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A Study utilizing halftone based digital proofing systems in the flexographic printing process

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A Study Utilizing Halftone Based Digital Proofing Systems In the Flexographic Printing Process

by

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Abstract

Contract proofing for printing has been traditionally done by press proofing. This is costly and wasteful, not just in terms of equipment and labor but also in terms of expendables. The advent of off-press proofing was greeted with some degree of uncertainty by the printing industry. With press proofing, the proof was literally a preview of what would happen on a press. The press proof, although often printed on a different press, generally used the same type of inks, plates and substrate that would characterize the final print. With offpress proofing, printers were comparing apples to oranges; instead of comparing a press sheet to a press sheet they were comparing a press sheet to an approximation of a press sheet. However, over time as printers learned to read off-press proofs, they became accepted as contract proofs. The same situation has now befallen digital proofs.

In the particular case of flexography, the proofing problem is a bit different. Off-press analog proofs were designed with lithography in mind, they were characterized to simulate lithographic dot gain. In order to make a proof that looks like a flexographic press sheet, two sets of films are required; one which compensates for flexographic dot gain (this is the set from which the job would be printed) and one which has extra dot gain built into the highlight and quarter tones (this is the set that the proof would be made from). This extra set of films is wasteful and time consuming to generate.

Digital proofing seems to be well suited for flexography, because the dot gain can be built into the proofing system and no extra film is required to create the proof. At the most basic level there are two types of digital proofers available; those which simulate halftone dots and those that do not. Whether or not the dots are necessary is open to discussion, however, in the case of flexography the dots appear to be crucial. For this research document it was decided that the halftone dots were preferred. The reason for this is that at about 133 lpi the rosette patterns formed by halftone dots are at the threshold of resolution by the human eye. For more course screen rulings this is even more critical. Much of flexography is printed at screen rulings of 133 lpi or lower, so very often the dots can be resolved by the eye. Therefore, the mindset at the **beginning** of the research was that if the dots can be resolved on the press sheet then the dots should be resolved on the proof.

The major thrust of this research was to observe whether or not a halftone-based digital proofer can simulate the appearance of a flexographic press sheet. A flexographic test form was created and printed on a film based substrate. A press sheet was sent to two vendors who manufacture halftone proofers. The proofing systems are not mentioned by name; they are instead referred to as Digital Proof A and B. They then attempted to match the press sheet as closely as possible. Thus, through reverse engineering, the vendors created a device profile for this set of printing conditions. Upon receipt of the proofs, they were compared to the press sheet in terms of optical density, hue (ΔE) and halftone dot size. Later, a visual assessment was executed to observe how closely the digital proofs matched the press sheet using a 3M Matchprint, that had been altered to approximate flexography, as the reference or control proof.

The results showed that there were significant differences between proof and press sheet in some instances and insignificant differences in others. In terms of the physical structure of the halftone dots, the 3M Matchprint had the closest match to the press sheet dot structure. In terms of physical dot size; digital proof A best matched the 50 and 75% dots and the Matchprint matched the 5% dots the best. In terms of optical density; digital proof A best matched the density of the 25% dots, digital proof B best matched the density of the 5% dots and the Matchprint best matched the 50 and 75% dot patches. In terms of ΔE values (color or hue difference); the Matchprint most closely matched the press sheet, digital proof B was next, and digital proof A was last.

In terms of a visual match, the three proofs were found to be statistically equal in their ability to visually match the press sheet. The visual match being the most powerful of the criteria; shows that the measurable differences in the proofs did not directly affect their ability to match the press sheet.
The results show that either of the two halftone digital proofs could have been used in place of the 3M Matchprint. The results also question the need for halftone dots in a proof. This is primarily because the two halftone digital proofs utilized a different RIP than the Agfa generated films for the 3M Matchprint and flexographic press sheet. Yet the visual observations made by the judges could not, at a normal viewing distance, discern this difference. The conclusion is that there is no visual difference between the halftone digital proofs and the 3M Matchprint proof in terms of visually matching the press sheet.

Chapter 1

Introduction

"The color proof, which is usually made before the production run for customer approval, is expected to be a reasonable representation of the printed job so the customer can determine what modifications, if any, are needed before printing. When approved it becomes the guide for pressmen to use during makeready to derive the OK sheet that is used for checking the printing during the run. If the proof does not reproduce the printing characteristics of the process there is the risk of difficulty in getting the printed job to match the proof, which can result in long, tedious, expensive corrections on the press, plate remakes, a dissatisfied customer and possibly job rejection." Michael H. Bruno, 1989[1]

Purpose and Rational for Study

The purpose of this research was to determine if a digital halftone proofing system is able to successfully predict the halftone dot structure, ink density and hue (ΔE) as well as visually approximate a flexographic press sheet printing on a plastic film substrate (polypropylene). This is a relevant subject to study because up to now, there has not been a proofing system that has been able to successfully compensate for the high amount of dot gain present in the highlight portion of the tone scale in the flexographic printing process, in a timely fashion. Digital proofing could save a great deal of time and materials (especially film) and seems to be well suited for direct or computer-to-plate technology.

There are two types of proofing; press proofing and off-press proofing. Off-press proofing is any type of proofing not done on a press; this includes the exposure based analog systems and all forms of digital proofing.

The initial form of proofing was press proofing, which used the same ink set and substrate as the final product. Press proofs are considered to be the best method of predicting the appearance of the printed job. Press proofing is not without its disadvantages; it is a labor intensive process and plates need to be made every time a proof is made. In a film based environment, this means films and plates need to be made each time a proof is to be made. This is a large amount of time and materials to waste in a production setting.

Different presses are used to proof and to print, "as tying up a production press for proofing is not economically advisable."[2] "All presses are different, not only in design, but in performance."[3] Even if the design of the proof press was similar to the design of the flexographic production press; there are certain variables such as, anilox roller and doctor blade compositions or ages, that will prevent the exact same result press to press.

In off-press analog proofing, a series of exposures are made to a photosensitive material. There are two categories of this type of proof; an overlay proof and an integral or single sheet proof. For proofing critical color, the overlay proofing systems are not accurate. This is due to a graying effect caused by each successive color being layed down. With integral proofs, color layers are laminated to a substrate, they do not suffer from the same inaccuracies in color that the overlay systems are subject to.

In the case of flexography, two sets of films are often made; one compensates for dot gain on press and one has additional dot gain built into it. The film with the additional dot gain is then used to make the proof; if the desire is to match the proof dot size to the press sheet.

The dot gain present in the midtone portion of the tone scale can be compensated for in the exposing process. Michael Bruno states that the polyester base on the 3M Matchprint, "acts as a spacer between the proof and the substrate which produces optical dot gain of about 20-24% in the middletones. This is equivalent to the mechanical dot gain experienced in average magazine printing . . ."[4]

However, the dot gain in the highlights of an image printed by flexography cannot be accounted for in an exposure based analog proofing system, without the use of multiple exposures and masks or generating multiple films. The mask insures that the highlights are exposed independently of the rest of the image. Exposing without the mask, in an attempt to match the highlights, will result in distorting the midtone gain—this is true regardless of whether a positive or a negative system is in use.

If a halftone digital proofing system could accurately predict the hue (ΔE), density, dot size, and visually approximate a flexographic press sheet, then press proofs or off-press analog proofs would not be required–thus saving valuable production time and materials (plates and film).

It should be pointed out that most digital proofing systems are **not** halftone based, but are continuous tone in nature. While these proofs are often pleasant

to the eye, and are valuable to prepress departments, they may not tell the press operator what they need to know. This is especially true in flexography, the highlight areas on the continuous tone proof might only bear a slight resemblance to the highlights on the press sheet. This is a problem because a contract proof; which is legally binding, is supposed to be an accurate representation of what will come off the press.

There are several halftone based digital proofing systems on the market today. Each uses different imaging schemes and color control varies from system to system, but each one promises a dot for dot representation of the printed page. Two systems were studied; in the interest of each of the companies investments – none were identified by either company or by product name (in the results section). They instead were referred to as Digital Proofing System A and B. A brief description of each is used to differentiate between the technologies that drive each system. A third system was to be studied; but the manufacturer dropped out of the project. It was later determined that the 3M Matchprint would be used as a reference and became the third (although not digital) proofing system.

This research investigated the three systems to determine their ability to simulate the reproduction of a flexographic pressrun in terms of halftone dot size, density, hue (ΔE) and in visual appearance. A pressrun was performed on a polypropylene substrate known as Primax, which is manufactured by Fasson. The results of this pressrun were used as the standard press sheet for the digital proofing system to match. None of the proofing systems had the ability to image onto this substrate, they instead imaged onto a substitute substrate.

Endnotes for Chapter One

[1] Bruno, Michael. *Principles of Color Proofing.*
Gama Communications, Salem. 1986. p 1.

[2] Sigg, Franz. Personal interview conducted at RIT on November 20, 1995.

[3] Bruno, Michael. *Principles of Color Proofing.*
Gama Communications, Salem. 1986. p 4.

[4] Ibid. p 159.

Chapter 2

Theoretical Basis

Flexography

Flexography is a direct rotary printing method which uses relief image plates made of a photopolymer or rubber. Unlike hard metal plates; flexo plates are displaceable. Since the process is a direct rotary process; for every revolution of the cylinder an image is produced. Charles Weigand said, "the plates are affixable to plate cylinders of various repeat lengths, inked by a cell-structured ink-metering roll, with or without a reverse-angle doctor blade, and carrying a fast drying fluid ink to plates that print onto virtually any substrate, absorbent or nonabsorbent."[1]

Flexography has the advantage of being able to print on a variety of substrates; from newsprint to plastic based films such as polyethylene. Both spot color and process color are often used by flexographic printers. The process is often used in the packaging portions of the printing industry. In fact, as Richard Neumann pointed out in Flexo & Gravure International; the percentage of package printing done using flexography has increased from 64% to 70% since 1990.[2]

The Flexographic Printing System. The typical flexographic printing system consists of the following: 1) ink fountain, 2) ink-fountain roller, 3) doctor blade (unless the press contains a two-roller system), 4) anilox or ink-metering roller, 5) printing plate cylinder, 6) the desired substrate, and 7) the impression cylinder (see fig. 1)

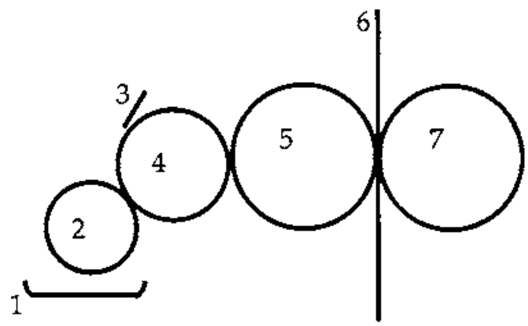

fig. 1 flexographic roller system

The ink-fountain roller takes ink from the ink fountain transferring it to the anilox roller. The anilox roll has cells engraved into it, the size and frequency of these cells meter the amount of ink transferred onto the plate. The doctor blade is used to scrape off any excess ink on the anilox roller to insure that a uniform amount of ink is transferred to the printing plate cylinder. The amount of ink transferred to the plate is directly related to the number and type of cells engraved into the roller. The high frequency cell counts contain many cells, which are smaller in circumference and shallower in depth when compared to courser cell counts. The higher cell counts are generally used for higher frequency halftone line screens.

In a two-roller flexographic system, one without a doctor blade, the ink-fountain roller (2) runs slower than the anilox roller (4); the excess ink is actually squeezed off in the interaction between the two rollers. Regardless as to whether

a doctor blade is used or not; the next action is ink being carried to the plate then to the desired substrate (6), while using the impression roller (7) to support the substrate.

Flexographic Printing Plates. Exposure of plates is a very critical process in flexography (this is true of any printing process), so the exposure process will be examined here. Printing plates for the flexo process are made of either a rubber or a photopolymer substance. "Rubber plates are flexible, resilient and have the printing image in relief."[3] These plates are duplicates made from a matrix, which is from an original pattern plate. The basic procedure for producing rubber plates is as follows: "1) making master pattern metal engravings or hard durometer photopolymer plates by exposure through a photographic negative and processing by acid etching (metals) or solvent wash (photopolymers), 2) making a phenolic matrix mold of the master pattern plate, 3) rubber plate molding from the matrix mold."[4]

A photopolymer is a light sensitive material, that is used in many printing processes for printing plates, films and proofing materials. Photopolymers are available in both liquid form and solid sheets in the needed plate thickness. The procedure for producing photopolymer plates is as follows: "1) back exposure of base to UV light to harden (cure) floor and establish relief depth, 2) face exposure of surface to UV light through the negative to harden (cure) printing images, 3) washout in appropriate solvent to remove unexposed polymer and leave printing images in relief, 4) dry to remove absorbed solvent and restore gauge thickness, 5) post expose to final cure of floor and character shoulders, 6) finish plates with chemicals or UV light to remove residual tackiness."[5]

Flexographic Substrates. One of flexography's greatest advantages is that it can print on many different types of substrates. However, when looking at the two leaders; paper and film-based stocks, it appears that film is becoming more popular. In the July 1995 issue of Flexo, Catherine Heckman cited "requests for film facestock applications have increased more rapidly than those for paper, averaging 15 to 20 percent versus paper growth at 8 to 10 percent, with the largest growth dominated by the health/beauty industry."[6]

Flexographic Inks. As with all printing processes using inks, flexographic inks have three components: 1) the colorant, 2) the vehicle, and 3) additives. The colorant is the portion of the ink from which it gets its color or hue. The material used as the colorant is either a dye or a pigment; the main difference between the two being that dyes are soluble in the vehicle. The vehicle is a nearly colorless fluid that is expected to carry the colorant from the inking system to the substrate. Flexographic inks are fluid inks that dry quickly between printing stations on a multicolor press.

Limitations of the Flexographic Process. The biggest problem in flexography seems to be the high amount of dot gain when compared to other conventional printing processes. This is due to the physical makeup of the printing plate; as stated earlier, the flexographic plate is made of rubber or a photopolymer which can be easily compressed. This compression is caused by the pressure between the plate cylinder and the impression cylinder. The result is that the dots are "squashed" and print larger than the film dots or the dots on the plate when not under printing impression. Highlight areas are most affected by this, as the

halftone dots are the smallest and will distort to a greater extent than the mid-tone and shadow areas when exposed to an equal amount of pressure. A process such as offset lithography does not encounter this as Don Alldian stated, ". . . conversely, the offset plate is hard or rigid and therefore does not experience the same squeezing effect."[7]

This amount of dot gain is, of course, in addition to the normal amounts of optical and mechanical dot gain associated with any printing process. According to Gary Field, mechanical or physical dot gain is "the gain in the dot area" and optical dot gain is "darkening of the white paper around the dot caused by light scatter within the substrate."[8] The darkening that Mr. Field refers to is in regard to lithography. Optical dot gain will occur regardless of substrate type, color or printing process.

Another consideration is image distortion due to plate curvature. All printing plates, regardless of construction will distort the print to some extent when curved around the plate cylinder, however, flexographic plate distortion is more noticeable. In order to remedy this situation the following equation could be used:

$$\frac{\text{factor based on plate thickness}}{\text{printed repeat length}} = \text{percent elongation}$$

The factor for plate thickness differs depending on whether or not the plate was separately mounted to a stickyback or premounted. Stickyback platemounting is done by mounting the printing plate onto an adhesive stickyback which is then attached to the plate cylinder. Premounting the plate or conventional plate mounting is done by attaching the plate directly onto the cylinder. If the plate

was mounted separately, the factor is 3.1416 (π) times twice the plate thickness. If the plate was to premounted the factor would be π times the plate thickness. The actual distortion compensation could be accomplished either photomechanically or electronically (on the desktop).

Trapping is also an issue in flexography. First, a distinction needs to be made between a prepress trap and a press trap. A prepress trap is what used to be more commonly known as "spreading" and "choking". "Trapping is the overlapping of various colors in a design to prevent their separating as a result of registration movement during printing."[9]

A press trap is how well a layer of ink transfers onto a substrate or another layer of ink. The trap that is addressed in this research is the prepress trap. Trapping is more critical in flexo than in lithography. This is because flexo presses generally operate at higher speeds. "The flexo press, therefore, needs to have additional color-to-color tolerances as opposed to the offset press."[10] The accepted trap amount in flexo is 0.031 (1/32) of an inch.

There is also a certain amount of difficulty in holding a vignette in the highlights. In other words the ability to "taper the size of the highlight dots until only the base color of the substrate shows."[11] What this means in the case of a halftone image is that, there will be a "cut off" in the highlights. Since the highlight dots are "squashed" on the plate, they print larger than they are supposed to. The tapering is not as effective as in lithography, in flexography the highlight dots gain to about a 10-14% dot, thus there is not a tapering transition from highlight to the base color of the substrate.

Proofing

What is a Proof?

A proof, in the graphic arts, is essentially a prediction of the appearance of the final printed product. There are several methods of doing this; one way is using a printing press to generate a proof under conditions similar to those that would be used for the final printed product. Another method is offpress proofing, which can be either analog or digital. Analog off-press proofs are film based, while digital proofs do not require film. Whether analog or digital, both utilize toners or dyes to simulate the inks of a given printing process. Yet another method of proofing is called soft proofing, which involves viewing a CRT calibrated for a given set of printing conditions.

A History in Proofing:

Press Proofing. The oldest method of proofing is printing under conditions very close to those of the production pressrun. Although the closest method of predicting the outcome of the press run, this approach is not time or materials effective. In flexography it is used quite frequently, because of the lack of an accurate off-press analog proofing system specifically for flexography.

Analog Off-press Proofing. The first photomechanical off-press proof was produced by the United States Army during World War II. This was an overlay system called Watercote and was often used by map makers to check their line work and color. The Watercote system was created by Direct Reproduction Corporation. As experiments with off-press proofing systems continued, they became more complex; halftones and process colors began to find their way into color proofing. According to Harvey T. Holzapple, "halftone proof[s] in process colors, presenting . . . an exact statement of the original separation negatives that will show exactly what [image] there is on your plates."[12]

The 3M Company introduced the Color Key System in 1960. It utilized dyes to approximate the process color ink set. The Color Key System is still used today, in order to check page layout, color breaks and the densities of colors. It is not, however, used to check for color accuracy.

In 1971, the DuPont Company introduced the Cromalin Proofing System. Prior to this, most customers demanded actual press proofs in order to verify final films. The Cromalin proofing system is a composite or integral proof in which color layers are laminated together to form a single sheet. "Because the Cromalin overcame many problems associated with overlays—such as the grayed whites and tinted highlights that result from light absorption and reflection among multiple layers of polyester film. It was gradually accepted as an alternative to press proofing for many although not all types of work."[13]

These film based proofing systems use light (generally UV) exposures to image onto an image carrier of some description, one for each of the process colors. The integral proofing systems like the Cromalin or the Matchprint are often used as contract proofs in place of a press proof. They are quite accurate in regards to halftone dot size, ink hue and density, as well as visually predicting what a press sheet will look like. Some of these systems proof directly onto the final substrate, while others simulate the final substrate. These systems were created to be used with lithography. Therefore, their inherent characteristics more closely match a lithographic press run. This can pose problems when they are used for flexography.

Today, there are many products that compete in the analog proofing circle—3M Matchprint, Enco Pressmatch, Fuji ColorArt, and Kodak Contract Proof are just a few. The companies that manufacture these proofing systems have developed or are developing digital proofing systems.

Digital Proofing. The **initial** purpose of digital proofing was to emulate the structure of the halftone dot; including adjustable line rulings, dot shapes and rosettes. This was dropped in favor of less costly continuous tone methods, after several companies lost large amounts of money in failed R&D.

During the 1980's, a number of companies were working on a new technology that would eventually lay the foundation for a digital proofing system. In 1987, DuPont and Xerox teamed up to produce the DX (DuPont/Xerox) system. By 1989, both DuPont and Xerox feared that final demand would be too small to

justify the expense of bringing it to the market. "It was felt that if the system were not rapidly perfected, cheaper ones [digital proofs] would arrive and undermine the markets desire for halftone based digital proofs."[14]

Meanwhile, the 3M company worked on a digital proofing technology and dubbed it the Digital Matchprint—which promised to accurately reproduce both color and halftone dots. Other companies have continued to explore the realms of digital proofing including; Kodak, Polaroid and Optronics. "These . . . systems differ in their basic technologies ranging from Kodak Approval's electrophotographic engine [author's note; the Approval actually uses a laser] to Optronics IntelliProofs imagesetting laser; but they are all extremely capable and have price tags that reflect it—$245,000 and up."[15] Only fairly large and successful firms can afford a system like this. In 1994, 3M discontinued the Digital Matchprint product stating that it would be too costly to upgrade the product.

As DuPont and Xerox had feared, other technologies have emerged and lowered the demand for digital halftone dots. Two types of digital proofers that are popular in the market at this time are; inkjet and dye sublimation. They range in price; from inexpensive desktop office printers to high priced proofers, suitable for advertising agencies and design firms.

At the present moment, the market is divided between "dots" and "no dots". A few large printers or shops can afford halftone based systems, and others who use inkjet for monitoring and approval through different stages in the process. The price range for the two markets is as follows: the best halftone proofers are

priced between $245,000 to 350,000, while production grade continuous tone inkjets sell for about $40,000 to 125,000; and dye sublimation printers are priced between $10,000 to 25,000.

Types of Digital Proofers:

According to Dr. Patrick King (VP of Technology at Polaroid Graphics Imaging), digital proofers can be divided into three categories; 1) digital color printer, 2) digital preproofer and 3) digital color proofers or halftone digital proofer. A digital color printer is best suited for an office environment rather than in graphic arts. Xerox, Canon, and Hewlett-Packard are among the companies involved in producing color printers.

> "The four basic technologies at this level of price and quality are ink jet, laser (electrostatic), thermal wax transfer and dye sublimation. These technologies enable the manufacture of low-cost devices in volume.
>
> The performance capabilities and specifications identify these devices as color printers. They can certainly be employed for concept proofing, but one should be realistic and maintain the lowest level of quality expectations."[16]

A digital preproofer is a more expensive version of a color printer. What this means is that the digital preproofer has a higher degree of control over color matching and a more advanced color engine. Preproofers use the same four basic technologies as color printers; thermal wax transfer, laser (electrostatic),

dye sublimation and ink jet. Two popular models of preproofers are the 3M Rainbow and the Iris 3024.

Thermal Wax. Thermal Wax proofers utilize colored ribbons, either CMY or CMYK, to image onto a special substrate. According to Michael Kieran, the ribbon is butted against a drum "which has been divided up into a grid of individually addressable pixels, typically 300 per linear inch. Each pixel for a given color heats up, melting the wax into the paper."[17]

Thermal Wax proofers are fairly inexpensive but are slow in actually outputting a proof. The difference between using three or four ribbons is mainly one of speed, but the CMYK option would be desirable if a large amount of black is to be present in the proof.

Thermal Wax proofers use an imaging technique known as error diffusion or dithering. Conventional halftone dots are not created, therefore attempting to match a halftone screen pattern is not possible. They have the ability to proof on mostly office sized stocks–up to about 11" x 17", but these substrates are made specifically for the proofer.

Laser (Electrostatic). Color Electrostatic devices commonly known as "color copiers", are similar to their black and white counterparts; they both use a photoconductor in the imaging process. "The major difference [between color and B&W] is that four toners are used, one each for cyan, magenta, yellow, and black."[18]

Most of these devices use dithering in order to create the image; however, when certain Raster Image Processors (RIPs) are used in conjunction with the device a simulated halftone pattern can be created. This halftone pattern should not be mistaken as the pattern that will appear on the press sheet. Most "color copiers" can support substrate sizes up to 11" x 17".

Dye Sublimation. A dye sublimation proof is identified by rich vibrant colors that are well suited for comps or scatter proofs. Dye sublimation was the first technology to be adopted by large advertising agencies and design studios. "Dye sublimation works with a special set of dyes carried on a page size ribbon. When warmed by the print head variable-intensity heat source, the dyes turn to gas and evaporate from the ribbon. They then diffuse into a specially coated thermal activated paper (varying in weight from a slightly heavier than fax paper to actual photographic quality paper) and revert to a solid. Different hues are determined by heat intensity; with higher temperatures. . . more dye is applied to the page . . .since up to 256 different temperature levels are available for each color, it's possible to obtain very precise color control."[19]

A dye sublimation proofing system lays down a grid of pixels at a relatively low resolution (150 to 300 dpi) but appears as a continuous tone image. Dye sublimation proofing systems are convenient and flexible because they are able to read, RIP, and process directly from the designer's disk. They are also able to proof on many sizes of paper from 8" x 10" to 11" x 17". Most dye sublimation proofers are PostScript based devices. Color images appear relatively sharp, while line art and type often seem fuzzy or soft (low resolution). The output

quality from these systems is better than the quality of a color copier (laser or electrostatic device) or a low-end inkjet proofer. ". . . before absolute color accuracy is critical, they [dye sub] give a good feeling for how a design is progressing, and they do so cost effectively."[20] A serious drawback to these systems is the high cost of consumables due to the need for a specific type of paper.

Inkjet Proofers. Inkjet proofers "range from inexpensive desktop units to those used in final stages of proofing by printers, tradeshops, publishers and service bureaus."[21] Inkjet digital proofers are considered the middle ground of the realm of digital proofing. An image that is produced by a production level model resembles a photograph in its sharpness, clarity of color and subtlety of tone. An inkjet proofer produces variable size dots that are too small to be seen individually—apparent resolution is higher than actual resolution. For example; 300 dots per inch would appear as 1200 to 1800 dots per inch.

"Inkjet images are created with microscopic droplets of ink—cyan, magenta, yellow, and black—that are sprayed from ultra fine nozzles to form dots of color on the page."[22] These dots do not form conventional halftone dots, therefore these devices cannot predict dot behavior such as dot gain. Inkjet proofers use water-based dyes and most substrates of film or paper capable of absorbing water based inks can be used.

These proofing systems *do not* attempt to reproduce halftone dots or predict moiré. Detail and color is quite consistent using inkjet systems. These proofs are often used for contract proofs because of the high rate of reliability and repeata-

bility. Although the initial cost for an inkjet proofing system is quite high, the operational and maintenance costs are fairly inexpensive—but require frequent cleaning and calibration procedures.

A digital color proofer or direct digital color proofer, or more specifically a halftone based digital color proofer, images halftone dots onto a substrate in order to match the dot gain of a specified printing condition. These systems have differing amounts of color control.

Digital Halftone Proofers. The current highend digital proofers are the halftone based systems. These halftone proofers according to Mac Byrd, "present an accurate representation of what the press sheet will look like, since they show actual halftone dots printed in SWOP dye. They're also more consistent . . . ."[23] They simulate the halftone structure at extremely high resolutions (up to 2400 dpi) and fine screen rulings (up to 200 lpi). They also control screen angles and dot gain, show certain types of moire', and calibrate output to reflect many types of paper characteristics and printing conditions. They can also be linearized and calibrated for a specific device profile or "fingerprint" of a particular printing press.

There are a variety of digital halftone proofing devices on the market and they do not share a common technology base. Some use lasers to image the device specific films or papers. Others use lasers with toners to proof on various common types of substrates, and still others have replaced ink and toner with a dry process laser imaging process that employs a thin film for transferring colors from donor sheets to receiver sheets, one for each color.

Advantages of Digital Proofing:

Analog proofing from the actual films used for platemaking is a good proofing method for evaluating the colors of the images and the quality and accuracy of the separation films. However, it is very time consuming, labor-intensive and consumes costly materials. It is also prone to errors inherent to its nature; such as fluctuations in the exposure, the chemistry and development time, the register of the separation films, and a variety of operator errors. By reducing some of the variables of the analog process, digital proofing is considered more consistent and repeatable from proof to proof. Because of its consistent nature, users of digital proofing methods are able to gain experience and a more reliable understanding of the relationship between proof and press.

"Because so many print jobs now remain filmless until platemaking . . . digital proofing seems an obvious and even necessary component of today's overall creative/productive process. This is especially true when a job involves several rounds of proofing."[24]

With full-scale computer electronic prepress systems (CEPS), a digital proofer can translate RGB files to CMYK, simulate SWOP standards, incorporate custom color setups, and manipulate image data to accommodate paper characteristics, ink types, and specific press conditions. This also allows the user to create proofs that can predict a variety of conditions apart from the data used to produce the separation films, such as different press configurations, different paper types, etc.

Another advantage of digital proofing is the time saved in sending jobs from customer to printer, when the files are digital. The process of making an analog proof is very lengthy, considering the time to RIP, imageset, and process the film, then to hand register and expose each separation film. It is now faster and easier to find problems with image quality and placement and color trapping with digital proofing. A customer can look at numerous rounds of proofs before the final sign-off and before committing the page to film. This can greatly alleviate the bottleneck at the RIP and imagesetter, as well as reduce the film costs.

With the sizes available for digital proofers, the customer is able to review complete pages with type and color images in place, instead of random proofs of each image separately. Even the smaller size proofing systems can accommodate 2 to 4 page spreads that can be evaluated as contract proofs and full-sized rough proofs that can be used to check imposition, general cleanliness and color bar positioning. Once again, the ability to check a full page or imposition for errors will reduce the waste of time and materials associated with errors found in traditional analog methods.

Dots or No Dots?

The largest issue in the debate over the quality of analog versus digital, is whether halftone dots are necessary in a proof. Traditionally, analog proofs have had halftone dots similar to those found on the press sheet. Many people believe that for a digital proof to be used as a contract proof; it must also have halftone dots similar to those on the press sheet. Others believe that if a continuous tone digital proofing system can visually match the press sheet; that would

be acceptable as a contract proof. The focus of this research was on halftone based digital proofing systems; originally the author felt that they were superior to the continuous tone systems. Based on the conclusions shown in later chapters; this belief has been questioned.

Concerning newer technologies like frequency modulated screening (FM), matching conventional halftone patterns is no longer necessary, but matching the FM dots would be nice. The FM screen has a larger amount of dot gain; but, the analog proofing materials (laminates, toners, inks, etc.) were developed for the tone reproduction characteristics of conventional halftone screens. The small size of the FM dot and the greater number of dots pose problems for analog proofing systems. To make an analog proof of a FM screened image, 2 sets of films are made—one to proof and one to print—and relating the proof to the print takes considerable time, effort and experience. With digital data, the proofer can manipulate the stochastic screen information to proof with the same tone reproduction and dot gain characteristics as the press itself.

Limitations of Digital Proofing:

"Digital proofing is somewhat of a problem for us at the moment because there is really no product on the market that does what we need it to do."[25] We want all the attributes of an analog proof in half the time and at half the cost. The problem is that a (generally non-halftone based) digital proof is created directly from the electronic file and only provides an estimate of the information and the quality of the film. The proof will not show a variety of problems; such as, prob-

lems with the imagesetter, out of register films, variances in dot densities from the imaging or processing system, variances in film emulsion, dirt and scratches on the final films, color shifts or moiré patterns caused by using different RIP's for generating films or proofs, incorrect line screening, and any operator errors.

Another concern with digital proofing is that the "connection between the proof and the film is broken."[26] Files can be changed purposely (or accidentally), after the final proof has been checked and before the films are made, creating a problem when the error is detected on press. This can be alleviated by repeated proofing, proper traffic control of the files and adequate quality management of the final films.

Digital proofing, like all new technologies, struggles with gaining respect and acceptance—not because it is inferior, but rather it is very difficult to change the mindset of the industry. Press operators, customers and art directors have experience reading analog proofs and analyzing the translation of type, color, and imagery to the press. It took time for people to learn to read all of the variations that can be present within a given analog proofing system and when this new technology was introduced it was not understood and considered problematic. As with the introduction of analog systems, digital systems will take some time to become mainstreamed. In fact, a digital proof is better suited to preview a final image because the electronic data can be manipulated to actually "fingerprint" the characteristics of the press. This offers the consumer a more accurate resemblance of the final printed piece. It will simply take time to become more accepted in the industry.

The Future of Digital Proofing:

The future of digital proofing is based on the need for cultural change in the industry and for manufacturer cooperation to establish standards to better facilitate the technology that already exists. "If presses can be calibrated to an agreed upon standard . . . then color management software could [theoretically] be used to match the final press output"[27] In a fully calibrated system, the color on the designer's screen should match the final press output. All printouts, pre-proof and proof would also match and technical problems like incorrect traps or overprints could be marked by the software. In this scenario, jobs could stay digital all the way to plate or paper. There would no longer be a need for film or film proofs. "In a film free world, a similar proofing arrangement may be offered for platemakers, where the same machine will create both plates and proofs . . . platemaker vendors already note their machines can be used to generate film to make a traditional proof." [28]

Halftone Proofing Systems

The purpose of this document is to test the ability of halftone digital proofers to represent a flexographic press sheet. Therefore, the remainder of this document will concern itself with information pertinent to the actual execution of the experiment. Short discussions on each of the three proofing systems are presented below. The chapter following this will deal with work in the field, this is where procedures for proofing for flexography will be examined.

The Optronics IntelliProof. The IntelliProof is a device that is capable of producing both film and proofs. The IntelliProof is a digital proofing system that resides within the vendors imagesetter, which is an external drum color laser imagesetter.

