Dot Reproduction Attributes of Compact Discs Using Various Screen Combinations on Waterless Offset Presses

Yung-Cheng Hsieh*, Ph.D.

During the complex process of compact disk (CD) printing, high quality print and stable production processes depend on the quality and consistency of the halftone dot reproduction. Based on intensive literature reviews on this topic and two of my earlier CD-printing research papers funded by the National Science Council (NSC) of Taiwan (Project number: NSC 2000-2815-C-144-001-H and NSC 2000-2511-S-144-002), this study illustrates that dot reproduction quality in CD printing can be improved significantly by establishing an optimum film output combination incorporating three factors: screen technology, screen resolution, and dot shape. This research was also funded by the National Science Council of Taiwan (NSC 2002-2212-E-144-001) and was designed to investigate dot reproduction attributes using various screen combinations on UV waterless offset presses. A series of experiments explore the best screen technology, screen resolution, and dot shape combinations for producing favorable dot reproductions.

This research was carried out through a serious of experiments in cooperation with one of the only three CD/DVD press manufacturers in Taiwan. Both AM and FM screen technologies were used in this study. Two screen resolutions, 175lpi and 300lpi, were employed to output the conventional AM dots, while the dot sizes for outputting the FM screening were 36μm (correspond to AM 175 lpi) and 21μm (correspond to AM 300 lpi). The dot shapes were round and diamond for AM, and diamond and worm-like for FM. The print attributes analyzed included dot gain, ink trapping, and print contrast. With the collaboration of the CD printing industry in Taiwan, the optimum dot output combination for waterless offset presses using UV inks were recommended.

*Associate Professor, Chair of Graphic Communication Arts Department, National Taiwan University of Arts, Taipei, Taiwan
E-mail: t0308@mail.ntua.edu.tw or hsiehisu@ms23.hinet.net

1. Introduction

CD decorating has become an area of extreme interest for printers in Taiwan over the past few years due to the increasing demand for digital products. One of the most exciting recent developments in CD printing is the use of offset lithographic printing. In general, CD printers typically rely on three printing processes to accomplish their disc-printing work—pad printing, screen printing, and offset printing. There has been a growing popularity in offset printing for compact discs, especially CD-ROM, not only because of the quality of image that can be achieved, but also for several technical reasons that inhibit screen printing on this new format. The ultraviolet (UV) waterless offset printing, an emerging segment of this market, is drawing more and more attention in CD, label and packaging printing. The main considerations for adopting UV waterless offset decorating includes better graphics, quality (longer runs), and finer screen resolution. According to my own survey, over 75 percent of the CD printers in Taiwan now use the UV waterless offset printing method for CD printing. The printers also indicated that the offset presses used are made in Taiwan, Germany, and Japan.

It is well known that one of the biggest advantages of FM screening is that it eliminates moiré patterns that can form in AM halftones due to the lack of screen angles. This makes FM screening more tolerant of misregistration, and presses can be run at higher speeds if necessary. In addition, FM screening has been advocated for high-end printing applications, such as fine art or photographic reproduction, because the small dots help render moiré-free detail in such content as fabrics, shiny jewelry and automobiles, and nature scenes and skin tones (Dennis, 2000). It offers production benefits as well. In particular, FM screening affords the option of scanning at lower resolutions—and creating smaller, easier-to-manage digital files—while still producing the detail that rivals what can be achieved with high-frequency screen resolutions. Therefore, the intention of this study was to investigate the dot reproduction attribute on CDs via UV waterless offset printing method using both AM and FM screening with various screen resolution (rulings) and dot shapes.

1.1 Needs and Purposes of the Study

The main consideration of adopting waterless offset decorating is for higher resolution and quality images. The CD-R and DVD industries have created a great market for the waterless offset printers; thus, the development of waterless offset technology is a key to win the global competition of the printing industry. In the complex process of CD decorating, high quality print and stable production process depend on the quality and consistency of the dot reproduction. It is well known that screen output technology has a great impact on dot reproduction quality and it is influenced significantly by several factors. My two earlier CD-printing related research projects, funded by the National Science Council

(NSC) of Taiwan (Project number: NSC 2000-2815-C-144-001-H and NSC 2000-2511-S-144-002), suggested that screen technology, screen resolution, and dot shape are the most dominant factors affecting dot reproduction attributes on CDs.

Therefore, I strongly feel that there is a need to study how to improve dot reproduction quality for CD printing industry through a series of experiments to establish the optimum and realistic screen output combination of screen technology, screen resolution, and dot shape. The purposes of this study were twofold: 1) to explore dot reproduction attributes of CDs using various screen combinations of the above three factors on ultraviolet (UV) waterless offset presses, and 2) to investigate further the optimum combinations of the three factors to achieve the best dot reproduction quality.

1.2 Limitations and Assumptions of the Study

The following limitations and assumptions must be considered when interpreting the results of this study:

1. The waterless printing plates used in this study were limited to aluminum-based plates only.
2. This study assumes that there was no operator effect on ink trapping, print contrast, and dot gain although only one experienced operator ran the press during the experiment.
3. Although all eight sets of plates for the press runs were made at the same time, their average tone value increases were not identical, and this study has to assume that this variation had no significant effects on the results of the study.
4. This study assumes that performances of the blankets, ink, and other materials used for the eight press runs were the same.
5. Since the pressroom temperature and relative humidity were controlled, there were no temperature and humidity effects on discs, ink, and the press.
6. No replication was done for this study.

2. Literature Review

2.1 AM Screening and FM Screening

Conventional halftone screening is called Amplitude Modulation (AM) screening. Amplitude means size; AM screening breaks up an image into dots of varying sizes to simulate the original image. FM screening, on the other hand, keeps the dots the same size and varies the frequency, or number, of dots and the location of those dots to simulate the original image. Figure 1 compares AM screening with FM screening.

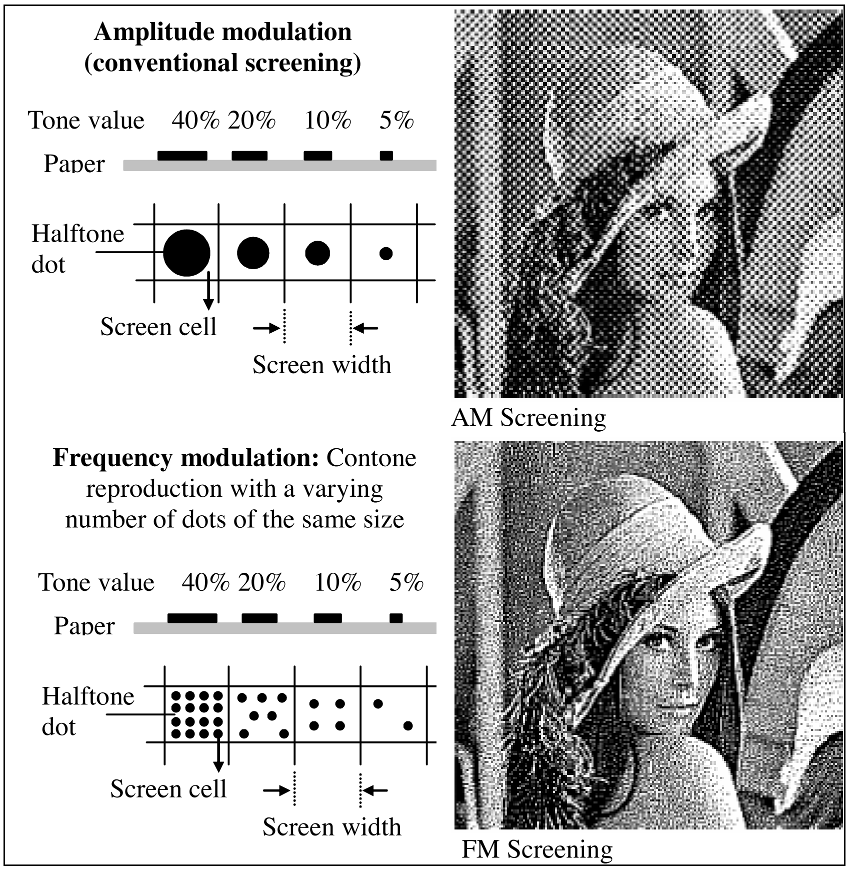


Figure 1. Comparison of AM screening with FM (AccuTone, R. R. Donnelley)
Source: *Handbook of Print Media.* (p. 93 & p. 98), Edit by Helmut Kipphan, 2001, German: Springer-Verlag Berlin Heidelberg.

In FM screening, the concepts of screen angle and frequency no longer apply. Because the dots are randomly placed, there is no direction (the screen angle used in AM screening) to the dots. The variable spacing of the dots means there is no fixed spacing, and therefore there is no screen frequency. Figure 2 shows enlarged simulations of AM and FM screening.

