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Analysis of Print Attributes of Amplitude Modulated (AM) vs. Frequency Modulated (FM) Screening of Multicolor Offset Printing

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Abstract

This research utilized an experimental research method. The purpose of this research study was to determine the significant differences that exist in the measurable print attributes (Print Contrast and Dot Gain) of AM vs. FM screening of multicolor offset printing. The experiment was conducted in film-based workflow. The GATF 11" x 17" Digital Four Color Test target was output by using Scitex AM and FM screening technologies. Due to excessive Tone Value Increase (TVI) during the platemaking process, the film output was adjusted to achieve linear plates. A pilot test was conducted to achieve the target ink density values (+/- 0.10) according to GRACoL standards. During the pilot test, 1,000 sheets were printed. Once the density values were achieved according to the standard ink density (SID) values, the press was run continuously without operator interference and another 1,000 sheets were printed, from which a total of 278 sheets were randomly selected for the densitometric analysis. Only the attributes of dot gain and print contrast were used to compare the two screening technologies, as they were the two attributes that measured patches made up of dots or screened tint percentages. Print attributes that utilize solid ink patches only were not compared, as one could expect similar results from both screening technologies. The findings of this study represent specific printing or testing conditions. The findings of this research comparing amplitude modulated screening with frequency modulated screening lead to the conclusion that FM screening provides greater print contrast than AM screening. This provides greater detail in the shadow areas of printed images. The findings make it difficult to draw conclusions regarding dot gain, as each of the screening technologies had statistically significant higher levels of dot gain for two of the four ink colors. Again, further study is needed to attempt greater control of variables. A computer-to-plate output workflow could be utilized to remove the inconsistencies of film-based workflows.

Introduction

In the process of multicolor offset printing, a paste ink of a given color – yellow, magenta, cyan, and black (CMYK) is transferred from the ink fountain to the series of inking rollers and then to the image areas of the plate (image carrier). The inked image area of the plate is then transferred to the blanket, and from the blanket, it is transferred to the paper. A continuous tone color, or black and white photograph, is composed of a full spectrum of shades and color, from near white to dense black. The method by which continuous tone of photograph is transformed to a printable image is called halftoning, in which varying percentages of the press sheet are covered with halftone dots to represent the varying tones in the image. In the conventional halftoning process, these dots are equally spaced. However, the size or diameter of the dots will vary according to the different amounts of light that were reflected from the different tones in the original photograph. The ink printed by each dot, of course, has the same density. At normal viewing distance, the dots of a printed image create an optical illusion of a continuous tone image.

There are two ways by which a continuous tone image is transformed into a halftone image prior to printing on the press: amplitude modulated (AM) and frequency modulated (FM) screening. In traditional graphic arts, screening was originally done using a screen-like pattern etched into a glass plate. A camera operator had several of these plates, each with a different pattern. The image to be reproduced was projected through a chosen screen onto film, and the resulting image looked like the original except that it was broken into small various size dots. This process is a representation of traditional AM screening process. In an electronic or digital environment, imagesetters and computer to platesetters (CTP) can create an electronic version of the AM and also FM halftone screen. Screening software in the imagesetter applies an electronic dot pattern to the electronic image.

In order to print a quality halftone image, the printer (or press operator) must carefully manage several variables and attributes which are associated with the printing process. The print attributes are individual characteristics within the printing process that can be monitored during the production process so as to maintain the color consistency. The commonly monitored attributes include solid ink density (SID), dot gain (DG) and print contrast (PC). For this study, only the attributes of dot gain (DG) and print contrast (PC) were used to examine the significant differences that exist in the two screening technologies, as they were the two attributes that measured patches made up of halftone dots or screened tint percentages. A majority of the image details (or quality) is evaluated with the use of these screened tints only.

Purpose of the Research

The purpose of this experimental research was to identify the significant differences that exist in the measurable print attributes (or characteristics) of Amplitude Modulated (AM) vs. Frequency Modulated (FM) screening of multicolor (CMYK) offset printing. The following questions were investigated.

1. Is there a difference in the print contrast (PC) values (CMYK) of the AM vs. FM screened image?
2. Is there a difference in the dot gain (DG) values (CMYK) at 50% dot area of the AM vs. FM screened image?

