Colorimetric Analysis of Screening Technologies in Digital Printing

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Abstract

This research project was developed to investigate potential differences between Amplitude Modulated (AM) and Frequency Modulated (FM) screening of multicolor (CMYK) digital printing. The study examined the attributes of print contrast, dot gain, gray balance and color variation and how they may vary based on the screening method used. The experiment was conducted in a color managed digital printing workflow. Color differences were identified in print samples of AM vs. FM screening. Methods used to measure print attributes are detailed, and data was collected, graphed and analyzed.

The study shows that measurable differences do exist and that visual changes in color can occur based on the screening method employed. A custom target was printed on the Konica-Minolta C6000 bizHub digital color press using Creo's AM and FM screening technologies. A pilot test was conducted to achieve the target toner density values (+/- 0.10) according to in-house standards. During the pilot test, 200 sheets were printed. Once density values were achieved, the digital press was run continuously without operator interference and another 200 sheets were printed (100 sheets for each screening option), from which a total of 160 sheets were randomly selected (80 sheets for each screening option) for the densitometric and colorimetric analysis.

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Only attributes that measured patches made up of dots or screened tint percentages were used to compare the two screening technologies. Print attributes that utilize solid patches only were not compared. The findings of this study represent specific printing or testing conditions. The findings of this research led to the conclusion that FM screening provides greater print contrast than AM screening. The findings make it difficult to draw conclusions regarding dot gain. Further study is needed to attempt greater control of variables.

Introduction

Over the past two decades, the printing (or the graphic arts) industry has been revolutionized. Technology, workflow, management strategy, markets, customer expectations have changed. Today, print is just one of many media channels which consumers can access. The value and role of printing is changing. Today the use of print is merged across multiple communications channels, such as: web, mobile, and social media. Due to advancements in computer networking and digital printing technologies, print media has become a powerful multi-channel marketing and communications tool. Modern printing has evolved from a craft-oriented field toward a color management science. This demands greater color reproduction control among the devices used in the print and imaging industry.

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 photographic images are transformed to a printable image is called halftoning. In this method, varying percentages of the printed 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 is reflected from the different tones in the original photograph. The ink (or dry toner) 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.

Because, in conventional halftoning, the dots vary in size (but are equally spaced from one another) this process is referred to as amplitude modulated (AM) screening.

“Amplitude” relates to the size of the dot. However, for several decades, digital imaging technology has been capable of reproducing images using an alternate screening method based on a pseudo-random distribution of consistent small dots. While these dots remain the same size throughout, the number of the dots varies in a given area to produce tonal variations throughout an image. Because the number of dots changes (instead of the size) this is called “frequency” modulated (FM) screening. The objective of this research is to determine the use and effect of digital screening applications to enhance the quality of digital color printing to satisfy the end-user of print media channel.

Literature Review

Digital print technologies can be described as methods that do not use image carriers such as printing plates. Traditional printing methods such as offset lithography and flexography use different types of plates, while gravure uses an engraved cylinder to transfer the image, and screen- printing uses stencils applied to framed mesh material. Each of these traditional printing methods uses pressure, or force, supplied by a machine to transfer some form of ink to the substrate. The goal of traditional printing methods is mass reproduction (thousands, or millions) of the same imaged product that is distributed from the point of manufacture.

Digital printing methods differ in that they usually do not have a direct physical impact on the substrate. Inkjet printing utilizes different methods of transferring liquid ink droplets to a substrate to create an image. Another digital printing technology known as Electrophotography, or laser printing, is commonly used and employs charged toner particles that transfer electrostatically to the substrate and create an image that is fused to the surface. Laser and ink-jet printing generate the majority of digitally printed materials although other methods, such as thermal transfer and ion deposition can be used. The technology of interest for this study is dry-toner electrophotography. The advantage of dry, toner-based digital print technology is that it can create varying images from one sheet to the next and it is more cost-effective for shorter production runs. Digital printing requires limited set-up of equipment to produce imaged products on demand and there is much less production waste. Additionally, the printing can be distributed to anywhere an appropriate output device can be found and it typically requires less skill of the person generating the imaged products than traditional printing methods.

In the digital printing environment, the screening software can create the digital version of the AM and also FM halftone screen. Screening software in the raster image processor (RIP) of a digital printing press applies a digital dot pattern to the color image during printing. Past advances have allowed greater flexibility in digital color image reproduction, such as color correction, gray component replacement, digital halftone color output, color management, image transfer, etc.