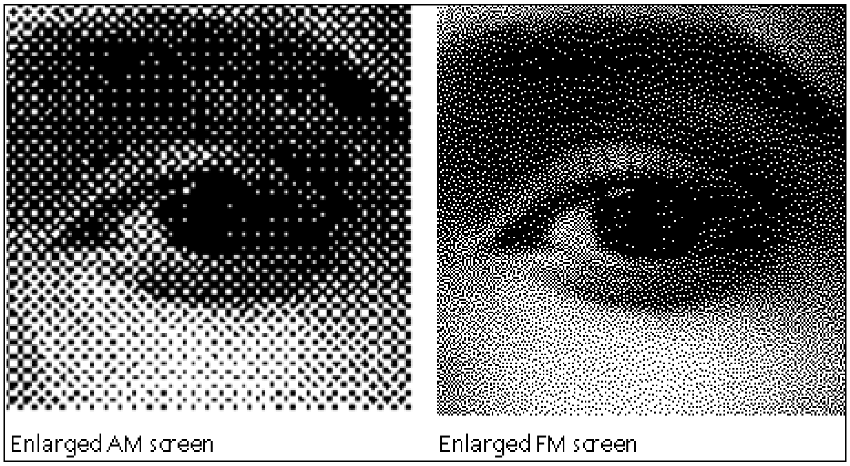


Figure 2. Enlarged simulations of AM and FM screening
Source: "Stochastic Screening," (1998). *PrePress Technology Reports,* Retrieved January 7, 2004, from http://www.prepress.pps.com/TechReports

2.2 Screen Resolution

Screen resolution is described in lines per inch (lpi) for AM (conventional) screening and micron (µm) for FM (stochastic) screen. Lines per inch refers to the number of halftone dots per linear inch in the halftone or color separation. FM screening process is quite different from the conventional line screens (AM). Instead of placing dots in rows and varying their size with tone value, FM screening randomly places the same size dots. As tone value increase with stochastic, so does the number of dots used to produce the proper tones. Depending on the resolution (2,400dpi /3,600dpi) different spot (dot) sizes can be selected as well. Spot sizes today vary from 10 microns to 35 microns (µm), depending on the vendor (Radencic, 2003).

The principle benefit gained from using a fine screen resolution is in reproducing more detail and texture of the original. Screen resolutions are chosen based on the amount of sharpness and detail in the original. The higher the screen resolution, the higher the amount of detail that is reproduced. The finer the screen resolution, the more the separation resembles a continuous-tone image, but the higher and more variable the dot gain on press. The screen resolution that is used generally depends on what type of substrate is being printed. Newspapers, for instance, usually print screen resolutions between 85 and 100 lpi because there is excessive dot gain on the newsprint substrate and dot gain at these screen resolutions is minimal. Magazine screen resolution usually goes from 130 to 150 lpi. A brochure using high-quality coated paper, however, may print halftones at 200 lpi or higher (Killeen, 1995, p. 30). The fine screen resolution is, however, more difficult to control at all stages: film contact, platemaking, and printing. *In this study, the substrate is compact disc, and it has not been studied for its proper screen resolution with FM screening and various dot shapes, especially when printed using waterless offset presses.*

2.3 Dot Shape

Dots may be square, elliptical, round, or other special shapes. Dot shape is important in rendering tonal reproduction. Shape distortion during ink transfer from plate to blanket and blanket to substrate creates poor color and a shift in gray balance. Some shapes, like the elliptical, are more prone to dot gain than are others. To reduce dot gain, some printers prefer round dots because the round shape maximizes the perimeter (Killeen, 1995, pp.28-30). In practice, it has not been possible to establish an ideal dot shape because applications and process techniques are often too diverse. For example, System A, which employs screening with square dots, may produce better print results than the screening with System B; but the latter system may produce a better chain dot than does System A. This variation in print quality is attributed not only to the algorithms used for screening (like that in the various software-based, digital screening processes), but also to the technical hardware components for exposing the screened images (Kipphan, 2001, pp. 91-92).

3. Experimental Design and Procedure

This study was an experimental research in nature, and it intended to explore the optimum screen output combinations for various tone levels. In the first stage, the study intended to establish the optimum output combination of halftone dots including screen technology, screen resolution, and dot shape, to reproduce the halftone dots between 10 percent and 90 percent. The screen technologies used for this study were AM and FM screens. For AM screening, the screen resolutions were 175lpi and 300lpi with round and elliptical dot shapes. As for FM dots, the dot sizes were 36µm (corresponding to AM 175 lpi) and 21µm (corresponding to AM 300 lpi) with diamond and worm-like shapes. The press used for this study was one of the only three made-in-Taiwan waterless offset CD presses. This section describes the test target, experimental procedures, experimental materials conditions, and data collection of the study.

3.1 Variables of the Study

Many variables affect dot reproduction from film to plate to substrate, and most of them are interdependent. However the dependent variables of the study were the dot gain, print contrast, and ink trapping on the discs. The independent variable was the various screen (halftone dots) output combinations. Table 2 summarizes the experimental variables and variables that were controlled and how they were controlled during the experiment.

Table 1. Comparative chart of screen resolution (lpi) and micro dot diameter (μm)

lpi	Dot Percent %（Highlight / Shadow）				
	5/95	10/90	15/85	20/80	30/70
100	63(Microns)	89	109	126	154
120	52	74	90	105	128
133	46	66	81	93	114
150	42	59	72	84	103
175	36	50	62	72	88
200	31	44	57	63	77
250	25	36	44	50	62
300	21	29	36	42	51

Source: "Problems & Ideas," by T. F. Frecska. (1996, March). *Screen Printing,* p.32.

Table 2. Experimental and controlled variables

Variable	Material/Equipment
Imagesetter	SCREEN MTR 1100
Plate	Toray Waterless offset plate (negative-working)
Plate Specification	610mm*295mm*0.24mm（l*h*t）
Plate Exposure	Foumong Co., Ltd. UV
Exposure Amount Control	UGRA Plate Control Wedge (85 exposure units)
Plate Develop	Guann Yinn Waterless Plate Processor
Developer Temperature	43℃
Substrate (Compact Disc)	118mm*17mm（d*t）
Offset Ink (CMYK)	DIC DG-4 UV
Screen Printing Ink (White)	UET Coat WI-262P
Press	GFS-1001
Blanket-to-impression Pressure	10mm
Printing Speed	50 strokes per minute
Plate Temperature	18~20 ℃(water-cooling)
Cooling System Temperature	20~23 ℃ (air-cooling)
Pressure room RH	36~38%
Experimental Location	Guann Yinn Co. Ltd., Taipei, Taiwan
Date	October, 2003
Press Operator	Mr. Huang

3.2 Test Form

A four color test form was designed for this study (See Figure 3). It consists of a photographic image located in the center, YMCK tone scales around the disc that ranged from 10 percent to 90 percent tone values in a 10 percent interval, and CMYRGB solid patches. The photograph on the test form is a GATF test image, which emphasizes complex color reproduction challenges.

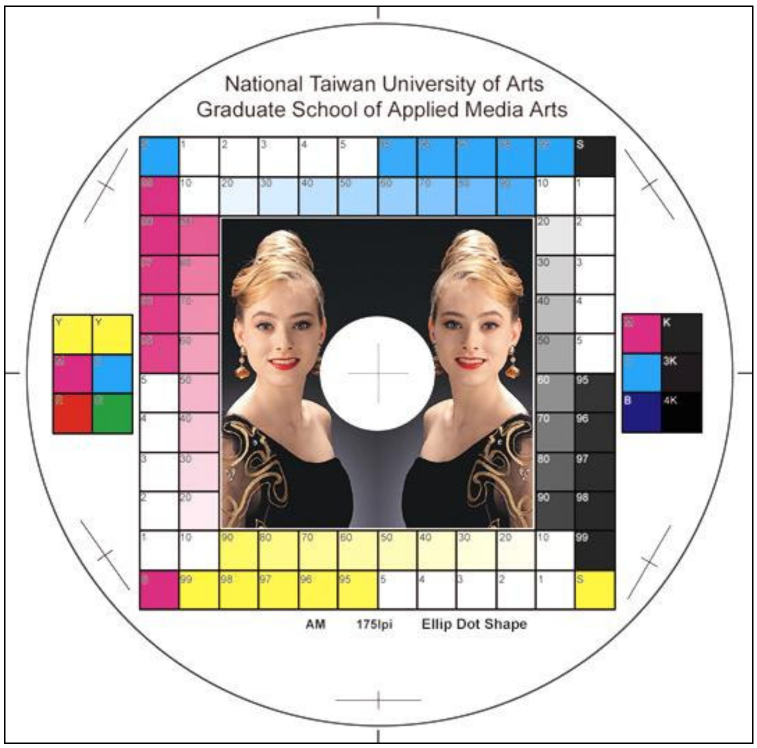


Figure 3. The test form for the experiment

3.3 Film Output

The imagesetter utilized to output the computer-generated film for this experiment was calibrated and linearized before the experiment. The imagesetter was SCREEN MTR 1100, and the measurement of dot area on the film was done with an X-Rite® 361DTP, a transmission densitometer. This densitometer was also used for the imagesetter calibration and linearization. Measuring dot areas on the film generated by the imagesetter was an important procedure to ensure that the imagesetter was linearized. In other words, there was zero gain for the dots on the computer-generated film because the imagesetter was verified to be at a stage of linearization. For example, 50 percent dots on the film were read as 50 percent by the transmission densitometer. Four sets of film were output for AM and FM dots, respectively. The detail of film outputting is displayed in Table 3.