According to the vendor, "The IntelliProof also increases the level of certainty in digital proofing. Unlike some digital proofing devices which simulate halftone dots, the IntelliProof employs the same screening algorithms to produce the dot as the ColorSetter (imagesetter) uses to produce film. As such, the IntelliProof matches the actual dot rather than emulating it, producing a proof in which prepress professionals can have confidence."[29]

The IntelliProof is the first Direct Color Proofing system that utilizes the same color laser imagesetter in the production of both separation film and large-format, full-color proofs with laser generated halftone dots. "By taking advantage of the same laser imaging, raster image processor, 2000 or 4000 dpi resolution, and halftone screening technologies used by the ColorSetter to image film separations, the IntelliProof system presently provides the only all digital means available to closely predict how a PostScript job will be printed on a four-color press."[30]

Red and green helium neon lasers were added to the standard blue argon ion used in the ColorSetter. The green helium neon laser is formed by modulating the signal of the normal red helium neon. The argon ion laser is used to image the film, while all three are used to image the digital proof. The RGB lasers pro-

duce cyan, magenta, and yellow halftone dots respectively. The black halftone dots are produced by all three lasers acting together.

Konica, a leading manufacturer of photographic supplies has produced a photosensitive paper that approximates a coated sheet. According to a Product Manager at Optronics, they did not initially intend on using the IntelliProof as a device for producing contract proofs. However, many of their customers have been successful in utilizing the proofs as contract proofs for their customers. This success has been partly attributed to the good design of the photopaper.

Proofs can be output automatically to a special light tight cassette or directly to a user supplied or optional in-line processor. "A variety of color controls, are also supported to ensure color consistency from proof to finished product, including references to SWOP/GAA standards, as well as adjustable dot gain controls to ensure that the halftone dots in the proof are substantially the same size as the halftone dots created by the printing process."[31] Look up tables (LUTs) are used to interpolate the look of many widely used and accepted conventional (analog proofing systems).

The Kodak Approval. The Kodak Approval is a device that outputs screened halftone proofs imaged directly onto the substrate that would be used for the press run. This substrate, at this point in time, is restricted to paper that is between 30#–110# stock and between .0025" and .006" in thickness.

The system also allows for control of dot gain from 3%–97% in 1% increments, specification of screen rulings, setting screen angles for each color, the option to

choose from five different screen shapes, and control of solid density of the colorant; all in an effort to attempt to match a set of printing conditions.

According to the vendor, "CMYK donor materials are brought into contact with the intermediate receiver and are digitally exposed by a thermal laser."[32] Color dyes are then transferred to the intermediate as halftone dots or line work. The intermediate is loaded onto the drum and does not change position for the entire proofing process.

"The thermal laser transfers color dyes from each donor to the receiver in the exact amounts needed to reproduce pixels at 1800 dpi."[33] The donor materials utilized by the Kodak Approval are advertised as being closely matched to SWOP or ISO colorants.

In early 1996, Kodak announced the Approval PS which is PostScript driven rather than Dolev driven as it has been in the past. This eliminates the need for a Scitex system and brings the Approval into the desktop environment. The PS version was the version used for this research project.

The Polaroid Dry Tech. The Polaroid Dry Tech is unique among the three systems researched in that it uses dried printing inks as its colorant. The printing inks are then transferred utilizing a laser to the substrate. The proofing substrate is the generally the same as the final printing substrate—this should also include the use of non-paper based substrates often seen in flexography.

The system also includes the option of custom colors; which would help out greatly when attempting to match spot colors on packaging. Since not all of the other proofers have the ability to use custom colors (most digital proofing systems use CMY or CMYK colorants) this point will not be addressed in the research and pressrun.

Digital proofing is a link for direct-to-plate and direct-to-print technology, this is especially true in the case of the IntelliProof. If the vendors platesetter was equipped with the IntelliProof—it would end the need for film; and the same imagesetter would be used, using the same files, using the same RIP to image both the color proof and the printing plate.

Film has already been eliminated in the gravure printing process and similar technology can be used to eliminate the need for film in other processes. In this environment, digital proofing will be the only practical alternative to press proofing because there would be no sense in taking an electronic file, making analog films for proofing and returning to electronic data for printing. Digital technology is also much more compatible with new screening technologies and it is easier to manipulate digital data to emulate other "untraditional" prepress and printing conditions.

Finally, it seems the standards of the graphic arts industry are changing. Quality color reproduction and printing was once much less accessible by the common market. With technology becoming more "user friendly" and the reduction in costs of supplies, customers tend to prefer speed and economy over perfection.

"All jobs are not equal in importance and therefore, all do not require the same level of monitoring and preview prior to printing . . . as confidence builds in our collective ability to "read" digital proofs, customers will be increasingly willing to accept them, as contract proofs."[34]

Endnotes for Chapter 2

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[2] Neumann, Richard. "Flexography–the Print Process of the Future for the Packaging Industry". *Flexo & Gravure International.* January 1995. p 7.

[3] Siconofli, Frank. *Flexography: Practices and Principles.* Foundation of Flexographic Technical Association, Ronkonkoma. 1991. p 104.

[4] Ibid. p 104.

[5] Ibid. p 104-105.

[6] Heckman, Catherine. "Film Facestock Update" *Flexo,* July 1995. p 24.

[7] Alldian, Don. "Offset to Flexo" Flexo, March 1995. p 164.

[8] Field, Gary. *Color and Its Reproduction.* Graphic Arts Technical Foundation, Pittsburgh. 1992. p 338.

[9] Alldian, Don. "Offset to Flexo" Flexo, March 1995. p 167.

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[11] Siconofli, Frank. *Flexography: Practices and Principles.* Foundation of Flexographic Technical Association, Ronkonkoma. 1991. p 418.

[12] Hogg, Charles. "Direct Digital Color Proofing"
Electronic Prepress Section of PIA., Alexandria, VA. 1994. p 8.

[13] Ibid. p 9.

[14] Ibid. p 10.

[15] Ibid. p 10.

[16] King, Patrick. "Proofing Technologies for Flexography"
Flexo, March 1995. p 146.

[17] Kieran, Michael. *Understanding Desktop Color.*
Peachpit Press, Berkeley. 1994. p 447.

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[22] Hogg, Charles. "Direct Digital Color Proofing"
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[23] Byrd, Mac. "Direct Digital Proofing"
Pre—, May/June, 1994. p 46.

[24] Hogg, Charles. "Direct Digital Color Proofing"
Electronic Prepress Section of PIA., Alexandria, VA. 1994. p 11.

[25] Hogers, Hans. "The Digital Proof"
Canadian Printer. April 1994. p 18.

[26] Hogg, Charles. "Direct Digital Color Proofing"
Electronic Prepress Section of PIA., Alexandria, VA. 1994. p 15.

[27] Hogers, Hans. "The Digital Proof"
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[28] Ibid. p 25.

[29] Optronics Product Literature. "Intelliproof"
Optronics: An Intergraph Division. 1994.

[30] Ibid. 1994.

[31] Ibid. 1994.

[32] Kodak Product Literature. "Approval"
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[33] Ibid. 1993.

[34] Hogg, Charles. "Direct Digital Color Proofing"
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Chapter 3

A Review of the Literature

Flexography: Principles and Practices

The book, Flexography: Principles and Practices, is full of information concerning every facet of the flexographic process, from art generation to ink formulations, press specifications to converting information for packaging. The book refers to both press and off-press proofing methods in some detail, off-press proofing is what is of concern at this point. Below is a quote concerning proofing, in general, for the flexographic process.

> "Traditional problems in proofing for flexography haven't been in editorial or graphics content but in image quality. This is especially true in proofing process color. The objective here is to have a proof that visually matches printing from the production press. Proofing image quality requires simulating [press] image quality. To obtain a visual match of a proof to production press requires matching the variables that affect color reproduction. All these variables can be classified under three headings: hue, density and dot size. If we can match these variables in the proof to the production press, we can obtain a visual match to the production press."[1]

The book next discusses the problems with off-press proofing methods; citing the biggest drawback as, "they [off-press proofing systems] are meant to simu-

late offset printing."[2] This means that even if there is a hue and density match to flexography, a conventional off-press proofing system will not be able to mimic the dot gain of flexography–at least not without altering the proofing operation. Although there are ways of dealing with this; such as giving different exposures using masks or by changing the dot sizes in Photoshop, this is time consuming and wasteful. Creating a photographic mask in order to expose areas selectively is no small task. Altering the dot sizes in Photoshop using the transfer curve function is easy enough, but requires that two sets of films be output. Changing the dot sizes in Photoshop, is similar to what digital proofing devices allow the user to do to match a given set of printing conditions–but digital proofing does not require an extra set of films.

Understanding Desktop Color

This is an excellent reference for anyone interested in digital prepress; it covers the entire spectrum of electronic imaging devices used in the graphic arts today. The author Michael Kieran covers quite a bit information concerning digital proofing.

Mr. Kieran identifies halftone based digital proofers as electrophotographic printers, and says of them, ". . . their output consists of halftone dots exactly like those on the printed sheet. In this respect they are closer than any digital printer to traditional film proofs."[3] He then goes on to mention that a big payoff is that these devices can output a proof in 20 minutes.

Digital Proofs. Kieran goes on to state that digital proofs are both a "challenge" and an "opportunity".

> "The challenge is in learning to interpret them properly, especially with cheap pre-proofs from thermal wax printers or intermediate proofs produced on dye sublimation printers, rather than with contract digital proofs created on more expensive ink jet or electrophotographic printers.
>
> The opportunity comes from the fact that digital proofs allow you to create working composites, or comps, prior to plotting film, which results in significant savings, especially if you end up making changes to the job prior to going to press. After all, if reviewing a film proof leads you to decide to make changes, you end up throwing away both the proof and four pieces of film. With digital proofing, you still toss away the proof, but no film is produced until you're confident (based on the digital proof) that everything looks right."[4]

Limitations of digital proofs. Kieran lists some "potential pitfalls" of digital proofing, the one most important for halftone based digital proofing systems is where and how the files are ripped. He states, ". . . because the raster image processor used to create the film is usually different than that used to create the proof, the screen angles, screen frequencies, and dot shape can vary between film and proof. . ."[5] Kieran goes on to say that this could result in undesirable effects such as undetected moire patterns and color shifts.

Where's the dot? The last portion of Kieran's discussion on digital proofing is concerned with whether or not halftone dots are necessary in a contract proof. His decision is that halftone dots **are** necessary. Kieran states that most digital proofing systems do not contain halftone dots and that this is not desirable from

a commercial printer's standpoint. "The results [from a non-halftone proofer] may look good, but are of little use to the press operator, who makes assessments of quality not on subjective grounds but on how closely the halftone dots on the press sheet match those on the proof."[6]

Electronic Proofing Technologies for Flexography

This is an article written by Dr. Patrick King, that appeared in the March 1995 issue of Flexo magazine. Dr. King begins by quoting British philosopher John Michael Osbourne's piece, *The Road to Nowhere*, as an example of a prevalent feeling many people have regarding digital proofing.

Dr. King states that analog or exposure film-based proofing systems compete for the marketshare by claiming to effectively mimic the press sheets of a printing process. He then flatly states that, "the fact is they can never precisely simulate a press sheet, particularly for all flexographic needs."[7]

On the subject of digital proofing, Dr. King feels that the initial expectation of a digital proofing system is that it would offer the same type of control over the image as imagesetters do. "This is a natural assumption, since they are often driven off the same terminal as an imagesetter. Theoretically, this assumption is correct, but in reality most DDCP [direct-digital color proofing] systems limit the operators ability to replicate the press sheet precisely."[8] This is a blanket statement, obviously the halftone based systems allow for more control than lower cost inkjet or dye sublimation color printers do.

On the topic of halftone dots, Dr. King has this to say about non-halftone based proofing systems:

> "Most dye sublimation systems do not create dots but rather color using dyes imaged at various densities. Ink jet and laser-based proofing systems generally create spots (typically 300 dpi) whose shapes do not even closely match the dots on a press sheet. Thermal wax transfer systems form images using extremely course, fuzzy addresses of color that should not even be construed as dots . . . the vast majority of DDCP systems do not possess sufficient control over the tone reproduction curve to be accurately fingerprinted to an offset press, let alone a flexo press."[9]

The Ideal DDCP. Dr. King explains that he feels that there are certain functions that the ideal digital proofing system should have: an open architecture system; sufficient tone curve control to mimic a printing system (this includes midtone control to simulate dot gain for lithography or highlight control to simulate dot gain in flexography); it should produce dots of many screen rulings, shapes, or type (AM or FM). "There should be no compromise."[10]

Control of the colorant density is also important because different processes will have differing amounts of solid density, even presses within the same printing process are subject to slightly different solid ink densities. Also, control of the actual color data (CIE Lab) is desirable because a magenta ink in flexography will not be identical to a magenta ink for lithography.

Offset to Flexo

This is an article written by Don Alldian that appeared in the March 1995 issue of Flexo magazine. Mr. Alldian discusses some items that need to be addressed when making color separations for flexography; some of which are also pertinent to proofing for flexography.

Much of what is mentioned in this article was addressed in chapter two of this document, but some of the information will be restated in a different form here. Mr. Alldian states that, flexography has a high degree of dot gain in the highlights. This is due to the softness of the plate, which is squeezed against the substrate causing the small highlight dots to appear much larger on the substrate than on the film.

Image trapping is also a concern because of the high speeds of the flexo presses. Flexo presses, therefore, require a greater degree of color-to-color tolerances. Both dot gain and image trapping need to be addressed in the proofing process. If they do not show the appropriate level of dot gain or trapping amount, then they are not the best choice for proofing for flexography.

Changing Paradigm

This is an article by Marlin Meitzen which appeared in the December 1995 issue of Flexo. The article covers how the change over from traditional prepress procedures has influenced the flexographic portion of the graphic arts industry.

Mr. Meitzen states that, "digital proofing has the unique ability to match almost any press condition including flexo."[11] He goes on to say that traditional analog proofing methods were engineered as predictors for lithography, but were not very effective for flexography.

Meitzen also states that one problem is in matching "special colors". These special colors are known as spot colors; they are a premixed ink color made from a recipe. Spot colors are often used in packaging and most corporate logos contain some spot color. The problem with proofing spot colors digitally is that digital proofing systems generally reside within the CMYK color space. This means that the spot color will be represented by a CMYK mixture.

Digital Color Proofing for Flexography

This is a two-part article written by Mark Samworth which appeared in the July & August 1995 issues of Flexo magazine. It covers a great deal of material, some of which conflicts with the original focus of this thesis research. For example, when discussing halftone dots, Mr. Samworth states that these dot based proofing systems have had little success in predicting a flexographic press sheet. Rather, he says that continuous tone inkjet has had the most success in matching flexo, but only when using FM screened images.

Mr. Samworth, when speaking of digital proofing for flexography versus analog off-press proofing methods, does state that:

"Digital proofing on the other hand, has no inherent characteristic. It does not inherently match offset any more than flexo, gravure, or letterpress. In digital proofing, colors are numbers. Color matching is a matter of manipulating numbers. The ability to match flexo is a matter of how accurately the numbers can be manipulated in comparison to flexo printing characteristics." [12]

Endnotes for Chapter 3

[1] Siconofli, Frank. *Flexography: Practices and Principles.* Foundation of Flexographic Technical Association, Ronkonkoma. 1991. p 427.

[2] Ibid. p 427.

[3] Kieran, Michael. *Understanding Desktop Color.* Peachpit Press, Berkeley. 1994. p 461.

[4] Ibid. p 468.

[5] Ibid. p 469.

[6] Ibid. p 470.

[7] King, Patrick. "Proofing Technologies for Flexography" *Flexo,* March 1995. p 146.

[8] Ibid. p 149.

[9] Ibid. p 149.

[10] Ibid. p 150.

[11] Meitzen, Marlin. "Changing Paradigm" *Flexo,* December 1995. p 41.

[12] Samworth, Mark. "Digital Color Proofing Flexography" *Flexo,* July 1995. p 16.

Chapter 4

Hypothesis

The purpose of this experiment was to observe whether or not halftone based digital proofing systems can accurately represent the appearance of a flexographic press sheet. In order to accurately represent a press sheet, the device must be able to mimic the hue (ΔE) of the printing inks, the optical densities of the inks, the halftone dot size of that printing condition, and visually approximate the appearance of it.

This is a relevant subject to study because up to now, there has not been a proofing system that has been able to successfully compensate for the high amount of dot gain present in the highlight portion of the tone scale in the flexographic printing process, while simulating midtone dot gain, in a timely fashion.

The digital devices that were used for this research were both halftone proofing systems. They are not mentioned by name in the results section; they are identified as digital proofing system A and B. Originally there was to be a third system; the Polaroid Dry Tech, however, the system was still in development when this project became a reality. Therefore, in February of 1996 Polaroid withdrew it's involvement with this project.

Research Question

Will the digital halftone color proofing devices to be tested have the ability to significantly predict the appearance of a flexographic press sheet in terms of ink hue (ΔE), optical ink density, halftone dot size and subjective impression of visual appearance?

The hue (ΔE), density, and dot size are quantifiable; they were measured and analyzed quantitatively. Visual appearance is based on the human visual system of an individual, this is not easily quantified. A panel of judges was used to determine how closely the digital proof matched the press sheet. In order to help establish whether or not the proofing devices were able to predict the flexographic press sheet; a 3M Matchprint (altered for flexography) was used as a third proofing technique. The rational here is that; if one or both of the digital proofs match the press sheet as closely or closer than the Matchprint then they are able to successfully predict flexography. The 3M Matchprint is a standard type of contract proofing system used in the graphic arts, hence its use as a control or standard in this research project.

Null hypothesis and alternative hypotheses

H_{01}: There is no significant difference in hue (ΔE), optical ink density and halftone dot size, when comparing digital halftone color proofs against flexographic printing.

H_{11}: There is a significant difference in hue (ΔE), optical ink density and halftone dot size, when comparing digital halftone color proofs with flexographic printing.

H_{02}: There is no significant difference when determining a closest visual match between the digital halftone color proofs and a 3M Matchprint to the flexographic press sheet.

H_{12}: There is a significant difference when determining a closest visual match between the digital halftone color proofs and a 3M Matchprint to the flexographic press sheet.

Limitations

I. A major limitation of this research is related to how well the digital proofs match each other. Since they utilize different imaging technologies it is expected that they will not be identical. The major thrust of this study is to determine if any of these systems produce a proof that matches the press sheet or at least as good a visual match as the Matchprint.

II. It was assumed that once the press was under control it remained under control for the duration of the press run.

III. It was assumed that the vendors did everything in their power to ensure that their systems were properly calibrated when generating proofs from the electronic data and that they attempted a close match to the press sheet.

Delimitations

This study only utilized the Flexographic printing process, the images were printed on polypropylene (Primax), using one ink set (Environmental), one press (Mark Andy 4120), and one type of printing plate (WR Grace Epic). The repeatability of the proofing systems was only to be tested if *all* the vendors were willing to output several proofs over a period of time (they were not willing). Only the process colors of cyan, magenta, yellow, and black were used. Even though "special" colors or spot colors are very popular in flexography; most digital proofing systems use CMYK colorants, making it more difficult to simulate spot colors.

Chapter 5

Methodology

This experiment was accomplished by;

1. Insuring that the printing system was under control. To make any kind of comparison between a flexographic halftone color proof and a flexographic press sheet, the press must be tested or finger printed to determine the characteristics required to produce a high quality color image. This test determined the tone reproduction requirements of the printing system.[1] This test also attempted to match the press sheet to a SWOP proof made with the 3M Matchprint 3 proofing system. In this way; the Matchprint was used as a reference to what the printed sheet strived (but failed) to mimic.

Utilizing prescanned images from the ISO package along with the targets contained therein, a test page based on the FTA/RIT test page was generated. The page included; 3 four-color halftone images, type at various point sizes, a trapping target to test the image trapping ability of the proofing system, a neutral density target, and a dot gain target. The type, dot gain, and image trapping targets were generated by the author using Adobe Illustrator, Photoshop, and QuarkXpress. To monitor gray balance; the GATF Gray Balance Target was used.

However, because the images were preseparated, the gray balance target was used as a reference rather than to determine the gray balance. Generally gray balance or neutrality is achieved by equal amounts of magenta and yellow with a slightly higher amount of cyan. In flexography a generic set of neutral shadow numbers might appear as 85% yellow, 85% magenta, and 95% cyan. These numbers would create a neutral tone for a certain set of printing conditions. It should be pointed out that, gray balance changes as the variables of press, ink set, and substrate change.

As a pretest to the actual pressrun, the test page was run to determine the minimum and maximum dot requirement, solid ink density, and amount of dot gain on the press. An evaluation of the press test results determined the characteristics required in the color images to be used for the next step of this research.

2. Electronic files were output from the Agfa SelectSet 5000 at RIT's Electronic Prepress and Publishing Laboratory.

3. Flexographic printing plates were made at RIT and the pressrun was performed on the Mark Andy 4120 Label press. This trial run determined the necessary tone reproduction and dot gain adjustments for the final press run, in order to match a SWOP proof as accurately as possible.

Based on the information from the pretest; the images were altered to compensate for the variables in the printing system. This was done by using the Jones Diagram and the Transfer function in Photoshop (please see appendix A for a

detailed description of this procedure). The altered electronic files were then output at RIT.

4. A second set of flexographic printing plates were made at RIT and the second press run was completed.

5. Sample press sheets were distributed to all vendors. They each attempted to match the press sheet as closely as possible. Also, whatever information about the process that was needed to properly match the proof to the press sheet was specified by the vendor.

6. After all materials were returned to RIT, the author attempted to create a 3M Matchprint Proof that more closely resembled flexography than the Matchprint for the press calibration portion of this research. To do this an extra set of films (altered for flexography) needed to be output. Next, the proofs were measured against the press sheet in regards to hue, optical density, halftone dot size, and visual likeness. The hue difference was measured in ΔE difference; with a ΔE of between 4-6 being considered acceptable. The hue difference was measured with a spectrophotometer. Density was measured with a densitometer to discern if there was a statistically significant difference between press sheet and proof.

Halftone dot size was measured by taking photomicrographs of the highlight, quarter-tone, mid-tone, three-quarter tone, and shadow regions of the proofs and corresponding press sheet. The dots were physically measured to observe how closely they match in size; proof versus press sheet. They were measured

using Werner Fei's scanning software at the Center for Imaging Science at RIT. The visual test was viewed by a mixed population of RIT judges, including but not limited to; printing and photography students, faculty and staff, and T&E Center staff.

Before the visual test was given, all participants had to first pass the AO HRR Pseudoisochromatic Plates color blindness test. Out of 31 participants, 1 was slightly color deficient, because it was only a minor deficiency all respondents are included in this study. The visual test was arranged in such a way that the observers viewed the proof and corresponding press sheet from a distance of 24". The observers were permitted to touch both proof or press sheet, but they were not allowed to pick them up off the viewing booth table. They were shown all four (two digital proofs, one analog proof and one press sheet) simultaneously.

The following written instructions were then given to each judge: "First, visually examine the flexographic press sheet, then visually examine the three (3) proofs. Please rate the proofs, from best to worst, in terms of how well they approximate the press sheet visually. Please be sure to rate the proofs in order of how well they match the press sheet and <u>not</u> in order of the most pleasing to the eye. Please disregard press problems; ie, out of register, as this was unavoidable during the press run.

The proofs are listed as A, B, and C; please rate them from 1-3 with 1 being best match to the press sheet and 3 being the worst match to the press sheet. Each

number can only be used once, for example if B is rated as 1 and A is rated as 3, then C has to rated as 2."

The viewing was done using a graphic arts viewing booth under the standard lighting condition of 5000° Kelvin, the same booth was used for the entire experiment.

It should be noted that the visual test was the final decision maker, even if one proofing system matched all the numbers closest to the press sheet–a different proof may have been picked as more closely matching the press sheet visually.

The statistical analysis was performed using an extension of t tests of hypothesis for the mean, known as ANOVA or Analysis of Variance. "The method permits us in a single test and with a single risk to answer questions of this kind: Do the data indicate that the members of a set of hypothesized population means differ among themselves? Are these differences significantly different from a chance result?"[2]

The actual test used for optical density and dot size was a two-factor ANOVA, this presents the possibility that "either or both of two main factors contribute to the differences in the data."[3] This is a four level test, one each for the proof types and one for the print.

The effect of the main factor "proofs/print" was shown by differences of row totals; the effect of the main factor "color" was shown by differences among col-

umn totals. There is only a single observation for each combination of the two factors "proofs/print" and "color". The data was collected without replication. Therefore, experimental error cannot be found directly based on the difference between replicates at the same combination of factor levels. Instead a sum of squares, a sum of squares for rows, a sum of squares for columns and a remainder from the total was found. "This remainder, called a residual, we will attribute to chance causes, and we will use this as a substitute for the error term."[4] The mathematical model for this experiment is as follows: $X_{pc} = \mu + R_p + C_c + e_{pc}$. Each observation X_{pc} is assumed to be determined by four possible effects; the general mean μ of the data, a possible row effect (proofs/print), a possible column effect (color) and error. The matrix that was used for the optical density and dot size tests is shown below.

	color				
proof/print	Cyan	Magenta	Yellow	Black	Tp
A					
B					
C					
Print					
Tc					

For the visual analysis, a single-factor ANOVA was used to determine if there was a statistical difference in how the judges rated the proof to the press sheet. The mathematical model for this experiment is as follows: $X_{jp} = \mu + C_p + e_{jp}$. The statement is interpretated in this way: Each piece of data (X_{jp} value) in the array is what it is because of three components: the general level of the data μ ; a possible effect associated with different levels of the factor contained within the

columns C, and the effect of error e. The matrix that was used for the visual analysis is shown below.

		A	B	C	proof
judges	1				
	2				
	...	...	...	...	
	31				
T					

Equipment Used

Macintosh Power PC 6100, 7100, & 8100

Photoshop 2.5 and 3.0

QuarkXPress 3.1

Illustrator 5.5

Microsoft Excel 5.0

ISO SCID images/targets

Agfa SelectSet 5000

W.R. Grace & Co. Flex-Light EPIC printing plates

Mark Andy 4120 flexographic label press

Fasson Primax - polypropylene substrate

Environmental Water-based inks

Digital Proofing Systems:

Kodak Approval

Optronics IntelliProof

X-Rite 918 Spectrophotometer-2° Observer using a D50 lightsource

X-Rite 418 Densitometer-" "

Microdensitometer-Imaging Lab Werner Fei Associates

3M Matchprint (Imation) III Color Proofing System

Endnotes for Chapter 5

[1] Noga, Joseph. Personal interview conducted at RIT on December 14, 1995.

[2] Rickmers, Albert D. *Statistics: An Introduction.* McGraw-Hill, New York. 1967. p 154.

[3] Ibid. p 167.

[4] Ibid. p 167.

Chapter 6

Results

The original scope of this project was to test three digital halftone proofing systems abilities to match a flexographic press sheet. One of the three vendors who was to supply a digital proof dropped out of the project. It was then decided to continue with just two proofing systems. Upon further discussions with Chester Daniels it was decided that it might be beneficial to add another type of proofing system to the study. Originally, the interest was in how closely the halftone digital proofs matched a flexographic press sheet. This, in retrospect appears to be a naive concept, in that the halftone digital proofs need only to be as successful as a standardized method of proofing for flexography.

Enter the 3M Matchprint, which is almost universally accepted as a form of contract proofing for most printing applications, including flexography. Therefore, the Matchprint was substituted as a third proofing system for study with the added feature of allowing the original mathematical models proposed for statistical analysis to be applied.

In order for the Matchprint to match the flexographic press sheet; it (the Matchprint) needed to be adjusted. In order to do this a seperate set of films was generated that matched the tone reproduction/dot gain traits of flexogra-

phy. This is not a new concept, separations are often altered to fit the needs of a particular printing system. Mark Samworth, of DuPont Printing and Publishing, has been experimenting with both analog and digital proofing methods for flexography for many years.

Halftone Dot Size

The photomicrographs represent the physical size of the halftone dots, and according to Dr. Jonathon Arney, almost totally exclude the effects of optical dot gain. When compared side to side, it can be shown that the press sheet and the 3M Matchprint have similar dot structures. The two digital proofs have similar dot structures but are very different from the press sheet and the Matchprint. This is because the press sheet and the 3M Matchprint were both generated using the Agfa Selectset's RIP and the two digital proofs used a Harlequin RIP. Figure 4, below illustrates this concept quite well.

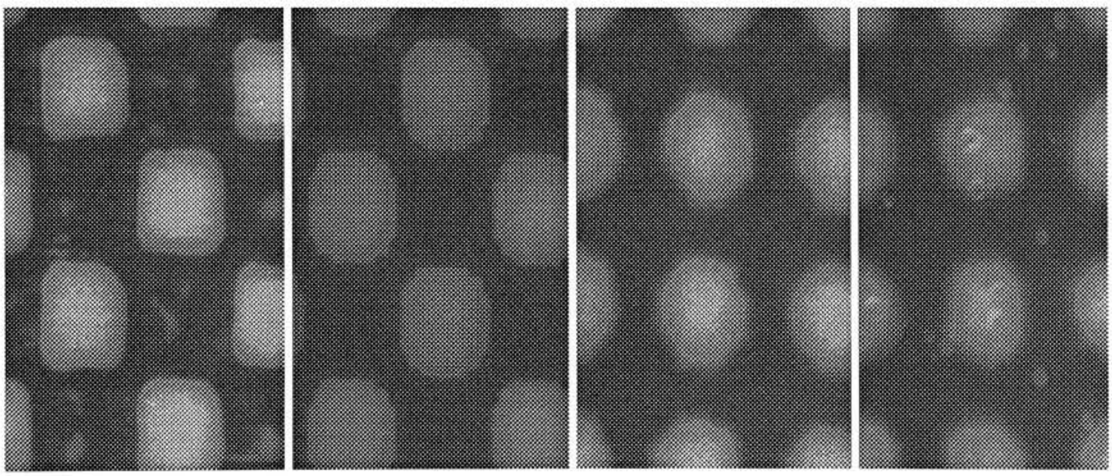

fig. 4 The micrographs shown above represent, from left to right, the flexographic press sheet, the 3M Matchprint, proofing system A, and proofing system B.

When viewed at this scale it is safe to state that the Matchprint most closely matches the press sheet; in terms of the physical or visual composition of the halftone dots. All of the images captured can be viewed in Appendix C; 80 images in total were captured 20 per press sheet/proof, 5 for each color (CMYK-5,25,50,75, and 95% dot patches).

When comparing the dot areas of the proofs and the press sheet; based on the statistics that were performed; the following was found:

In order for a significant difference to occur at a 95% confidence level; the F-value for the difference among rows had to be at least 3.8626. This would indicate a statistical difference between the press sheet and the proofs (Matchprint included). The F-value for the difference among rows for the 95% dots was 0.36, therefore the difference between 95% dots is not significant.

ANOVA Summary Table for 95% Dot Area

Source	Sum of Sq	df	Mean Square	Calculated F Ratio	Critical F Ratio
Proof/Print	2.02	3	0.67	0.36	3.86
Color	13.81	3	4.60	2.43	3.86
Error	17.07	9	1.90		
Total	32.9	15			

*=significant difference

The F-value for the difference among rows for the 75% dots was 4.99, therefore the difference between 75% dots is significant.

ANOVA Summary Table for 75% Dot Area

Source	Sum of Sq	df	Mean Square	Calculated F Ratio	Critical F Ratio
Proof/Print	55.77	3	18.59	4.99*	3.86
Color	2.38	3	0.79	0.21	3.86
Error	33.56	9	3.73		
Total	91.71	15			

*=significant difference

Digital proof A was the closest in dot size for the 75% dots at a difference of +3.4, the Matchprint (proof C) was next with a difference of -7.7, and digital proof B was the least closest match at a difference of +13.1.

The F-value for the difference among rows for the 50% dots was 8.45, therefore the difference between 50% dots is significant.

ANOVA Summary Table for 50% Dot Area

Source	Sum of Sq	df	Mean Square	Calculated F Ratio	Critical F Ratio
Proof/Print	97.39	3	32.46	8.45*	3.86
Color	36.33	3	12.11	3.15	3.86
Error	34.58	9	3.84		
Total	168.3	15			

*=significant difference

Digital proof A was the closest in dot size for the 50% dots at a difference of -4.7, the Matchprint (proof C) was next with a difference of -11, and digital proof B was the least closest match at a difference of +13.7.

The F-value for the difference among rows for the 25% dots was 2.19, therefore the difference between 25% dots is not significant.

ANOVA Summary Table for 25% Dot Area

Source	Sum of Sq	df	Mean Square	Calculated F Ratio	Critical F Ratio
Proof/Print	17.50	3	5.83	2.19	3.86
Color	49.23	3	16.41	6.17*	3.86
Error	23.93	9	2.66		
Total	90.66	15			

*=significant difference

The F-value for the difference among rows for the 5% dots was 5.88, therefore the difference between 5% dots is significant.

ANOVA Summary Table for 5% Dot Area

Source	Sum of Sq	df	Mean Square	Calculated F Ratio	Critical F Ratio
Proof/Print	65.69	3	21.90	5.88*	3.86
Color	121.15	3	40.38	10.84*	3.86
Error	33.52	9	3.72		
Total	220.36	15			

*=significant difference

The Matchprint (proof C) was the closest in dot size for the 5% dots at a difference of +3.6, digital proof A was next with a difference of -4.7, and digital proof B was the least closest match at a difference of -17.8.

Overall in matching the dot sizes of the press sheet; digital proof A was statistically better for the 75% dots and for the 50% dots, and the Matchprint was statistically a better match for the 5% dots.

Density

When comparing the density of the proofs to the press sheet; based on the statistics that were performed; the following was found:

In order for a significant difference to occur at a 95% confidence level; the F-value for the difference among rows had to be at least 3.8626.

This would indicate a statistical difference between the press sheet and the proofs (Matchprint included). The F-value for the difference among rows for the density of the 95% dots was 1.71, therefore the difference between the density of the 95% dots is not significant.