Introduction of digital screening technology for the halftone reproduction process began in the early 1970's. According to Lau & Arce, "the halftoning process of projecting a continuous-tone original through a halftone screen has been replaced with a raster image processor" (2008, p.4). They continue: "When first introduced, RIP's imitated the halftone patterns of contact screens…forming a regular grid of round dots that vary in size according to tone. These techniques are commonly referred to as amplitude modulated or AM digital halftoning due to their modulating of the size of the printed dots" (2008, p. 5).

Turning to the advent of FM screening, Lau & Arce stated, "early FM halftoning techniques… suffered from a periodic structure that added an unnatural appearance." A better approach was developed that "proposed the revolutionary error-diffusion algorithm…leading to a stochastic arrangement of printed dots" (2008, p.6). This technique was incorporated with electronic dot generation via high-end electronic color scanners to create an alternative to traditional photomechanical screening techniques (Stanton & Warner, 1994).

Today, most digital printing environments utilize a digital half-toning process for color 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 (Pnueli & Bruckstein, 1996). Advancements in digital technology enable the industry to engage in short-run color printing that can achieve levels of color quality comparable to the traditional offset printing process. Also, modern digital printing employs various screening techniques for digital color output.

One question that emerged from exploring differences between printing methods was: is it appropriate to compare digital printing systems through measures of quality (such as dot gain) used for traditional printing? The response to this is debatable and also dependent on what variables are examined as well as the measures used. In the case of dot gain, it seems there is evidence to support a study of "digital dot gain". Goyat, Amaranand & Kuldeep, (2011) studied dot gain in digital printing as it related to cylinder pressure and toner-based liquid ink. Their study utilized samples created by an HP Indigo 5500 digital press. Since that machine is a unique hybrid offset/digital press, the results, which did reveal dot gain as a result of cylinder pressure on "electro-inks", would not be generalizable to this study.

In 2003, McIlroy posited "all printing processes exhibit dot gain, or more correctly, tone value increase, to varying extents." McIlroy continued by stating, "this includes desktop inkjets, laser printers, digital presses, and any conventional printing press" (p. 261). This establishes not only that dot gain is likely to be a measurable factor in digital print but provides a basis for defining dot gain and how to measure it. Leurs supports this definition and further refines it by stating "Dot gain is sometimes referred to as TVI (tone value increase). TVI is a more generic description of the difference in tone value between a requested value and the final output. It is also a more suitable name for processes in which, some devices may not actually deliver a dot in the final output" (2013). This explanation is particularly useful in relating dot gain to various methods of screening for digital print—which this study intends to investigate by comparing traditional halftone screening methods and stochastic screening methods.

In 1999, Lau, Arce & Gallagher explored digital halftoning methods and observed that "FM halftones are more susceptible than AM halftones to printer distortions such as dot gain, the increase in size of a printed dot from its intended size (p. 1575). They also concluded that the "major relationship between halftone patterns and the amount of dot gain seems to be the perimeter-to-area ratio of printed dots. That is, the halftone screen having the greatest perimeter-to-area ratio of printed dots will be far more susceptible to the distortions caused by dot gain. FM halftoning, having a much higher ratio than AM halftoning, is, therefore, more susceptible" (p.1577). Their research involved the development of dithering techniques that offered control of stochastic dot patterning through an algorithm that was less complex than existing solutions and these could also be tuned to varying printer characteristics by adjusting pattern coarseness.

Electrophotographic printing technologies today have reached a level of quality that is comparable to traditional printing methods. In studies of print quality using process color ink systems, there are a number of variables that may cause tonal variations. This is no different when using dry toner-based colorants found with electrophotography systems. Environmental, mechanical, and technical issues, such as dot gain, can have negative influences on the accuracy of color reproduction. Measuring, and recording, certain print characteristics may enable the technologist to make controlled adjustments and then check these variables to see if positive changes can be affected and maintained. Factors such as print contrast and gray balance were selected as the print attributes to be evaluated for this study. These were chosen because they are established measures of issues that may influence colorimetric change.

Print contrast is typically used as a measure of change, often related to dot gain, which can occur in shadows and/or darker tones of images. In traditional print methods, print contrast is a good indicator of print quality–particularly the detail that can be held in shadow areas. Print contrast indicates the ability of a printing system to hold image detail in the upper tone region. If unable to maintain print contrast detail in the tones from 75% and up, an image will show "flat" black shadow areas.