Limitations of the Study

The print characteristics associated with the AM and FM screened images are characterized by, but not restricted to, inherent limitations; for example: type of printing process, type of paper, type of ink, etc. There are several variables affecting the facsimile reproduction of AM and FM screened images and most of them are mutually dependent on each other. The scope of the research was limited to the offset (lithography) printing systems and materials used at the University of Wisconsin-Stout's graphic communications laboratory, and the findings were not expected to be generalizable to other printing environments. Only the attributes of dot gain and print contrast were used to compare the two screening technologies, as they were the two attributes that measured patches made up of dots or screened tint percentages. Print attributes that utilize solid ink patches only were not compared, as one could expect similar results from both screening technologies. The research methodology, experimental design, and statistical analysis were all selected in alignment with the purpose of the research with full awareness of the aforementioned delimitations. It is quite likely, however, others could find this study meaningful and useful.

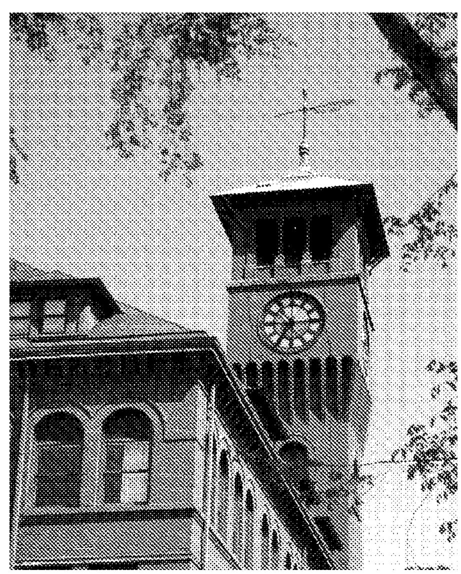
Review of Literature

In recent year's advances in computer hardware, digital imagesetters, CTP, raster image processor (RIP) and software allowed a greater flexibility in electronic image reproduction, such as color correction, gray component replacement, digital halftone film output, halftone plate output, digital printing, etc. Today, digital halftones have become the standard for halftone film and plate output (Ma, 2003). Introduction of electronic screening technology for the halftone reproduction process began in the early 1970's. It incorporated electronic dot generation via high-end electronic color scanners as an alternative to the traditional photomechanical screening technique (Stanton & Warner, 1994). Today, most electronic prepress environments utilize a digital halftoning process for film or plate output. A digital halftone is a binary picture, [h(x, y)], each point being either completely black or completely white, that gives the impression of an image containing a spectrum of shades of gray or continuous tone (Bruckstein & Pnueli, 1995).

Amplitude Modulated (AM) Screening

In AM screening, the dot frequency is constant and dot amplitude varies. AM screening breaks the image into dots of varying sizes, which are clustered together, at a fixed screen angle. For each color (CMYK) to be overprinted, the halftone CMYK separations need to be generated at a particular screen angle to avoid moiré pattern. The dot is generated from a cluster of laser spots. A halftone cell (or grid) is then divided into a matrix of single recording dots (laser spots). Since there is always a physical and mathematical relationship between the number of gray levels, the resolution of the output device, and the screen ruling, there is always a tradeoff between resolution and the number of reproducible gray levels (Dollak, Flemming & Fryzlewicz, 2004). The number of laser spots within a halftone cell depends on the following parameters:

Figure 1: AM Halftone Image



screen frequencies/screen angles, imagesetter resolution/gray levels, dot size, and dot shape/dot patterns. The outcome of the clustering is a continuous tone pattern – lighter or darker shades or tones (See Figure 1 on page 3).