Table 3. The film and plate output for the experiment

Screen Technology	Resolution	Dot Shape	Quantity	Note
AM	175 lpi	Elliptical	One Set	Each set of film was output for negative-working plates
		Round	One Set	
	300 lpi	Elliptical	One Set	
		Round	One Set	
FM	36 μm	Diamond	One Set	
		Worm-like	One Set	
	21 μm	Diamond	One Set	
		Worm-like	One Set	

3.4 Platemaking

The plates used in this study were Toray waterless offset plate (negative-working). Eight sets of CMYK plates were exposed for the experiment; therefore, a total of 32 plates were made. Extreme care was taken to standardize the exposure time and development time to achieve the same percentage of dot gain for all plates that were used to run the experiment. The UGRA Plate Control Wedge was used to standardize the exposure amount for the plates, and the standardized amount was 85 units. In addition, an ACME Plate Dot Reader was utilized to read the 50 percent tints (five times for each 50 percent patch) of the plates to obtain the midtone dot areas for the purpose of assessing the consistency of the platemaking process.

The plate dot areas at 10 percent, 20 percent, 25 percent, 30 percent, 40 percent, 50 percent, 60 percent, 70 percent, 75 percent, 80 percent, 90 percent tints were read using a Micro Optical Image Capture System (MOICS). The MOICS used for this experiment is a specially designed unit by the author, and it was verified to be highly valid and reliable in his previous research funded by NSC of Taiwan (Hsieh, 2003). The system consists of the following:

- High precision optical microscope (20X ~ 1800X)
- High precision XY-table
- Halogen lamp, cool light source
- CCD Video Camera
- 15” LCD monitor
- Digital video processing system
- Computer system
- Software application
- Sony color video printer.

The readings were then recorded and analyzed by the Minitab software package. The average dot areas of the various tints are displayed in Table 4.

Table 4. Plate readings on the plates

Tints	AM				FM				Dot Gain /Dot Loss
	175 lpi		300 lpi		36μm		21μm		
	Round	Elliptical	Round	Elliptical	Worm -like	Diamond	Worm -like	Diamond	
10%	11	12	11	12	8	11	9	12	-2%~ 2%
20%	23	22	23	23	17	22	17	22	-3%~ 3%
30%	35	33	34	33	27	32	27	32	-3%~ 5%
40%	45	44	46	45	39	42	38	44	-2%~ 6%
50%	54	55	55	58	50	52	50	56	0% ~ 8%
60%	63	65	65	68	62	62	62	66	2% ~ 8%
70%	73	74	75	78	74	71	73	75	1% ~ 8%
80%	82	84	83	86	84	81	83	84	1% ~ 6%
90%	91	92	92	94	92	91	91	94	1% ~ 4%

3.5 Printing

The CD press used for this study was a made-in-Taiwan waterless offset machine. Two print tests were run, with the first operation serving as a pilot test to familiarize the press operator with printing the test form, while the second operation served as the actual printing experiment where printed discs were sampled. After each press run, the press was shut down and cleaned, the run counter was set to zero, and the desired materials and conditions were made ready for the next run. Before applying the process color, a white ink film was printed by a screen printing unit built into the press. During each press run, the ink density was balanced out across the discs to 1.0 for the yellow, 1.4 for the magenta, 1.3 for the cyan, and 1.5 for the black (based on GRACoL recommendation).

3.6 Data collection

The protective layers (gumming) were washed off before measuring and loading the printing plates. One hundred printed compact discs were collected for each press run after the press was determined to be at equilibrium and the desired solid ink density was achieved. Consequently, a total of 800 (8*100) printed discs were gathered for the eight runs, and then, 50 discs were systematically sampled for each of the eight treatment combinations for a total sample size of 400 (8*50). Finally, a Gretag D118C reflective spectrodensitometer using Yule-Nielsen equation with an n-factor value of 1.12 and the status “T” filter was applied to measure 75 percent print contrast (PC), dot areas (DA) at 10 percent, 20 percent, 30 percent, 40 percent, 50 percent, 60 percent, 70 percent, 90 percent, and ink trapping (IT)of the final printed discs for this study. The optimum n-factor value for reading compact discs was determined based on the author's previous study published in Journal of Graphic Technology, Volume 1, No, 1 (Hsieh, 2001, pp. 69-78). That study concludes that the optimum n-factor range of the Yule-Nielsen equation to measure dot areas on the compact discs printed via UV waterless offset process is between ***1.11*** and ***1.16***, and the most suitable n-factor value is ***1.12***. Therefore ***1.12*** is the n-factor value applied to all the measurements in this experiment. It is important to note that each specific measured area on the sampled disc was read five times to reduce the measuring error. Thus, the final data entered into the computer for the analysis was a mean of five readings from the spectrodensitometer.

4. Results and Findings

This section reports the overall results and findings through analyses of the data obtained from the complex measurement on the discs. All the analyses were done with SPSS 11 and Minitab 13 statistical software packages. The eight screen output combinations were AM/Elliptical/175lpi (denoted as AM/E/175), AM/Round/175lpi (AM/R/175), AM/Elliptical/300lpi (AM/E/300), AM/Round/300lpi (AM/R/300), FM/Diamond/36μm (FM/D/36), FM/Worm-like/36μm (FM/W/36) , FM/Diamond/21μm (FM/D/21), FM/Worm-like/21μm (FM/W/21).

4.1 AM Screening

The overall results of dot reproduction attributes for AM screening are displayed in Table 5. The 10 percent – 90 percent dot gain percentages, print contrast, and ink trapping are listed and categorized according to the four screen output combinations.

Dot Gain (Tone Value Increase, TVI) of AM Screening

According to Table 5, for AM screening, the combination of AM/Elliptical/175lpi yielded the greatest dot gain (TVI) at 10 percent tone level for all four process colors, and AM/Round/300lpi had the least dot gain with the greatest standard deviation value for all four colors. For the 20 percent tint, the least dot gain occurred when the AM/Round/175lpi combination was applied. For the 30 percent and 40 percent tints, the least dot gain value occurred when the AM/Elliptical/175lpi combination was applied. In addition, the least dot gain size for the tone values between midtone and shadows occurred when the combination of AM/Round/175lpi was applied (see Table 5 and Figure 4). On the other hand, the overall results indicated that the combination of AM/Elliptical/300lpi printed a greater dot gain than did the other three. As for the dot reproduction stability, as shown in the S.D. (Standard Deviation) columns of Table 5, the combinations with 300 lpi resolutions had a smaller dot reproduction variability than did those with 175lpi for all four colors.