Gray balance is a useful measure of color reproduction because it indicates problems that will impact all other colors. Correct gray balance is a fundamental measure for proper color balance. Printing that does not maintain gray balance will have a color cast that does not only show in the gray area but throughout the entire image. Dry toner electrophotographic processes must follow and maintain calibration procedures just like other printing methods. Grays produced using the primary CMY toner colorants must be measured and adjusted regularly to avoid color shifts. The value of a stable, predictable process is essential to any color-managed workflow.

Amplitude Modulated (AM) vs. Frequency Modulated (FM) Screening

As stated earlier, industry has utilized the electronic version of AM screening in the film-based workflow. Although FM screening became available during the early 1990's, the printers using a film-based workflow generally did not adopt it. The microdot was difficult to transfer clearly to the plate via the vacuum frame. 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 didn't gain popularity in the industry initially. In the last five years, those using a digital printing workflow began to adopt FM screening technology, and variations that prevented the adoption of FM screening in film-based workflow have been reduced.

AM screening creates the illusion of tonal values, from highlight through shadow, by altering the size of the uniformly spaced dots. FM screening creates this illusion with 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 in between the dots that form an image results in loss of details in AM screening. In FM screening, loss of detail is minimized due to the small dot size and close spacing of microdots. Another limiting factor of AM screening is the ability of printers to maintain dots at low and high ends of the tonal range. As screen resolution (measured in lines per inch, or LPI) increases, it becomes difficult to hold a clear highlight area in an image. Similarly, FM screening uses very small dots, so the problem associated with high LPI, AM screened highlights will also be present over most of the tonal range in FM screening. Therefore, FM screening possesses a higher level of dot gain than AM screening (Chung & Ma, 1995).

Purpose of The Research

The purpose of this experimental research was to identify the differences that exist in the measurable print attributes (or characteristics) of Amplitude Modulated (AM) vs. Frequency Modulated (FM) screening of multicolor (CMYK) digital printing. 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. Only the attributes of print contrast (PC), dot gain (DG), gray balance (GB) and color variation of halftone dots (at 25%, 50%, and 75%) were tested to examine the differences that exist in the two screening technologies, as they were the attributes that measured patches made up of halftone dots or screened tint percentages. A majority of the image detail (or quality) is evaluated with the use of these screened tints only. The following questions were investigated:

1. Is there a difference in the print contrast (PC) of (CMYK) of the AM vs. FM screened digital printed image?
2. Is there a difference in the dot gain (DG) of (CMYK) at 50% dot area of the AM vs. FM screened digital printed image?
3. Is there a difference in the gray balance (GB) of (CMYK) of the AM vs. FM screened digital printed image?
4. Is there a difference in the color (CMYKRGB) variation at highlights (HL), mid-tones (MT), and shadow (SD) areas of the AM vs. FM screened digital printed 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 substrate, type of colorant, 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 delimited to the color electrophotography printing systems and materials used at the university graphics technology laboratory, and the findings are not expected to be directly transferable to other printing environments. Only attributes such as print contrast, dot gain, gray balance and tonal color variations were used to compare the two screening technologies because they were attributes that could be measured using 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.

Research Methodology

The experiment was conducted in a Color Managed Workflow (CMW). The digital color press used in this experiment is a Konica-Minolta C6000 bizHub color printer (or digital press). It uses a Creo IC-307 raster image processor (RIP) server (front-end system) with AM and FM screening applications. Mohawk brand, 80 lb., matte-coated digital color printing paper was used for printing of both screening samples. Each screening sample run in the experiment was considered as a group, noted by letter “K” (K = 2). One hundred samples for each group were printed, noted by letter “n” (n = 100). For the two groups, a total of 200 samples were printed, noted by letter “N” (N = 200). A one-page 11” x 17” custom test image (CCSU Test Image) was created for proofing and printing use for the experiment. The test target contained the following elements: an ISO300 target and generic images for subjective evaluation of color, an ISO 12647-7 control strip, and a SpotOn! control strip. Colorimetric data was extracted by using an X-Rite spectrophotometer from the printed samples (or from the control strips) for statistical analysis to determine if significant differences exist between the two screening technologies. A detailed method of this experiment is summarized in the following paragraphs. The digital color-printing laboratory made use of the CMW for accurate color reproduction.