Frequency Modulated (FM) Screening

In FM screening, the dot frequency varies and dot size is constant (Ma, 2003). FM screening, also referred to as stochastic screening, can be regarded as an electronic implementation of screenless printing (Chung & Ma, 1995). The word stochastic means "involving a random variable" – it uses randomly placed dots instead of AM halftone dots aligned along the screen angle. FM screening uses a microdot placement. The dot size is fixed, but the number of dots within a halftone cell varies according to the tonal value being imaged (Bouman & He, 2004). The minimum size of the dots is limited only by the output device resolution and dots are measured in microns (µm). A typical modern 2400 DPI imagesetter has a laser spot size of 10.6 µm (microns, 10^{-6}) and the size of a microdot is 21 µm (Chung & Ma, 1995). In FM screening, screen angles are not required when generating a CMYK separation. This results in the eradication of the moiré pattern in the printed image (Dollak, et al. 2004). FM screening, though, uses smaller dots that are not restricted to a fixed grid pattern. By varying the number of dots in a given area, any desired gray level can be generated. The dots are smaller than the AM screening, therefore FM screening can represent more detail and support higher resolution printing (See Figure 2).

AM vs. FM Screening

For over twenty years, industry has been utilizing the electronic version of AM screening in the film-based workflow. Although FM screening became available during the early 1990's, it was not adopted by the printers in the film-based workflow. The microdot was difficult to transfer clearly to the plate via the vacuum frame (Zarwan, 2003). Any variation in the film-to- plate creation process would distort the final FM tone values, making the process unreliable. As a result, FM screening did not gain much popularity in the industry initially. In the last five years, however, CTP workflow began to adopt FM screening technology, and the variations that prevented the adoption of FM screening in film-based workflow have been greatly reduced.

AM screening creates the illusion of highlight through shadow by altering the size of the uniformly spaced dots. FM screening creates this illusion with very small, randomly spaced spots. More spots create shadow and less spots create highlight in the image. The random nature of the spots eliminates the possibility of moiré and other AM screening artifacts. The spacing of fixed distances inbetween the dots that form an image results in loss of details in AM screening. In FM screening this loss of detail is minimized due to the small dot size and close spacing of microdots. The limiting factor of AM screening has been the ability of printers to maintain dots at the low and high ends of the tonal range. As LPI increases it becomes more difficult to hold clear highlight area in an image. Similarly, FM screening uses very small dots, and the problem associated with AM screening highlight will be present over most of the tonal range in FM screening. Additionally, FM screening possesses a higher level of dot gain than the AM screening (Chung & Ma, 1995).

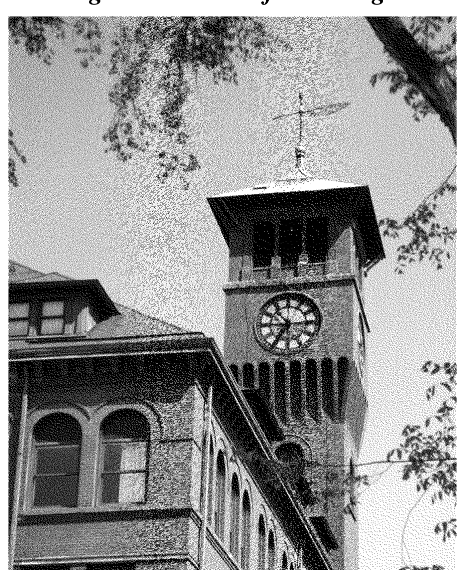
Densitometry

A densitometer is a scientific instrument that is designed to determine, indirectly, the light absorbed by a surface (Brehm, 1992). There are two types of densitometers: transmission and reflection densitometers. Transmission densitometers measure the amount of light that is transmitted through a transparent material such as a halftone film or color negative. Reflection densitometers measure the amount of light reflected from printed material or continuous tone photographs (Brehm, 1992). In the prepress and printing/press areas of the industry, densitometry allows us to find a balance for accurate tone reproduction. Hsieh (1997) stated that a densitometer can measure either incident light reflected from a substrate (reflection density) or light transmitted through a film (transmission density), or both. In prepress and printing/press areas, the Status T densitometers have been used extensively for measuring densities. Status T is the ANSI/ISO (American National Standard Institute/International Standard Organization) standard for wideband densitometer response for measuring print attributes (Brehm, 1992). These instruments are important quality control tools for the industry. In the printing/press area, a reflection densitometer allows us to measure characteristics of print attributes such as solid ink density, ink trap, dot gain, print contrast, gray balance, etc. In the prepress area, a transmission densitometer allows us to measure halftone film density and dot area values, which are used to linearize the filmsetter.