ANOVA Summary Table for 95% Dot Density

Source	Sum of Sq	df	Mean Square	Calculated F Ratio	Critical F Ratio
Proof/Print	0.0829	3	0.02763	1.71	3.86
Color	1.2987	3	0.43290	26.80*	3.86
Error	0.1454	9	0.01616		
Total	1.5270	15			

*=significant difference

The F-value for the difference among rows for the density of the 75% dots was 5.34, therefore the density difference between 75% dots is significant.

ANOVA Summary Table for 75% Dot Density

Source	Sum of Sq	df	Mean Square	Calculated F Ratio	Critical F Ratio
Proof/Print	0.0491	3	0.01637	5.34*	3.86
Color	0.3303	3	0.11010	35.89*	3.86
Error	0.0276	9	0.00307		
Total	0.4070	15			

*=significant difference

The Matchprint (proof C) was the closest in density for the 75% dots at a difference of -.12, digital proof A was next with a difference of +.30, and digital proof B was the least closest match at a difference of +.43.

The F-value for the difference among rows for the density of the 50% dots was 7.68, therefore the difference between 50% dots is significant.

ANOVA Summary Table for 50% Dot Density

Source	Sum of Sq	df	Mean Square	Calculated F Ratio	Critical F Ratio
Proof/Print	0.0105	3	0.00350	7.68*	3.86
Color	0.0654	3	0.02180	47.85*	3.86
Error	0.0041	9	0.00460		
Total	0.0800	15			

*=significant difference

The Matchprint (proof C) was the closest in density for the 50% dots at a difference of +.01, digital proof A was next with a difference of +.14, and digital proof B was the least closest match at a difference of +.25.

The F-value for the difference among rows for the density of the 25% dots was 17.12, therefore the difference between 25% dots is significant.

ANOVA Summary Table for 25% Dot Density

Source	Sum of Sq	df	Mean Square	Calculated F Ratio	Critical F Ratio
Proof/Print	0.0066	3	0.00220	17.12*	3.86
Color	0.0097	3	0.00323	25.17*	3.86
Error	0.0012	9	0.00013		
Total	0.0175	15			

*=significant difference

Digital proof A was the closest in density for the 25% dots at a difference of +.15, the Matchprint (proof C) was next with a difference of +.16, and digital proof B was the least closest match at a difference of +.22.

The F-value for the difference among rows for the density of the 5% dots was 18.11, therefore the difference between the density of the 5% dots is significant.

ANOVA Summary Table for 5% Dot Density

Source	Sum of Sq	df	Mean Square	Calculated F Ratio	Critical F Ratio
Proof/Print	0.0100	3	0.6700	18.11*	3.86
Color	0.0200	3	4.6000	36.23*	3.86
Error	0.0017	9	1.9000		
Total	0.0317	15			

*=significant difference

Digital proof B was the closest in density for the 5% dots at a difference of +.01, digital proof A was next with a difference of +.10, and the Matchprint (proof C) was the least closest match at a difference of +.16.

Overall in matching the density of the press sheet; digital proof A was statistically better for the 25% dots, digital proof B was statistically better for the 5% dots, and the Matchprint was statistically better at matching the densities for the 50% and the 75% dots.

ΔE Differences and Lab Measurements

Since ΔE is a value with a minimum acceptance level; the ANOVA concept is almost meaningless, because a statistical difference may or may not be an acceptable color difference. The ANOVA function was performed, but it's results are only meant to be used as a reference and hold no real validity to this experiment.

When comparing the ΔE data of the proofs; based on the statistics that were performed; the following was found:

For cyan; the Matchprint (proof C) had the lowest average ΔE with 7.279934, digital proof B was next with an average ΔE of 9.570762, and digital proof A had the highest average ΔE of 15.04495. None of these ΔE's fall within the acceptable range of 4-6. For magenta; the Matchprint (proof C) had the lowest average ΔE with 5.234695, digital proof B was next with an average ΔE of 6.013594, and digital proof A had the highest average ΔE of 7.047025. Only the Matchprint falls within the acceptable range of 4-6. For yellow; the Matchprint (proof C) had the lowest average ΔE with 2.305384, digital proof B was next with an average ΔE of 2.430476, and digital proof A had the highest average ΔE of 9.069113. Both the Matchprint and digital proof B fall within the acceptable range of 4-6. For black; the Matchprint (proof C) had the lowest average ΔE with 5.165557, digital proof B was next with an average ΔE of 5.626475, and digital proof A had the highest average ΔE of 8.184361. Both the Matchprint and digital proof B fall within the acceptable range of 4-6.

	ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
average ΔE's for Cyan	15.04495	9.570762	7.279934
"" Magenta	7.047025	6.013594	5.234695
"" Yellow	9.069113	2.430476	2.305384
"" Black	8.184361	5.626475	5.165557

A grand mean, called average ΔE's for all colors here, was calculated and the Matchprint (proof C) had the lowest average ΔE for all colors with 5.165557, digital proof B was next with an average ΔE for all colors of 5.626475, and digital proof A had the highest average ΔE for all colors of 8.184361. Both the Matchprint and digital proof B fall within the acceptable range of 4-6. This number represents how well (on average) the proof matched the press sheet in terms of color overall.

The ANOVA data shows that there are significant differences between ΔE's for the 50, 75, and 95% dots. This is probably due to digital proof A being so far off from the colors present on the flexographic press sheet.

Visual Analysis

When examining the data for the visual analysis of how closely proofs matched the press sheet; based on the statistics that were performed; the following was found:

In order for a significant difference to occur at a 95% confidence level; the F-value for the difference among columns had to be at least 3.3404. This would indicate a statistical difference for how well the proofs (Matchprint included) matched the press sheet. The F-value for the difference among columns was

0.804364, therefore the difference for how well the proofs visually matched the press sheet is not significant. This means that all three proofs visually match the press sheet equally.

ANOVA Summary Table for Visual Analysis

Source	Sum of Sq.	df	Mean Square	Calculated F Ratio	Critical F Ratio
Ranking (y_3)	3.16	2	1.58	0.80	3.34
Error	55	28	1.96		
	58.16				

*=significant difference

Upon inspecting the raw data, it appears that digital proofing system B is the best match, digital proofing system A is a close second, and the Matchprint is third. The scores were 57, 59, and 70 respectively; with the lowest score being the best match. The ANOVA data shows that this variation is not significant. Therefore, the differences in score are not a focal point for this experiment.

Chapter 7

Summary and Conclusions

As shown by the findings of the previous chapters; the 3M Matchprint is the closest match to the press sheet based on dot structure. In terms of physical dot size; digital proof A best matched the 50 and 75% dots and the Matchprint matched the 5% dots the best. In terms of optical density; digital proof A best matched the density of the 25% dots, digital proof B best matched the density of the 5% dots and the Matchprint best matched the 50 and 75% dot patches. In terms of ΔE values (color or hue difference); the Matchprint most closely matched the press sheet, digital proof B was next, and digital proof A was last.

With the exception of the dot structure (please see Appendix C for photomicrographs) all the aforementioned findings were based on statistical analysis. An ANOVA was applied to the visual analysis data but these data are based on the subjective judgements of the observers. As mentioned at the onset of the study; the visual analysis would be the deciding factor to determine which proof best matched the original. This analysis indicates that on the basis of a panel of judges, all proofs matched the press sheet equally. The judges could not consistently rank the proofs in the same order. The inference therefore is that the proofs are equally good representations of the flexographic print.

The original hypothesis for this experiment was:

H_{01}: There will be no significant difference in hue (ΔE), optical ink density and halftone dot size, when comparing digital halftone color proofs against flexographic printing.

H_{11}: There will be a significant difference in hue (ΔE), optical ink density and halftone dot size, when comparing digital halftone color proofs with flexographic printing.

Based on the results, H_{01} is rejected and H_{11} is accepted; as there is a significant difference for at least some of the criteria. Upon closer examination, the original hypothesis was much too stringent for this application; leading to it's unavoidable failure. One way to attempt to match the color on one halftone device to another halftone device is to change the size of the halftone dots. This method reduces the chances of matching both color and halftone dot size, instead a middle ground must be found. This is because, generally the base colors of the colorants do not match; in order to simulate a color match, more or less CMYK is required which is characterized on the output by larger or smaller halftone dots. On certain types of devices the same could be said of the relationship between color and density.

Another way to attempt to match the outputs of two different halftone devices would be to match the colorants used by each system. This method would most probably not occur at the applications level and would require a fairly large budget complete with R&D facility and engineering staff. For most printers, changing the size of the halftone dots would be more realistic.

With Chester Daniels guidance, this alternative (and more realistic) hypothesis was conceived;

H_{02}: There will be no significant difference when determining a closest visual match between the digital halftone color proofs and a 3M Matchprint to the flexographic press sheet.

H_{12}: There will be a significant difference when determining a closest visual match between the digital halftone color proofs and a 3M Matchprint to the flexographic press sheet.

The visual analysis showed that there was no statistical difference between proofs in terms of their ability to visually match the flexographic press sheet. Therefore, H_{02} is accepted and H_{12} is rejected.

The results of this experiment show that a digital halftone color proofing system can be used as a contract proofing device for flexography. This does not mean that either digital proof was a facsimile reproduction of the press sheet; rather it means that they both are the equivalent of the 3M Matchprint.

Questions, Answers, and Recommendations for Further Study

This experiment raises some valid questions; is it preferred to use the same RIP for film and proof generation?, are halftone dots needed to match the press sheet?, can an exposure based proofing system be used for flexography as a contract proof?, and is a visual match based only on numbers?

Digital proof B, in raw data form, was the closest visual match to the press sheet. Digital proof B was generated using a Harlequin RIP while the film was generated using Agfa's RIP. The Matchprint was made from the Agfa's films; the author's assumption was that the Matchprint would match more closely than the others. This is because different RIPs use different screening algorithms, meaning that the halftone dots will have different physical characteristics. The results suggest that the desired result can be reached using different RIPs.

This, in turn, suggests that perhaps halftone dots are not necessary at all in order for a proof to match a certain set of printing conditions. This is another topic altogether, one that could and should be studied.

An exposure based proofing system can be used as a contract proof for flexography; but the film needs to be altered so that the resulting proof approximates flexography rather than lithography.

In terms of numbers; the Matchprint had the lowest average ΔE differences, but it was not a better visual match than the other two proofs. In this case the numbers were not totally accurate, or more appropriately "you need to look at the big picture rather than it's individual components". Our present measuring systems are not capable of individually predicting a final resulting match between images produced by different systems. A combination of these individual responses is required and the character of this combination is not presently clear.

This experiment is only a partial answer to the question of proofing for flexography. Other topics of possible research include; continuos tone color proofing for flexography, proofing for non-traditional substrates (metals or foils), a cost analysis of digital proofing for flexography, and proofing special (spot) colors using digital proofers. Or the entire experiment could be redone changing one or two variables like halftone screen ruling, press, or inkset.

There are also many other similar scenarios where the outcome could have been different. For example; if a courser screen ruling had been used (85 lpi) the importance of the physical structure of the halftone dots might have played a more important role and it is possible that a visual match would not have been obtained with the digital proofs. If this courser screen ruling had been used; it might not have been appropriate to use a continuous tone digital proof.

On the other hand if a finer screen ruling had been used (175 lpi), it is possible that the physical structure of the halftone dots would not have been very important at all. However, this higher screen ruling would not be advisable on the press that was used for this experiment.

If a different ink set had been used, the results could have been different. The inks that were used were (according to the manufacturer) formulated with SWOP in mind. Neither of the digital proofing systems that were used allow for colors to be adjusted in terms of CIE Lab values. However, many other systems do; for example, DuPont has a continuous tone digital proofing system which does not even address the concept of halftone dots. It deals with color only in

terms of Lab values and attempts to match color based on them. Regardless, this experiment only scratched the surface of how digital proofing can aid the flexographic printer.

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Appendix A

"Building a Test Page Using the ISO Standard Colour Image Data"

The purpose of this section is to describe how the test page was put together as well as discussing the legal ramifications of using the ISO/DIS 12640 Graphic Technology - Prepress Data Exchange - Standard Colour Image Data (SCID). This section also reviews the procedure followed to "fingerprint" the Mark Andy 4120 printing press.

What Is the ISO Standard Colour Image Data and Why Is It Being Used?

The Standard Colour Image Data is a group of images that are CMYK TIFF files. The images are split into two categories; Natural images and Synthetic images. The Natural images are digital photographic images of scenes containing people or familiar objects. They illustrate a variety of visually assessed reproduction requirements; i.e., high-key detail, low-key detail, flesh tones and textures. The Synthetic images are a mixture of qualitative and quantitative targets. They are either resolution or color charts that are used to illustrate requirements such as gray balance and color fidelity.

All the images are available in two resolutions; 16 pixels/mm and 12 pixels /mm. The 16 pixel/mm images have their data encoded as 28 to 228, which represents printing values of 0 to 100% dot. The 12 pixel/mm images have their data encoded as 0 to 255, which represents printing values of 0 to 100% dot. The 12 pixel/mm images were used for this research project.

The purpose of the SCID images is to characterize the output of a printing or imaging system. Thus scanners and digital cameras are not included in this process. ISO states that, "the differences between scanners make it nearly impossible to repeatably create the same data file from a reference image on film. Such differences would make it impossible to compare other performance characteristics between systems or sites."[1]

Scanners can be calibrated using the ISO 12641, Graphic Technology - Prepress Digital Data Exchange - Colour Targets for Input Scanner Calibration.

The ISO is the International Organization for Standardization, working in conjunction with ISO is the American National Standards Institute (ANSI) which is the U.S. member of ISO.

Legal Issues

The "Guidelines for use" section of the ISO document lists some rules that should be followed. In short, the list explains that the images must have an identifier; they must read ISO 300 in the image area and a resolution identifier

[1] International Organization for Standardization. *Graphic technology – Prepress digital data exchange – Standard colour image data (SCID)*. pg iii.

must be present. Also, all color or tonal manipulations to the images must be global changes. In terms of sharing, the "Guidelines for distribution and sharing" states that none of the information in or derived from the standards can be sold for profit.

According to Guideline for distribution and sharing A.3.3., "Copies of these data files, or derivative files, may be exchanged between participants in test and evaluation programs. The sponsoring organization shall be capable of showing ownership of a copy of this International Standard."[2] This research project has been carried out under the sponsorship of the Rochester Institute of Technology. The Technical and Education Center of the Graphic Arts (T&E) holds RIT's license to the The Standard Color Image Data. Dave Cohn, a senior technologist at T&E, can be contacted at (716) 475-2686 to verify this.

Assembling the Page

All images were saved as EPS files, because the needed transfer curve information to compensate for dot gain can only be imbedded in EPS files. EPS files are also known to RIP faster than TIFF files. The following images were used; N4A, N7A, N8A, S6A, S7A, S8A, and S9A. The GATF gray balance chart, from the GATF digital test form has been included to monitor neutrality. In addition to these, two dot gain targets were constructed using Adobe Illustrator 5.5; one contains halftone dots from 5–100% in 5% increments and the other from 1–10% in 1% increments. Also, a trap target and type at various point sizes were created using QuarkXpress 3.31. The trap target is important because, the proofing

[2] International Organization for Standardization. *Graphic technology – Prepress digital data exchange – Standard colour image data (SCID)*. pg 21.

system must have the ability to show the spreading of the yellow type into the colored boxes. A trap of 1/32 of an inch was used, as it is the standard trap for flexography. This target is different than the GATF Trap target, because where as the GATF target shows the amount of trap required for a given set of printing conditions; this trap target shows whether or not the proofing system can simulate the trap of the press. A reduced monochromatic reproduction of the entire test page is shown in fig. A1.

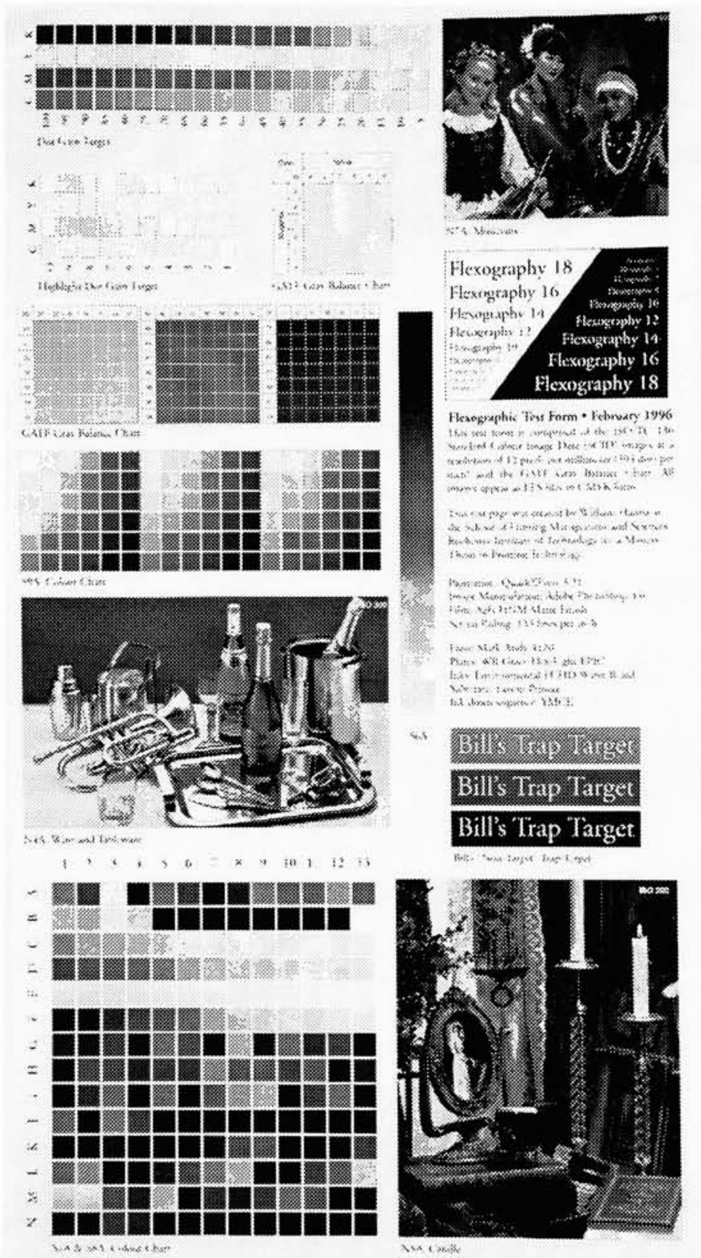


fig. A1; shows the test form in monochrome.

The following information is taken from the Standard Colour Image Data literature, it explains what each Natural image should be used for. Natural image N4A Wine and Tableware; "Image of glassware and silverware used to evaluate the reproduction characteristics of highlight tones and neutral colours"[3], N7A Musicians; "Image of three women used to evaluate the reproduction of different skin tones and fine image detail"[4], and N8A Candle; "Low-key image of a room scene containing miscellaneous objects used to evaluate dark colours, particularly browns and greens."[5] Target S9A is a color fidelity target, S6A is a vignette, and S7A & S8A makeup a target used for the evaluation of color fidelity in addition to dot gain and neutrality.

Press Calibration and Fingerprinting

The underlying mindset here was to calibrate the press to a known set of conditions. Several options were considered, under the guidance of Franz Sigg, it was decided that most were beyond the scope of this research. The method used was an attempt to match the flexographic press sheet to a SWOP proof (3M Matchprint III using SWOP colorants and base).

The assumption was that by matching the densities of the proof, as closely as possible, the press sheet would closely match the proof. This would theoretically take gray balance into account at the point which dot gain was compensated for.

[3, 4, 5] International Organization for Standardization. *Graphic technology – Prepress digital data exchange – Standard colour image data (SCID).* pg 4.

In the interest of time it was decided that the original films would be output at RIT rather than elsewhere. The first "calibration" press run was a failure, it was later determined that the original inks were formulated to be run at approximately 800–1000 feet per minute and while the actual run was at 175 feet per minute. In the process of discovering this, the amount of available substrate was totally exhausted. Properly formulated inks were then obtained and additional substrate was ordered. During this "down time", the films from Optronics were obtained.

Upon exposing the films to plate, it was discovered that the film was incorrectly identified as matte finish film. Since the film was not a matte finish film, the film was not able reach the proper "draw down" in the vacuum frame. The resulting plates suffered from image distortion.

These films were next contacted onto a matte finish film. However, an acceptable dot-for-dot contact was not produced. It was then decided that all the films would be output at RIT. The matte finish film was output and photopolymer plates were successfully made. An acceptable "calibration" run was achieved from this set of conditions.

After the "calibration" pressrun, a sample press sheet was compared to the proof. A Jones Diagram, for each color, was plotted as follows; quadrant 1 was the flexographic press sheet, quadrant 2 was the SWOP proof, quadrant 3 was a 45° angle curve used to transfer graph data, quadrant 4 was the necessary alterations to calibrate flexography to the appearance of the SWOP proof. The press

sheet was graphed as dot area on film vs. density on the press sheet. The proof was graphed as dot area on film vs. density on the proof.

The two did not have an identical D-max, therefore the data needed to be interpolated. This was done by lowering the D-max of the proof to the D-max of the press sheet, except for Cyan where the D-max of the proof had to be raised to match Flexography. Figure A2 shows the interpolation, while figures A3-A6 show the Jones diagrams that were plotted.

Density of Flexographic press sheet vs. 3M Matchprint to determine Interpolation of Jones Diagrams

	C			M			Y			K		
% dot	Press sheet	Matchprint	Interpolated	Press sheet	Matchprint	Interpolated	Press sheet	Matchprint	Interpolated	Press sheet	Matchprint	Interpolated
2	0.07	0.03	0.03	0.07	0.03	0.03	0.03	0.03	0.03	0.07	0.03	0.03
5	0.13	0.08	0.08	0.12	0.09	0.09	0.07	0.07	0.07	0.12	0.08	0.07
10	0.16	0.11	0.12	0.16	0.12	0.11	0.10	0.10	0.09	0.17	0.12	0.10
15	0.22	0.16	0.17	0.20	0.18	0.17	0.14	0.14	0.13	0.23	0.17	0.13
20	0.30	0.21	0.22	0.25	0.23	0.21	0.20	0.19	0.17	0.31	0.23	0.18
25	0.38	0.26	0.27	0.31	0.28	0.26	0.25	0.23	0.21	0.38	0.28	0.22
30	0.43	0.31	0.33	0.37	0.32	0.29	0.31	0.27	0.24	0.43	0.33	0.26
40	0.59	0.41	0.43	0.51	0.43	0.39	0.44	0.35	0.31	0.59	0.45	0.35
50	0.71	0.52	0.55	0.61	0.56	0.52	0.51	0.44	0.40	0.70	0.59	0.47
60	0.84	0.64	0.67	0.72	0.67	0.62	0.59	0.53	0.48	0.82	0.73	0.59
70	0.95	0.75	0.79	0.84	0.80	0.74	0.65	0.61	0.55	0.97	0.89	0.72
80	1.13	0.89	0.93	0.98	0.94	0.87	0.72	0.71	0.64	1.12	1.08	0.89
90	1.26	1.05	1.10	1.09	1.13	1.05	0.77	0.81	0.73	1.32	1.35	1.13
100	1.28	1.23	1.28	1.24	1.33	1.24	0.82	0.91	0.82	1.50	1.74	1.50

The difference between the 3M & the press sheet was .05 density; therefore all proof densities were multiplied by (.05 * % dot), this number was then added to the proof density at a given % dot.

The difference between the 3M & the press sheet was .09 density; therefore all proof densities were multiplied by (.09 * % dot), this number was then subtracted from the proof density at a given % dot.

The difference between the 3M & the press sheet was .09 density; therefore all proof densities were multiplied by (.09 * % dot), this number was then subtracted from the proof density at a given % dot.

The difference between the 3M & the press sheet was .25 density; therefore all proof densities were multiplied by (.25 * % dot), this number was then subtracted from the proof density at a given % dot.

figure A2; shows the interpolation needed to properly create a Jones Diagram to calibrate Flexography to SWOP.

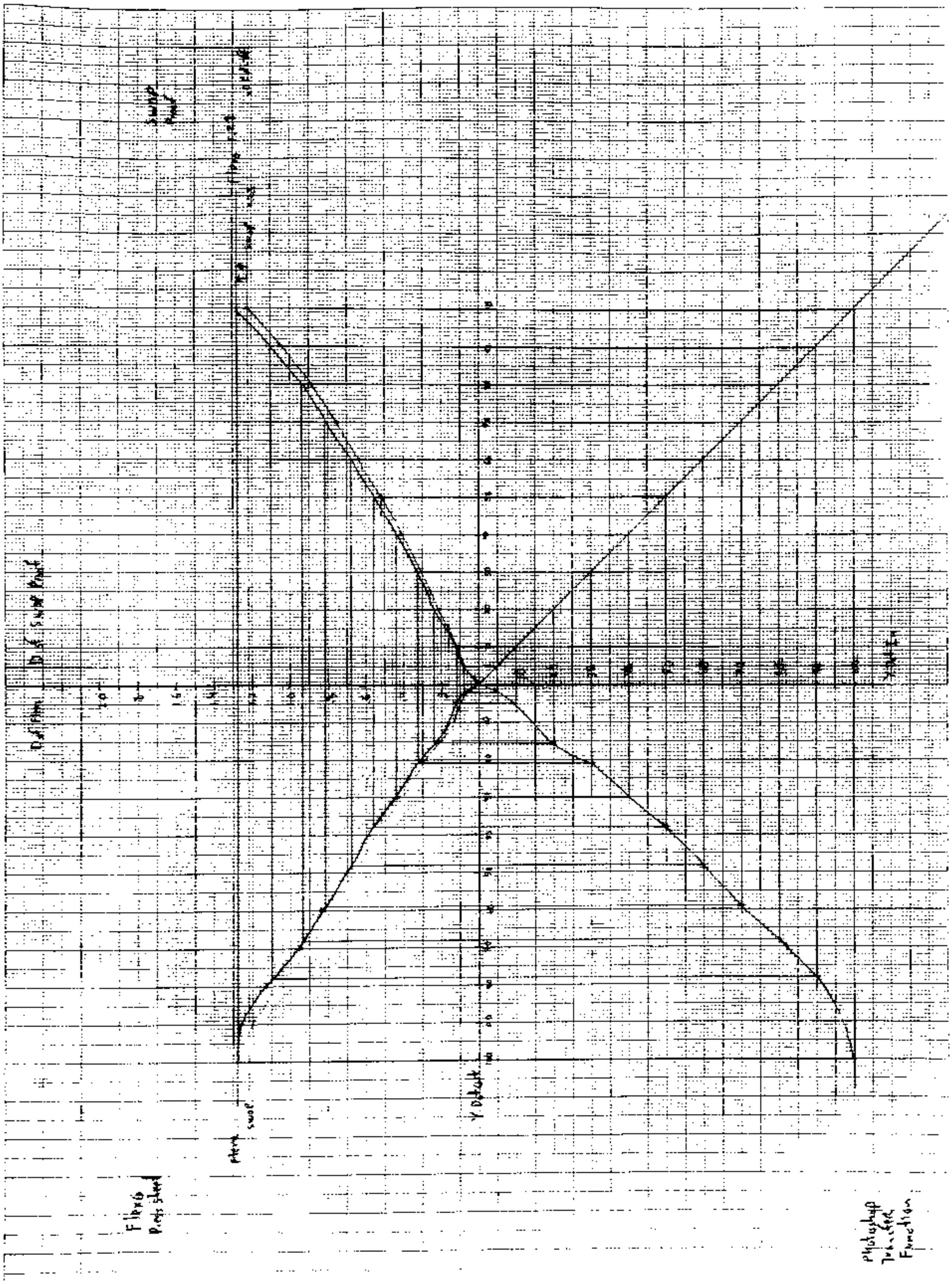


figure A3; shows the Jones Diagram for Cyan.

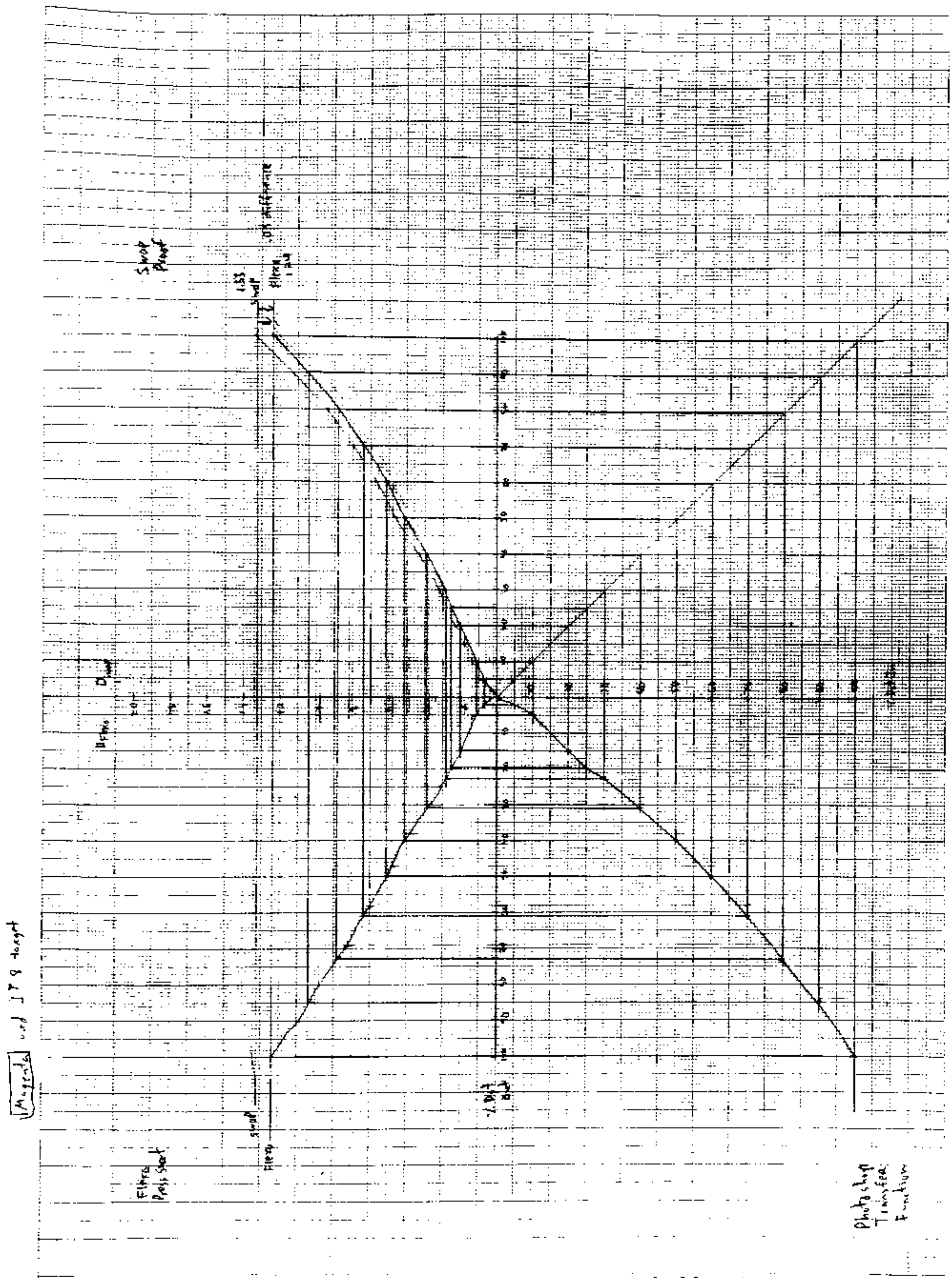


figure A4; shows the Jones Diagram for Magenta.