Printer Calibration

One of the important issues in getting acceptable print quality is maintaining a stable level of toner density (printer density) in the Konica-Minolta bizHub C6000 digital press used for the experiment. Fluctuation may result from many controlled and uncontrolled variables, such as room humidity, temperature, printer settings, paper, age of toner, and inaccurate calibration or linearization of the printer. Therefore, calibrating the printer daily was very important. The calibration process for the printer used in the experiment was performed per the guidelines given by the device manufacturer. The CMYK calibration chart (with various tonal gradations) was printed via the Creo IC-307 RIP application with both screening technique options, but without using any previous calibration data, at 200 LPI (see Figure 1).

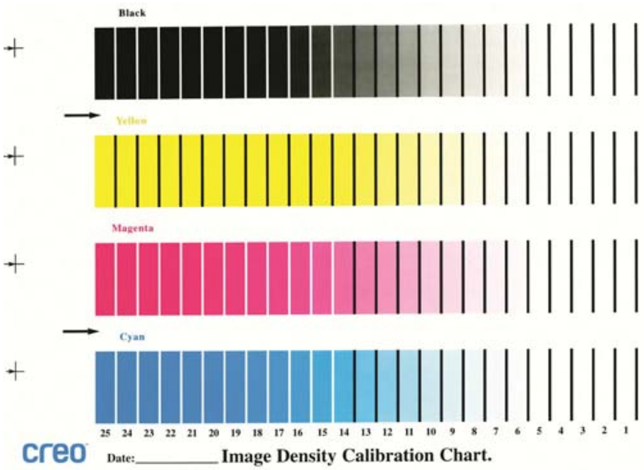

Figure 1: *CMYK printer calibration chart (for Konica-Minolta bizHub C6000)*

An X-Rite EyeOne Pro spectrophotometer was used to scan the printed chart. The device was calibrated against its reference white patch prior to using it to calibrate the printer (or measure the chart). The calibration data (CMYK density ranges) was saved in the calibration lookup tables of the RIP and a calibration curve was created (see Figure 2).

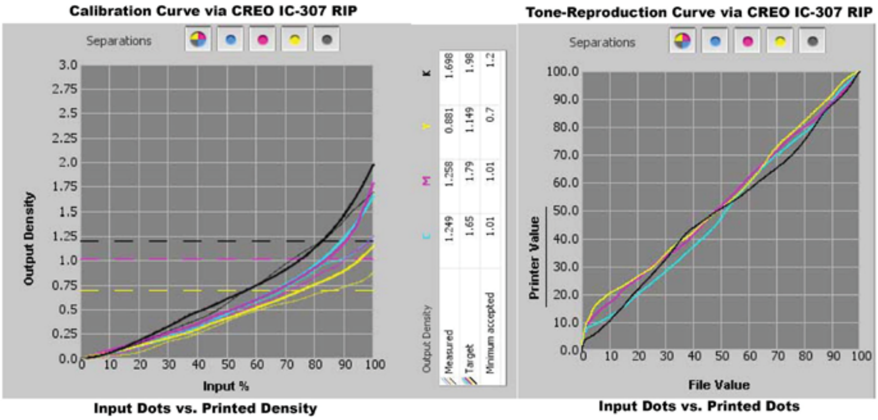

Figure 2: *Calibration Curve of CMYK SID and CMYK Dots*

Test Image for Printing

An 11” x 17”, one-page, custom test image was created for proofing and printing use for the experiment (see Figure 3). The test target contained the following elements: an ISO 300 image for subjective evaluation of color, an ISO 12647-7 control strip, an IT8.7/4 target only with 378 patches (created via Color Port) and a SpotOn! control strip. Colorimetric and densitometric data was extracted from both the control strips. Color management settings were disabled in the Adobe InDesign CS-6 page layout application. All of the image elements were imported into the page layout program, and a PDF file was made without compressing the image data. The PDF file was sent to the Digital Press RIP.