Print Attributes

In 1996 a committee was formed by the Graphic Communications Association (GCA) to develop a document containing general guidelines and recommendations that could be used as a reference source across the industry for quality printing. With the support of representatives from International Prepress Association (IPA) and GATF, the committee developed the standards for general requirements for applications in commercial offset lithography (GRACoL), and since then the GRACoL have

Figure 2: FM Halftone Image



become de facto standards for sheetfed offset printing (GCA, 2002). The GRACoL standards provide a broad spectrum of recommendations regarding the production of sheetfed offset printed materials. It consists of guidelines and charts giving aim points and tolerances for a variety of print attributes (Hutton & Stanton, 1999).

Print attributes are defined as the individual characteristics within the printing process that can be measured and monitored during the production so as to maintain the quality consistency. The most commonly monitored print attributes, and the ones concentrated on by the researchers, include solid ink density, ink trapping, hue error, dot gain, print contrast, grayness, and gray balance (Lustig, 2001). Hutton & Stanton (1999) stated that some attributes are not monitored because they are not readily measurable.

Dot Gain (DG)

Dot gain, also called tone value increase (TVI), is defined as the apparent halftone dot size increase from the halftone film to the printed sheet (Hsieh, 1997). It is caused by several technical variables associated with prepress and press devices and directly affects reproduction accuracy by causing darker tones or stronger colors. Due to both technical reasons and the effect of light entrapment, printing without dot gain is impossible (Hsieh, 1997). Lychock (1995) stated that dot gain is inherent to the printing process and will always be there in the conventional pressrooms. Dot gain is a function of density and compares a tint CMYK patch to a solid CMYK patch. Dot gain includes both mechanical gain and optical gain. The mechanical gain is the actual growth of the physical halftone dot and the optical gain is how the dot appears to the human eye due to the refraction of light on the substrate (X-Rite, 2003).

Most of the pictorial information in printed halftone images is present in the tonal or tinted areas. Measuring dot gain value at 25% (highlight), 50% (midtone), and 75% (shadow) dot area for each CMYK color is a quick indication of the tone reproduction quality.

Dot gain affects the midtones (50%) the most. This is due to the fact that the 50% dot is the largest dot formed in the halftoning process (Lychock, 1995). Dot gain can cause an overall loss of definition and details, color changes, and problems with contrast, ink hues, ink density, and trapping (Hsieh, 1997). The dot gain between the three CMY colors is critical for gray balance and for maintaining critical overprint colors such as flesh tones, green grass, and blue sky (X-Rite, 2003). Apparent dot area is the percentage of dot area, as measured and calculated with a densitometer, using the Murray-Davies (M-D) equation. The following equation is used to calculate the dot gain or TVI values (ANSI/CGATS.4-1993, Reaffirmed 1998, p.7).

Percentage of Apparent Dot Area =
$(1\text{-}10^{-(D(t) - D(p))}) / (1\text{-}10^{-(D(s) - D(p))}) \times 100$
where: $D_{(t)}$ = Density of tint
$D_{(s)}$ = Density of solid
$D_{(p)}$ = Density of the paper/substrate

Print Contrast (PC)

Print contrast is also known as shadow detail. PC indicates how well shadow detail is maintained or kept open in a halftone printed image. It is a ratio of the 75% screen dot density to solid density. It means the visual performance characteristic that illustrates the printing system's ability to hold image details in the upper tonal areas. PC is a good indication of print quality because shadow detail carries important information in many CMYK printed images. PC values correlate well to the subjective evaluations of print quality, such as low print contrast values versus high print contrast values (X-Rite, 2003). PC values require both high density and sharp printing to maintain shadow detail. The following equation is used by the densitometers to calculate the percentage print contrast values (ANSI/CGATS.4-1993, Reaffirmed 1998, p.8).

Percentage of Print Contrast =
$(D_{(s)} - D_{(t)}) / (D_{(s)}) \times 100$

where: $D_{(s)}$ = Density of solid
$D_{(t)}$ = Density of tint, typically 75%

Research Method

This research utilized an experimental research method. It was intended to determine the significant differences that exist in the measurable print attributes (or characteristics) of Amplitude Modulated (AM) vs. Frequency Modulated (FM) screening of multicolor (CMYK) offset printing. A detailed method of this experiment is summarized in the following paragraphs.