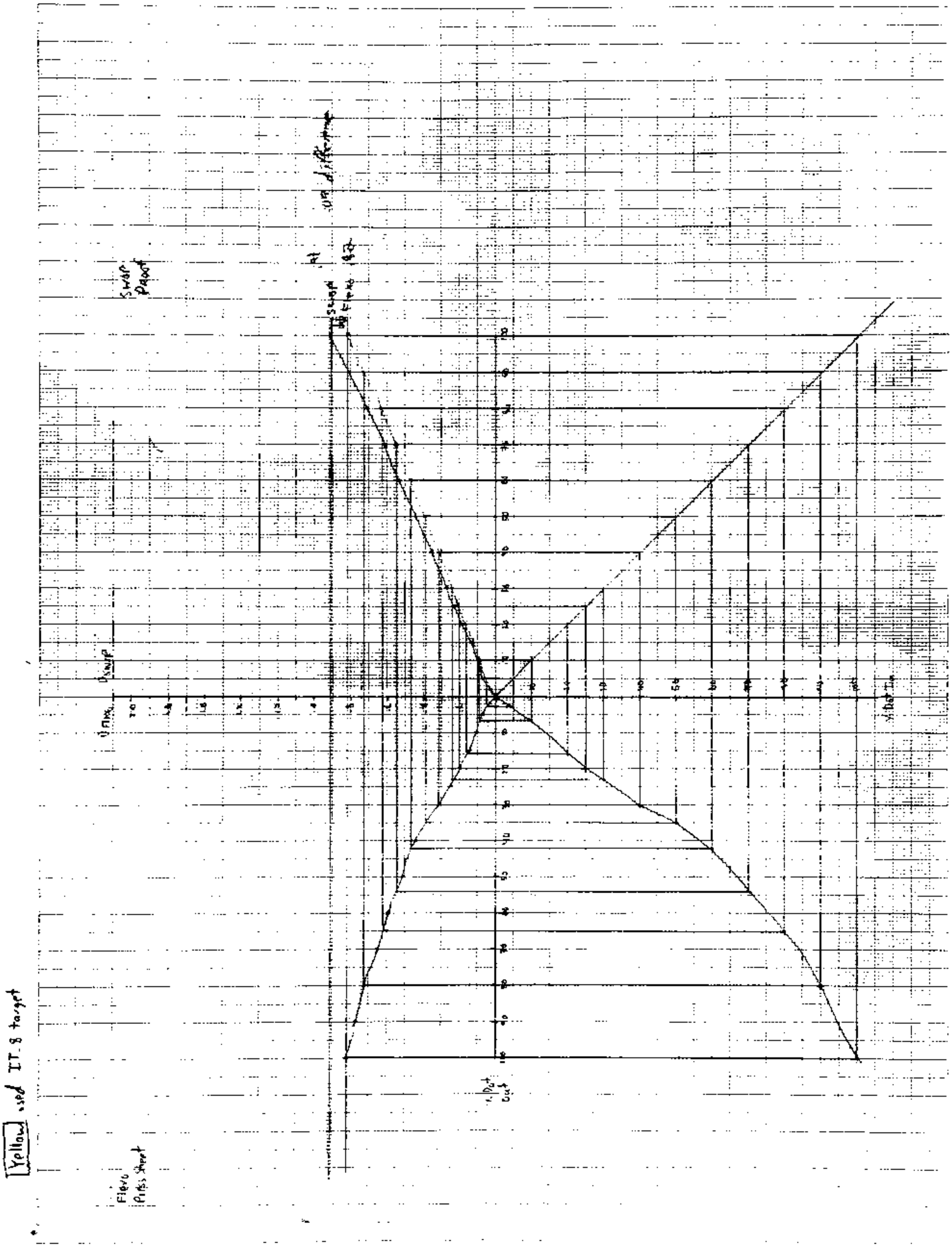


figure A5; shows the Jones Diagram for Yellow.

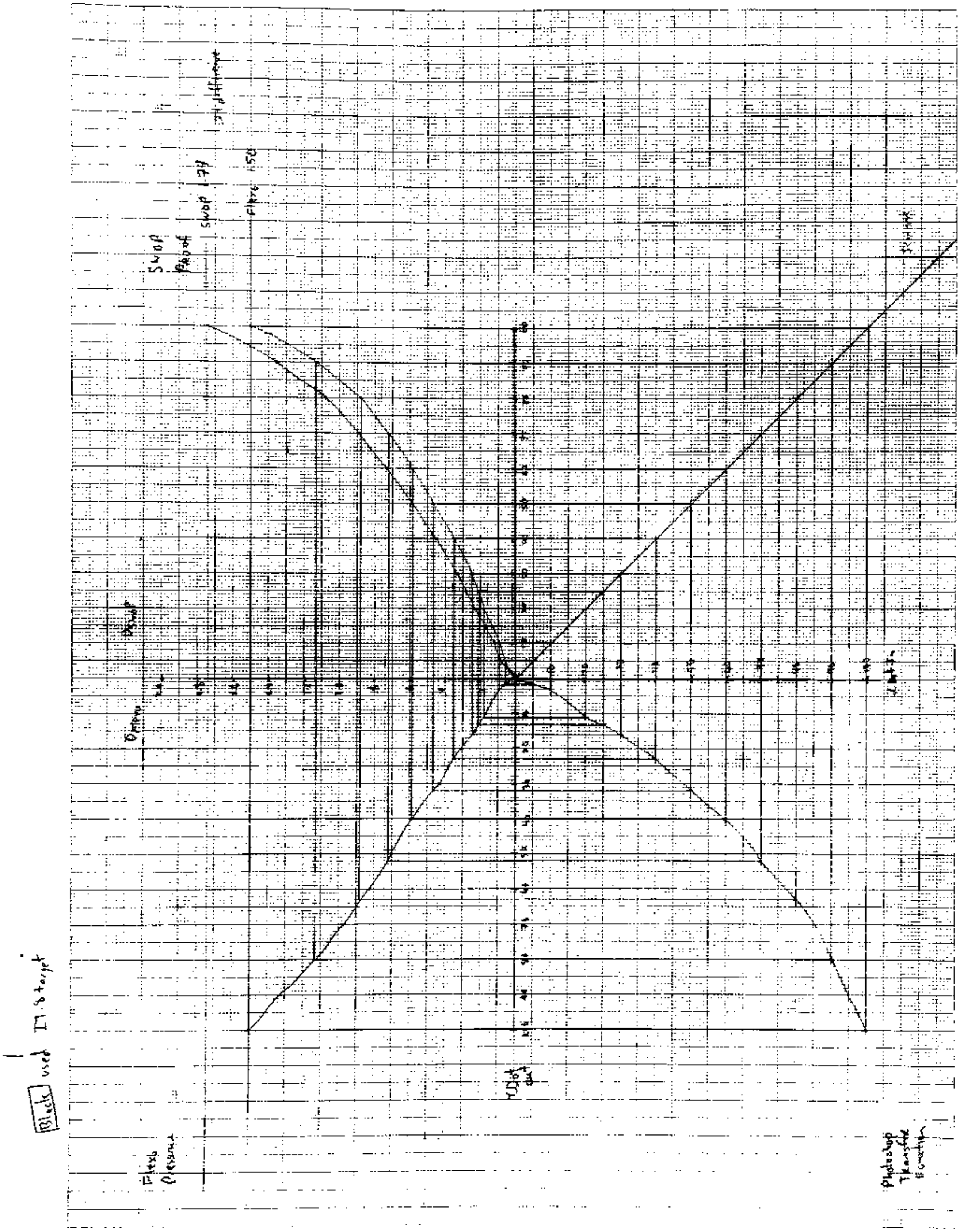


figure A6; shows the Jones Diagram for Black.

The necessary changes were made to the three ISO halftone photographic images in Photoshop using the Transfer Curve Function. A compensated set of films were output and new printing plates were made. These plates were then printed; however, an undesirable pink color cast was present on the press sheets. Initially it was hypothesized that the dot gain compensation had been done incorrectly, thus destroying the gray balance of the original press run. Upon further investigation, Chester Daniels suggested that the magenta plate could be defective. Another magenta plate was made and run on the press. This minimized the color cast and produced acceptable results. Apparantly, the original magenta plate for this press run had a "low spot" on a portion of the image area. This, in turn, required an increase in magenta plate pressure for the entire plate to print without "skipping" dots; which created a pink color cast.

The "compensated" press run had lighter images when compared to the "calibration" press run. However, the images did not exactly match those on the SWOP proof. This is most likely due to the extreme dot gain in the highlights and quarter tones associated with flexography. The dot gain can only be compensated for up to a certain point. If the dot gain is over-compensated for, then there would be little or no dots on film in the highlights. Therefore, an exact match to SWOP was not achieved; this is still acceptable because the digital proofing system needs to be able to mimic the characteristics of flexography. In the end the press sheet was a meeting point between the SWOP analog proof and what could be considered normal flexography.

Matching the Proofs to the Press Sheet

A press sheet was sent to both Kodak in Rochester and Optronics and Chelmsford. Both made several attempts to match the press sheet over the course of the next few months. After they had felt that a good match had been achieved they sent the proofs back to the author in Rochester.

The author then attempted to create a 3M Matchprint that matched the press sheet. This was done by measuring the dot sizes on the color tint patches of the press sheet and comparing them to the corresponding dot patches on the Matchprint that was used to calibrate the press.

Since the original Matchprint simulates lithographic dot gain and the goal here was to simulate flexographic dot gain, a seperate set of films needed to be out-put. The dot sizes were increased as needed in order to simulate flexography. The following two figures illustrate this; figure A7 shows the values entered into the Photoshop Transfer Curve Function and figure A8 shows the % dot on the 3M Matchprint calibrated to match the press sheet vs. the flexographic press sheet.

% dot entered into Photoshop to match the Matchprint

% dot	C	M	Y	K
5	15	18	14	12
10	16	18	16	15
15	21	23	24	20
20	27	29	28	26
25	31	33	32	32
30	37	38	38	37
35	42	43	41	42.5
40	47	48	48	49
45	52	52.7	51	53.4
50	56	56	56	56
55	60	60	61	61
60	64	65	65	64
65	67	68	69	67
70	73	73	74	72
75	77	77	79	76
80	81	81	82	80
85	85	85	86	85
90	90	90	90	90
95	95	95	95	95
100	100	100	100	100

figure A7; shows the values entered into Photoshop to attempt to match the 3M Matchprint to the Flexographic press sheet.

% dot of Press sheet vs. Matchprint

% dot	C Press sheet	C Matchprint	C Δ	M Press sheet	M Matchprint	M Δ	Y Press sheet	Y Matchprint	Y Δ	K Press sheet	K Matchprint	K Δ
5	28	32	4	37	40	3	28	30	2	24	28	4
10	37	36	-1	42	42	0	34	31	-3	34	34	0
15	43	41	-2	47	46	-1	45	37	-8	41	40	-1
20	50	51	1	53	54	1	51	47	-4	49	49	0
25	55	57	2	58	61	3	57	54	-3	57	57	0
30	62	63	1	63	65	2	62	59	-3	62	63	1
35	67	68	1	69	70	1	67	64	-3	68	69	1
40	72	73	1	73	74	1	72	68	-4	75	75	0
45	77	77	0	78	78	0	75	72	-3	79	78	-1
50	79	80	1	81	80	-1	80	75	-5	81	80	-1
55	83	83	0	84	83	-1	83	79	-4	85	83	-2
60	85	85	0	87	86	-1	85	81	-4	86	85	-1
65	88	87	-1	89	88	-1	88	84	-4	90	87	-3
70	91	90	-1	91	90	-1	91	87	-4	92	89	-3
75	93	92	-1	93	92	-1	94	90	-4	94	92	-2
80	95	94	-1	95	94	-1	96	92	-4	96	94	-2
85	97	96	-1	95	95	0	97	94	-3	100	96	-4
90	100	100	0	98	100	2	98	100	2	100	100	0
95	100	100	0	99	100	1	99	100	1	100	100	0
100	100	100	0	100	100	0	100	100	0	100	100	0

figure A8; shows the % dot areas of the press sheet, the calibrated Matchprint and the difference between the two.

Appendix B

Data and Statistics

The purpose of this section is to illustrate all data collected and all statistical operations used to determine the validity of the Hypothesis.

Dot Size ANOVA for 5% Dot

		Cyan	Magenta	Yellow	Black	Tp
Proof/Print	A	14.5	17.7	13.9	9.2	55.3
	B	8.6	13.2	11.2	9.2	42.2
	C	16.3	18.7	17.0	11.6	63.6
	Print	15.0	22.1	12.2	10.7	60.0
						221.1
	Tt	54.4	71.7	54.3	40.7	221.1

Column Mean Variance	121.15
Row Mean Variance	65.69
Total Sum of Squares	220.36

	Sum of Sq	df	Mean Square
Row Means	65.69	3	21.90
Column Means	121.15	3	40.38
Residual	33.52	9	3.72
Total	220.36	15	

F Rows for difference among rows

F=21.90/3.35

F= 5.88

F Columns for difference among columns

F= 40.38/3.35

F= 10.84

Dot Size ANOVA for 25% Dot

		Cyan	Magenta	Yellow	Black	Tp
Proof/Print	A	35.6	32.1	38.7	32.2	138.6
	B	30.3	34.7	34.9	32.0	131.9
	C	34.0	36.4	38.3	33.1	141.8
	Print	32.6	34.5	34.8	30.5	132.4
						544.7
	Tt	132.5	137.7	146.7	127.8	544.7

Column Mean Variance	49.23
Row Mean Variance	17.50
Total Sum of Squares	90.66

	Sum of Sq	df	Mean Square
Row Means	17.50	3	5.83
Column Means	49.23	3	16.41
Residual	23.93	9	2.66
Total	90.66	15	

F Rows for difference among rows

F=5.83/2.66

F= 2.19

F Columns for difference among columns

F= 16.41/2.66

F= 6.17

Dot Size ANOVA for 50% Dot

		Cyan	Magenta	Yellow	Black	Tp
Proof/Print	A	60.9	63.0	65.0	61.0	249.9
	B	63.5	69.7	70.0	67.1	270.3
	C	61.9	62.1	60.1	59.5	243.6
	Print	62.4	68.1	62.7	61.4	254.6
						1018.4
	Tt	248.7	262.9	257.8	249.0	1018.4

Column Mean Variance	36.33
Row Mean Variance	97.39
Total Sum of Squares	168.30

	Sum of Sq	df	Mean Square
Row Means	97.39	3	32.46
Column Means	36.33	3	12.11
Residual	34.58	9	3.84
Total	168.30	15	

F Rows for difference among rows

F=32.46/3.84

F= 8.45

F Columns for difference among columns

F= 12.11/3.84

F= 3.15

Dot Size ANOVA for 75% Dot

		Cyan	Magenta	Yellow	Black	Tp
Proof/Print	A	83.0	82.6	83.8	87.4	336.8
	B	84.7	86.8	86.3	88.7	346.5
	C	83.9	81.9	80.9	79.0	325.7
	Print	83.4	84.1	82.9	83.0	333.4
						1342.4
	Tt	335.0	335.4	333.9	338.1	1342.4

Column Mean Variance	2.38
Row Mean Variance	55.77
Total Sum of Squares	91.72

	Sum of Sq	df	Mean Square
Row Means	55.77	3	18.59
Column Means	2.38	3	0.79
Residual	33.56	9	3.73
Total	91.71	15	

F Rows for difference among rows

F=18.59/3.73

F= 4.99

F Columns for difference among columns

F= .79/3.73

F= 0.21

Dot Size ANOVA for 95% Dot

		Cyan	Magenta	Yellow	Black	Tp
Proof/Print	A	99.8	99.8	94.5	100.0	394.1
	B	98.4	99.0	99.6	99.7	396.7
	C	99.0	99.9	96.6	99.9	395.4
	Print	98.9	98.4	97.7	97.9	392.9
						1579.1
	Tt	396.1	397.1	388.4	397.5	1579.1

Column Mean Variance	13.81
Row Mean Variance	2.02
Total Sum of Squares	32.89

	Sum of Sq	df	Mean Square
Row Means	2.02	3	0.67
Column Means	13.81	3	4.60
Residual	17.07	9	1.90
Total	32.90	15	

F Rows for difference among rows

F=.67/1.9

F= 0.36

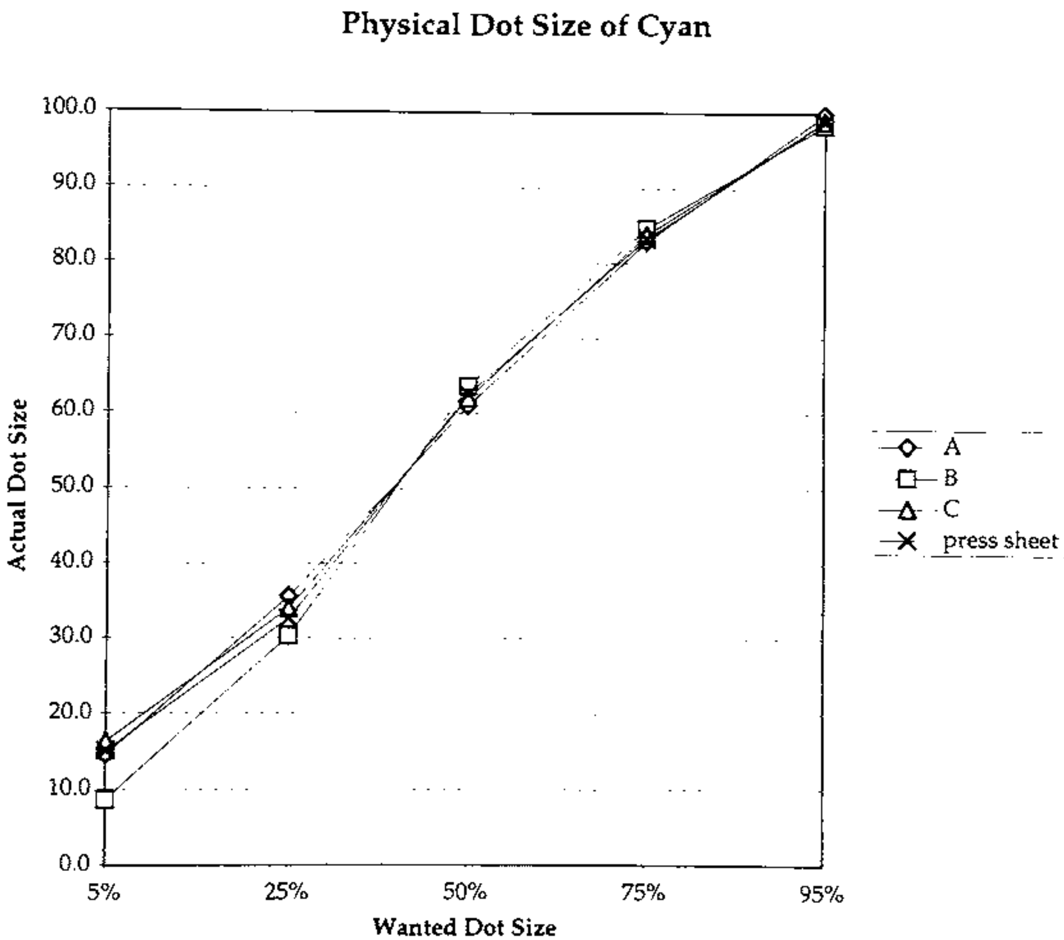
F Columns for difference among columns

F= 4.6/1.9

F= 2.43

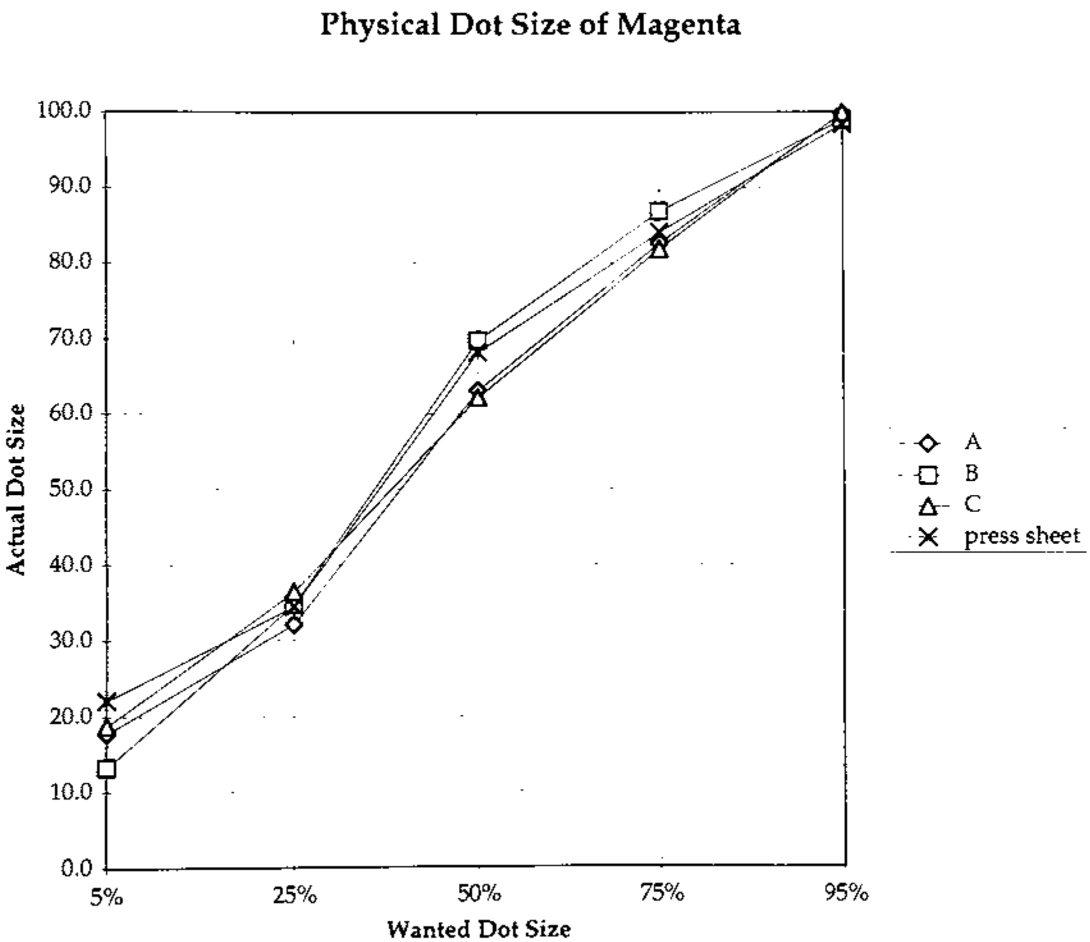
Cyan

	A	B	C	press sheet
5%	14.5	8.6	16.3	15.0
25%	35.6	30.3	34.0	32.6
50%	60.9	63.5	61.9	62.4
75%	83.0	84.7	83.9	83.4
95%	99.8	98.4	99.0	98.9



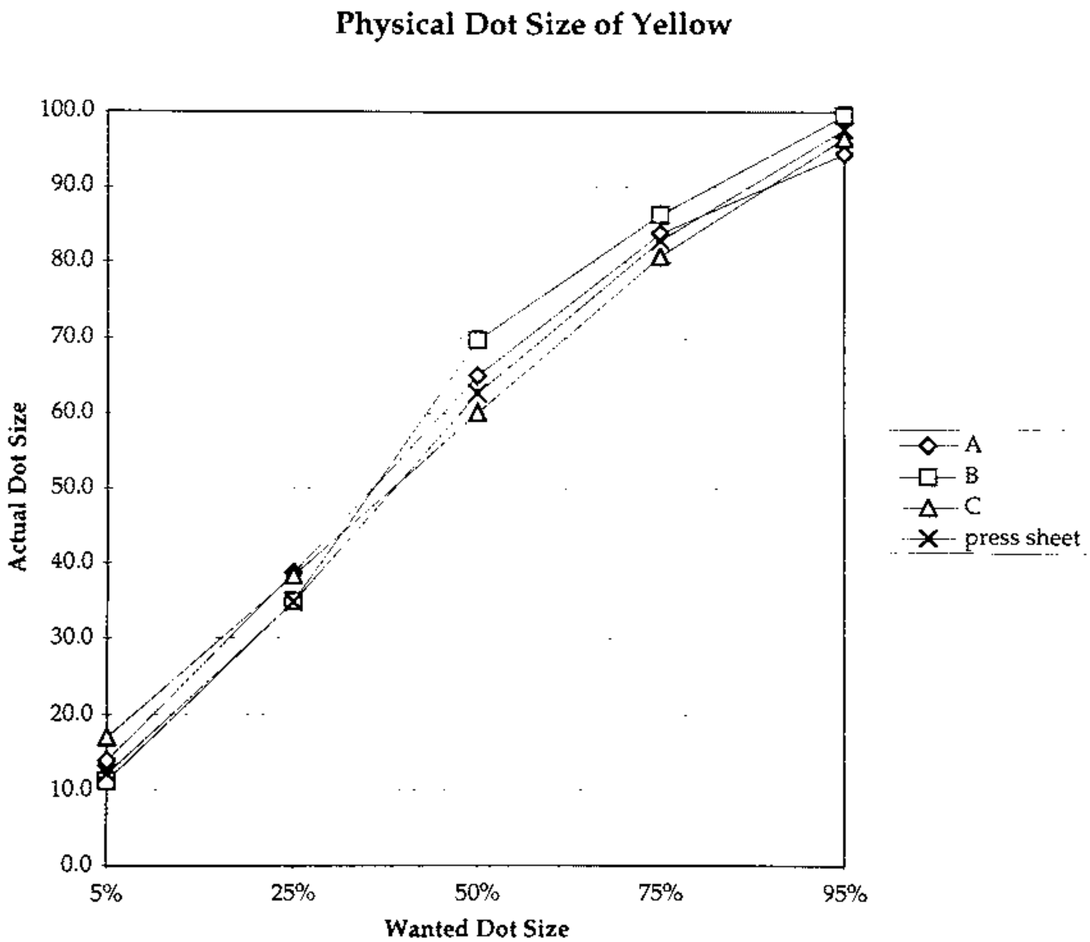
Magenta

	A	B	C	press sheet
5%	17.7	13.2	18.7	22.1
25%	32.1	34.7	36.4	34.5
50%	63.0	69.7	62.1	68.1
75%	82.6	86.8	81.9	84.1
95%	99.8	99.0	99.9	98.4



Yellow

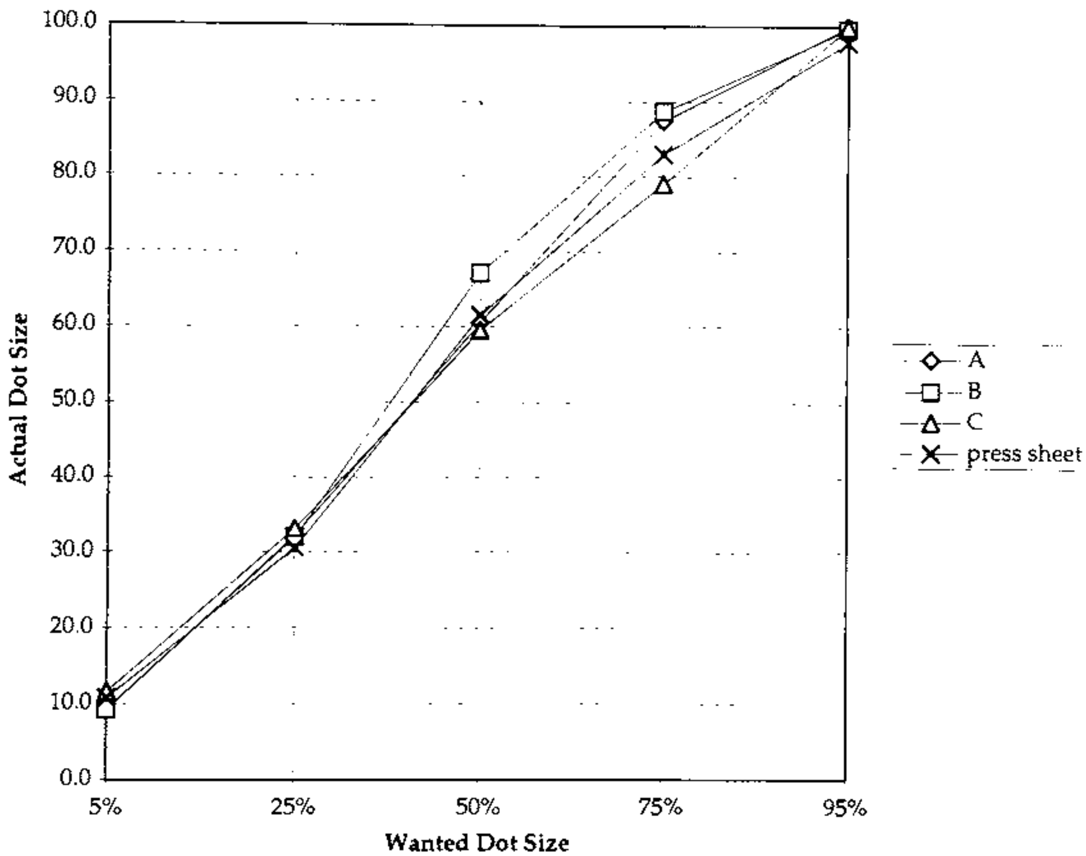
	A	B	C	press sheet
5%	13.9	11.2	17.0	12.2
25%	38.7	34.9	38.3	34.8
50%	65.0	69.7	60.1	62.7
75%	83.8	86.3	80.8	82.9
95%	94.5	99.6	96.6	97.7



Black

	A	B	C	press sheet
5%	9.2	9.2	11.6	10.7
25%	32.2	32.0	33.1	30.5
50%	60.5	67.0	59.5	61.4
75%	87.4	88.7	79.0	83.0
95%	100.0	99.7	99.9	97.9

Physical Dot Size of Black



ANOVA for 5% Density

		Cyan	Magenta	Yellow	Black	Tp
Proof/Print	A	0.18	0.21	0.13	0.13	0.65
	B	0.12	0.18	0.13	0.11	0.54
	C	0.18	0.23	0.15	0.15	0.71
	Print	0.16	0.18	0.12	0.09	0.55
						2.45
	Tt	0.64	0.80	0.53	0.48	2.45

Column Mean Variance 0.0151
Row Mean Variance 0.0050
Total Sum of Squares 0.0217

	Sum of Sq	df	Mean Square
Row Means	0.0100	3.00	0.00333
Column Means	0.0200	3.00	0.00667
Residual	0.0017	9.00	0.00018
Total	0.0317	15.00	

F Rows for difference among rows

F=0.00333/0.00018
F= 18.11

F Columns for difference among columns

F=0.00667/0.00018
F= 36.23

ANOVA for 25% Density

		Cyan	Magenta	Yellow	Black	Tp
Proof/Print	A	0.38	0.37	0.33	0.40	1.48
	B	0.38	0.42	0.35	0.40	1.55
	C	0.37	0.40	0.33	0.39	1.49
	Print	0.34	0.36	0.29	0.34	1.33
						5.85
	Tt	1.47	1.55	1.30	1.53	5.85

Column Mean Variance 0.0097
Row Mean Variance 0.0066
Total Sum of Squares 0.0174

	Sum of Sq	df	Mean Square
Row Means	0.0066	3.00	0.00220
Column Means	0.0097	3.00	0.00323
Residual	0.0012	9.00	0.00013
Total	0.0175	15.00	

F Rows for difference among rows

F=0.00220/0.00013
F= 17.12

F Columns for difference among columns

F= 0.00323/0.00013
F= 25.17

ANOVA for 50% Density

		Cyan	Magenta	Yellow	Black	Tp
Proof/Print	A	0.69	0.70	0.55	0.75	2.69
	B	0.69	0.75	0.59	0.77	2.80
	C	0.64	0.67	0.53	0.72	2.56
	Print	0.65	0.68	0.56	0.66	2.55
						10.60
	Tt	2.67	2.80	2.23	2.90	10.60

Column Mean Variance	0.0654
Row Mean Variance	0.0105
Total Sum of Squares	0.0801

	Sum of Sq	df	Mean Square
Row Means	0.0105	3.00	0.00350
Column Means	0.0654	3.00	0.02180
Residual	0.0041	9.00	0.00046
Total	0.0800	15.00	

F Rows for difference among rows

F=0.00350/0.00046

F= 7.68

F Columns for difference among columns

F= 0.02180/0.00046

F= 47.85

ANOVA for 75% Density

		Cyan	Magenta	Yellow	Black	Tp
Proof/Print	A	1.08	1.00	0.72	1.25	4.05
	B	1.06	1.10	0.79	1.23	4.18
	C	0.92	0.94	0.73	1.04	3.63
	Print	1.02	0.98	0.73	1.02	3.75
						15.61
	Tt	4.08	4.02	2.97	4.54	15.61

Column Mean Variance	0.3303
Row Mean Variance	0.0491
Total Sum of Squares	0.4070

	Sum of Sq	df	Mean Square
Row Means	0.0491	3.00	0.01637
Column Means	0.3303	3.00	0.11010
Residual	0.0276	9.00	0.00307
Total	0.4070	15.00	

F Rows for difference among rows

F=0.01637/0.00307

F= 5.34

F Columns for difference among columns

F= 0.11010/0.00307

F= 35.89

ANOVA for 95% Density

		Cyan	Magenta	Yellow	Black	Tp
Proof/Print	A	1.56	1.30	0.83	1.85	5.54
	B	1.45	1.44	0.93	1.80	5.62
	C	1.25	1.34	0.91	1.73	5.23
	Print	1.39	1.26	0.89	1.35	4.89
						21.28
	Tt	5.65	5.34	3.56	6.73	21.28

Column Mean Variance	1.2987
Row Mean Variance	0.0829
Total Sum of Squares	1.5270

	Sum of Sq	df	Mean Square
Row Means	0.0829	3.00	0.02763
Column Means	1.2987	3.00	0.43290
Residual	0.1454	9.00	0.01616
Total	1.5270	15.00	

F Rows for difference among rows

F=0.02763/0.01616

F= 1.71

F Columns for difference among columns

F= 0.43290/0.01616

F= 26.80

ΔE's calculated from Lab values

Cyan

5% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
79.97	-2.63	-12.86	75.12	-2.48	-9.55	83.19	-0.08	-11.09	80.87	-2.92	-13.38

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
5.87376	4.47256	1.07912

25% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
69.41	-4.96	-24.53	65.63	-6.54	-16.38	69.04	-5.02	-21.59	71.41	-6.78	-24.09

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
9.1218	2.9638	2.73971

50% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
57.11	-7.75	-38.96	53.96	-9.83	-25.62	56.74	-10.35	-30.89	61.61	-12.14	-35.55

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
13.8638	8.48657	7.15194

	press sheet			proof A			proof B			proof C		
	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
75% dot patch	48.31	-9.49	-52.68	44.97	-13.33	-32.61	47	-12.76	-39.74	54.27	-14.41	-45.21

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
20.7052	13.4109	10.7484

	press sheet			proof A			proof B			proof C		
	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
95% dot patch	43.2	-8.77	-63.15	39.1	-14.85	-38.56	41.69	-14.55	-45.62	49.06	-16.79	-52.34

	ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
	25.6602	18.52	14.6805
average ΔE's for Cyan	15.04495	9.570762	7.279934