Table 5. Descriptive statistics of dot reproduction attributes for AM screening

Dot Reproduction Attributes		AM / E / 175 lpi		AM / E / 300 lpi		AM / R / 175 lpi		AM / R / 300 lpi	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
10% Dot gain /loss	Y	9.54	1.3126	6.58	1.0120	5.96	1.3845	5.90	1.6320
	M	13.38	1.7130	9.20	1.8406	7.88	1.8254	7.38	1.3076
	C	7.14	1.3704	7.02	1.8460	4.06	2.2077	6.68	2.1231
	K	10.42	1.4441	8.94	1.5308	6.54	1.7168	6.54	1.5935
20% Dot gain /loss	Y	13.14	1.1068	13.34	1.0994	11.50	1.2976	12.00	1.4569
	M	16.92	2.1931	15.30	2.3409	12.60	2.0203	13.92	1.6015
	C	9.56	1.7747	10.86	2.5636	8.92	2.1744	11.88	2.4960
	K	15.64	2.2836	18.98	2.1617	13.14	1.9167	16.62	1.9784
30% Dot gain /loss	Y	17.02	1.1156	15.84	.9553	18.46	1.0144	13.56	2.2054
	M	18.02	2.1236	18.30	2.9294	19.36	1.9770	20.94	1.8780
	C	11.60	1.7379	12.60	2.7627	14.82	1.9968	17.00	2.3905
	K	17.52	2.5970	21.04	2.2943	20.00	2.0000	20.64	2.4054
40% Dot gain /loss	Y	18.44	.8609	18.54	.9941	18.98	1.0200	19.66	2.6773
	M	19.08	2.3460	20.00	3.3258	20.54	2.3230	26.62	2.2847
	C	16.34	1.9858	12.48	2.8873	14.50	2.1020	23.16	2.4525
	K	17.82	2.3620	21.54	2.2334	22.06	1.8451	28.52	1.9085
50% Dot gain /loss	Y	21.78	.8873	24.00	.9476	17.20	1.1066	22.60	1.9691
	M	21.56	2.0320	24.04	2.7772	18.10	1.9614	25.88	2.1631
	C	14.48	1.9192	16.98	2.4948	12.14	1.9693	22.02	2.5192
	K	18.84	2.1320	23.96	1.7723	19.24	1.7209	28.54	2.0224
60% Dot gain /loss	Y	19.08	.9223	21.40	1.0498	14.66	1.0806	20.66	1.2875
	M	21.20	1.9272	25.28	2.0902	16.28	1.6787	23.94	1.6214
	C	12.80	1.8844	19.12	2.4297	10.24	1.8133	19.06	2.3071
	K	19.06	2.0938	26.06	1.6214	17.00	1.5386	25.98	1.7082
70% Dot gain /loss	Y	15.50	.9091	19.26	1.0461	12.06	.9564	18.70	.5803
	M	16.66	1.5729	20.02	1.6474	13.10	1.4321	19.38	1.3076
	C	10.14	1.6164	15.38	2.0091	8.26	1.4401	15.28	1.9277
	K	15.72	1.6041	21.30	1.3132	14.14	1.1608	20.86	2.4909
80% Dot gain /loss	Y	12.66	.7982	14.86	.8084	10.02	1.7899	14.60	1.1780
	M	13.86	1.1608	15.20	1.0302	11.04	1.1058	14.34	.8715
	C	7.58	1.3864	11.40	1.3248	6.34	1.1886	11.28	1.3856
	K	12.40	1.2454	15.98	.7420	11.14	.8332	15.66	.7174
90% Dot gain /loss	Y	8.62	.6024	9.46	.5425	7.60	.7284	9.38	.8053
	M	9.06	.5500	9.36	.5628	7.88	.6273	8.94	.5115
	C	4.22	.7900	6.28	.5360	3.80	.7559	6.16	.5481
	K	7.78	.8640	8.84	.4219	7.32	.4712	8.68	.4712
Print Contrast	Y	23.70	2.2790	18.68	2.8674	31.82	2.2919	19.38	2.3114
	M	21.50	2.8012	17.98	2.7367	29.54	2.2425	19.54	2.0624
	C	38.74	1.9775	35.50	2.9847	43.16	1.6826	36.08	2.8128
	K	33.68	2.0448	24.80	2.3905	40.26	1.4682	26.00	2.5794
Ink Trapping	R	77.38	2.4234	75.54	2.1401	73.92	2.2483	77.32	2.2537
	G	98.44	1.9183	93.92	1.7825	99.24	1.0797	95.24	1.6728
	B	94.12	2.2914	89.56	1.8644	92.92	1.7825	87.88	1.7571

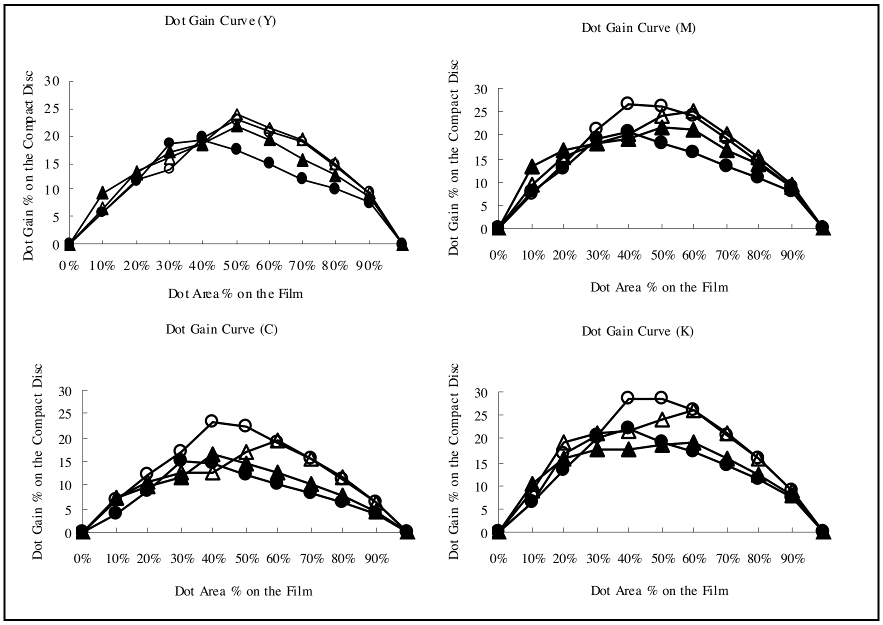


Figure 4. 10%~90% dot gain curve of AM screening

Note: ▲ AM/Elliptical/175lpi Combination △ AM/Elliptical/300lpi Combination
● AM/Round/175lpi Combination ○ AM/Round/300lpi Combination

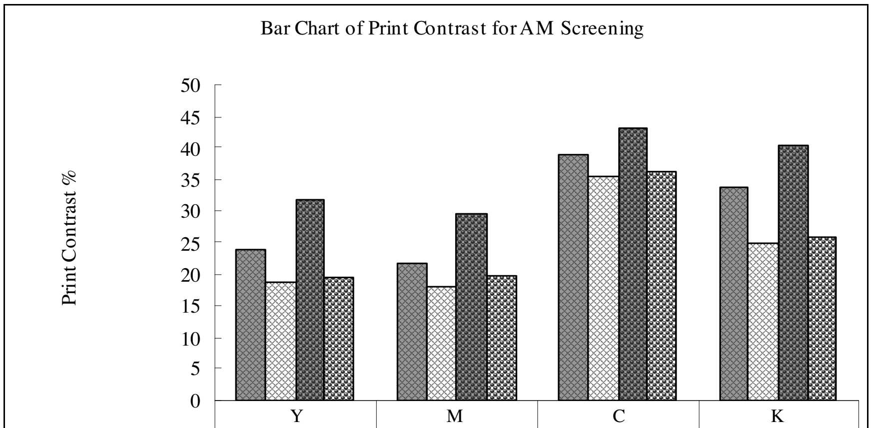
Print Contrast of AM Screening

Print contrast (PC) is a measure of shadow contrast and is the degree to which viewers can distinguish printed tones in the shadow area of a reproduction. In other words, PC is an objective characteristic of printing relating to the shadow detail rendered by the process. PC is calculated in a manner that compares density reading differences between a three-quartertone tint area (usually a 75 percent or 80 percent tint) and a solid patch. The formula is the following:

$$\% \ PC = \frac{Ds - Dt}{Ds} \times 100$$

Ds = Density of the solid patch (including paper density)
Dt = Density of the three-quartertone patch (including paper density)
(Tritton, 1997).

Table 5 and Figure 5 indicate that the AM/Round/175lpi combination had the greatest print contrast percentage values for all CMYK colors among the four combinations, followed by AM/E/175, AM/R/300, and AM/E/300. In other words, the AM/Round/175lpi combination printed the greatest tonal range in shadows for CMYK color, and the AM/E/300 combination printed the smallest print contrast. Regardless of dot shape, the combinations with 175lpi printed greater print contrast than did those with 300 lpi.



	Y	M	C	K
AM/Elliptical/175lpi	23.7	21.5	38.74	33.68
AM/Elliptical/300lpi	18.68	17.98	35.5	24.8
AM/Round/175lpi	31.82	29.54	43.16	40.26
AM/Round/300lpi	19.38	19.54	36.08	26

Figure 5. Bar chart of print contrast for AM screening

Ink Trapping of AM Screening

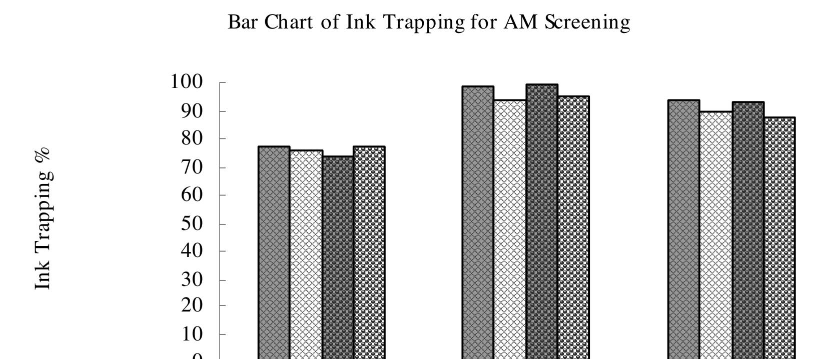
Ink trapping is a print attribute that relates to the two-color overprint colors of blue, green, and red. It estimates the amount of ink that is transferred to a previously printed ink film compared to the transfer of ink to an unprinted substrate. The print sequence must be known to make trapping measurements (Stanton, 1991).