During the printing, in the color management option of the RIP, adjustments were made to print the test image, which included the following: a specific rendering intent, specific predefined (default) recommended profiles, lines per inch (LPI), AM/FM screening, and calibration data. In the CMYK emulation option of the RIP, adjustments were made to emulate the printing with a default profile and to print the test image with various AM and FM screening options. A recommended default destination profile was used to print the images. The device manufacturer recommended these two default profiles as predefined printing profiles. The final color printing/output was limited to these profiles, and other image color adjustment techniques were applied (rendering intents, LPI, calibration curve, etc.). The same test image file was used for printing with both screening (AM and FM) options. For printing with AM screening technique, a 1200 x 1200 dot per inch (DPI) resolution was used – and for printing with FM screening, 600x600 DPI was used because the FM screening of the RIP supports only 600 DPI.

Printed Color Samples for the Analysis

A total of 200 prints (copies) were printed, 100 for each screening technique of the same image on 80 lb. matte-coated paper (K = 2, n = 100, N = 200). Colorimetric data for various color quantification for each group was generated from the printed colors (SpotOn!, ColorPort 378 patches for Eyeone_iO device, ISO 12647-7 control strip and other tone-scale control strips) by using an FD-5 spectrodensitometer and an Eye-One-Pro spectrophotometer with interface applications, such as SpotOn!, X-Rite Color Port, and the Profile Maker (PM). Dot gain values at 50% tones and solid ink densities of printed samples (CMYK colors) of both screening options were measured by using the SpotOn! application.

The colorimetric data (measured via Color Port) from IT8.7/4 target was used to create the device profiles of AM and FM screens by using the PM application. Additionally, L* a* b* data was also collected from the gray patches (overlap of CMY) to determine the gray balance deviation of both screens. A total of 160 printed sheets were measured, 80 for each screening option (K = 2, n = 100, N = 200). The 378 patches tacget contained only a small subsample of an IT8.7/4 target. It contained very few patches to prove an accurate match to a specific industry standard. However, it contained enough patches to monitor the accuracy of a color reproduction system against a reference target, such as the IT8.7/4. Table 1 presents the variables, materials, conditions, and equipment associated with the scanner, monitor, and printer of this experiment (see Table 1).

The sample size was selected in order of the specific confidence interval (= 0.05). A random sampling technique was used to identify the sample size because of the large size (N = 100) of the total population. After the samples were printed, multiple devices were used to collect the colorimetric data from each sample. Glass, G.V. & Hopkins, K.D. (1996), provides an objective method to determine the sample size when the size of the total population is known. The total population for this study was 100 (N) printed sheets for each screening option (AM and FM). The following formula was used to determine the required sample size, which were 80 (n) printed sheets of each screening option for this study.

$$n = \chi^2 NP (1-P) / d^2 (N-1) + \chi^2 P (1-P)$$

where: n = the required sample size
χ^2 = the table value of chi-square for 1 degree of freedom at the desired confidence level (3.84)
N = the total known population size
P = the population proportion that it is desired to estimate (.50)
d = the degree of accuracy expresses as a proportion (= 0.05)

Two sets of print runs (2 groups, K = 2) were conducted. Each run with 100 samples used each screening technique (AM and FM). From each sample, a total of 80 samples were pulled randomly. A total of 160 random samples were pulled for the purpose of data collection. Colorimetric data (L* a* b*) and densitometric values of these 8 0 were measured (AM screen samples) by using a spectrophotometer. The same procedures were applied for the second group (FM screen samples). Densitometric and colorimetric data was collected for the following print attributes: SID, Dot Gain, Print Contrast, Gray Balance, and Color variation among the both screened printed samples.