Magenta

5% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
76.74	14.39	-5.8	72.61	15.9	-4.66	77.63	17.95	-7.57	76.16	19.86	-4.91

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
4.54275	4.07414	5.5722

25% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
65.97	27.08	-7.4	63.89	25.16	-5.89	64.34	33.52	-7.89	66.26	30.32	-5.55

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
3.20825	6.66113	3.74222

50% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
52.59	43.59	-8.39	50.64	38.92	-6.55	51.29	49.54	-6.31	55.06	42.68	-5.8

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
5.38489	6.43575	3.69284

75% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
43.9	57.77	-7.99	42.39	48.61	-6.01	42.87	62.69	-4.04	47.07	52.49	-4.74

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
9.49242	6.39295	6.96346

95% dot patch	press sheet			proof A			proof B			proof C		
	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
	39.05	68.21	-7.52	37.11	55.89	-5.68	38.28	72.37	-2.58	40.23	63.42	-3.76

	ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
	12.6068	6.50401	6.20275
average ΔE's for Magenta	7.047025	6.013594	5.234695

Yellow

5% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
89.02	-3.99	11.77	83.26	-1.82	10.82	89.08	-2.13	11.89	90.24	-3.3	14.47

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
6.22808	1.86483	3.04212

25% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
88.01	-7.97	26.93	81.25	-4.56	25.3	87.69	-7.03	29.34	88.31	-6.31	28.22

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
7.74484	2.60655	2.12361

50% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
86.37	-10.37	40.1	79.09	-5.27	35.66	85.33	-8.78	41.62	87.01	-8.53	38.95

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
9.93589	2.43313	2.26223

75% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
85.05	-11.16	45.92	77.7	-5.61	41.62	84.26	-9.18	47.65	85.29	-9.01	45.56

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
10.1644	2.74543	2.1931

95% dot patch

	press sheet			proof A			proof B			proof C		
	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
	84.88	-11.14	49.28	76.81	-5.61	43.68	83.51	-9.41	50.46	84.35	-9.31	49.33

	ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
	11.2723	2.50244	1.90586
average ΔE's for Yellow	9.069113	2.430476	2.305384

Black

5% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
80.52	2.82	-5.41	74.58	1.43	-1.9	80.06	3.14	-4.51	78.37	1.76	-2.07

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
7.03817	1.06019	4.11117

25% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
62.19	4.18	-7.72	56.1	1.87	-2.48	58.92	3.92	-5.15	60.58	2.96	-3.53

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
8.35953	4.16718	4.65152

50% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
44.17	4.95	-6.86	38.61	2.32	-2.47	39.08	2.95	-3.35	42.26	2	-2.94

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
7.55663	6.49832	5.26469

75% dot patch

press sheet			proof A			proof B			proof C		
L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
29.8	3.93	-3.18	22.36	1.54	-1.95	23.27	1.92	-1.07	29.24	1.18	-1.4

ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
7.91066	7.15074	3.32333

95% dot patch	press sheet			proof A			proof B			proof C		
	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
	20.86	5.12	-2.61	11.71	1.03	-3.44	12.08	3.28	-0.33	14	0.74	-0.24

	ΔE of press sheet vs. A	ΔE of press sheet vs. B	ΔE of press sheet vs. C
	10.0568	9.25594	8.47708
average ΔE's for Black	8.184361	5.626475	5.165557

[redacted]

ANOVA for ΔE of 5% Dot

		Cyan	Magenta	Yellow	Black	Tp
Proof vs Print	A	5.87	4.54	6.23	7.04	23.68
	B	4.47	4.07	1.86	1.06	11.46
	C	1.08	5.57	3.04	4.11	13.80
						48.94
	Tc	11.42	14.18	11.13	12.21	48.94

Column Mean Variance	1.89
Row Mean Variance	21.03
Total Sum of Squares	43.30

	Sum of Sq	df	Mean Square
Row Means	21.03	2.00	10.52
Column Means	1.89	3.00	0.63
Residual	20.38	6.00	3.40
Total	43.30	11.00	

F Rows for difference among rows

F=10.52/3.4

F= 3.10

F Columns for difference among columns

F= 0.63/3.4

F= 0.19

ANOVA for ΔE of 25% Dot

		Cyan	Magenta	Yellow	Black	Tp
Proof vs Print	A	9.12	3.21	7.74	8.36	28.43
	B	2.96	6.66	2.60	4.17	16.39
	C	2.74	3.74	2.12	4.65	13.25
						58.07
	Tc	14.82	13.61	12.46	17.18	58.07

Column Mean Variance	4.08
Row Mean Variance	32.10
Total Sum of Squares	67.14

	Sum of Sq	df	Mean Square
Row Means	32.10	2.00	16.05
Column Means	4.08	3.00	1.36
Residual	30.96	6.00	5.16
Total	67.14	11.00	

F Rows for difference among rows

F=10.52/3.4

F= 3.11

F Columns for difference among columns

F= 0.63/3.4

F= 0.26

ANOVA for ΔE of 50% Dot

		Cyan	Magenta	Yellow	Black	Tp
Proof vs Print	A	13.86	5.38	9.94	7.56	36.74
	B	8.49	6.44	2.43	6.50	23.86
	C	7.15	3.69	2.26	5.26	18.36
						78.96
	Tc	29.50	15.51	14.63	19.32	78.96

Column Mean Variance	46.50
Row Mean Variance	44.52
Total Sum of Squares	116.72

	Sum of Sq	df	Mean Square
Row Means	44.52	2.00	22.26
Column Means	46.50	3.00	15.50
Residual	25.70	6.00	4.28
Total	116.72	11.00	

F Rows for difference among rows

F=22.26/4.28

F= 5.20

F Columns for difference among columns

F= 15.50/4.28

F= 3.62

ANOVA for ΔE of 75% Dot

		Cyan	Magenta	Yellow	Black	Tp
Proof vs Print	A	20.72	9.49	10.16	7.91	48.28
	B	13.41	6.39	2.75	7.15	29.70
	C	10.75	6.96	2.19	3.32	23.22
						101.20
	Tc	44.88	22.84	15.10	18.38	101.20

Column Mean Variance	180.45
Row Mean Variance	84.60
Total Sum of Squares	290.89

	Sum of Sq	df	Mean Square
Row Means	84.60	2.00	42.30
Column Means	180.45	3.00	60.15
Residual	25.83	6.00	4.31
Total	290.88	11.00	

F Rows for difference among rows

F=42.30/4.31

F= 9.82

F Columns for difference among columns

F=60.15/4.31

F= 13.97

ANOVA for ΔE of 95% Dot

		Cyan	Magenta	Yellow	Black	Tp
Proof vs Print	A	15.05	7.05	9.07	10.06	41.23
	B	9.57	6.01	2.43	9.26	27.27
	C	7.28	5.23	2.30	8.48	23.29
						91.79
	Tc	31.90	18.29	13.80	27.80	91.79

Column Mean Variance	69.66
Row Mean Variance	44.35
Total Sum of Squares	134.39

	Sum of Sq	df	Mean Square
Row Means	44.35	2.00	22.18
Column Means	69.66	3.00	23.22
Residual	20.38	6.00	3.40
Total	134.39	11.00	

F Rows for difference among rows

F=22.18/3.4

F= 6.53

F Columns for difference among columns

F= 23.22/3.4

F= 6.84

Observations-visual match closest to press sheet

	A	B	C	Proof
1	3	1	2	
2	1	2	3	
3	1	3	2	
4	3	1	2	
5	2	1	3	
6	2	3	1	
7	3	1	2	
8	1	2	3	
9	3	2	1	
10	2	1	3	
11	1	2	3	
12	2	1	3	
13	3	1	2	
14	1	2	3	
15	1	3	2	
16	1	2	3	
17	2	1	3	
18	1	2	3	
19	2	3	1	
20	3	2	1	
21	3	1	2	
22	2	3	1	
23	1	2	3	
24	3	1	2	
25	2	3	1	
26	1	2	3	
27	1	2	3	
28	3	1	2	
29	2	3	1	
30	2	1	3	
31	1	2	3	
total	59	57	70	186

Out 3.16129
Within 55

	Sum of Sq	df	Mean Sq
Out	3.16	2	1.58
Within	55	28	1.96
	58.16		

F Ratio

F=1.58/1.96

F= 0.804364 $F_{95}(2,28)= 3.34$

Appendix C

Photomicrographs

The purpose of this section is to show the electronic images that were captured at the Center of Imaging Science under the supervision of Dr. Jonathon Arney. The images were captured using a monochrome live-action CCD camera attached to a microscope. One problem that was encountered was, the flexographic printing dots are "hollow"; this caused a dilema as to whether or not the hollow center was "dot" or "not dot". It was decided, with Dr. Arney's assistance, that both a densitometer and the human visual system would consider the hollow portion of the dot as part of the dot. Figures C-1 and C-2 show how the threshold was adjusted on the microdensitometer in order to include the hollow portion as part of the dot.

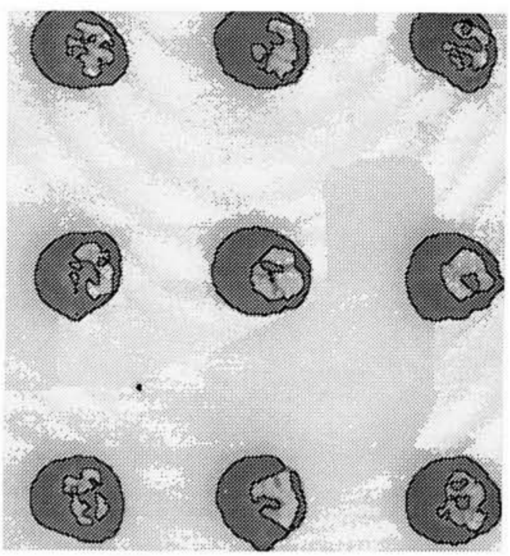


figure C-1; the microdensitometer set at a threshold of 111, excludes the center.

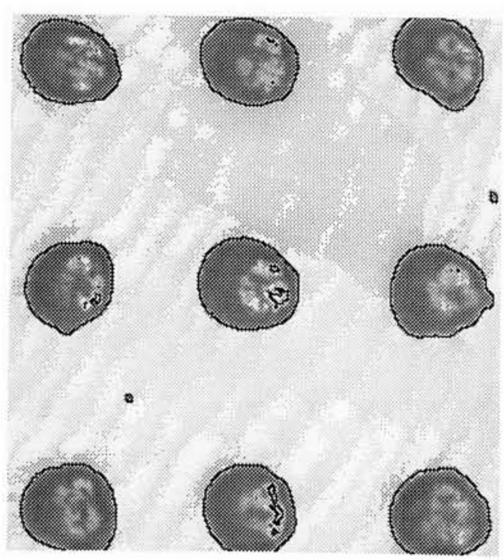


figure C-2; the microdensitometer set at a threshold of 141, includes the center.

Flexographic Press Sheet-Cyan

figure C-3; micrograph of the 5% cyan dot on the flexographic press sheet.

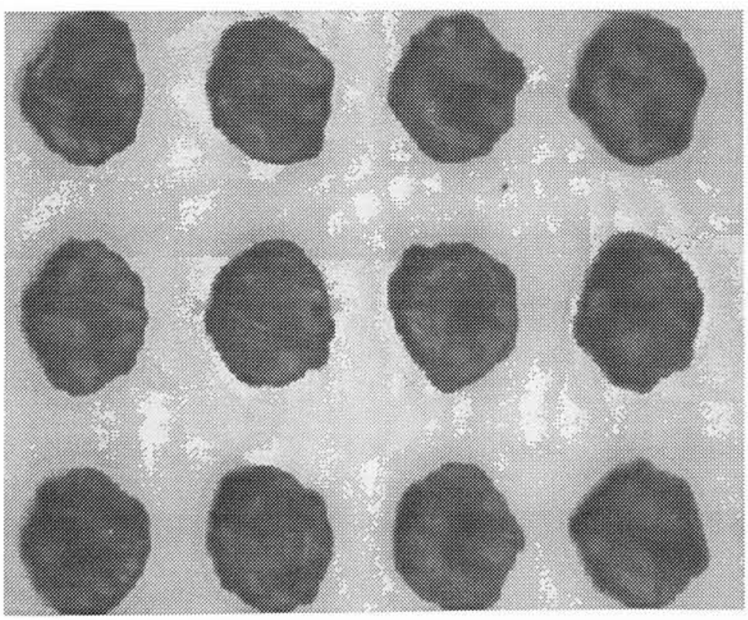


figure C-4; micrograph of the 25% cyan dot on the flexographic press sheet.

Flexographic Press Sheet-Cyan

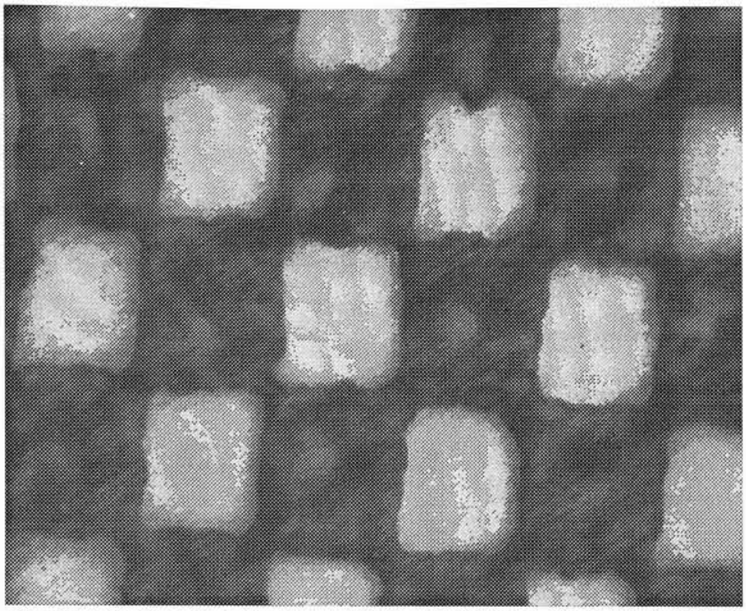


figure C-5; micrograph of the 50% cyan dot on the flexographic press sheet.

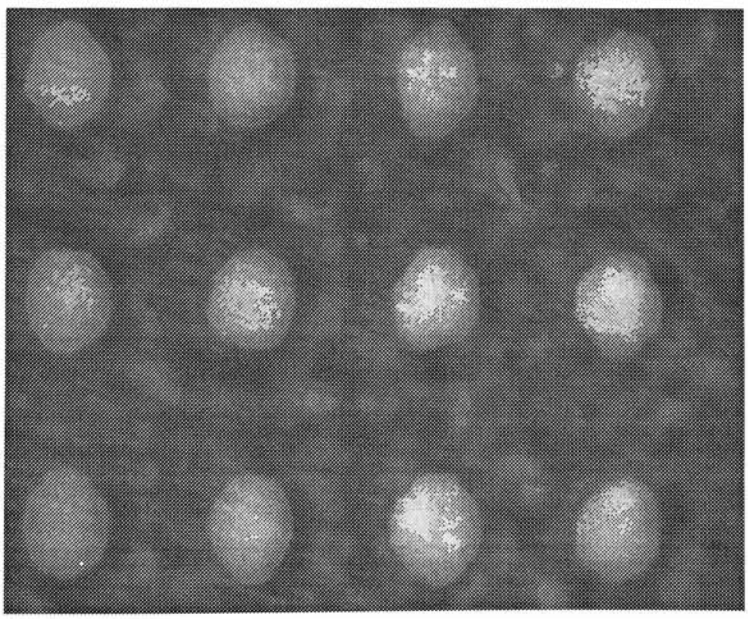


figure C-6; micrograph of the 75% cyan dot on the flexographic press sheet.

Flexographic Press Sheet-Cyan

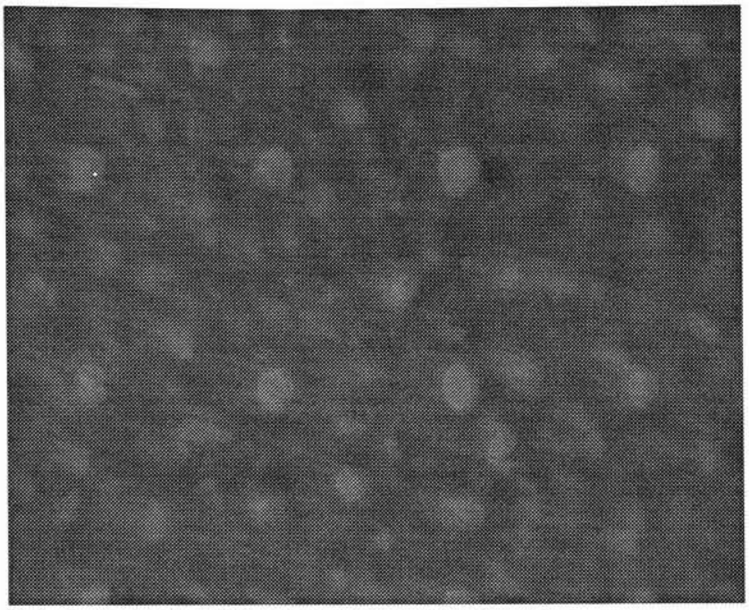


figure C-7; micrograph of the 95% cyan dot on the flexographic press sheet.

Flexographic Press Sheet-Magenta

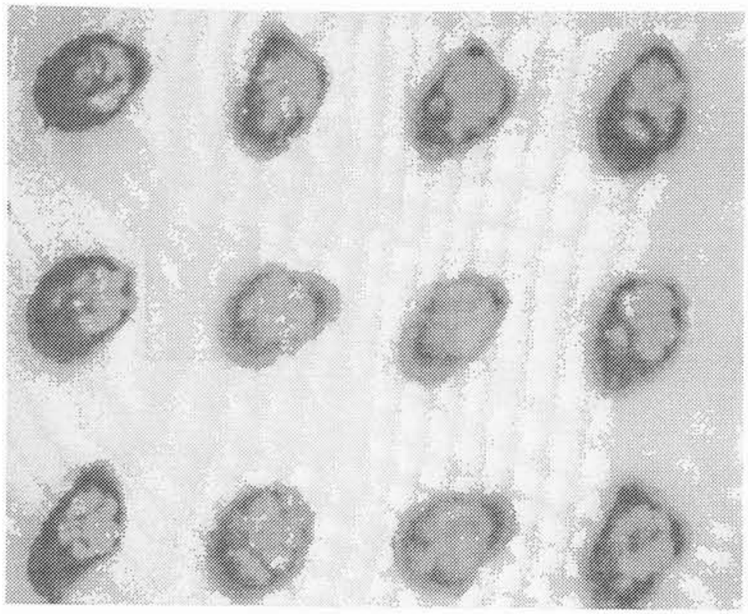


figure C-8; micrograph of the 5% magenta dot on the flexographic press sheet.

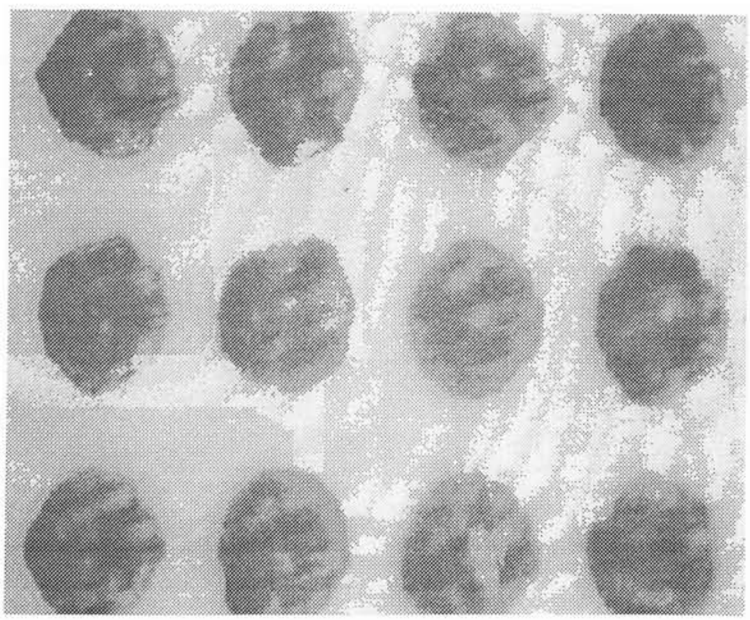


figure C-9; micrograph of the 25% magenta dot on the flexographic press sheet.

Flexographic Press Sheet-Magenta

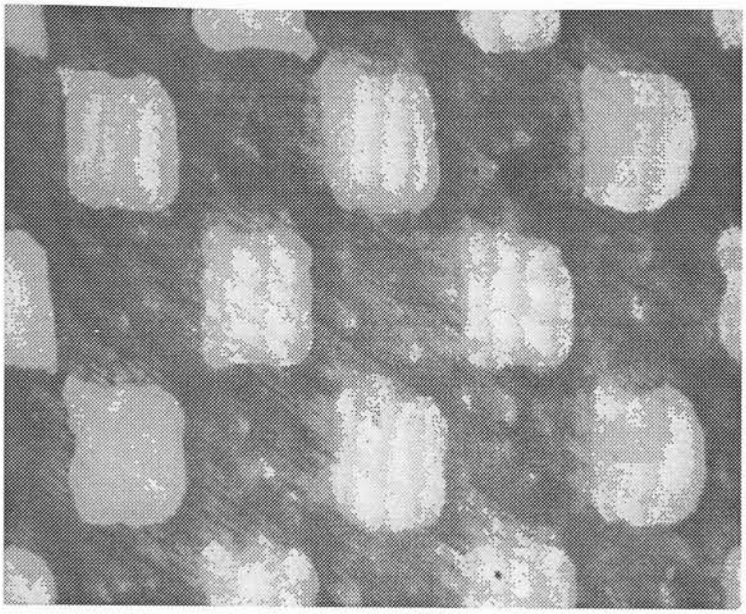


figure C-10; micrograph of the 50% magenta dot on the flexographic press sheet.

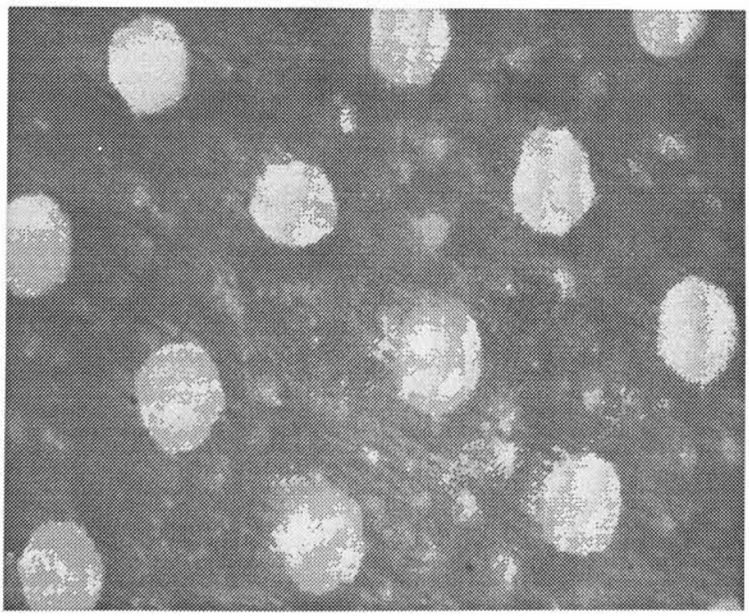


figure C-11; micrograph of the 75% magenta dot on the flexographic press sheet.

Flexographic Press Sheet-Magenta

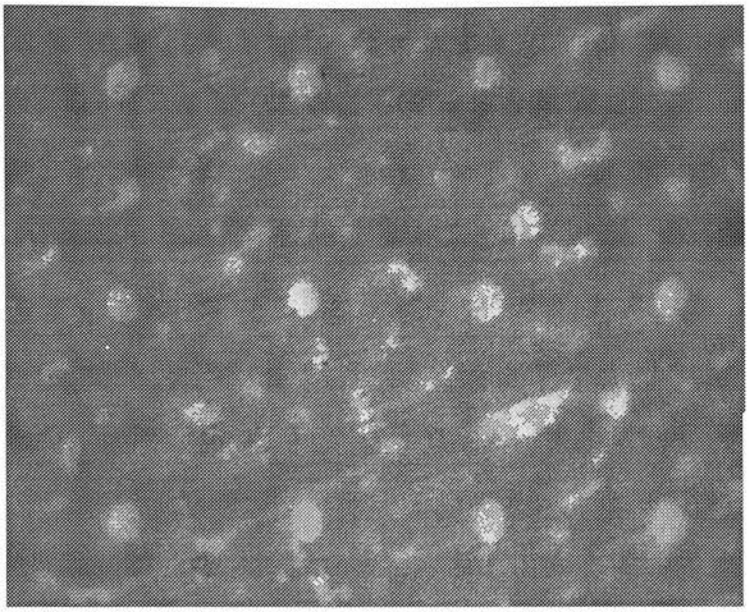


figure C-12; micrograph of the 95% magenta dot on the flexographic press sheet.

Flexographic Press Sheet-Yellow

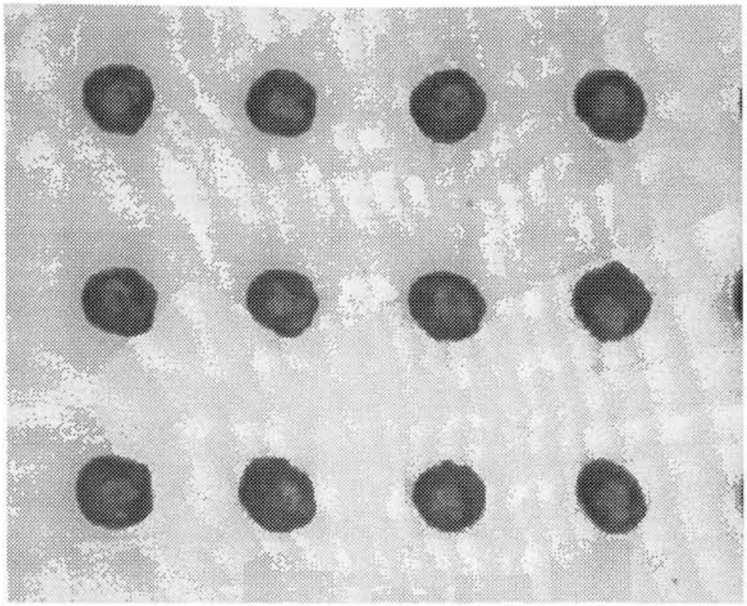


figure C-13; micrograph of the 5% yellow dot on the flexographic press sheet.

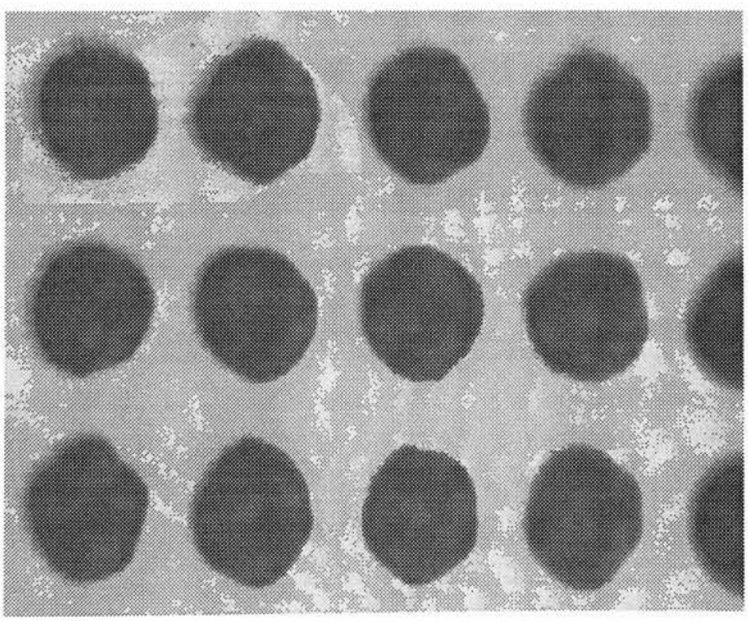


figure C-14; micrograph of the 25% yellow dot on the flexographic press sheet.

Flexographic Press Sheet-Yellow

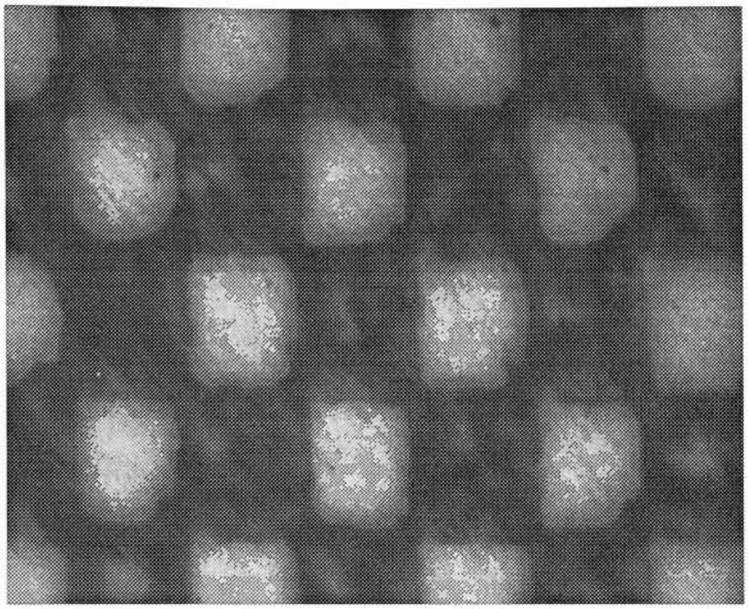


figure C-15; micrograph of the 50%yellow dot on the flexographic press sheet.

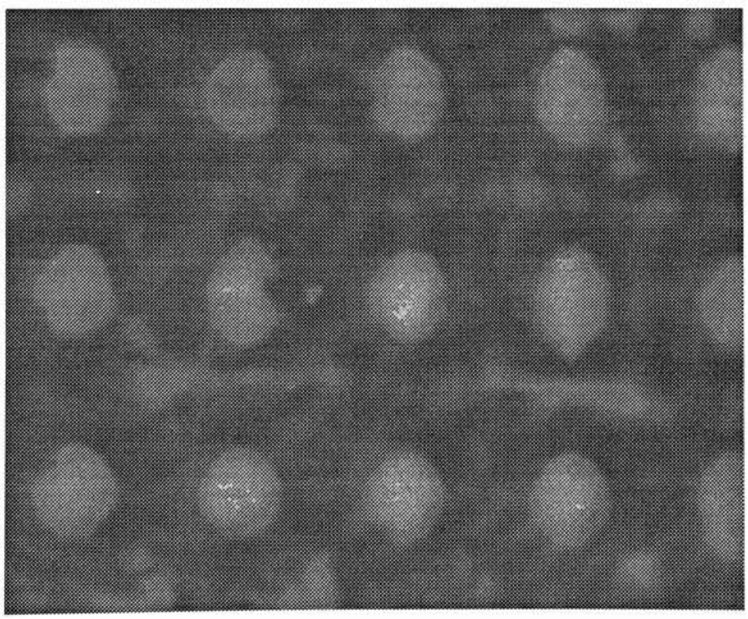


figure C-16; micrograph of the 75%yellow dot on the flexographic press sheet.

Flexographic Press Sheet-Yellow

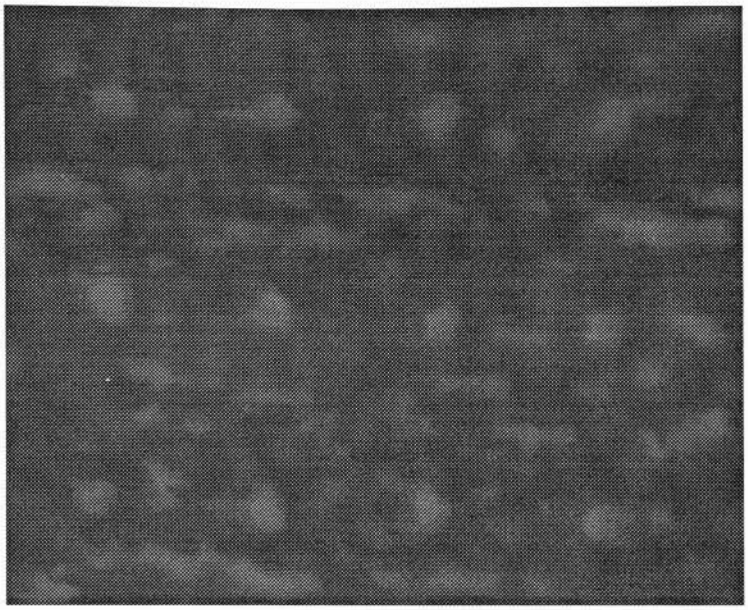


figure C-17; micrograph of the 95% yellow dot on the flexographic press sheet.