In the lithographic industry, acceptable trapping is generally somewhere between 75 percent and 95 percent; the higher the percentage, the better the ink trapping. There are various equations used to calculate ink trapping, but the Preucil trapping equation is the most frequently used and is applied for this study:

$$\text{Trap}\ (\%) = \frac{D_{1+2} - D_1}{D_2} \times 100$$

where D_{1+2} = density of the overprint
D_1 = density of first color
D_2 = density of second color (Tritton, 1997).

Table 5 and Figure 6 show that the AM/E/175 combination had a greater ink trapping than did the other three AM combinations. In addition, the combinations with 175lpi yielded greater ink trapping than did 300lpi combinations.



	R-MY	G-CY	B-CM
AM/Elliptical/175lpi	77.38	98.44	94.12
AM/Elliptical/300lpi	75.54	93.92	89.56
AM/Round/175lpi	73.92	99.24	92.92
AM/Round/300lpi	77.32	95.24	87.88

Figure 6. Bar chart of ink trapping for AM screening

4.2 FM Screening

The overall results of dot reproduction attributes for FM screening are displayed in Table 6. The 10 percent – 90 percent dot gain percentages, print contrast, and ink trapping are listed and categorized according to the four screen output combinations.

Dot Gain of FM Screening

For FM screening, the combinations of **FM/Worm-like/36µm** printed smaller dot gain than did the other three FM combinations (see Table 6 and Figure 7), especially at between 30 percent and 50 percent tints for all CMYK colors. The combinations with worm-like dots, regardless of the resolutions, printed smaller dot gain than did those with diamond dots at between 10 percent and 50 percent tone levels for all four colors. For the tone values between 60 percent and 90 perecnt, the 36µm dots yielded smaller dot gain than did the 21µm dots for all four colors, regardless of the dot size (screen resolution). In addition, Table 6 indicates that there is no particular trend in dot reproduction variability (standard deviation column) among the four combinations.

Table 6. Descriptive statistics of dot reproduction attributes for FM screening

Dot Reproduction Attributes		FM/D/36µm		FM /D/21µm		FM/W/36µm		FM/W/21µm	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
10% Dot gain /loss	Y	5.26	1.2090	3.30	1.4033	2.78	.9750	1.02	.8204
	M	7.42	1.2137	5.60	1.1606	1.38	1.0079	1.90	.9313
	C	2.54	1.1643	1.24	1.2382	2.86	1.1430	1.38	1.0476
	K	9.88	1.4518	5.84	1.9729	2.42	.9055	.96	.6987
20% Dot gain /loss	Y	9.80	1.1066	7.46	2.3142	1.14	.7287	.76	.8704
	M	14.64	1.7815	12.46	1.6189	3.00	1.3702	5.12	1.3944
	C	6.86	1.5520	5.26	1.5754	.94	.9775	1.16	.9765
	K	23.14	2.1572	15.38	1.8282	2.88	1.0428	3.20	1.3248
30% Dot gain /loss	Y	12.92	1.1578	11.38	1.6274	1.92	1.1036	4.58	2.6733
	M	18.66	1.9960	18.34	1.7333	8.80	1.9691	12.04	2.0599
	C	9.44	2.1108	9.94	2.0742	2.92	1.8935	5.28	1.8299
	K	27.86	2.3648	22.18	1.8482	8.68	1.3915	12.50	2.8446
40% Dot gain /loss	Y	15.72	.9044	14.72	1.5784	6.00	2.0898	8.48	1.5016
	M	21.30	2.1309	22.50	2.1213	14.58	2.3997	18.86	3.0103
	C	10.88	1.8029	13.56	2.0816	7.32	1.7195	9.84	2.2620
	K	29.62	2.1655	27.74	1.9358	14.78	1.8548	19.48	2.3320
50% Dot gain /loss	Y	17.44	1.3118	18.48	1.8321	10.16	1.5566	12.14	1.2124
	M	21.48	1.9820	24.54	2.0325	19.48	2.5091	24.42	2.5322
	C	11.82	1.8592	16.42	2.2047	11.18	1.7922	14.88	2.3268
	K	29.54	2.0821	30.56	1.6922	19.10	1.7757	24.44	2.0520
60% Dot gain /loss	Y	17.78	.5455	19.02	1.8570	13.44	.7866	17.94	1.1502
	M	21.76	1.8245	24.80	1.4428	22.42	2.3043	26.54	1.8094
	C	10.72	1.9382	15.96	2.2128	13.82	1.6622	18.32	2.0548
	K	26.32	1.5312	29.12	1.1891	21.68	1.4769	27.08	1.5497
70% Dot gain /loss	Y	17.22	.7083	18.74	1.3822	16.24	1.0984	19.24	.9381
	M	18.40	1.3702	21.48	1.0925	20.74	1.6513	23.44	1.3426
	C	10.08	1.5758	15.30	1.6690	13.22	1.6449	17.20	1.7613
	K	22.50	1.1995	24.30	.7354	20.14	1.0882	23.80	.8330
80% Dot gain /loss	Y	14.72	.9044	16.36	.9638	14.18	.7197	16.70	.9742
	M	14.88	.9398	16.82	.6908	16.06	.9127	17.74	.7231
	C	7.42	1.3716	11.94	1.0382	9.44	1.2149	12.44	1.0910
	K	16.58	.6091	17.78	.5817	15.34	.6581	17.40	.5345
90% Dot gain /loss	Y	8.62	.7253	9.44	.7329	8.86	.6064	9.82	.3881
	M	8.46	.5425	9.66	.4785	9.34	.5573	9.72	.4536
	C	2.86	1.0882	5.50	.7354	3.96	.7814	5.42	.6728
	K	8.56	.5014	9.02	.4734	8.00	.4949	8.88	.3283
Print Contrast	Y	19.80	2.8997	13.92	2.5462	17.20	1.6413	12.58	2.7411
	M	19.34	2.2462	12.48	1.8653	13.06	2.6218	9.06	1.9210
	C	41.64	4.7241	33.58	2.3827	35.94	2.5105	31.50	2.3146
	K	25.66	2.4711	15.18	1.8592	22.50	2.1117	17.34	1.8363
Ink Trapping	R	74.58	1.9069	74.20	2.0603	80.12	1.4934	75.76	3.2612
	G	98.30	1.6933	93.56	1.7398	96.66	1.7683	93.36	2.5133
	B	93.00	2.3035	91.42	2.7781	87.82	1.8592	87.88	2.1819

