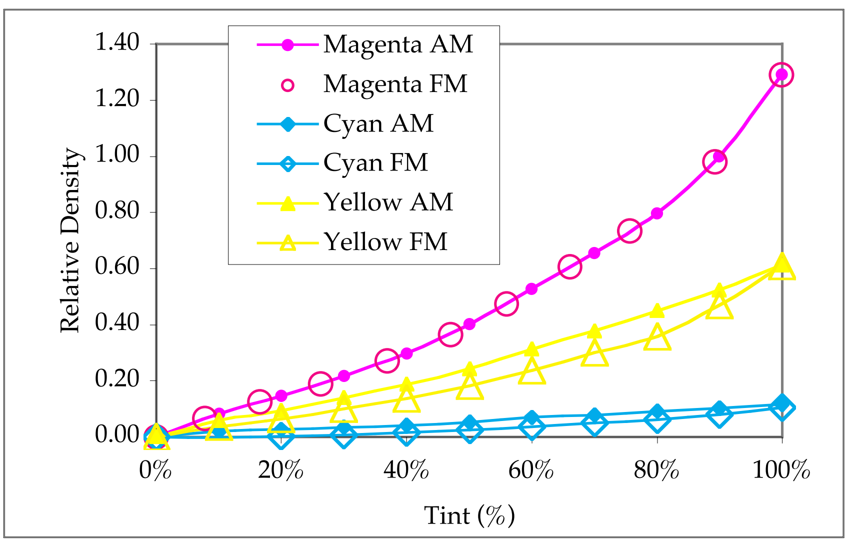


Figure 11. Cyan, magenta and yellow densities measured from magenta tone scales screened with FM and AM.

When printed to the same density standards, FM presswork can be shown to require less ink per sheet than AM presswork. Many factors influence ink mileage, so a simple test was designed to isolate and quantify ink mileage of FM screens and 150 lpi AM screens.

Various test plates were made with FM and AM screens. An 8% cutback curve was applied to the FM screens to align tonality with AM presswork and compensate for physical and optical gain differences. The total number of pixels on each plate was recorded as a measure of tonal compensation and as a predictive measure of ink consumption.

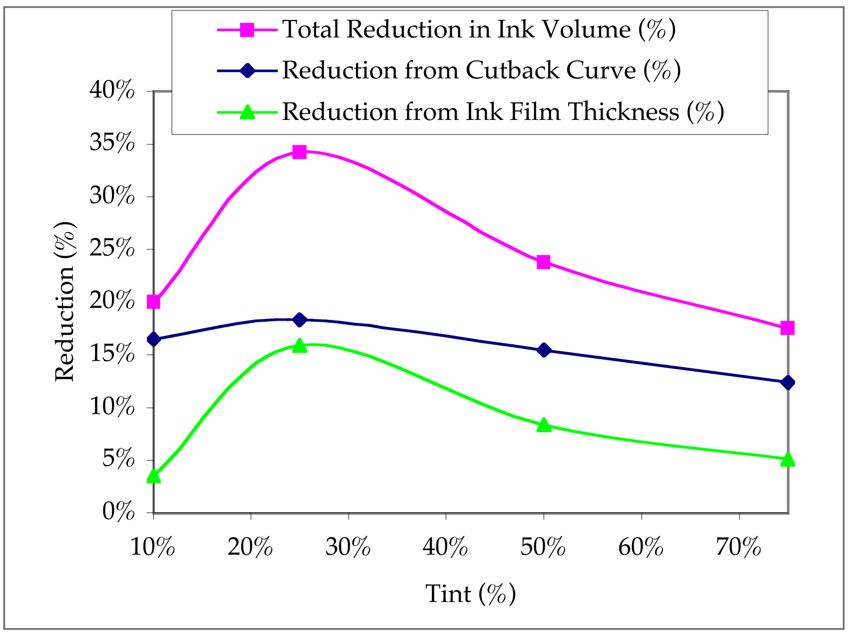


Figure 12. Ink Mileage results for Staccato® 20 (FM) and 150 lpi. Tints of 10%, 25%, 50% and 75% were evaluated.

The test plates were printed with a metered volume of ink and the resulting number of impressions was recorded.

The total reduction in ink volume is approximately 50% greater than expected from the pixels counted on each plate. The additional ink savings must be coming from an overall reduction in FM ink film thickness. Therefore, tonal compensation curves account for about 66% of the reductions in ink volume. Ink film reductions account for the remaining 33%. The results are charted in Figure 12.

Ink mileage improvements have been corroborated in sheetfed, heatset web and coldset web environments. However, results may vary with the brand of screen, content, ink, water, paper and press. Ink mileage improvements are only observed in screened areas; such as vignettes, screened-back solids and separated images printed at the same densities as comparative AM presswork. There are no ink mileage improvements in solid areas, text, spot colors or where FM ink densities are higher.

Tonal Stability

It has long been noted by printers that with AM and FM screens of equal density, the FM screen will gain less when solid ink densities are increased on press. Microdots are more sensitive to ink/water imbalances, ink failure and emulsification; however with process controls in place to ensure stable ink and water performance, it can be shown that FM microdots are more resistant to physical dot growth during a press run.