Flexographic Press Sheet-Black

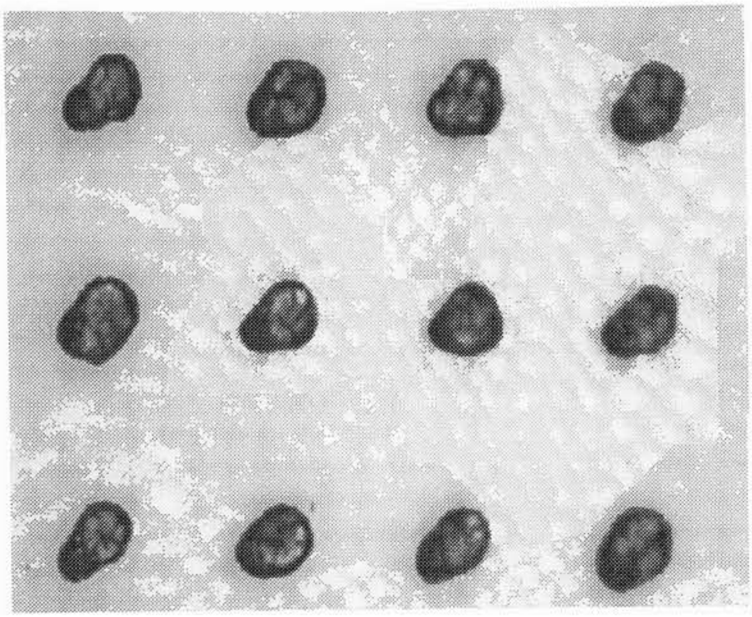


figure C-18; micrograph of the 5% black dot on the flexographic press sheet.

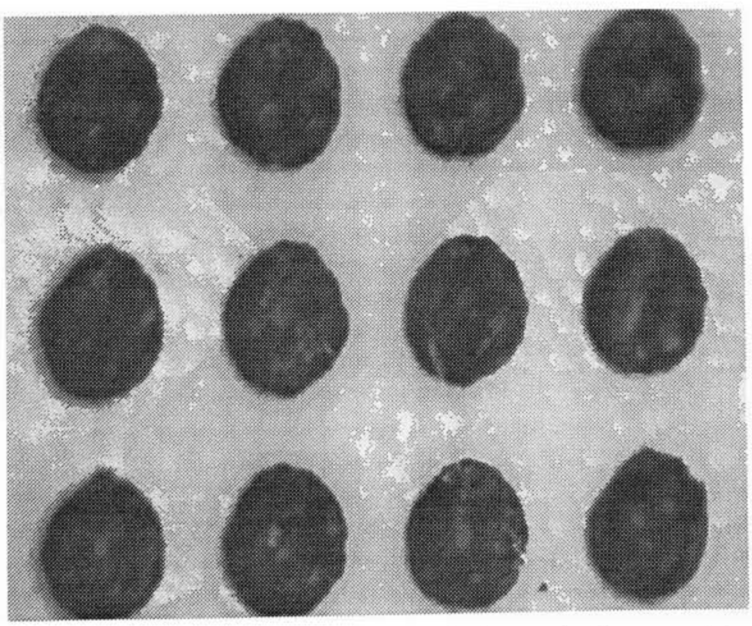


figure C-19; micrograph of the 25% black dot on the flexographic press sheet.

Flexographic Press Sheet-Black

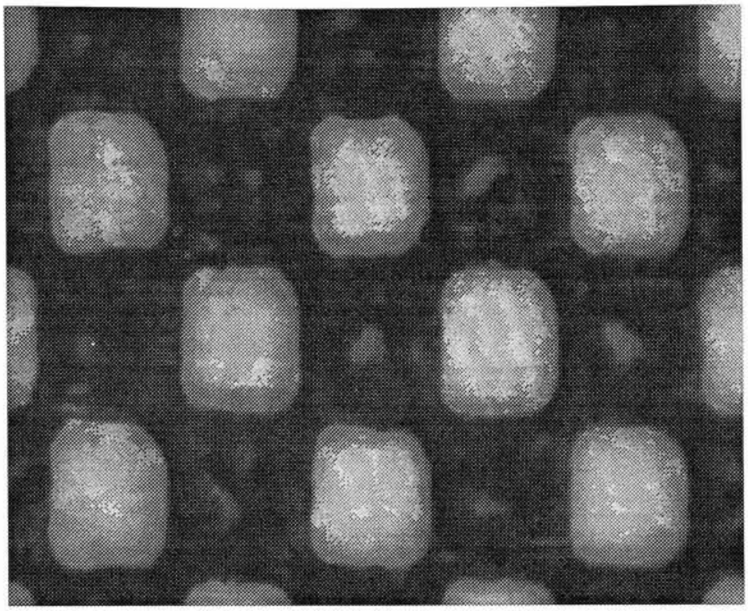


figure C-20; micrograph of the 50% black dot on the flexographic press sheet.

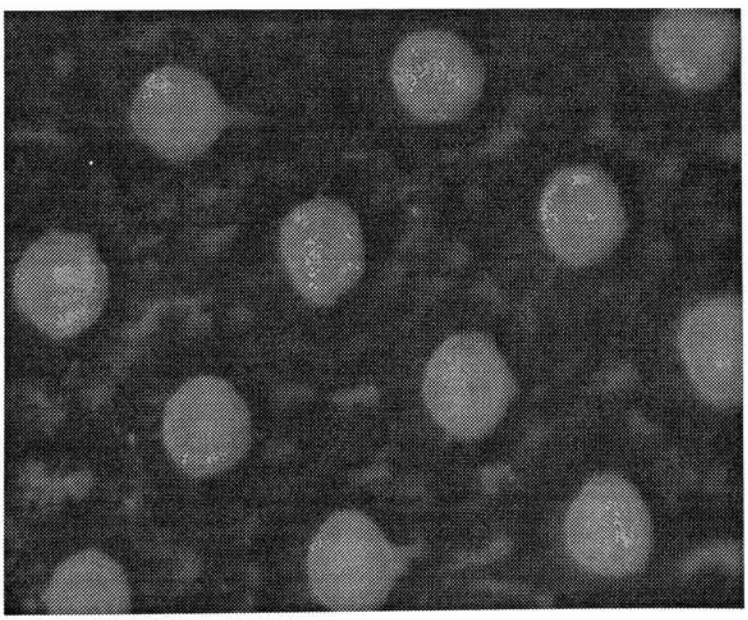


figure C-21; micrograph of the 75% black dot on the flexographic press sheet.

Flexographic Press Sheet-Black

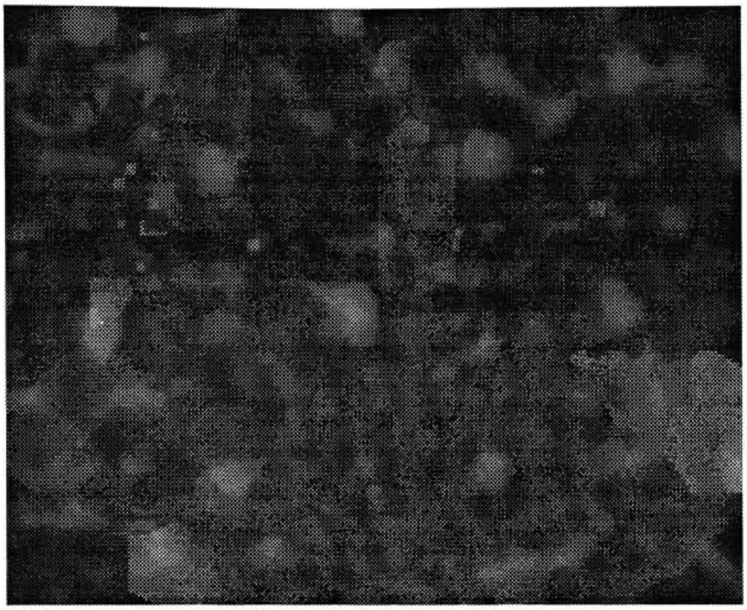


figure C-22; micrograph of the 95% black dot on the flexographic press sheet.

3M Matchprint-Cyan

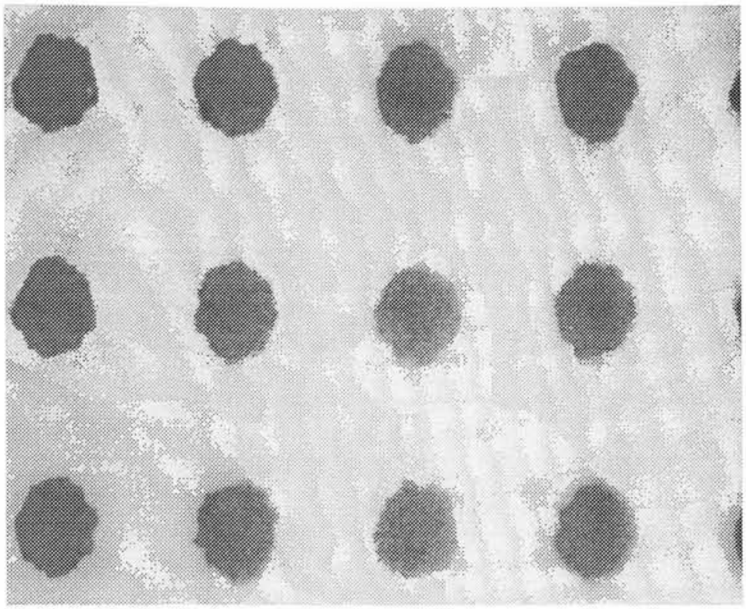


figure C-23; micrograph of the 5% cyan dot on the 3M Matchprint.

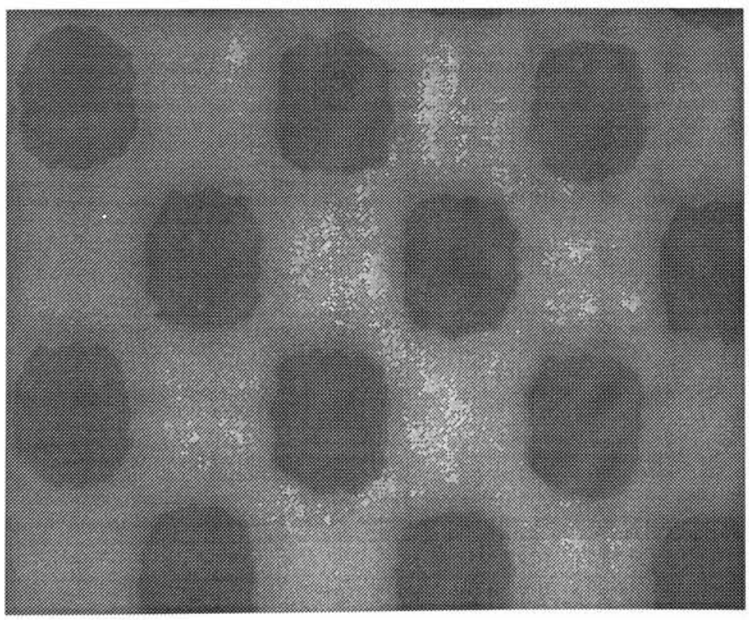


figure C-24; micrograph of the 25% cyan dot on the 3M Matchprint.

3M Matchprint-Cyan

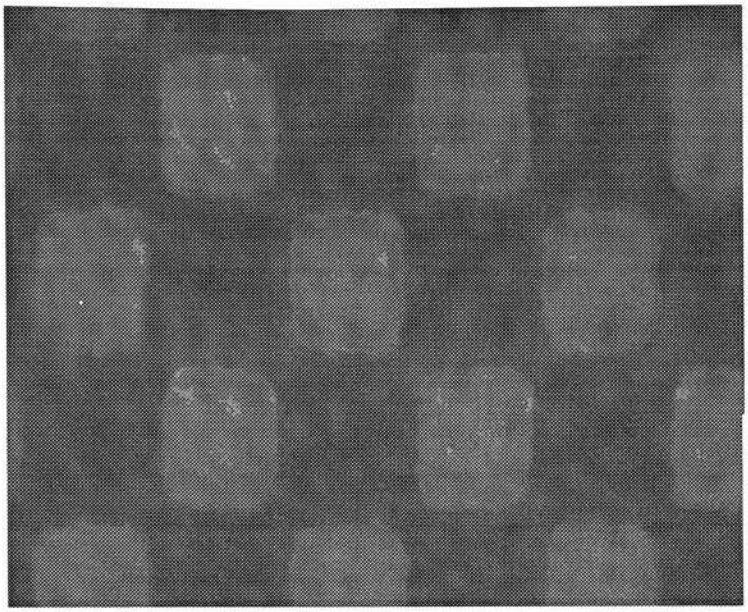


figure C-25; micrograph of the 50% cyan dot on the 3M Matchprint.

figure C-26; micrograph of the 75% cyan dot on the 3M Matchprint.

3M Matchprint-Cyan

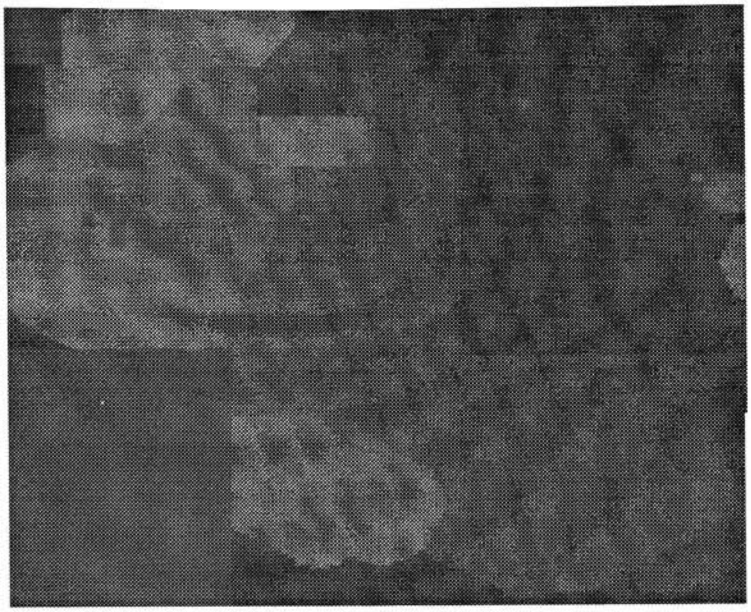


figure C-27; micrograph of the 95% cyan dot on the 3M Matchprint.

3M Matchprint-Magenta

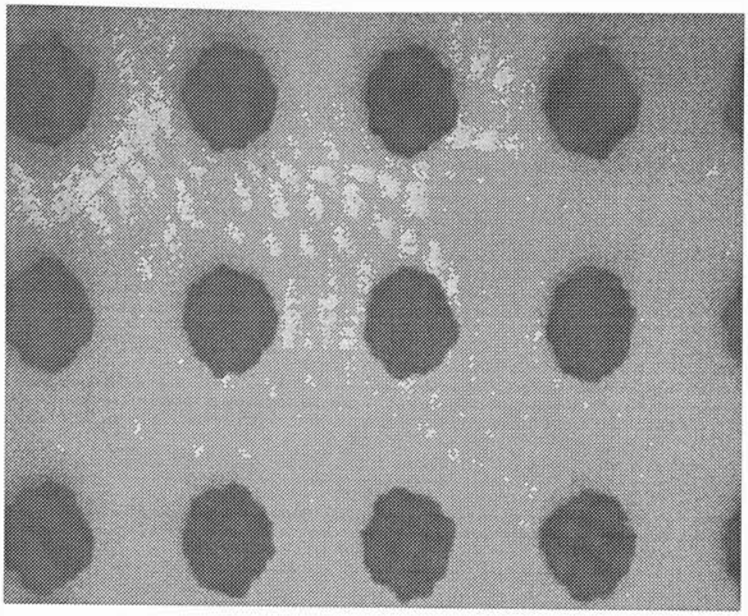


figure C-28; micrograph of the 5% magenta dot on the 3M Matchprint.

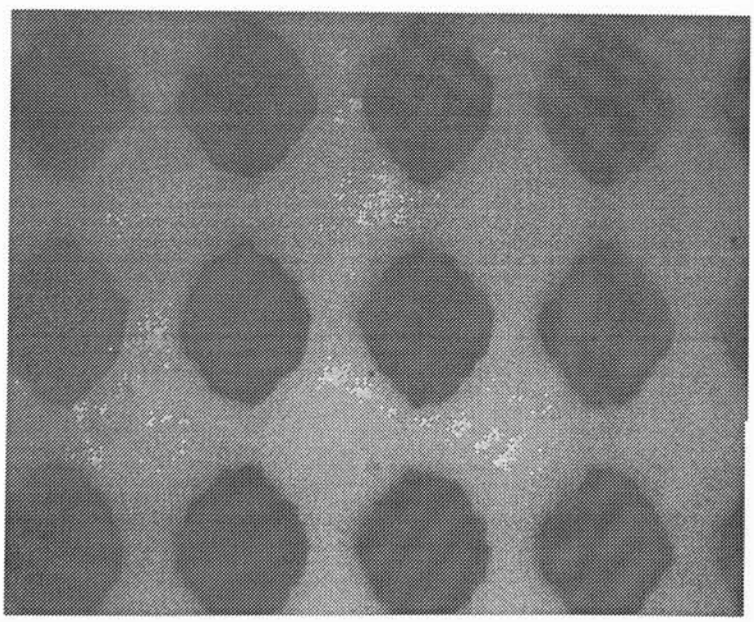


figure C-29; micrograph of the 25% magenta dot on the 3M Matchprint.

3M Matchprint-Magenta

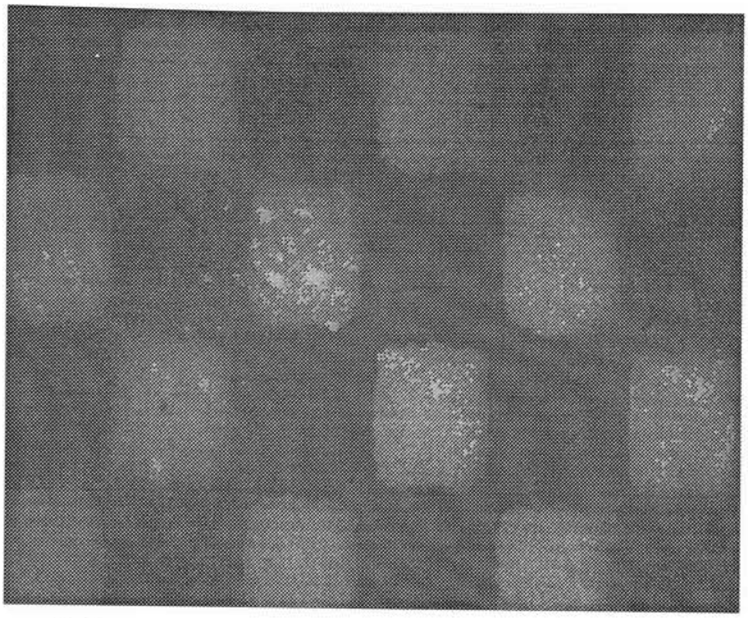


figure C-30; micrograph of the 50% magenta dot on the 3M Matchprint.

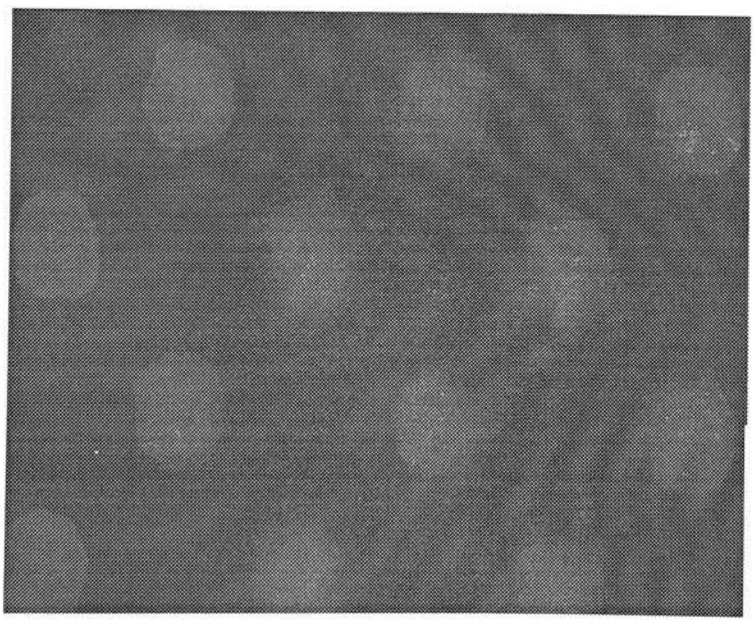


figure C-31; micrograph of the 75% magenta dot on the 3M Matchprint.

3M Matchprint-Magenta

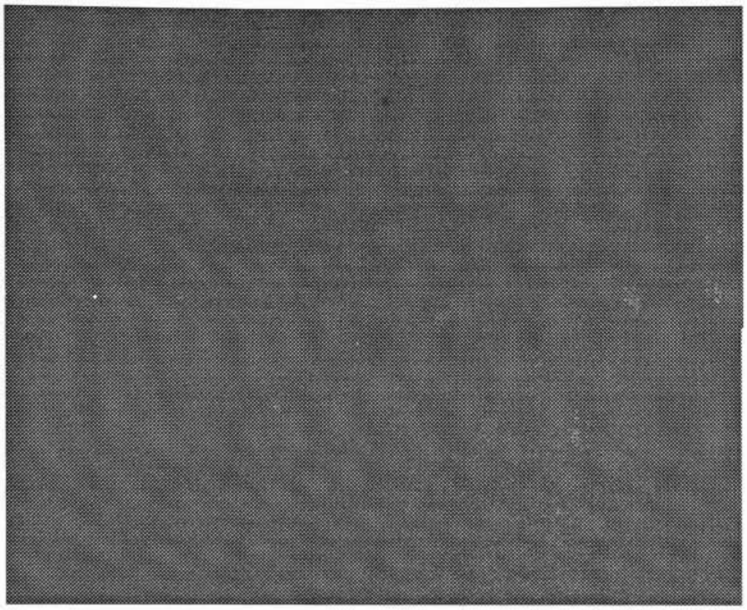


figure C-32; micrograph of the 95% magenta dot on the 3M Matchprint.

3M Matchprint-Yellow

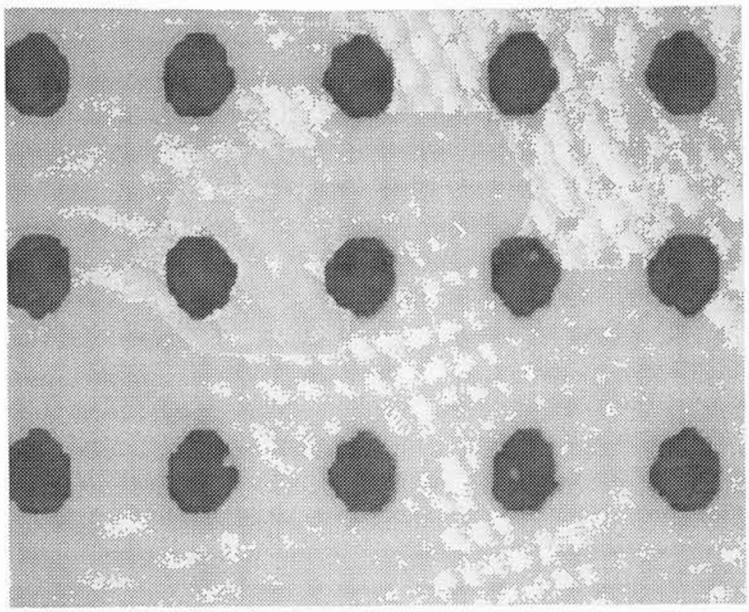


figure C-33; micrograph of the 5% yellow dot on the 3M Matchprint.

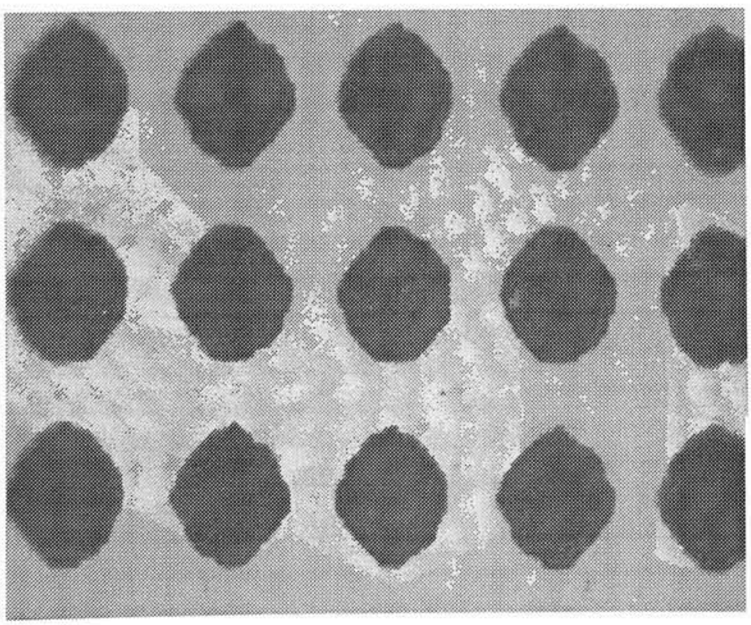


figure C-34; micrograph of the 25% yellow dot on the 3M Matchprint.

3M Matchprint-Yellow

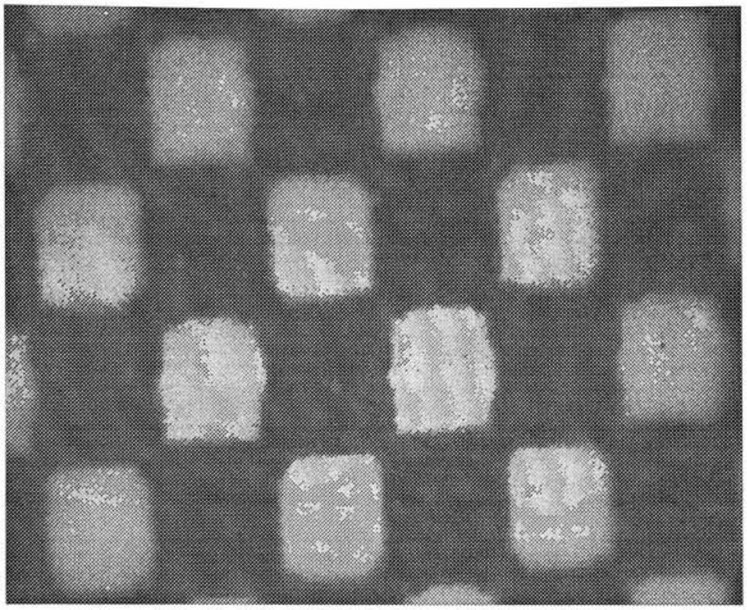


figure C-35; micrograph of the 50% yellow dot on the 3M Matchprint.

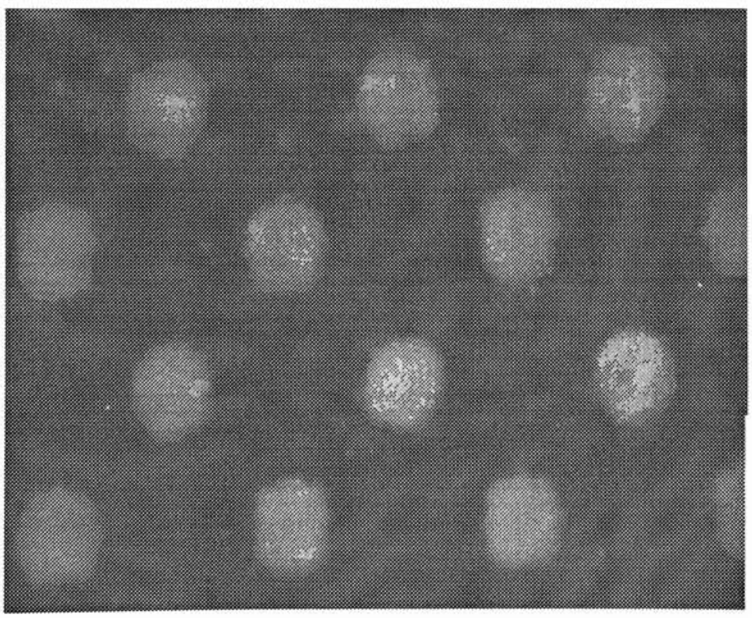


figure C-36; micrograph of the 75% yellow dot on the 3M Matchprint.

3M Matchprint-Yellow

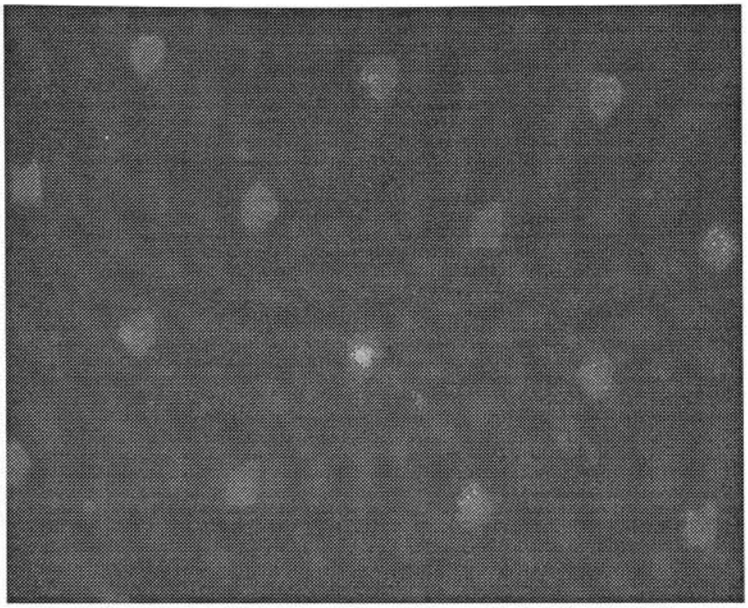


figure C-37; micrograph of the 95% yellow dot on the 3M Matchprint.

3M Matchprint-Black

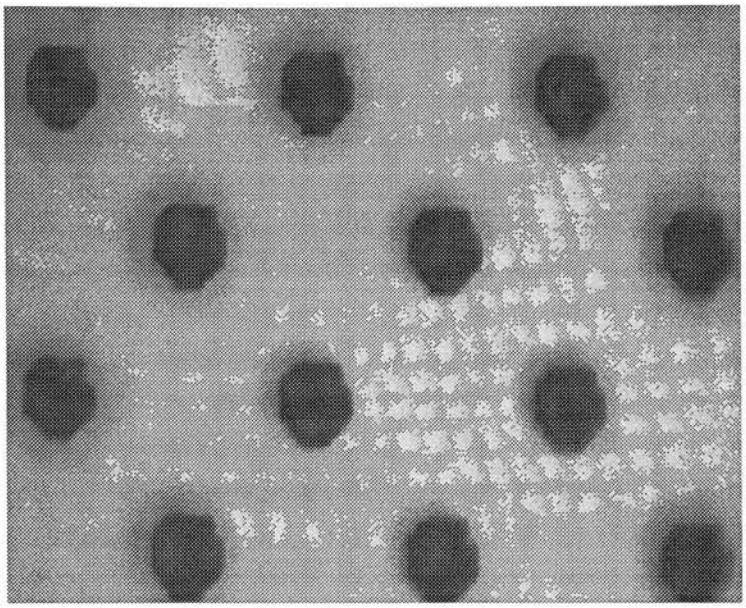


figure C-38; micrograph of the 5% black dot on the 3M Matchprint.

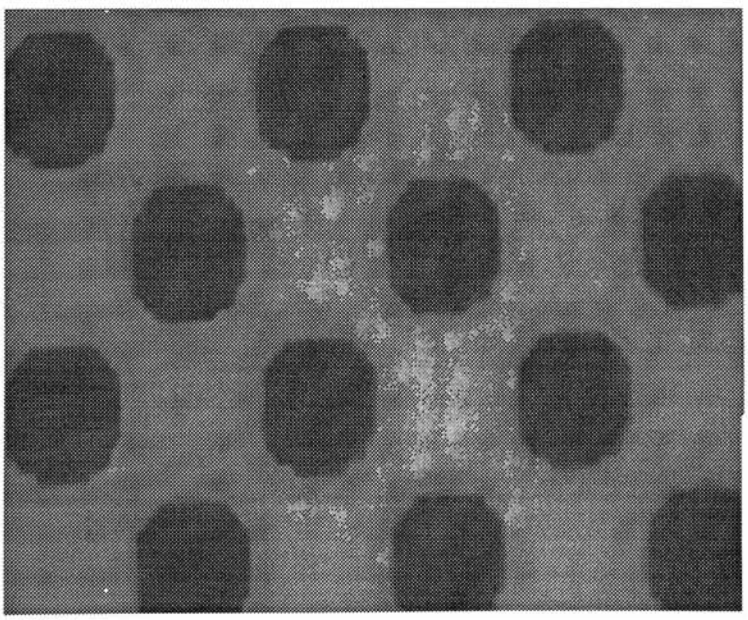


figure C-39; micrograph of the 25% black dot on the 3M Matchprint.

3M Matchprint-Black

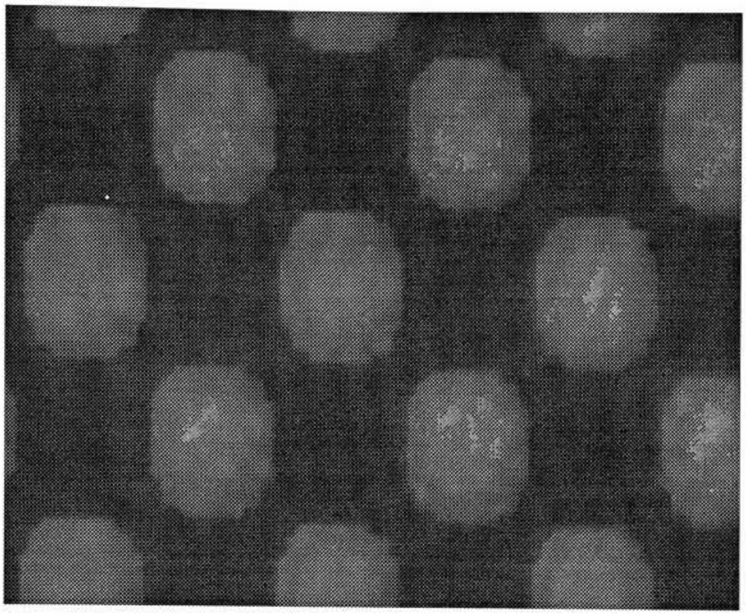


figure C-40; micrograph of the 50% black dot on the 3M Matchprint.