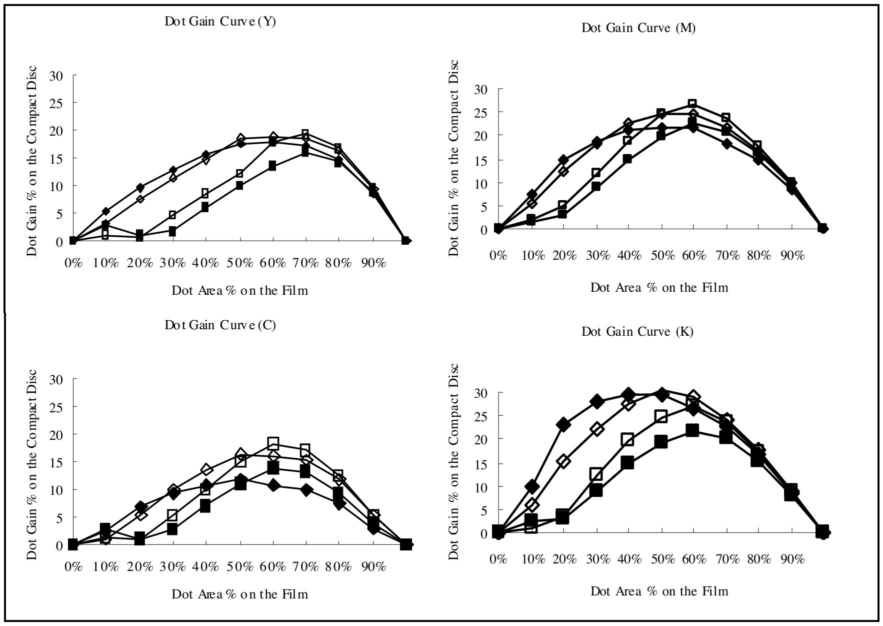


Figure 7. 10%~90% dot gain curve of FM screening

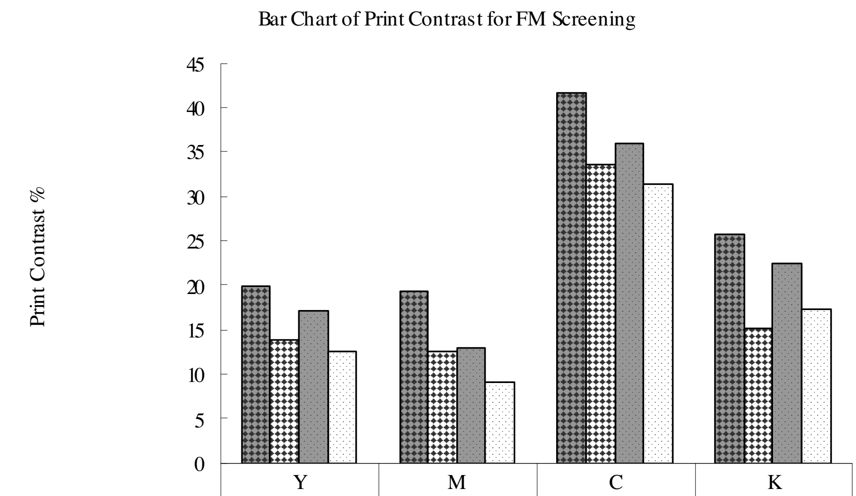
Note: ◆FM/Diamond/36μm Combination ◇ FM/Diamond/21μm Combination
■ FM/Worm-like/36μm Combination □ FM/Worm-like/21μm Combination

Print Contrast of FM Screening

Table 6 and Figure 8 indicate that the FM/Diamond/36μm combination had the greatest print contrast percentage values for all CMYK colors among the four combinations, followed by FM/W/36, FM/D/21, and FM/W/21. In other words, the FM/Diamond/36μm combination printed the greatest tonal range in shadows for CMYK color, and the FM/W/21 combination printed the smallest print contrast for all four colors excluding black. It is important to note that 36μm dots yielded greater print contrast for CMYK colors than did 21μm dots regardless of dot shape; furthermore, diamond dots printed greater print contrast than did worm-like dots for all four colors if the dot size was held constant. Figure 8 also shows that the contrast of cyan is significantly greater than that of the other three colors.

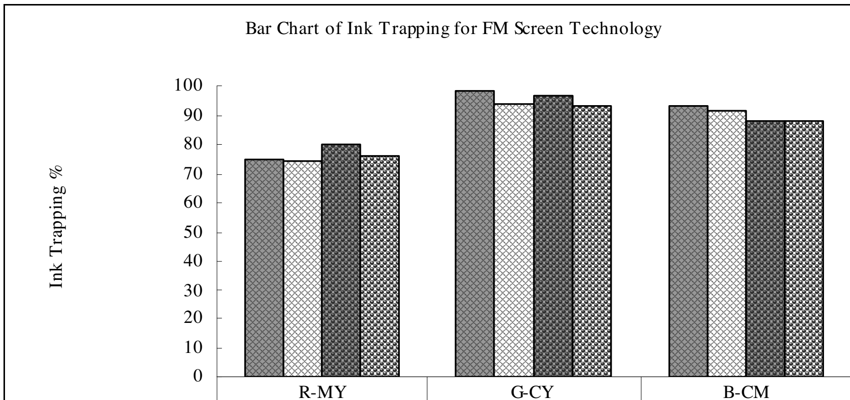
Ink Trapping of FM Screening

Figure 9 shows that the FM/D/36 combination printed the greater ink trapping for Green (CY) and Blue (CM) than did the other three FM combinations. In addition, the combinations with 175lpi yielded greater ink trapping than did 300lpi combinations. According to Figure 9, it appears that there is no sufficient evidence to support that the dot size (screen resolution) or dot shape is correlated with ink trapping.



	Y	M	C	K
FM/Diamond/36μm	19.8	19.34	41.64	25.66
FM/Diamond/21μm	13.92	12.48	33.58	15.18
FM/Worm-like/36μm	17.2	13.06	35.94	22.5
FM/Worm-like/21μm	12.58	9.06	31.5	17.34

Figure 8. Bar chart of print contrast for FM screen technology



	R-MY	G-CY	B-CM
FM/Diamond/36μm	74.58	98.3	93
FM/Diamond/21μm	74.2	93.56	91.42
FM/Worm-like/36μm	80.12	96.66	87.82
FM/Worm-like/21μm	75.76	93.36	87.88

Figure 9. Bar chart of ink trapping for FM screen technology

4.3 Dot Reproduction Comparison between AM and FM screening

This section describes the dot reproduction comparison between AM and FM screening. Regardless of dot shape and screen resolution, the overall results show (see Table 7, Table 8 and Figure 10) that the AM screening printed greater dot gain than did the FM screen, between 10 percent and 50 percent tone levels for all colors, but the dot gain size of the AM screening is smaller than that of the FM screening after 50 percent tone levels (between 60 percent and 90 percent tints).

Table 7. Dot gain comparison between AM & FM screening

Dot Reproduction Attributes		AM		FM	
		Mean	S.D.	Mean	S.D.
10% Dot gain/loss	Y	6.995	2.011	3.090	1.881
	M	9.460	2.897	4.075	2.751
	C	6.225	2.283	2.005	1.343
	K	8.110	2.279	4.775	3.699
20% Dot gain/loss	Y	12.495	1.460	4.790	4.179
	M	14.685	2.600	8.805	5.114
	C	10.305	2.533	3.555	2.882
	K	16.095	2.951	11.150	8.738
30% Dot gain/loss	Y	16.220	2.284	7.700	4.912
	M	19.155	2.524	14.460	4.632
	C	14.005	3.063	6.895	3.528
	K	19.800	2.692	17.805	7.930
40% Dot gain/loss	Y	18.905	1.637	11.230	4.398
	M	21.560	3.943	19.310	3.886
	C	16.620	4.668	10.400	2.981
	K	22.485	4.385	22.905	6.403
50% Dot gain/loss	Y	21.395	2.864	14.555	3.806
	M	22.395	3.682	22.480	3.104
	C	16.405	4.297	13.575	2.975
	K	22.645	4.398	25.910	4.952
60% Dot gain/loss	Y	18.950	2.837	17.045	2.446
	M	21.675	3.906	23.880	2.665
	C	15.305	4.435	14.705	3.423
	K	22.025	4.427	26.050	3.083
70% Dot gain/loss	Y	16.380	3.017	17.860	1.595
	M	17.290	3.112	21.015	2.267
	C	12.265	3.599	13.950	3.120
	K	18.005	3.572	22.685	1.885
80% Dot gain/loss	Y	13.035	2.285	15.490	1.389
	M	13.610	1.878	16.375	1.332
	C	9.150	2.596	10.310	2.341
	K	13.795	2.269	16.775	1.109
90% Dot gain/loss	Y	8.7650	1.007	9.1850	0.784
	M	8.8100	0.792	9.2950	0.715
	C	5.1150	1.300	4.4350	1.377
	K	8.1550	0.857	8.6150	0.599

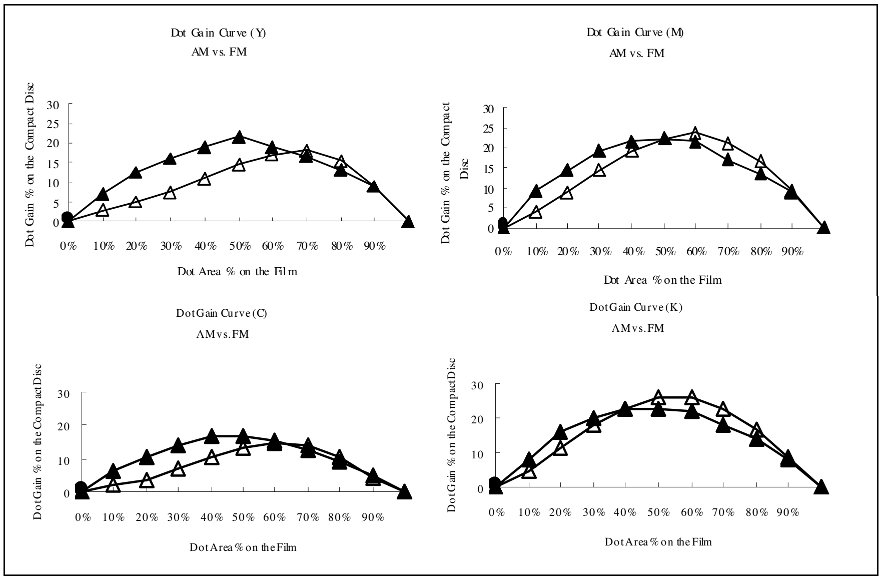


Figure 10. 10 percent~90 percent dot gain curve of AM & FM screen technology

Note: ▲ AM screen technology △ FM screen technology

Table 8. Print contrast & Ink Trapping comparison between AM & FM screening

Dot Reproduction Attributes		AM		FM	
		Mean	S.D.	Mean	S.D.
Print Contrast	Y	23.395	5.780	15.875	3.766
	M	22.140	5.096	13.485	4.305
	C	38.370	3.871	35.665	4.920
	K	31.185	6.623	20.170	4.636
Ink Trapping	R	76.040	2.669	76.165	3.268
	G	96.710	2.743	95.470	2.860
	B	91.120	3.165	90.030	3.213

According to Table 8 and Figure 11, the AM screening yielded 75 percent greater print contrast than did the FM screening for all colors, but there is no significant difference in ink trapping percentage between the two screening technologies. In addition, based on the standard deviation column of Table 7 and Table 8, the variability of dot reproduction (in terms of dot gain, print contrast, and ink trapping) is not significantly different from each other between AM and FM dots.