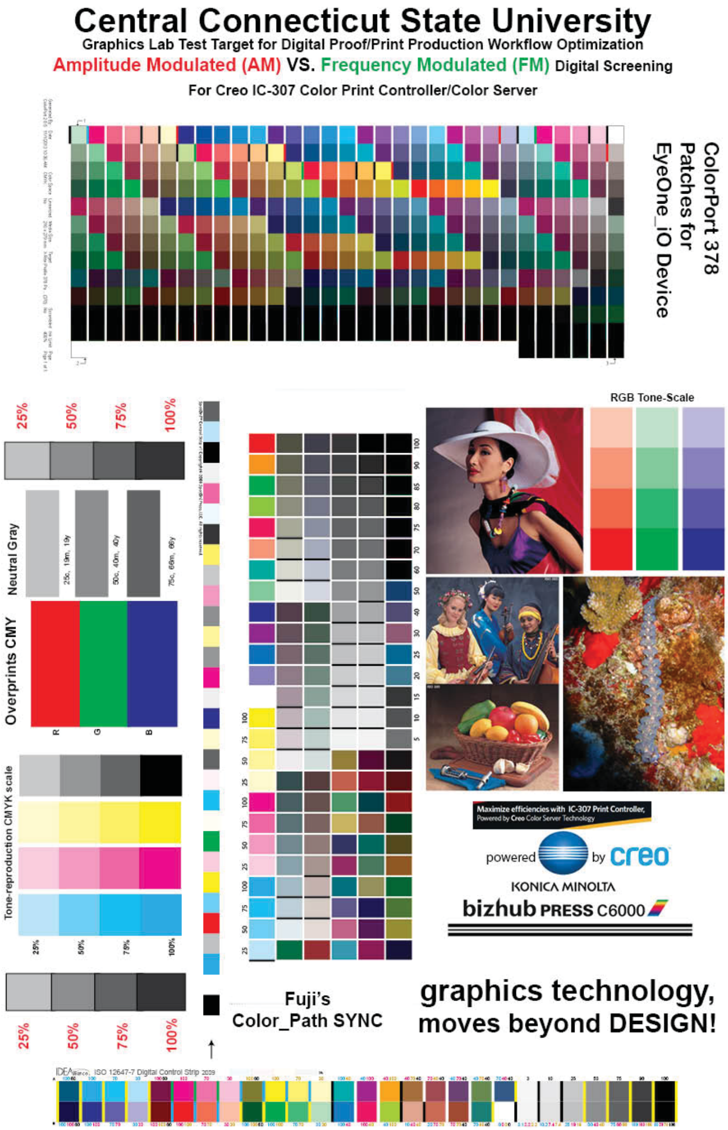

Figure 3: Test image for printing with digital AM and FM Screening Techniques

Variable: Material/Condition/Equipment	
Test images	Custom Test Target
Control strips	ISO 12647-7, and SpotOn!Press
Profiling Software	X-Rite ProfileMaker 5.0.10
Profile Inspection Software	Chromix ColorThink-Pro 3.0
Image Editing Software	Adobe PhotoShop CS-6
Page Layout Software	Adobe InDesign CS-6
Source Profile (RGB)	Adobe 1998.icc
Emulation Profile (CMYK)	None
Destination Profile (CMYK)	Custom, Konica-Minolta.icc
Color Management Module (CMM)	Adobe (ACE) CMM
Rendering Intents	Absolute
Computer & Monitor	Dell OPTIPLEX/LCD
Raster Image Processor (RIP)	Creo IC-307 Print Controller
Printer	Konica-Minolta bizHub C6000 Color Laser
Achieved CMYK SID for both print runs	C = 1.24; M = 1.27; Y = 0.89; and K = 1.59
Screen Ruling	200 LPI
Print Resolution for AM Screen	1200 x 1200 DPI
Print Resolution for FM Screen	600 x 600 DPI
Toner	Konica-Minolta Color Laser
Paper (sheetfed)	MOHAWK 80 lbs. matte-coated
Type of Illumination/Viewing Condition	D50
Color Measurement Device(s)	X-Rite Eye-One-PRO Spectrophotometer with Status T, 2 angle, and FD-5 Spectrodensitometer
Data Collection/Analysis Software	FUJIFILM ColorPath Verified, SpotOn! Press, and MS-Excel

Table 1: *Experimental and Controlled Variables*

Statistical Method Applied For The Experiment Data Analysis

Microsoft Excel was used to analyze the collected data to determine the colorimetric variation (COLVA) between the two screening methods. Since the K = 2, no inferential statistics were used to determine the significant differences that exist among the (K = 2, n = 100, and N = 200) group mean color deviations of the various screening methods. Only the descriptive statistics were used.

Data Analysis & Research Findings

The descriptive statistical method was used to analyze the collected data. Subjective judgment on color difference was not used in this study. The subjective judgment of color difference could differ from person to person. For example, people see colors in an image not by isolating one or two colors at a time (Goodhard & Wilhelm, 2003), but by mentally processing contextual relationships between colors where the changes in lightness (value), hue, and chroma (saturation) contribute independently to the visual detection of spatial patterns in the image (Goodhard & Wilhelm, 2003). Instruments, such as colorimeters and spectrophotometers, could eliminate subjective errors of color evaluation perceived by human beings.