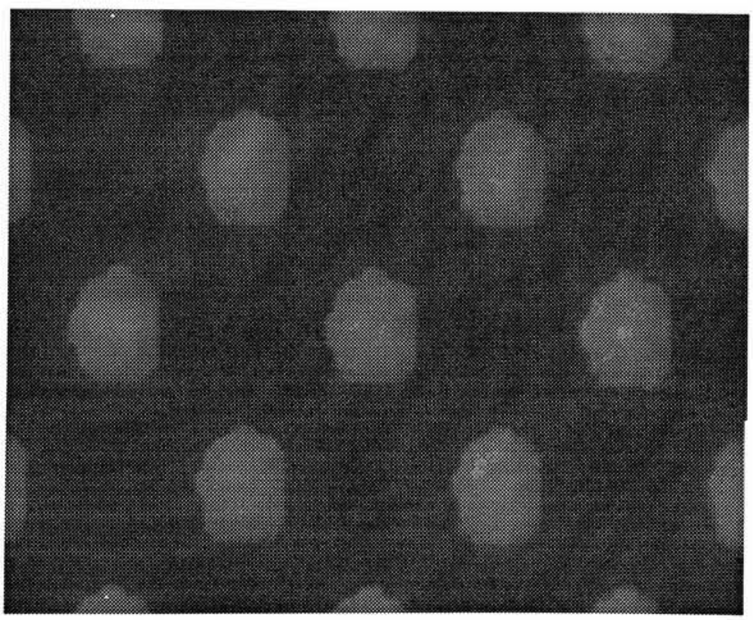


figure C-41; micrograph of the 75% black dot on the 3M Matchprint.

3M Matchprint-Black

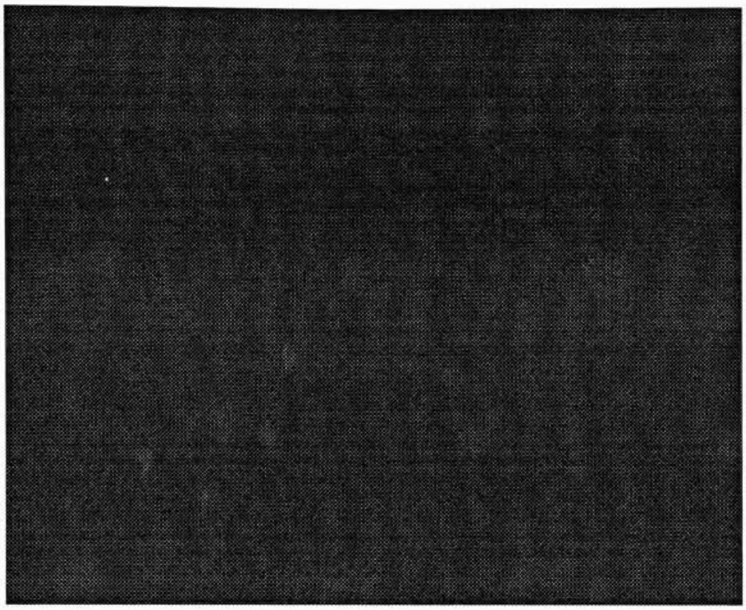


figure C-42; micrograph of the 95% black dot on the 3M Matchprint.

Digital Proofing System A-Cyan

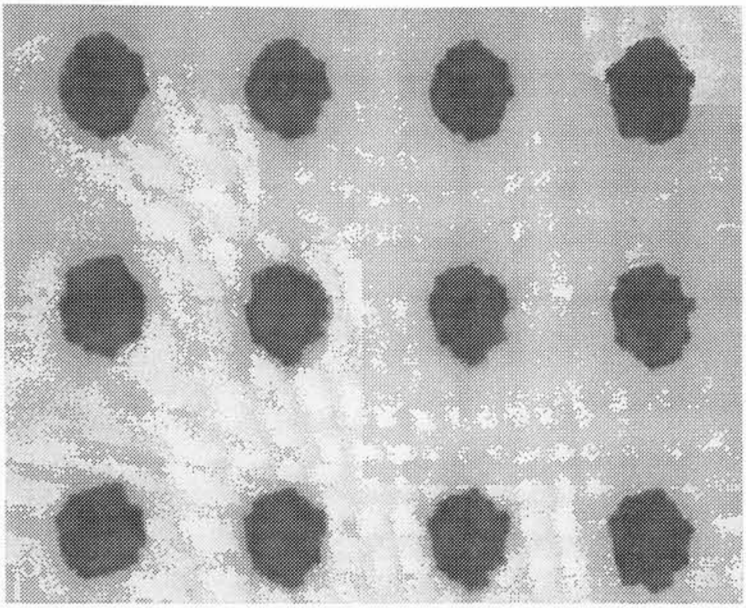


figure C-43; micrograph of the 5%cyan dot on Digital Proofing System A.

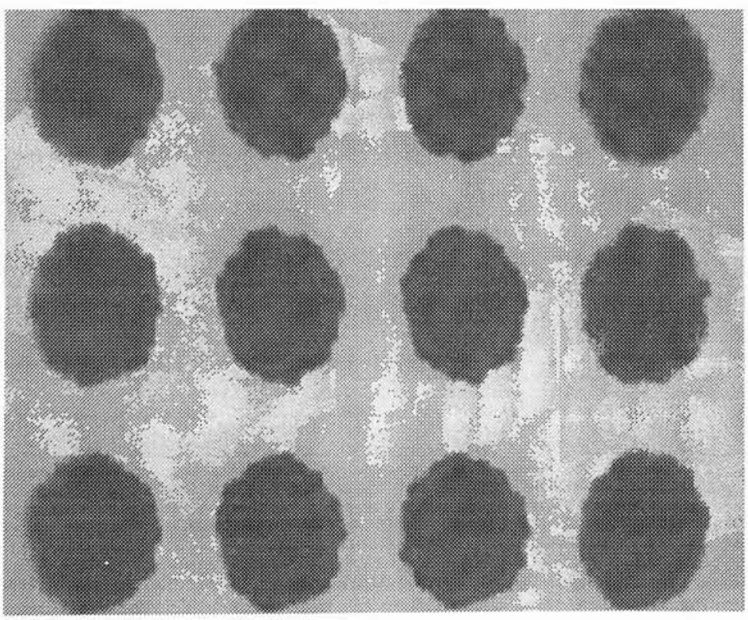


figure C-44; micrograph of the 25% cyan dot on Digital Proofing System A.

Digital Proofing System A-Cyan

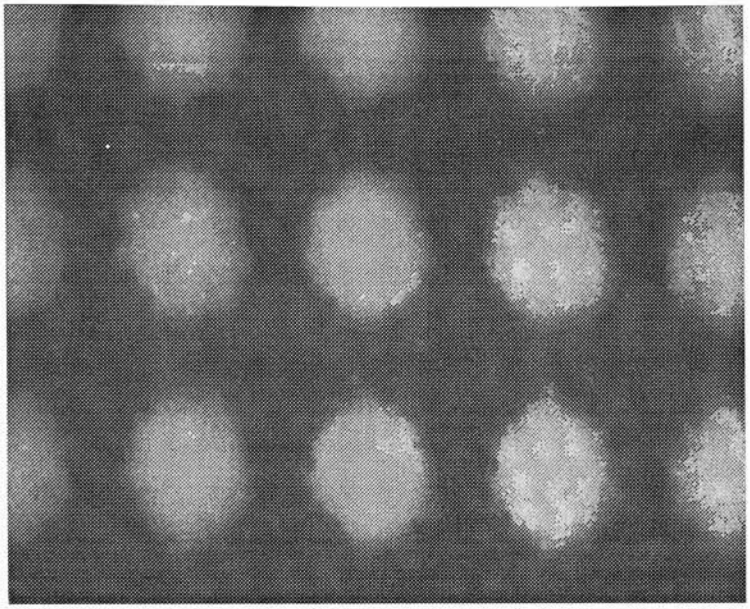


figure C-45; micrograph of the 50% cyan dot on Digital Proofing System A.

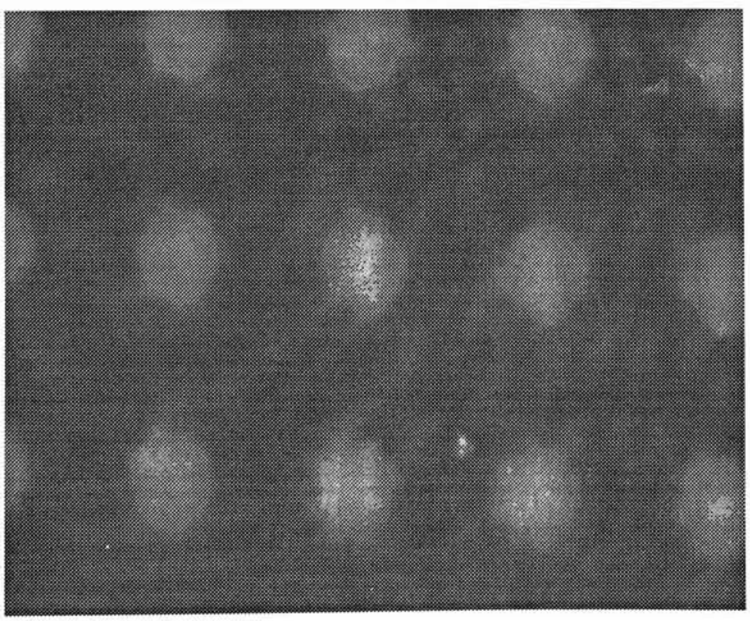


figure C-46; micrograph of the 75% cyan dot on Digital Proofing System A.

Digital Proofing System A-Cyan

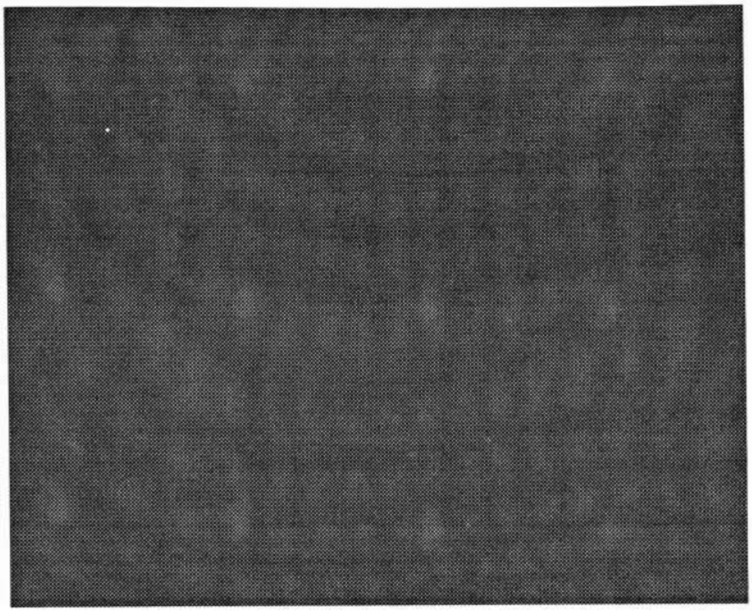


figure C-47; micrograph of the 95% cyan dot on Digital Proofing System A.

Digital Proofing System A-Magenta

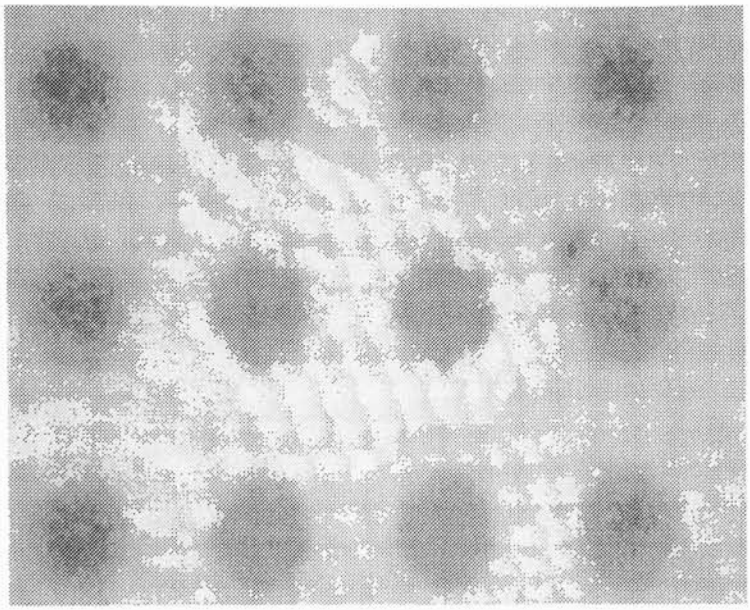


figure C-48; micrograph of the 5% magenta dot on Digital Proofing System A.

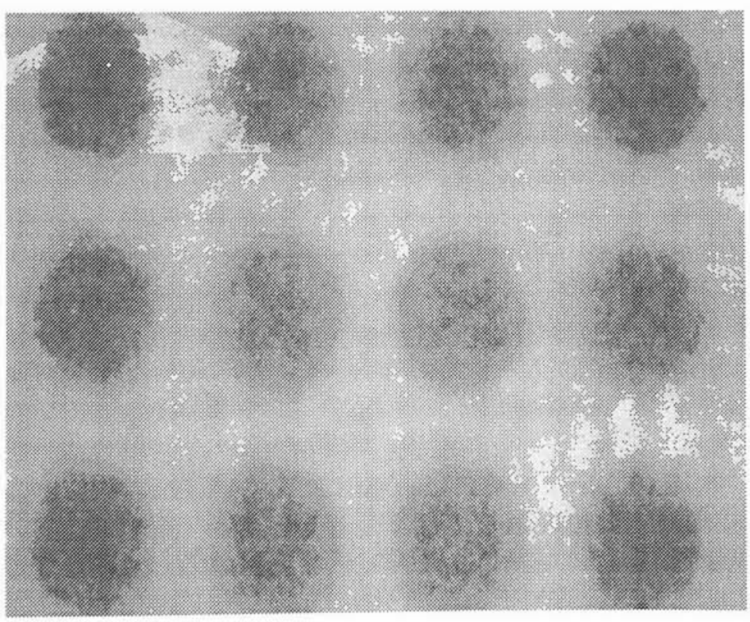


figure C-49; micrograph of the 25% magenta dot on Digital Proofing System A.

Digital Proofing System A-Magenta

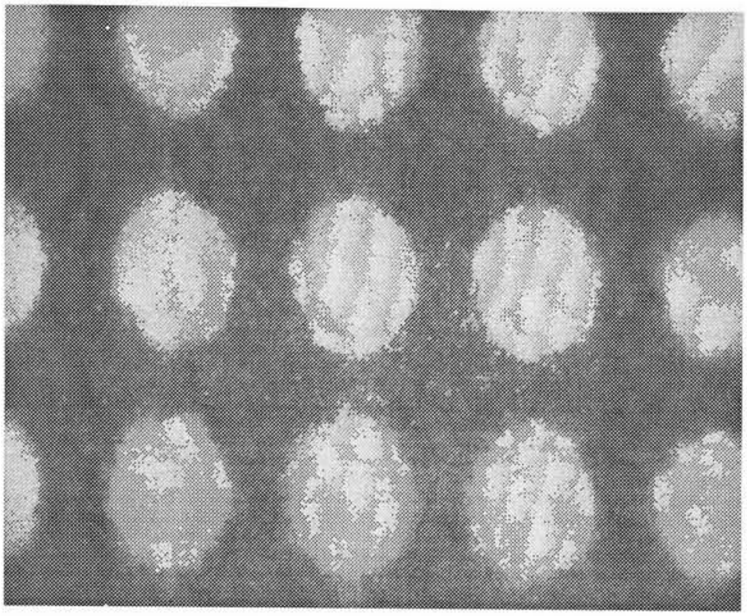


figure C-50; micrograph of the 50% magenta dot on Digital Proofing System A.

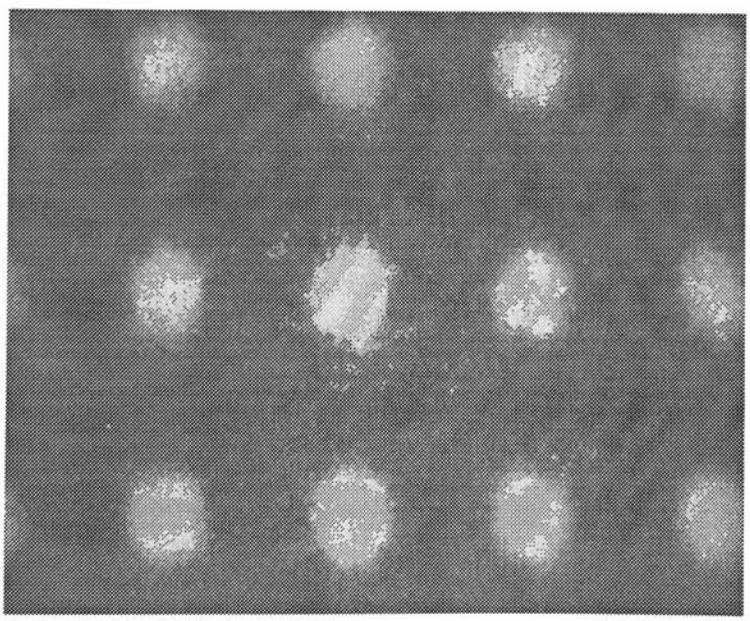


figure C-51; micrograph of the 75% magenta dot on Digital Proofing System A.

Digital Proofing System A-Magenta

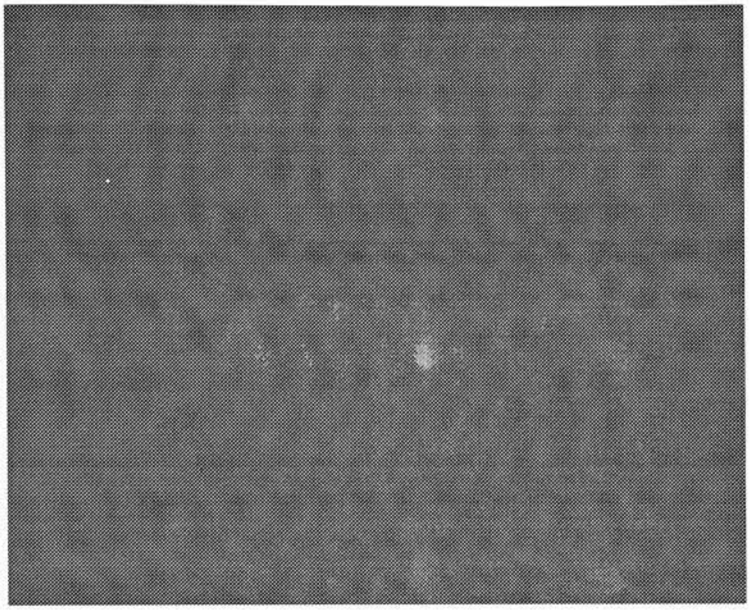


figure C-52; micrograph of the 95% magenta dot on Digital Proofing System A.

Digital Proofing System A-Yellow

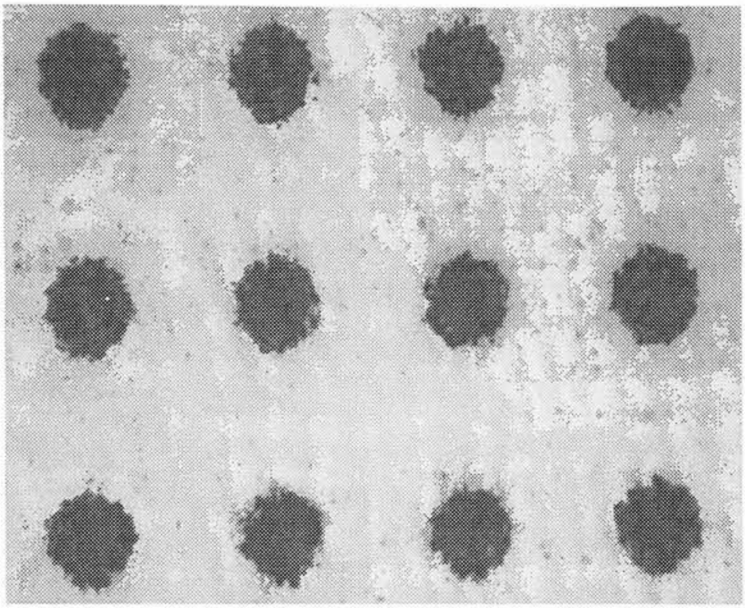


figure C-53; micrograph of the 5% yellow dot on Digital Proofing System A.

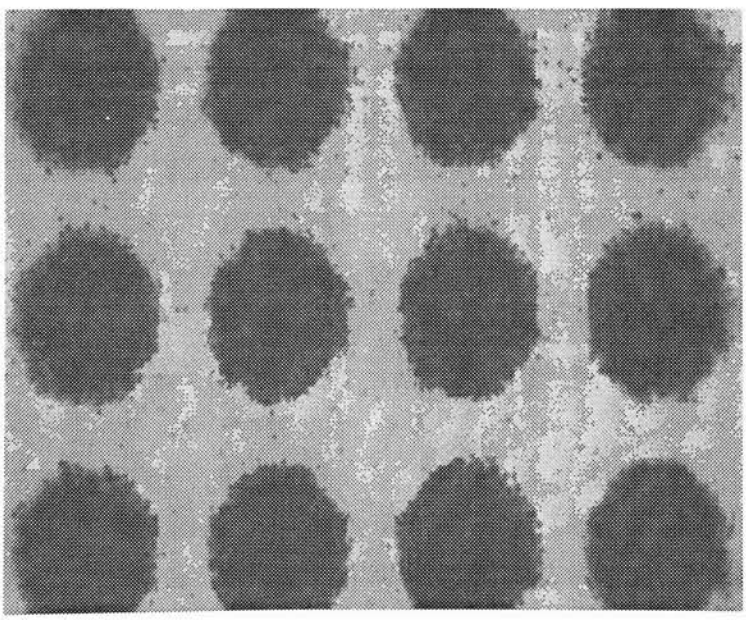


figure C-54; micrograph of the 25% yellow dot on Digital Proofing System A.

Digital Proofing System A-Yellow

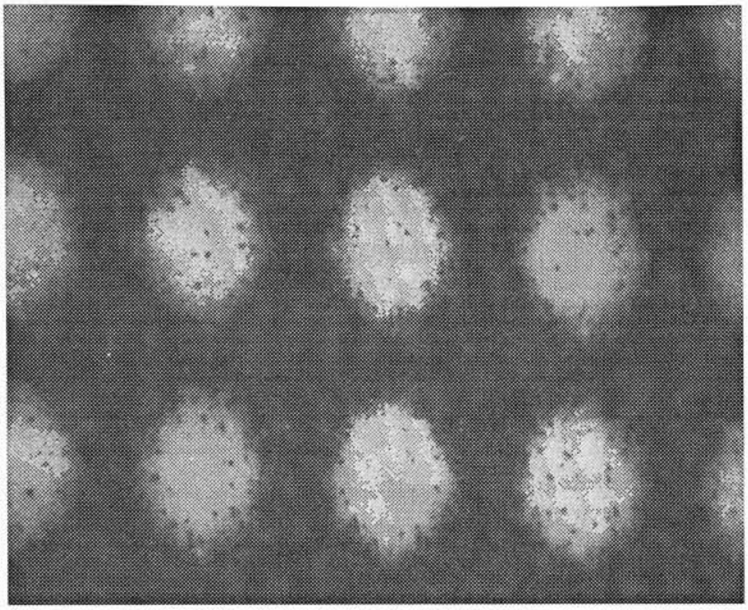


figure C-55; micrograph of the 50% yellow dot on Digital Proofing System A.

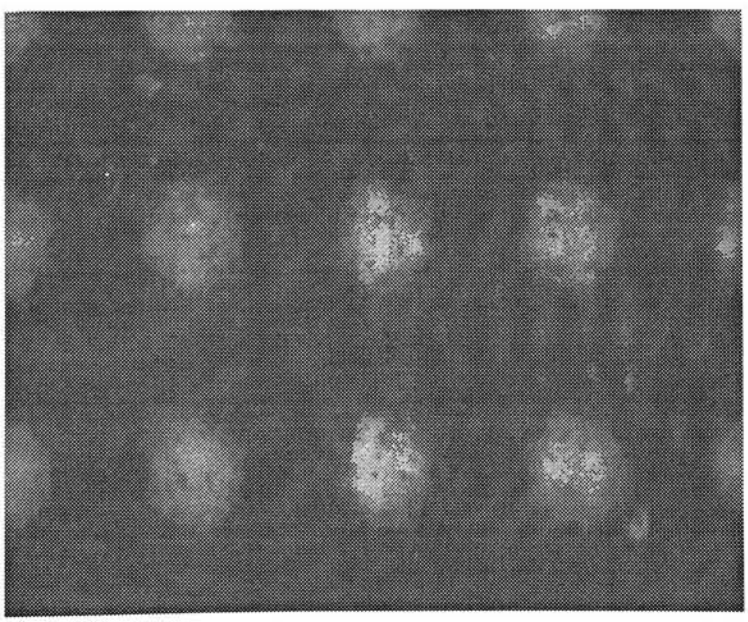


figure C-56; micrograph of the 75% yellow dot on Digital Proofing System A.

Digital Proofing System A-Yellow

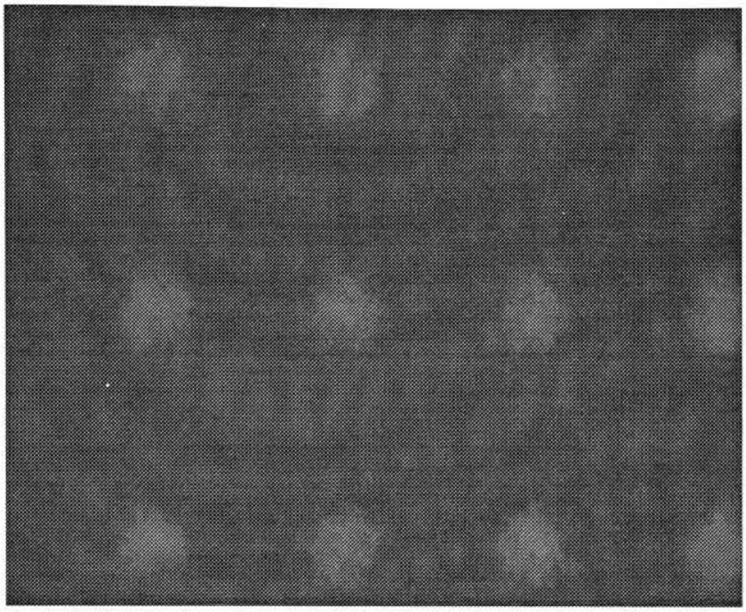


figure C-57; micrograph of the 95% yellow dot on Digital Proofing System A.

Digital Proofing System A-Black

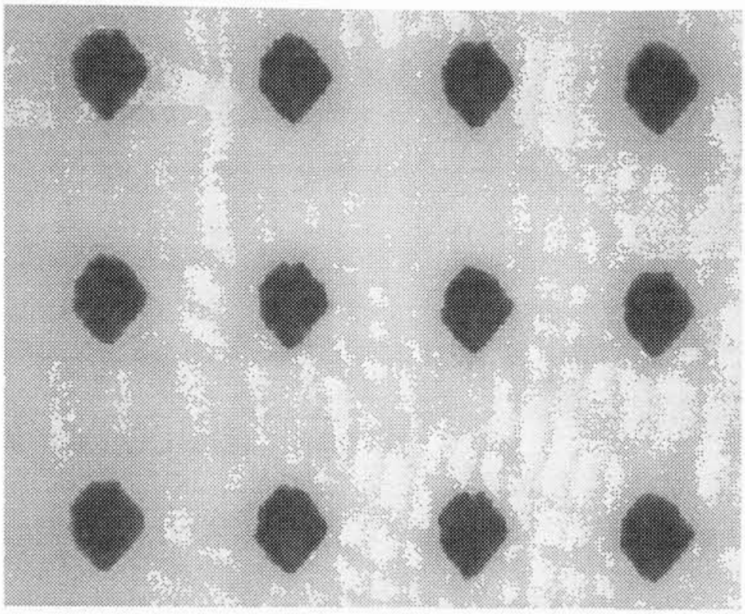


figure C-58; micrograph of the 5% black dot on Digital Proofing System A.

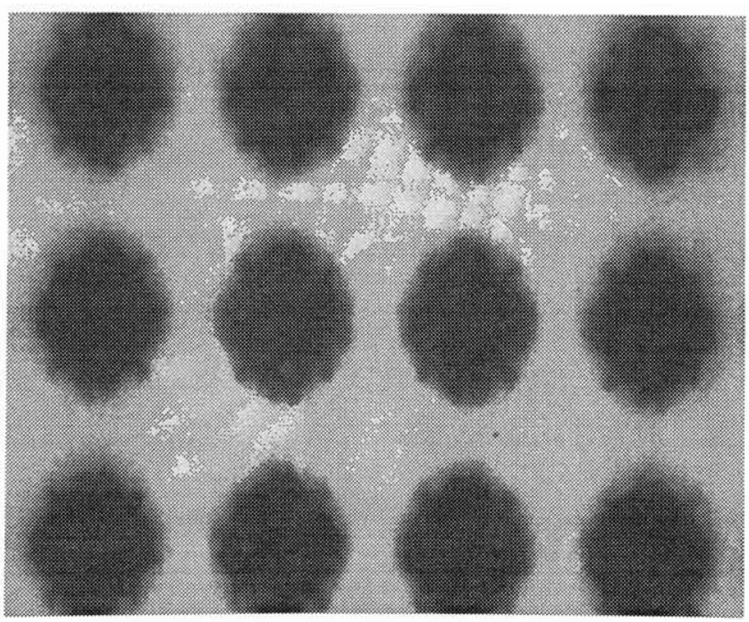


figure C-59; micrograph of the 25% black dot on Digital Proofing System A.

Digital Proofing System A-Black

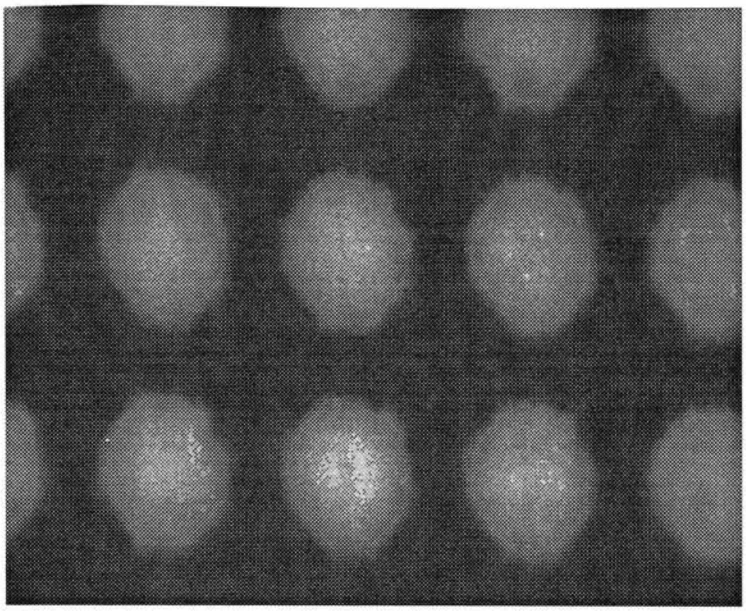


figure C-60; micrograph of the 50% black dot on Digital Proofing System A.

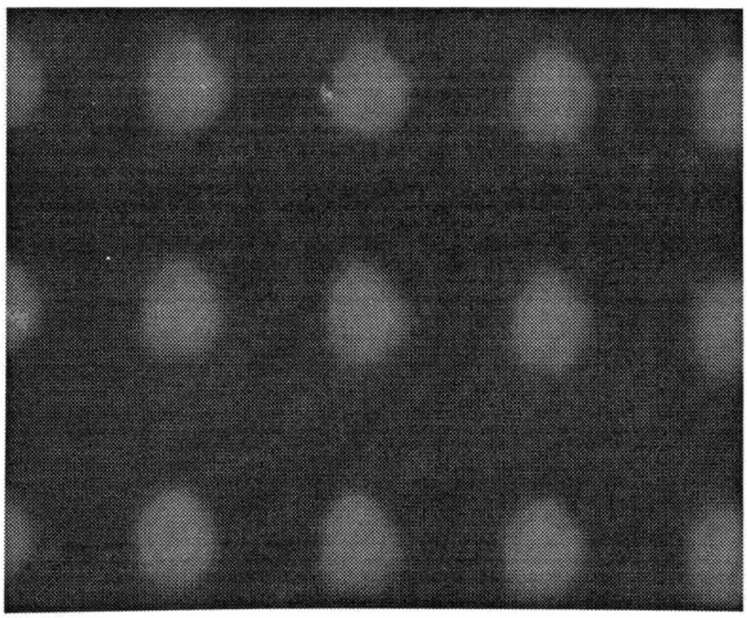


figure C-61; micrograph of the 75% black dot on Digital Proofing System A.