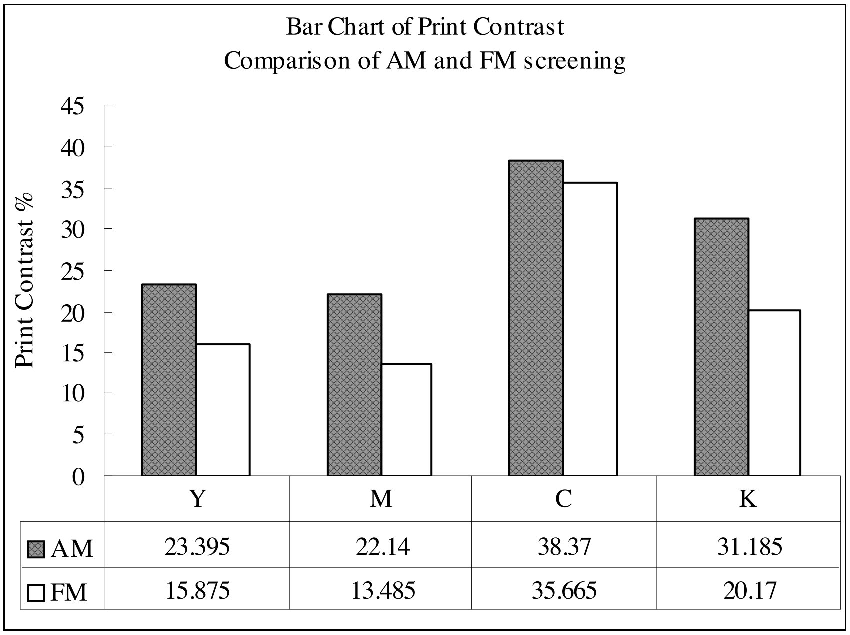


Figure 11. Bar chart of pint contrast for AM & FM screening

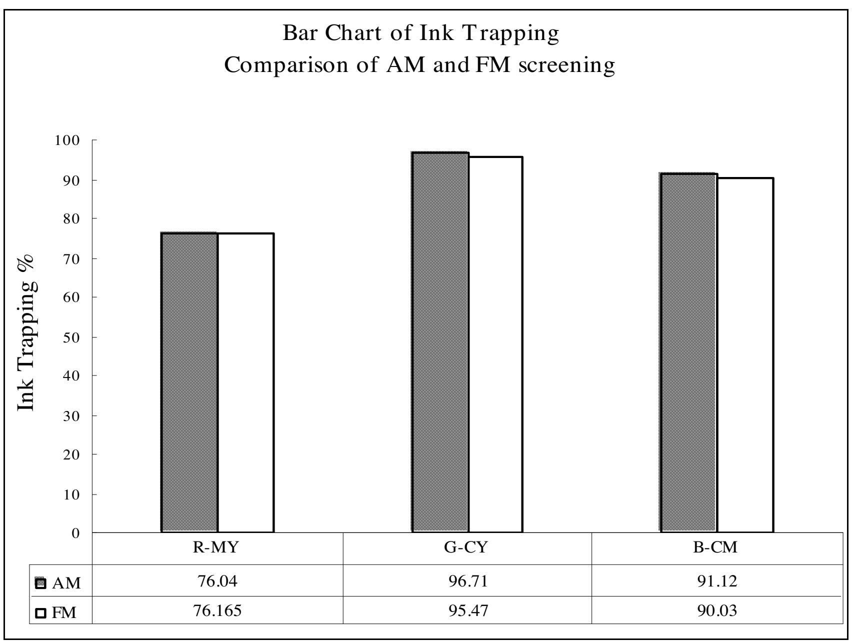


Figure 12. Bar chart of ink trapping for AM & FM screening

4.4 Dot Reproduction Comparison between Various Screen Resolutions

In this study, the screen resolutions for AM dots were 175lpi and 300lpi, and those for FM dots were 36µm (corresponding to AM 175 lpi) and 21µm (corresponding to AM 300 lpi). Figure 13 and Table 9 indicate that the 170lpi/36µm resolution printed greater dot gain at 10 percent and 20 percent tints than did the 300lpi/21µm resolution. In contrast, 170lpi/36µm resolution printed smaller dot gain than did the 300lpi/21µm for the rest of the tone values (30 percent to 90 percent), regardless of dot shape. As shown in Table 9, Figure 14, and Figure 15, the higher the resolution, the greater the print contrast and ink trapping. In other words, the 170lpi/36µm resolution printed greater print contrast and ink trapping than did the 300lpi/21µm resolution, regardless of dot shape.

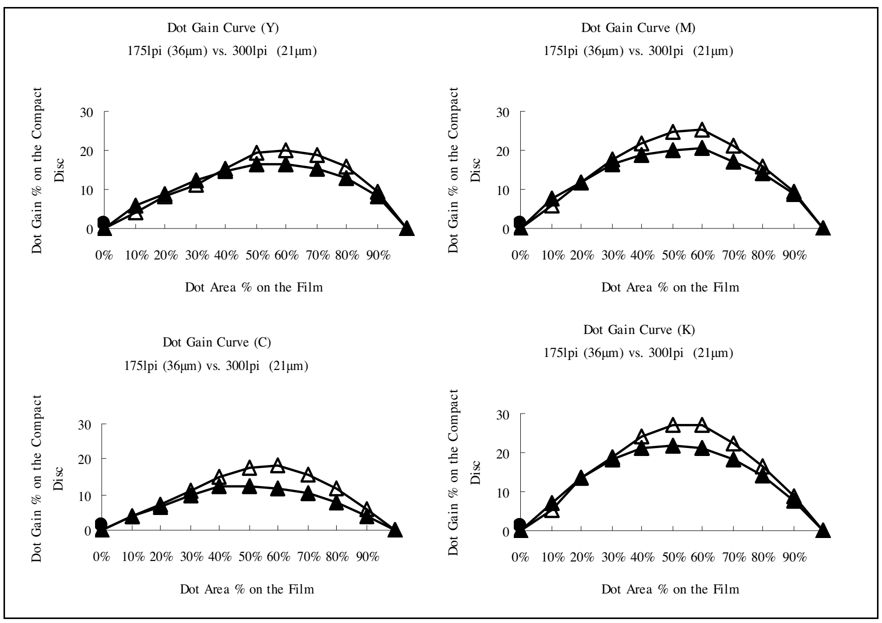
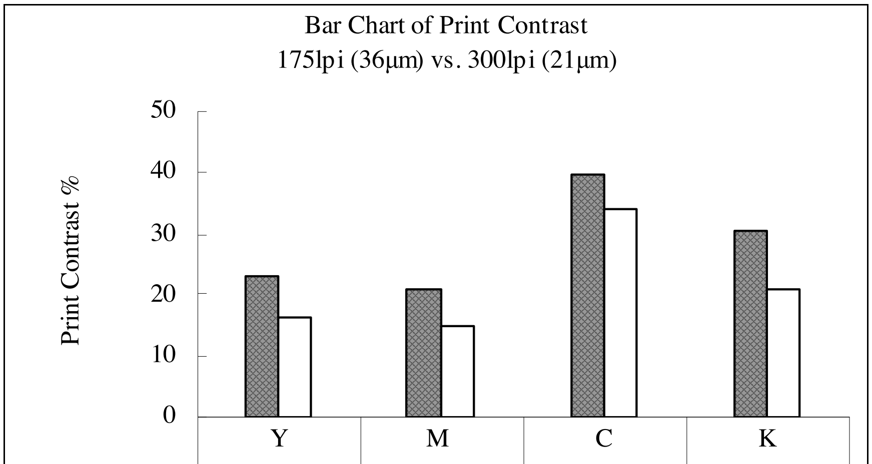