Print Contrast (PC)

The mean scores and the standard deviations associated with the print contrast of AM and FM (CMYK) screened images are compiled in Table 2. Numerical 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 two (CM) of four color inks (CMYK) of the FM screened image was higher than the AM screened image, while yellow color print contrast was higher in the AM screened image. No difference was found in the black color print contrast of either screened images. 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: 38% for the FM screened image and 37% for the black color of the AM screened image. In addition, cyan color of the AM screened image had the smallest standard deviation when compared to the other colors (see Table 2).

	AM Screen (N=80)		**FM Screen (N=80)**	
Process Ink	M (%)	SD (%)	M (%)	SD (%)
Cyan	35	0.56	38	1.00
Magenta	33	2.00	39	2.22
Yellow	31	1.00	29	1.00
Black	37	1.00	37	1.00

Table 2: *Comparison of Mean Scores (AM and FM screening) of CMYK Print Contrast at 75% Tint*

Dot Gain (DG)

The mean scores and standard deviations associated with the measured dot gain at the 50% dot area of AM and FM (CMYK) screened images are compiled in Table 3. Using the systems tested, the greatest amount of variance between the screening technologies was evident in Yellow and Magenta. Even though yellow showed the greatest difference between screening methods with 3.13% variation in dot gain, it was the most consistently reproduced color between the samples in each category as evidenced by the standard deviation calculations. Cyan and Black provided similar results between the two screening methods, yet black produced, by far, the most gain at over 25% in the midtones. FM screened black midtone dots produced the widest range of variation among the samples tested with a standard deviation value of nearly 4% (see Table 3).

	AM Screen (N=80)		**FM Screen (N=80)**	
Process Toner	M (%)	SD (%)	M (%)	SD (%)
Cyan	16.98	1.49	16.59	1.09
Magenta	11.96	0.61	13.61	1.58
Yellow	15.37	0.88	18.50	0.85
Black	25.78	1.63	25.78	3.92

Table 3: *Comparison of Mean Scores (AM and FM screening) of CMYK Dot Gain (DG) at 50% Dot Area*

Gray Balance (GB)

Three levels of gray patches were printed to determine gray balance results of both screening systems. Highlight gray was made-up of cyan 25% dots, 19% magenta, and 19% yellow; for midtone gray, the cyan 50% dots, 40% magenta, and 40% yellow; for shadow gray, the cyan 76% dots, 66% magenta and yellow 66%. These patches were part of the printed test image, 100 copies of each group (each screen). Printed patches of gray were measured in colorimetric L* a* b* mode to determine the visual/numerical gray differences of the both screened image/colors. The average L* a* b* values for the three different levels (highlight, midtone and shadow) were plotted for each screening method (see Figure 4). In general, the gray balance in the shadow (or three-quarter) tone tended toward a yellowish cast with the FM screened samples being the most visually evident. Color casts in the midtone grays were much less noticeable but tended toward green based on plotted measurements. In the highlight (or quarter) tones it was also visually difficult to discern any color cast, however Figure 4 indicates that, on average, a slight bluish cast is measured.