Prepress

A layout was created for a 19" x 25" press sheet utilizing two identical test form images in order to compare the print characteristics of AM vs. FM screened output. The GATF 11" x 17" Four-Color Test Form was used as the test image. The GATF 11x17 Four-Color Test Form image contained the following elements. During the printing, these elements are used to evaluate the subjective and objective aspects of the image quality (see Figure 3 on page 6).

- GATF Two-Tiered Color Bar
- GATF Image Fit Target
- GATF Gray Balance Target
- GATF Highlight/Shadow Target
- GATF Ink Coverage Target
- GATF Star Targets
- GATF High-Key Photograph
- GATF Memory Colors Photograph
- GATF Portrait Photograph
- IT8.7/3 Basic Data Set
- Tone Scales in all four process colors (patches for 1, 3, 5, 10, 20, 25, 30, 40, 50, 60, 70, 75, 80, 90, 95, 98, 99, and 100 percent coverage)
- GATF Transfer Grids

One side of the layout was output using a conventional halftone screen at 175 lines per inch (LPI), while the other side of the layout was output using a stochastic screen. Two color control bars were placed at the tail edge of the sheet so that one could be imaged with each screening technology. Full-length color bars were added so that an X-Rite ATD scanning densitometer could be used for press sheet measurement and analysis (see Figure 4 on page 7). The layout was assembled on a Macintosh G5 computer using Photoshop 7.0, Illustrator 10.0 and QuarkXPress 6.0

applications.

The test form (see Figure 3) was output to film using a Scitex Dolev 400 imagesetter with an output resolution of 2540 dpi, driven by a Scitex PS/M raster image processor (RIP). The conventional halftone side of the test form was output at 175 lpi with Scitex Class screening to four film separations. A composed dot shape (round in highlight and shadow; elliptical in the midtones) was used. The stochastic side of the test form was output to four additional film separations with Scitex Fulltone screening at the normal setting.

An X-Rite 361T transmission densitometer was used to ensure linear film output. Following plate exposure/processing calibration, test plates were imaged. Due to excessive Tone Value Increase (TVI) during the platemaking operation, the film output was adjusted to achieve linear plates (see Figure 5 on page 8).

The four conventional film separations and four stochastic separations were stripped on flats and exposed onto four offset plates. Two separate exposures of the conventional and stochastic films onto each plate allowed longer drawdown times required for the stochastic exposures and avoided misregistration due to cutting and reassembling films into common color flats. FM screened films required longer vacuum drawdown times in order to completely evacuate the air between the plate and film. Tight contact between plate and film required 20 minutes of vacuum drawdown time. Table 1 (page 8) presents the variables, materials, conditions, and equipment associated with the prepress part of this experiment.

Figure 3: The GATF 11" x 17" Four Color Digital Test Form

Press

After the plates were made, a pilot test was conducted to achieve the target ink density values according to GRACol standards. During the pilot test, 1000 sheets were printed. Once density values were achieved according to the standard ink density (SID) values, the press was run continuously without operator interference and another 1000 test sheets were printed, from which a total of 278 sheets were randomly selected for the analysis. This sample size was selected in order of the specific confidence interval ($\alpha = 0.05$). An X-Rite ATD scanning densitometer was used to collect the data. Table 2 presents the variables, materials, conditions, and equipment associated with the press/printing part of this experiment (see Table 2 on page 9).

Data Analysis and Research Findings

A total of 278 randomly selected samples (printed sheets) were analyzed. Data was generated by using an X-Rite ATD scanning densitometer to measure both AM and FM color bars

Figure 4: AM and FM Screen Layout (or Printed Press Sheet)

on the printed sheets. Descriptive and inferential statistics were the statistical methods used to analyze the data. An independent one tail t-test was conducted to determine if any statistical differences exist between the mean scores of AM and FM (CMYK) screened images. Analyzed results are presented in the following section.