Figure 13. 10 percent~90 percent dot gain curve of various screen resolutions
Note: ▲175lpi/36µm △300lpi/21µm

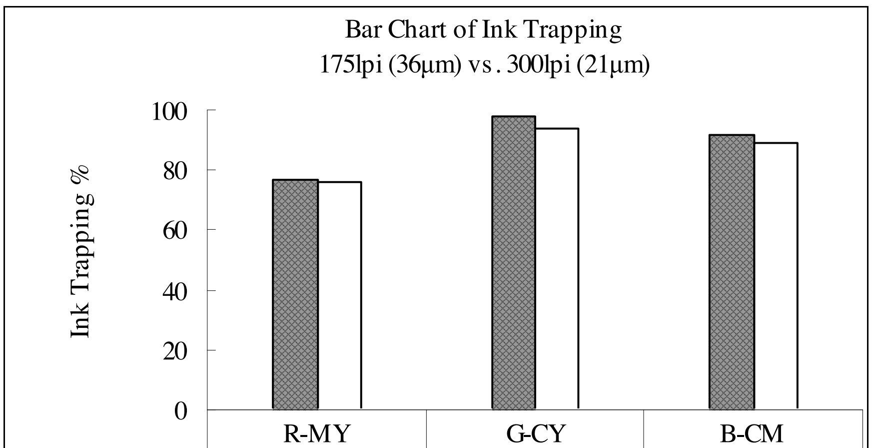
Table 9. Dot reproduction attributes comparison among various screen resolutions

Dot Reproduction Attributes		175lpi/36μm		300lpi/21μm	
		Mean	S.D.	Mean	S.D.
10 Dot gain/loss %	Y	5.885	2.715	4.200	2.540
	M	7.515	4.505	6.020	3.019
	C	4.150	2.374	4.080	3.213
	K	7.315	3.494	5.570	3.275
20 Dot gain/loss %	Y	8.895	4.764	8.390	5.158
	M	11.790	5.627	11.700	4.315
	C	6.570	3.793	7.290	4.793
	K	13.700	7.512	13.545	6.396
30 Dot gain/loss %	Y	12.580	6.589	11.340	4.652
	M	16.210	4.757	17.405	3.944
	C	9.695	4.771	11.205	4.829
	K	18.515	7.180	19.090	4.519
40 Dot gain/loss %	Y	14.785	5.395	15.350	4.729
	M	18.875	3.470	21.995	4.032
	C	12.260	3.955	14.760	5.598
	K	21.070	5.952	24.320	4.426
50 Dot gain/loss %	Y	16.645	4.352	19.305	4.868
	M	20.155	2.568	24.720	2.476
	C	12.405	2.251	17.575	3.583
	K	21.680	4.941	26.875	3.355
60 Dot gain/loss %	Y	16.240	2.438	19.755	1.924
	M	20.415	3.107	25.140	1.982
	C	11.895	2.337	18.115	2.582
	K	21.015	3.869	27.060	1.979
70 Dot gain/loss %	Y	15.255	2.155	18.985	1.054
	M	17.225	3.171	21.080	2.068
	C	10.425	2.371	15.790	2.006
	K	18.125	3.589	22.565	2.128
80 Dot gain/loss %	Y	12.895	2.149	15.630	1.342
	M	13.960	2.126	16.025	1.574
	C	7.695	1.702	11.765	1.295
	K	13.865	2.357	16.705	1.111
90 Dot gain/loss %	Y	8.4250	0.823	9.5250	0.657
	M	8.6850	0.799	9.4200	0.588
	C	3.7100	1.001	5.8400	0.733
	K	7.9150	0.749	8.8550	0.442
Print Contrast	Y	23.130	5.999	16.140	3.933
	M	20.860	6.404	14.765	4.740
	C	39.870	4.052	34.165	3.178
	K	30.525	7.253	20.830	5.146
Ink Trapping	R	76.500	3.197	75.705	2.697
	G	98.160	1.885	94.020	2.076
	B	91.965	3.196	89.185	2.614



	Y	M	C	K
175lpi/36μm	23.13	20.86	39.87	30.525
300lpi/21μm	16.14	14.765	34.165	20.83

Figure 14. Bar chart of print contrast for various screen resolutions



	R-MY	G-CY	B-CM
175lpi/36μm	76.5	98.16	91.965
300lpi/21μm	75.705	94.02	89.185

Figure 15. Bar chart of ink trapping for various screen resolutions

5. Conclusions and Recommendations

The overall results indicates that the FM/Wormlike/36µm combination printed the smallest dot gain between 10 percent and 40 percent tone levels for all CMYK colors among the 8 combinations, and the AM/Round/175lpi combination printed the smallest dot gain between 60 percent and 90 percent tone levels. In addition, the results show that FM dots printed much greater dot gain than did AM dots between 60 percent and 90 percent tints (midtone and shadows). In particular, the black color printed using the FM/W/21 combination was found to have far greater dot gain than did the other combinations. It is also important to note that FM/Diamond/36µm printed excessive dot gain between 10 percent and 40 percent tints for all four colors. Among the four colors, black was found to have the greatest dot gain.

The study also concludes that the AM/Round/175lpi is the optimum combination to reproduce dots at 20 percent, 50 percent, 60 percent, 70 percent, 80 percent, and 90 percent areas; as for the 30 percent and 40 percent dots, the AM/Elliptical/175lpi is the optimum combination for all four colors. If we take into account the print contrast and ink trapping, the AM/Round/175lpi would be the best choice. If FM screening has to be used, this study suggests that the FM/Worm-like/36µm combination would be a good choice, in terms of small dot gain, especially in highlight and midtone areas.

Comparing the dot reproduction between AM and FM screening, this study found that the FM screening is a better choice than AM screening, in terms of dot gain size, but for reproducing dots between 60 percent and 90 percent areas, the AM screening is a better choice. In addition, the AM screening yielded 75 percent greater print contrast than did the FM screening for all colors, but there is no significant difference in ink trapping percentage between the two screening technologies. Therefore, this study recommends that a hybrid screening technology, with FM dots applied to the tone levels less than 50 percent and AM dots applied to the tone levels greater than 50 percent, might an effective way to reduce dot gain and improve print contrast.

Comparing the dot reproduction between the screen resolutions of 175lpi/36µm and 300lpi/21µm, this study concludes that the 300lpi/21µm resolution is a better choice than 175lpi/36µm to print highlights (10 percent and 20 percent tints) for all four colors, but 175lpi/36µm resolution is the better choice to print midtones and shadows (30 percent to 90 percent), regardless of dot shape. In addition, the 170lpi/36µm resolution printed greater print contrast and ink trapping than did the 300lpi/21µm resolution.

Based on the above conclusions, this study recommends that a hybrid screening technology should be considered to print on compact discs using UV waterless offset process. To achieve the least dot gain and greatest print contrast, a hybrid technology containing FM/21µm dots for highlights (less than 25 perecnt tone values) and AM/175lpi dots for the rest of the tone scales is strongly recommended. It is necessary to conduct further research to investigate the dot reproduction quality on compact discs using the UV waterless offset process with the hybrid screening output combination of FM/21µm dots for highlights (less than 25 percent tone value) and AM/175lpi dots for the rest of the tone scales.

References

Dennis, Anita.
2000 "CTP breathes new life into FM screening" Retrieved June 5, 2003, from http://www.seyboldreports.com/Specials/FMscreen/fm.html

Frecska, T. F.
1996 "Problems & Ideas," Screen Printing., vol. 86, no. 3, p. 32.

Hsieh, Yung-Cheng.
2001 "The optimal "n" value of Yule-Nielsen equation for measuring dot area on CDs using waterless process with UV inks," Journal of Graphic Technology., vol. 1, no. 1, pp. 69-78.

Hsieh, Yung-Cheng., Wu, Yu-Ju., & Lin, Wha-Hwat.
2003 "An Experimental Research to Compare Devices for Measuring Aluminum Lithographic Printing Plates," TAGA Proceedings., pp. 250-273.

Killeen, Cindy L.
1995 "Dealing with Dot Gain," GATFWorld., vol. 7, no. 3, pp. 27-36.

Kipphan, Helmut (Ed.)
2001 "Handbook of Print Media," (German: Springer-Verlag Berlin Heidelberg.)

Radencic, Gregory M.
2003 "Stochastic and Hybrid Screening Printability Study," (Pittsburgh, PA: GATFPress.)

Stanton, Anthony.
1991 "GATF 19×25-in. Sheetfed Color Printing Test Kit User's Guide," (Pittsburgh, PA: GATFPress.)

Stochastic Screening.
1998 PrePress Technology Reports. Retrieved January 7, 2004, from http://www.prepress.pps.com/TechReports/screeningtr.html

Tritton, Kelvin.
1997 "Colour control in lithography," (Pira International., Surrey, UK)