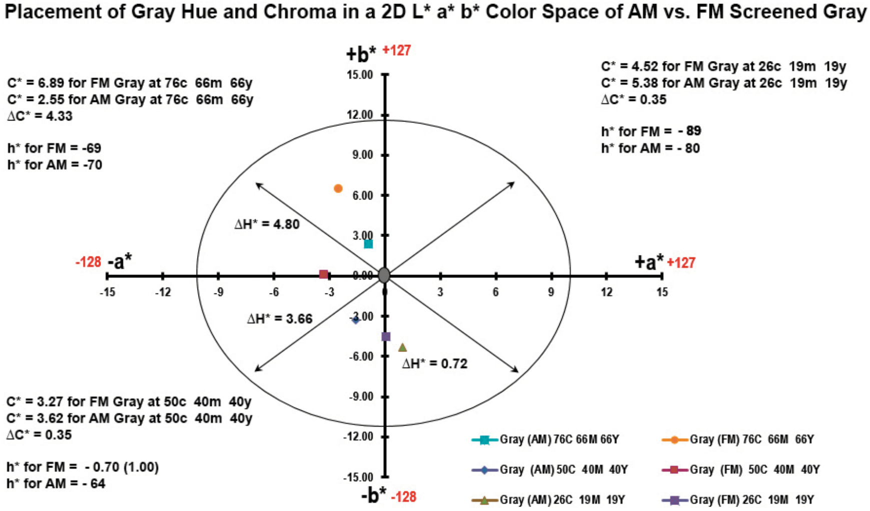

Figure 4: *GB Variation of AM and FM Screening Techniques*

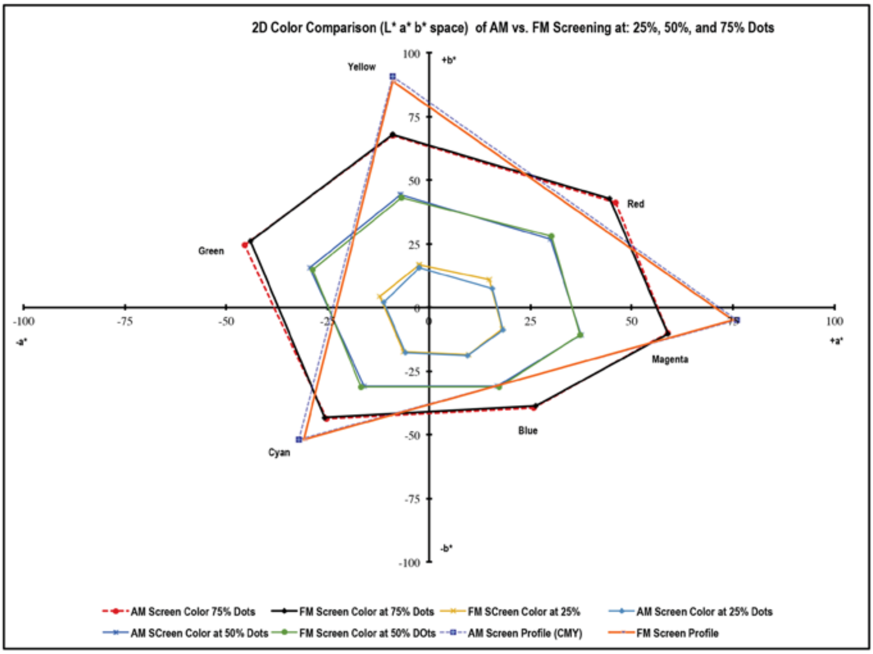

Figure 5: *Color Variation of AM and FM Screening Techniques*

Color Variation (CV)

Solid colors of both screened images were not compared, because the solid area of the image is not made-up of halftone dots. As such, color variation/colorimetric variation at 25%, 50%, and 75% dot areas of the samples were measured in the CIE L* a* b* color mode and a 2D gamut was constructed for visual comparison of colors for both screened images (see Figure 5). Image color profiles of both screened versions were also mapped with the color variation data. While comparing the colors, no visual differences were noticed among the FM and AM screened colors, except the noticeable difference in the color hues (L* a* b* values) at 25% of red (AM = 86.23, 15.48, 7.41; vs. FM = 85.98, 14.94, 11.10) and green (AM = 87.88, -11.23, 2.05; vs. FM = 88.06, -12.12, 4.56) colors of both screens.

Conclusions

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, toner, 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 who use their systems to produce similar tests and compare results to the outcomes of this study may therefore find it meaningful and useful. The results of this research study comparing amplitude modulated (AM) screening with frequency modulated (FM) 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 toner 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.

Measurable differences were identified when testing for dot gain in 50% control patches – verifying that dot gain does occur in toner based systems. Even small differences in dot gain at the midtone area can lead to color shift. Numerical difference was found when comparing the dot gain of the AM screened image to the FM screened image on all four toner colors (CMYK). Dot gain in two (M & Y) of four (CMYK) color toners of the FM screened image was much higher than the AM screened image, while amount of dot gain of cyan and black colors were similar in both variations of screened images. The greatest dot gain at 50% dot area was found in the black color of both screened images.

In a comparison of gray balance, each screening technique produced completely different gray hues, some with color casts. Numerical and visual differences do exist in comparing the gray balance of AM vs. FM screened images. The measured L*a*b* values were different for AM and FM screened highlight, midtone and shadow test patches. However, the plotted values showed a pattern in that each screening method showed a tendency toward similar color casts based on the tonal level. For example, highlight tones showed a bluish cast; midtones a greenish cast; and shadow tones showed a yellowish cast in each screening method. Most of these differences were hard to discern, but some were visually evident.

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