A series of images was printed with 150 lpi AM and FM screening. The FM presswork was compensated to align tonality with AM presswork. The test pages were printed at normal ink density levels and again in a second pass through the press at exaggerated ink densities. It is visually demonstrable that the midtones of AM screens gain more with changes in solid ink density. The results of these tests are charted in Figure 13. FM microdots are more resistant to ink accumulation than the larger AM dots, making it possible for press operators to boost saturation without compromising print contrast while producing midtones that are more resistant to density fluctuations. Conversely, it is more difficult to adjust FM tonality on press, making the accuracy of tone reproduction curves and the consistency of dot area on plate more critical than with conventional AM screens.

From the ink mileage tests, we know that tonal compensation reduces the physical area of ink on the plate and that the microdots carry a thinner ink film. The microdots are not able to accumulate as much ink as larger AM dots. It should be noted that the gain seen in the tests is a result of dot growth and not increases in ink film thickness.

For instance, an ink film with a density of 1.5 absorbs 97% of the light. A large 50% dot will render a tonal value of 0.5*97% = 49.5%. By raising the ink density to 2.0 (absorbs 99% of light), one might expect to see a tonal value of 48.5%; however, in reality the additional ink causes physical gain, which has a far greater impact on tonal value.

Therefore, lithographic resistance to physical dot gain is a function of the proportion of surrounding water, where FM microdots with smaller Effective Dot Diameter are more resistant to physical gain. By extension, water levels play a critical role in the performance of FM. Use water levels rather than density to control microdots with small levels of water and just enough ink to achieve desired densities. It is not advisable to mix AM and FM screens on press, because the lithographic behavior of one may hinder working with the other.

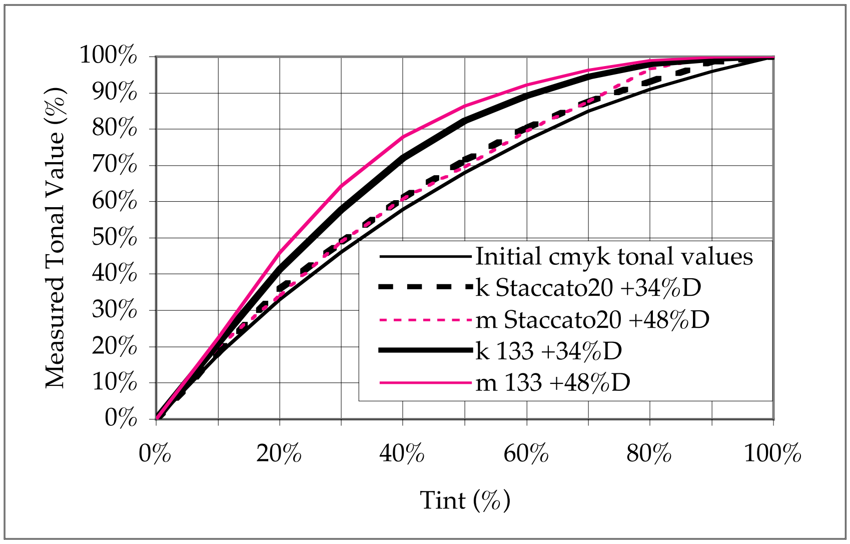


Figure 13. Tonal values of 133 lpi and Staccato 20 (FM) at normal densities (Initial cmyk Tonal Values) and high densities (+%D).

Good process control and tonal compensation curves will ensure good make-ready times with FM. On the other hand, inconsistencies and inaccuracies on plate can make it difficult for press operators to bring FM presswork up to color.

Drying

It has been observed that FM microdots dry faster on press than larger AM screens. This is attributable to the decreased volumes of ink and increased dot perimeter that flashes off volatiles at a faster rate than larger AM dots. Drying times are unaffected in areas of solid ink.

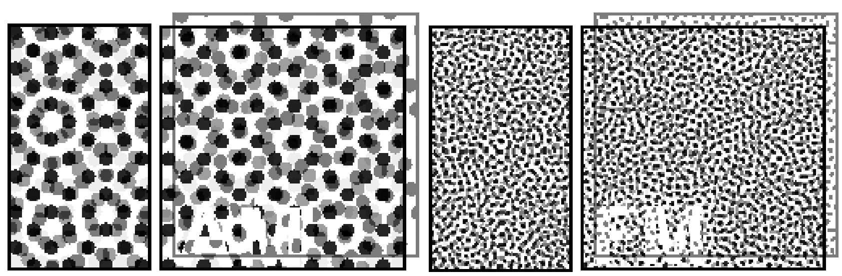
Reducing drying time translates into less setoff, less powder coating, faster turn-around, and improved performance on perfecting presses. Faster drying, smaller volumes and less susceptibility to physical gain yields better performance on a full range of substrates, which includes fine paper, uncoated stock, recycled paper, newsprint, plastics, metals, and foils.