Print Contrast (PC)

The mean scores, standard deviations, and t-values associated with the print contrast of AM and FM (CMYK) screened images are compiled in Table 3. Statistically significant differences were found when comparing the print contrast of the AM screened image to the FM screened image on all four-color inks (CMYK). The print contrast in three (CMY) of four color inks (CMYK) of the FM screened image was higher than the AM screened image, while black ink color print contrast was higher in the AM screened image. A low print contrast indicates loss of details in shadow areas, while high print contrast requires both high density and sharp printing to maintain the shadow details. It was determined by the researchers that the FM screened image presented sharper pictorial information when compared to the AM screened image. Shadow detail of the FM screened image was noticeably better than the AM screened image. This visual result is in agreement with the print contrast values of the two screening methods. The largest print contrast was found in cyan color: 37.51% for the FM screened image and 33.51% for the AM screened image. In addition, magenta color of the AM screened image and yellow color of the FM screened image had the smallest standard deviation when compared to the other colors (see Table 3 on page 9).

Dot Gain (DG)

The mean scores, standard deviations, and t-values associated with the dot gain at the 50% dot area of AM and FM (CMYK) screened image are compiled in Table 10. A significant difference was found in the dot gain at the 50% dot area when comparing the dot gain of the AM screened image to the FM screened image on all four color inks

(CMYK). Dot gain in two (CY) of four color inks (CMYK) of the AM screened image was higher than the FM screened image, while dot gain of magenta and black color inks were higher in the FM screened image. All details in an offset printing are achieved by the use of halftone dot. The greatest dot gain at 50% dot area was found in the yellow color of both screened images, while the magenta color of both screened images had the smallest standard deviation when compared to the other colors. Even small differences in dot gain at the midtone area can lead to color shift (see Table 4 on page 9).

Figure 5: Plate Linearization of AM vs. FM Screened Image

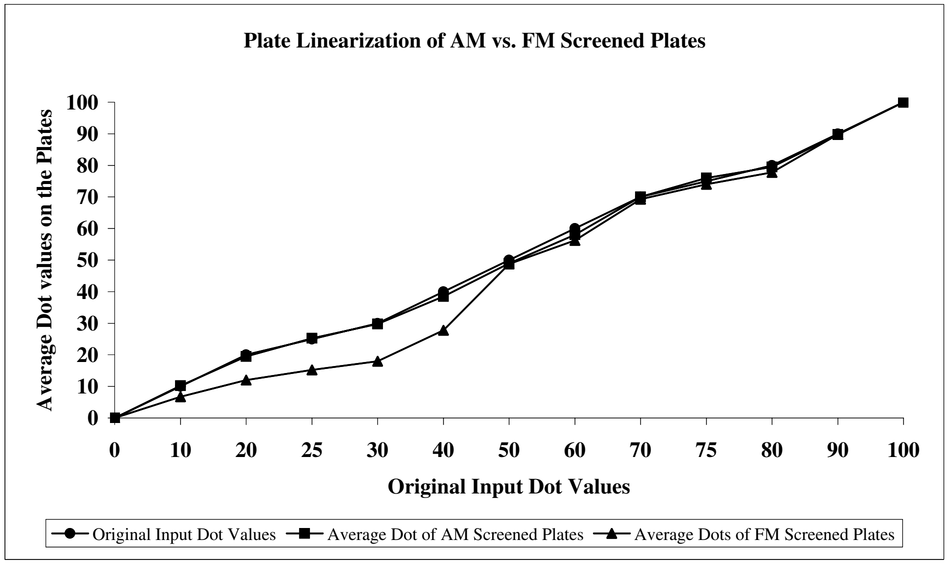


Table 1 – Prepress: Experimental and Controlled Variables

Variable	Material/Condition/Equipment
Test Image	GATF 11” x 17” Four Color Test Form
RIP	Scitex PS/M 6.1
Film Imagesetter	Scitex Dolev 400
Film	LaCrosse Litho Precision Image HN/RLD
Paramount Plus Imagesetter Film	
Film Processor	Glunz and Jensen MultiLine 720
Film Chemistry	LaCrosse Litho Precision Image Universal Developer and Fixer
Transmission Densitometer	X-Rite 361T
AM Screen Line Ruling	175 LPI
AM Screen Dot Shape	Scitex Composed Dot
AM Screen Output Format	Scitex clc175r10c
AM Screen Angles	C = 105°, M = 45°, Y = 90°, & K = 75°
FM Screen Output Format	Scitex ft100 normal
Plate	LaCrosse Precision Image CIS Grained Negative Acting plates
Plate Exposure Frame	Burgess Industries VacuLux
Plate Exposure Controller	Burgess Industries MS-50 Integrator
Plate Exposure Timing	AM 5.5 units, & FM 5.5 units
Plate Drawdown Timing	AM 60 Seconds, & FM 20 minutes
Plate Processor	Imation 3M Viking Plate Processor
Plate Chemistry	LaCrosse Precision Universal Developer