Digital Proofing System A-Black

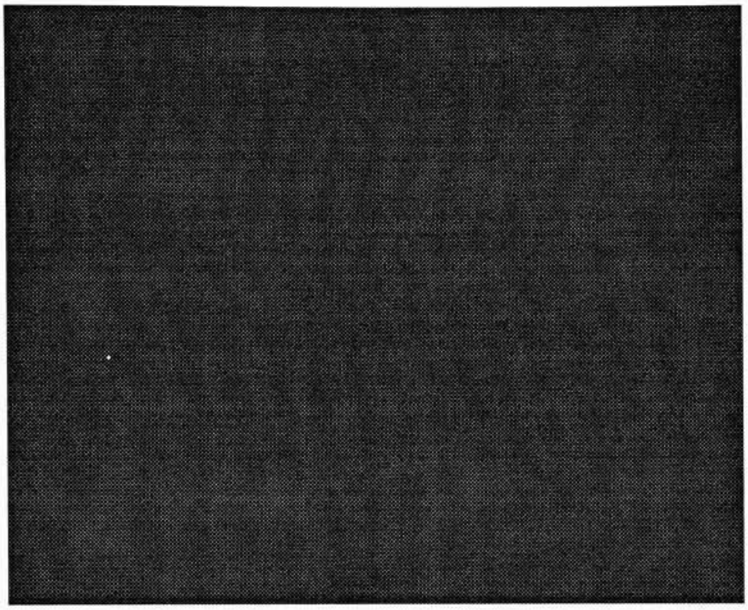


figure C-62; micrograph of the 95% black dot on Digital Proofing System A.

Digital Proofing System B-Cyan

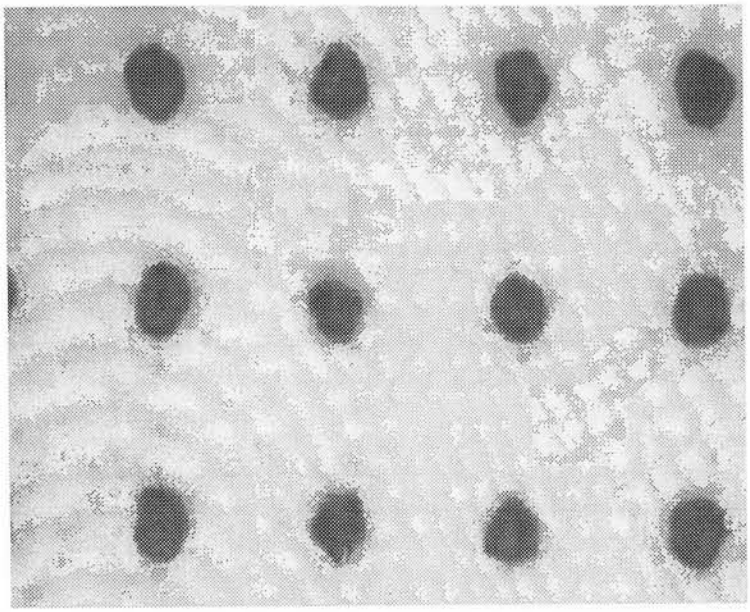


figure C-63; micrograph of the 5% cyan dot on Digital Proofing System B.

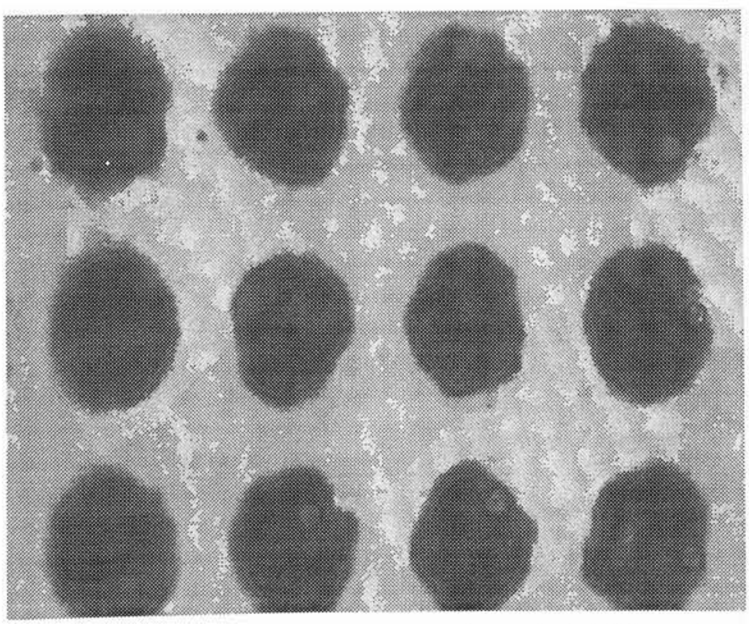


figure C-64; micrograph of the 25% cyan dot on Digital Proofing System B.

Digital Proofing System B-Cyan

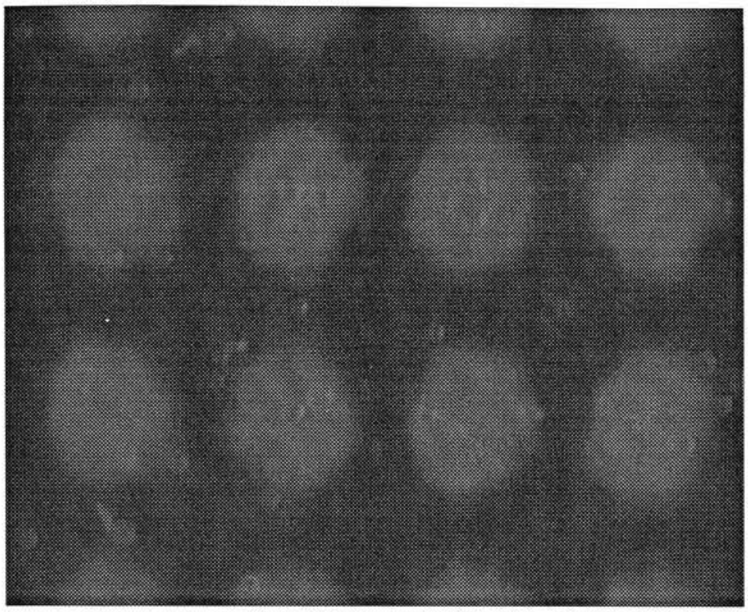


figure C-65; micrograph of the 50% cyan dot on Digital Proofing System B.

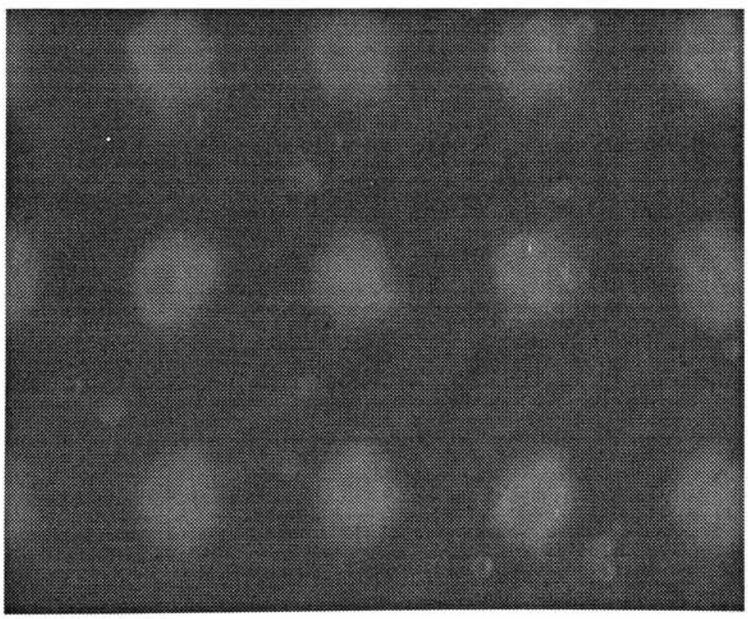


figure C-66; micrograph of the 75% cyan dot on Digital Proofing System B.

Digital Proofing System B-Cyan

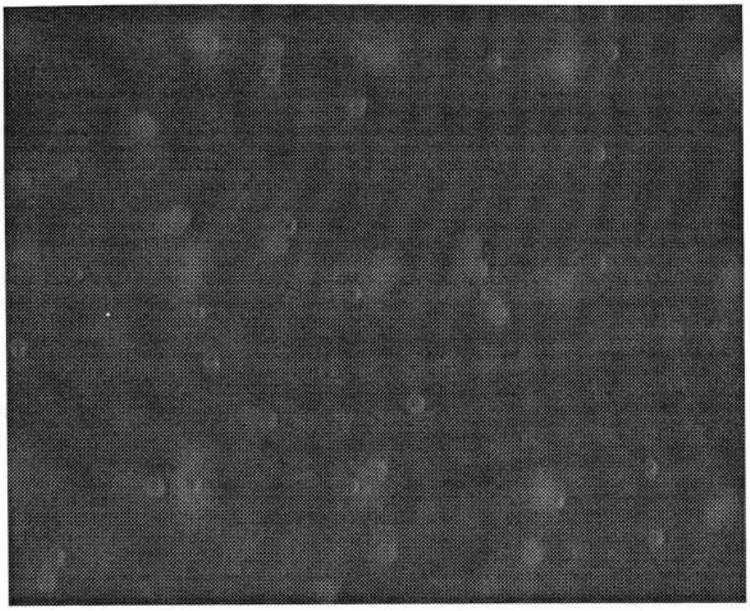


figure C-67; micrograph of the 95% cyan dot on Digital Proofing System B.

Digital Proofing System B-Magenta

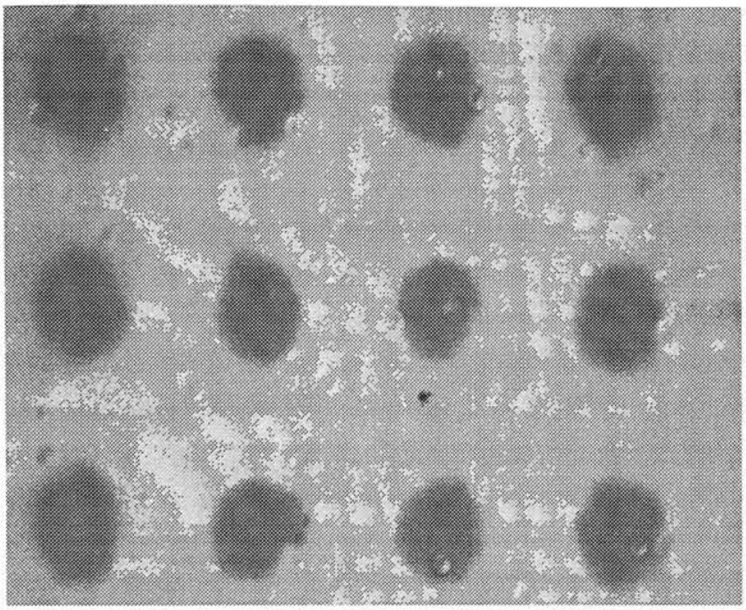


figure C-68; micrograph of the 5% magenta dot on Digital Proofing System B.

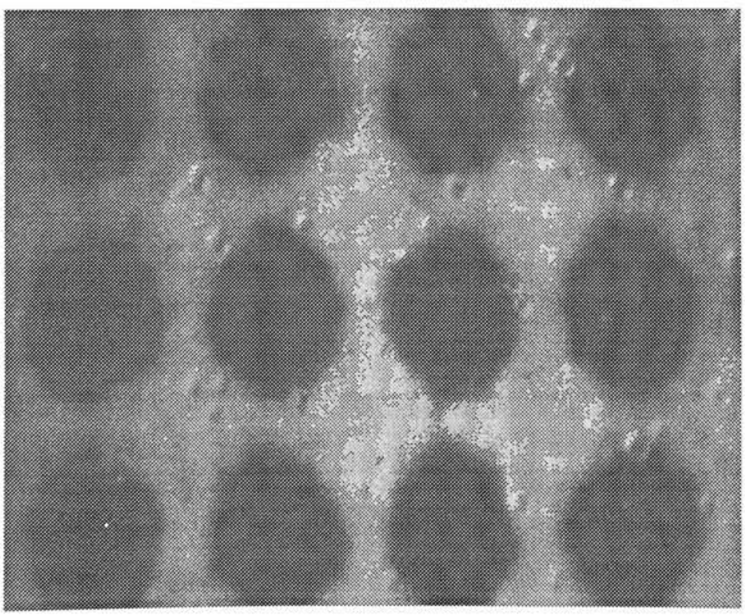


figure C-69; micrograph of the 25% magenta dot on Digital Proofing System B.

Digital Proofing System B-Magenta

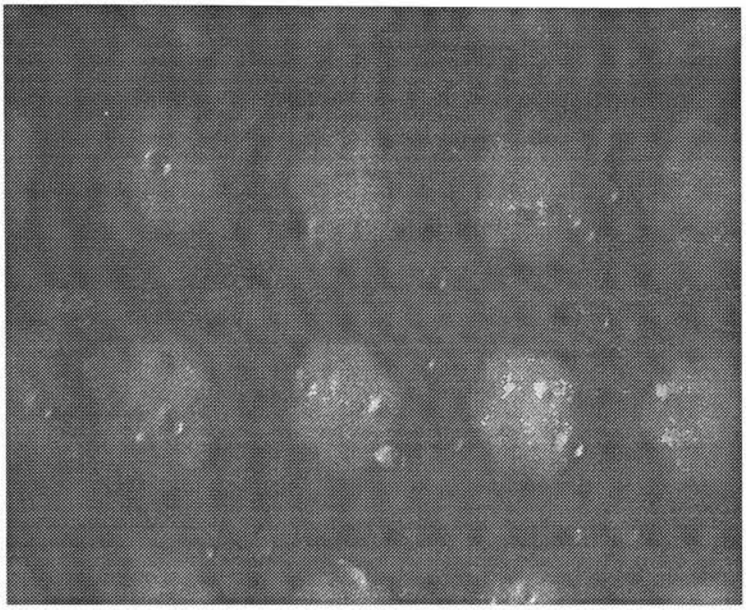


figure C-70; micrograph of the 50% magenta dot on Digital Proofing System B.

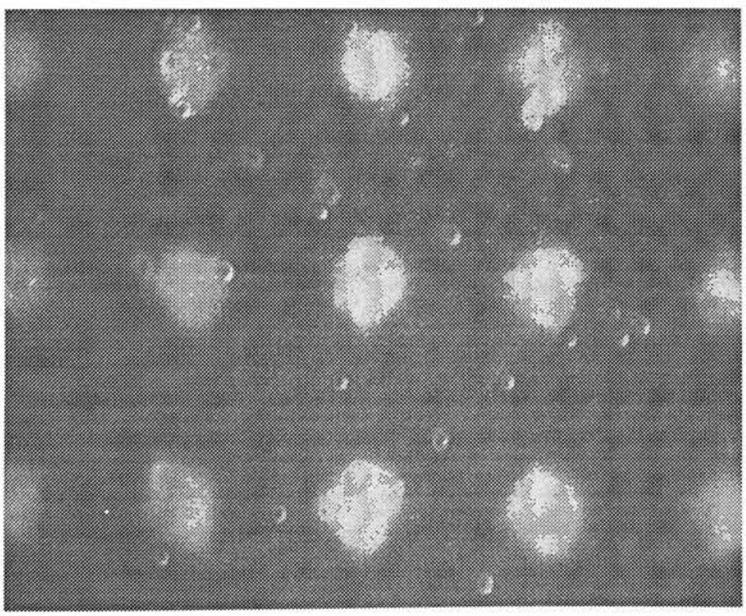


figure C-71; micrograph of the 75% magenta dot on Digital Proofing System B.

Digital Proofing System B-Magenta

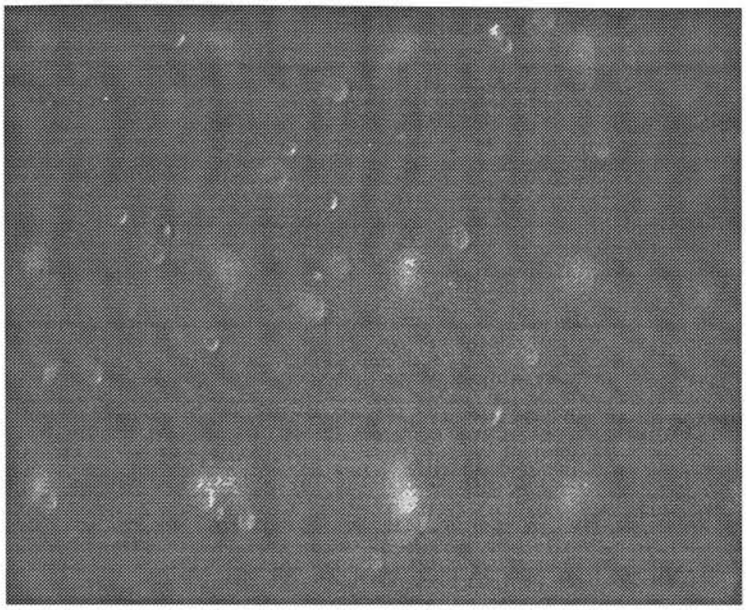


figure C-72; micrograph of the 95% magenta dot on Digital Proofing System B.

Digital Proofing System B-Yellow

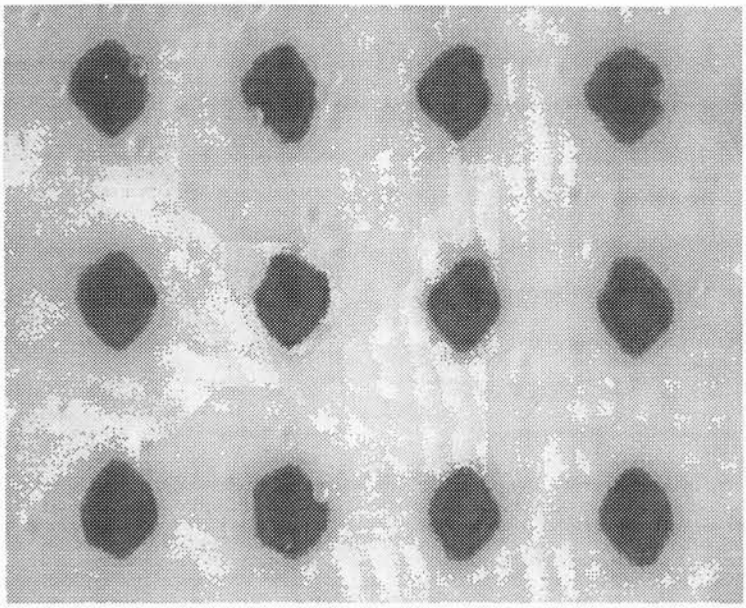


figure C-73; micrograph of the 5% yellow dot on Digital Proofing System B.

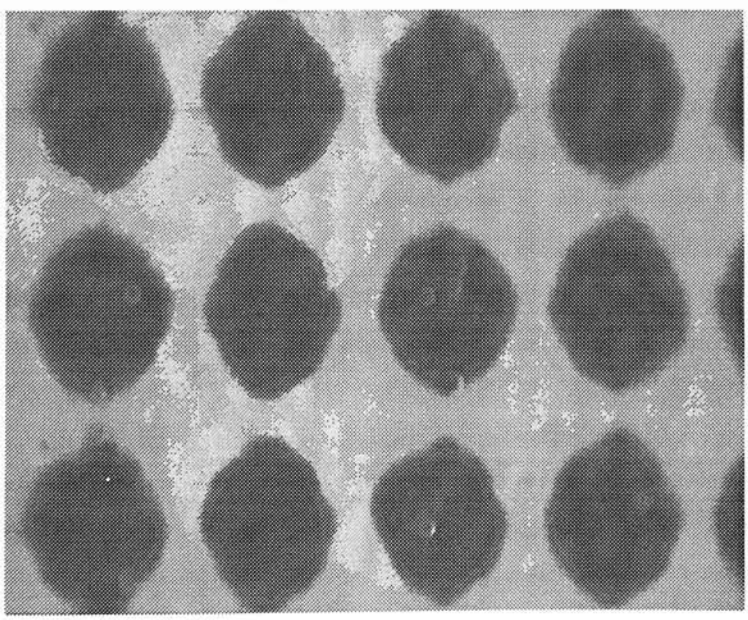


figure C-74; micrograph of the 25% yellow dot on Digital Proofing System B.

Digital Proofing System B-Yellow

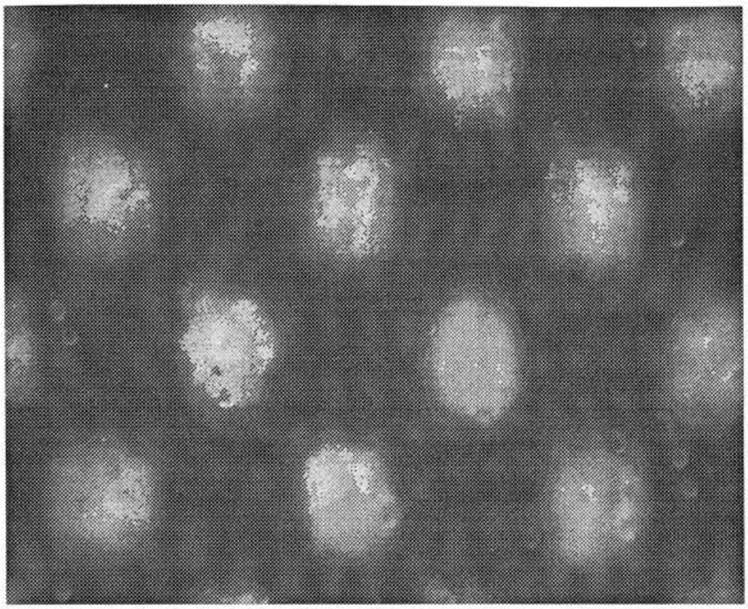


figure C-75; micrograph of the 50% yellow dot on Digital Proofing System B.

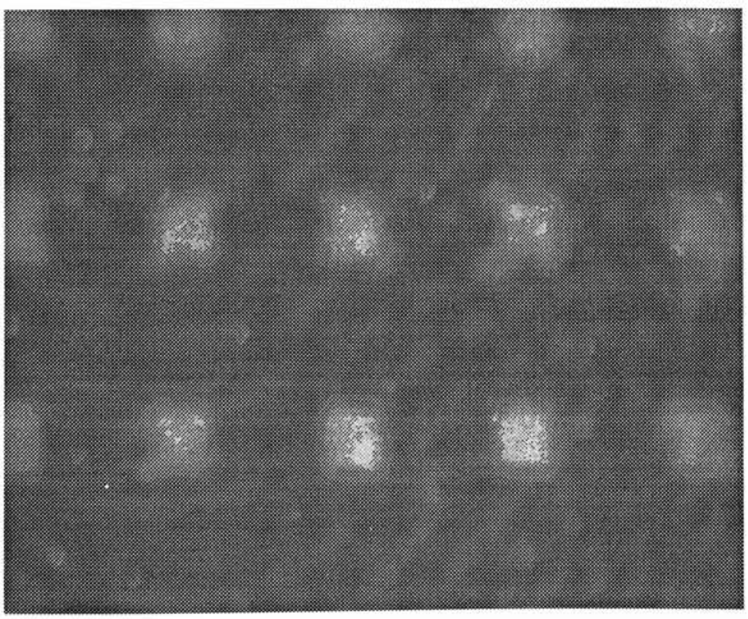


figure C-76; micrograph of the 75% yellow dot on Digital Proofing System B.

Digital Proofing System B-Yellow

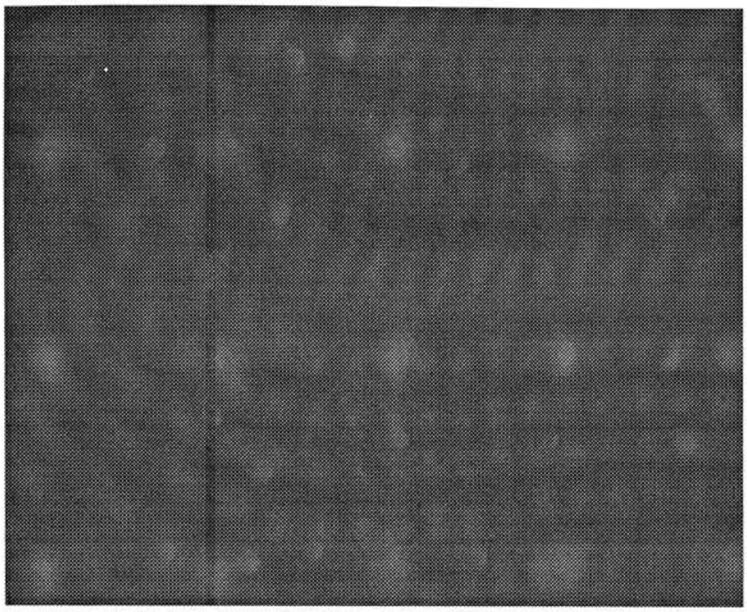


figure C-77; micrograph of the 95% yellow dot on Digital Proofing System B.

Digital Proofing System B-Black

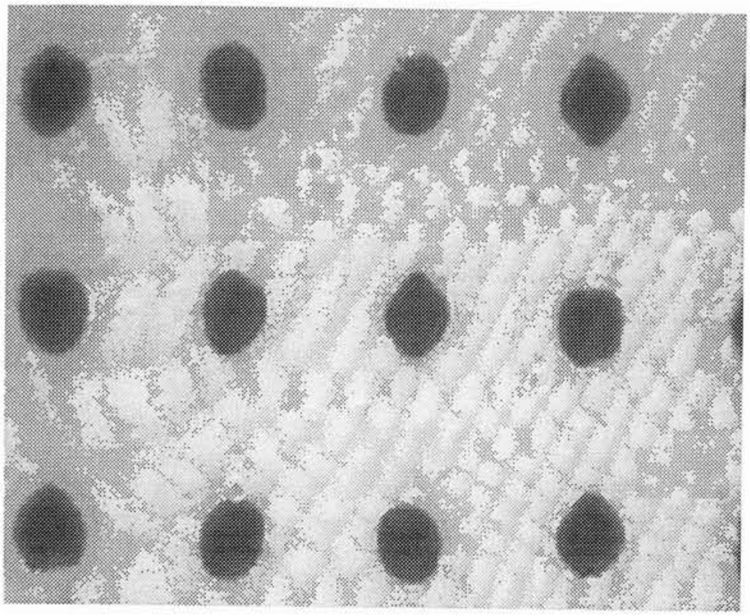


figure C-78; micrograph of the 5% black dot on Digital Proofing System B.

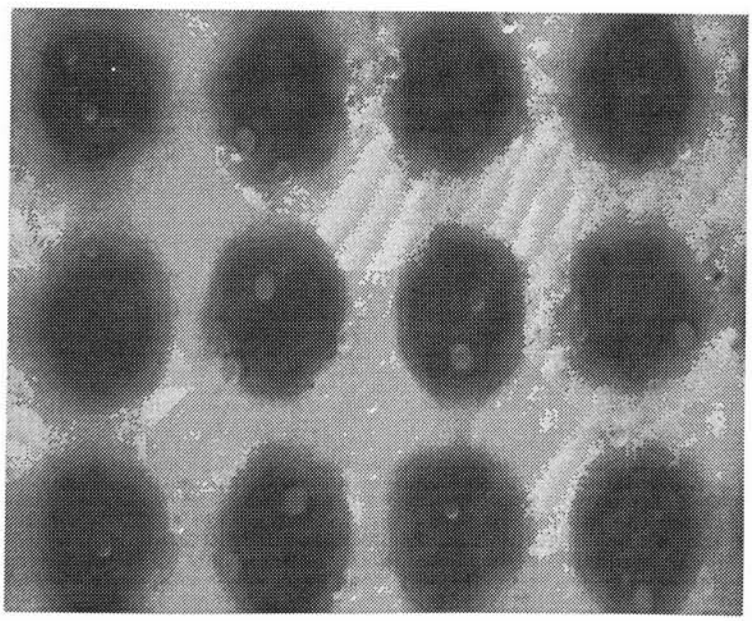


figure C-79; micrograph of the 25% black dot on Digital Proofing System B.

Digital Proofing System B-Black

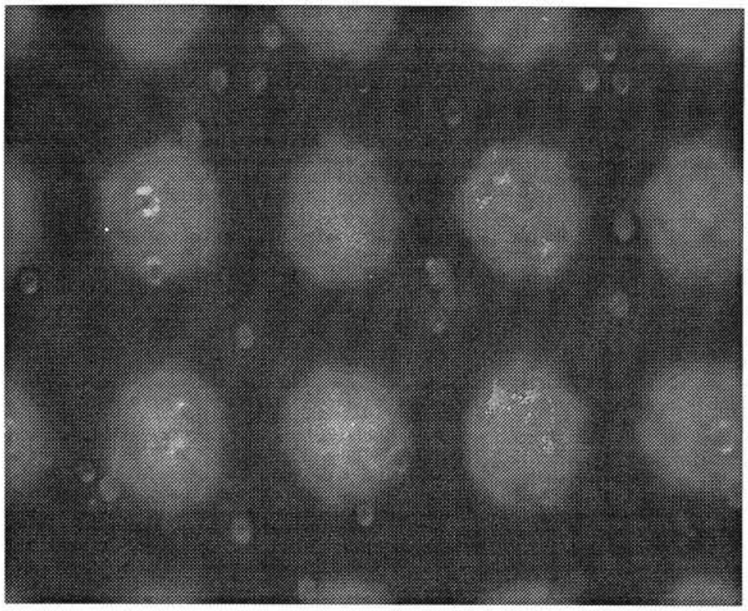


figure C-80; micrograph of the 50% black dot on Digital Proofing System B.

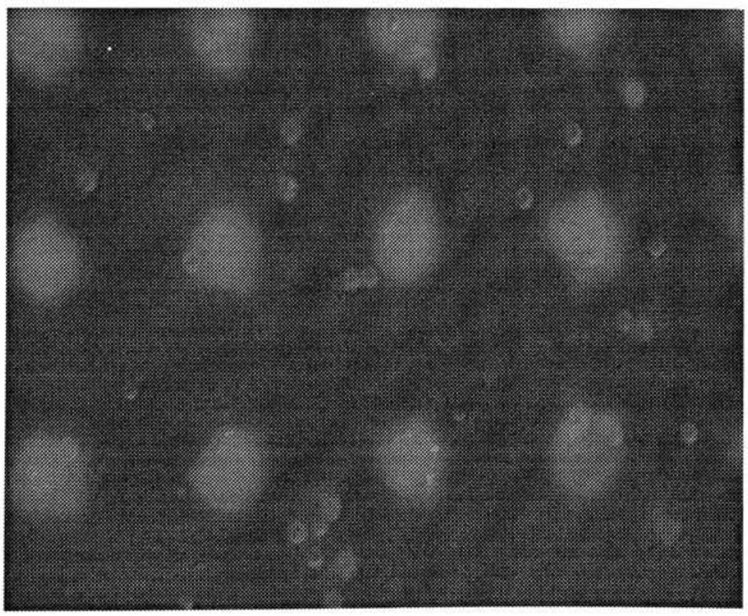


figure C-81; micrograph of the 75% black dot on Digital Proofing System B.

Digital Proofing System B-Black

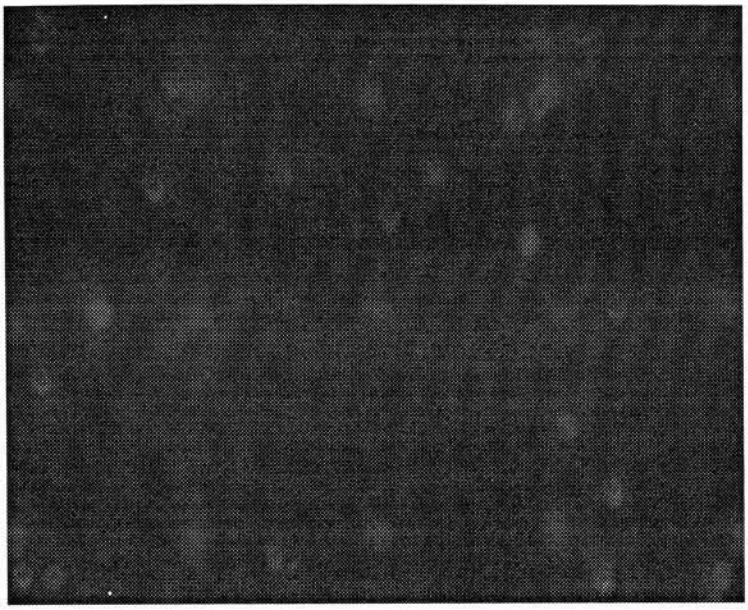


figure C-82; micrograph of the 95% black dot on Digital Proofing System B.

Appendix D

Visual Analysis Test Form

William Hanna: Thesis Observations 8/13/96-8/15/96

Instructions: First, visually examine the flexographic press sheet, then visually examine the three (3) proofs. Please rate the proofs, from best to worst, in terms of how well they approximate the press sheet visually. Please be sure to rate the proofs in order of how well they match the press sheet and not in order of the most pleasing to the eye. Please disregard press problems; ie, out of register, as this was unavoidable during the press run.

Below the proofs are listed as A, B, and C; please rate them from 1-3 with 1 being best match to the press sheet and 3 being the worst match to the press sheet. Each number can only be used once, for example if B is rated as 1 and A is rated as 3, then C has to rated as 2.

A _____ B _____ C _____