Faster drying may increase the rate of ink piling and paper picking, which leads to more frequent blanket washes and reduced run length. This is only a concern on heat set web presses and can be counteracted with coarser FM microdots or by increasing the lubricity of the ink, through reductions in ink viscosity, increases in roller temperatures and reformulations of fountain solution.

Misregistration

Registration problems are inevitable because of web and sheet growth, impression-to-impression changes, and job-to-job variations. Small misregistrations of conventional AM screens (150 lpi) change the arrangement of overprinting dots and visibly degrade the rosette structure, destroying fine image detail and obscuring fine linework, text, and knock-outs. Misregistration may even cause a color shift as the overprint ratios of wet and dry trap change.

FM doesn’t reduce the magnitude of misregistration, but the four color structure of microdots retains its “look and feel” and is not visibly impacted by misregistration. FM holds detail in images, preserves the integrity of text, knockouts, and linework. Some FM algorithms can reduce color shifts, because the overprint characteristics of the microdots are not altered with misregistration (see Figure 14).



AM: registered out of register FM: registered out of register

Figure 14. Misregistration causes less visual degradation of a Staccato (FM) dot structure than an AM screen.

In PIRA's tests, color shifts caused by misregistration are smaller with FM screens than with AM. They found that 0.006 inches of misregistration caused a color shift of 2.4 DeltaE with 150 lpi elliptical AM screens, and a DeltaE of 0.8 to 1.6 with 21 micron FM screening. DeltaE will be different for different FM screen algorithms.

Run Length

FM screens may lead to shorter run lengths on heatset web presses, because the microdots on the plate are less tolerant of calcium carbonate fiber buildup. Modern papers made with styrene and silicon, may lead to lithographic issues, because the contaminating particulate can easily build up on microdots and repel ink. This can cause causing blinding and premature wear that translates into shorter run lengths for the plate. Smoother blankets, lower viscosity inks, desensitized chrome rollers, tighter temperature controls and coarser screens can all help.

Implementation

The lithographic behavior of microdots also leads to a number of performance traits to monitor during implementation.

As we have shown, FM microdots are more sensitive to reproduction variations and require disciplined process control. FM screens may exacerbate lithographic issues that are otherwise tolerable in routine AM presswork. Emulsification, piling, ink viscosity and ink-water imbalance can reduce the printability and effectiveness of FM presswork.

Good press maintenance, stable inking and consistent coating will eliminate problematic artifacts and streaks caused by worn rollers, scored blankets, solvent stains, and non-uniform water films. Printing with microdots demands lithographic discipline, requiring printers to resolve issues and instabilities. Testing and print characterization requires greater cooperation with owners, prepress and the pressroom. Defining targets, standards and objectives help set realistic expectations that can be met on the pressroom floor.

Microdots require finely pigmented inks that flow well and adjustments to flow and viscosity may optimize performance. Low viscosity and lubrication helps ink shear and transfer to the sheet. Viscosity can be controlled with pigment vehicle, water pickup, or by increasing ink temperature. Transfer is poor with coarsely pigmented inks, like metallic and fluorescents, and may require larger microdots. High-pigment, low-gain inks may be too viscous, because the microdots are predisposed to pile and may print inconsistently.

Microdots are more sensitive to blanket surface tension, making release from the blanket more critical. Smooth, cast and buffed blankets exert less tension and release ink more readily to coated and higher quality uncoated paper. Coarser blankets carry more ink and are better suited to coarser microdot structures.

Where environmental restrictions allow, alcohol helps lower surface tension and ink viscosity and promotes better release of microdots.

Conclusions

When determining the economic impact of printing with FM and AM, one cannot consider the benefits in isolation. The behavior at the perimeter of the microdot structure has a significant impact on performance, color, stability and cost. The behavior of all AM and FM screens can be compared by using the metric of effective dot size or diameter introduced in this paper. One must also take into consideration the impacts on make-ready, run length, blanket washes, plates, competitive differentiation, market share, and implementation costs. Above all, process stability in plate making and the pressroom are paramount to the success of any FM or AM microdot implementation.

Acknowledgements

John Fowler, Gordon Pritchard, Aaron Thompson and Mark Nissen of Creo Inc. for their ongoing insight, patience and assistance.

Selected Bibliography

Anderson, M.

1996 "A study in how the ink set, solid ink density and screening method influence the color gamut in four color process printing," Thesis for the degree of Masters Science in the School of Printing Management and Science in the College of Imaging Arts and Science of the Rochester Institute of Technology, 63 pp.

Gustavson, S.

1997 "Dot Gain in Colour Halftones," Dissertation No. 492, Linkøping Studies in Science, Imaging Processing Laboratory, Dept. of Electrical Engineering, Linkøping University, Sweden,148 pp.

Laberge, M.

1999 "The Influence of Laser Spot Shape on the Stability of the Printing Process," TAGA Proceedings 1999, pp. 328-337

Rosenburg, A.

1999 "Colour Gamut Improvement When Using FM-Screening," TAGA Proceedings 1999, pp 594-605

Tritton, K.

1997 "Stochastic Screening," Pira International/PRINTWEEK test series (published by Pira International, UK), 90 pp.