Conclusions and Recommendations

The conclusions of this study are based upon an analysis of the data and major findings. The findings of this study represent specific printing or testing conditions. The screening technologies, paper, ink, dampening solution, film and plate imaging system, and printing process that were used are important factors to consider when evaluating the results. The findings of the study cannot be generalized to other printing conditions. However, others may find this study meaningful and useful.

The findings of this research, comparing amplitude modulated screening with frequency modulated screening suggest that FM screening provides greater print contrast than AM screening under the specific printing conditions used. This provides greater detail in the shadow areas (CMY) of printed images. The black ink print contrast ran counter to this conclusion, which suggests the need for further study to explore factors or variables that may have contributed to this result. Variables to explore include print order or printing unit: ink color interaction.

The findings make it difficult to draw conclusions regarding dot gain, as each of the screening technologies had statistically significant higher levels of dot gain for two of the four ink colors. Again, further study is needed to attempt greater control of variables.

A computer-to-plate output workflow could be utilized to remove the inconsistencies of film-based workflows. Another recommendation is that the two screened images be printed during separate press runs, as the ink/water balance requirements for the two screens could be considerably different. A more deliberate process of press calibration would also be recommended in a future study of this topic. The margin for error is much smaller with FM screened images, requiring a carefully calibrated and controlled press platform. Future studies could also utilize instruments that measure spectral data rather than ink density alone. This would provide a greater level of quantitative analysis when making a comparison between the two screening technologies. Qualitative analysis is also something to be pursued. A panel of experts could be utilized to provide qualitative analysis regarding their preference for one screening technology vs. another.

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Table 2 – Press: Experimental and Controlled Variables

Variable	Material/Condition/Equipment
Target SID values for AM & FM screened image (+/- 0.10)	K = 1.57, C = 1.27, M = 1.32, and Y = 1.01
Achieved average SID values for AM & FM screened image	K = 1.58, C = 1.31, M = 1.35, and Y = 1.09
Paper (Substrate)	Fortune Gloss 80lb C2S
Ink	Flint Sheetfed Process Colors
Printing Press	Heidelberg SM-74 Four Color
Press Speed	6000 IMPH
Blanket to Impression Pressure	0.01mm
Ink Sweeps (KCMY)	53, 53, 55, and 52
Dampening Solution	RBP Fountain Solution
Dampening Solution PH	5.0
Dampening Sweeps (KCMY)	51, 45, 45, and 50
Print Measurement Control	X-Rite ATD Scanning Densitometer
Press Operator	Bhaskar Gaddam

Table 3 – Comparison of Mean Scores (AM and FM screening) of CMYK Print Contrast at 75% Tint

	AM Screen N = 278		FM Screen N = 278		
Process Ink	M (%)	SD (%)	M (%)	SD (%)	t-value
Cyan	33.51	1.46	37.51	3.57	1.90*
Magenta	25.91	1.30	32.87	2.22	7.56*
Yellow	22.36	1.45	23.52	1.79	3.39*
Black	33.29	4.68	31.65	5.31	2.64*

*t 0.05 (554 df) = 1.648

Table 4 – Comparison of Mean Scores (AM and FM screening) of CMYK Dot Gain (DG) at 50% Dot Area

	AM Screen N = 278		FM Screen N = 278		
Process Ink	M (%)	SD (%)	M (%)	SD (%)	t-value
Cyan	17.73	3.49	16.77	3.00	1.98*
Magenta	19.50	1.61	20.52	1.58	36.51*
Yellow	21.02	2.88	20.59	2.85	12.94*
Black	17.98	4.63	22.52	3.92	6.46*

*t 0.05 (554 df) = 1.648

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