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A comparison of the random dot and the conventional halftone printing process with respect to color characteristics

Sanat Hazra

A COMPARISON OF THE RANDOM DOT AND THE CONVENTIONAL HALFTONE PRINTING PROCESS WITH RESPECT TO COLOR CHARACTERISTICS

by

Sanat Hazra

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Printing in the College of Graphic Arts and Photography of the Rochester Institute of Technology

May, 1981

Thesis advisors: Dr. J.L. Silver
Mr. Anson Hosley

Certificate of Approval -- Master's Thesis

School of Printing
Rochester Institute of Technology
Rochester, New York

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's Thesis of

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AN ABSTRACT

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ABSTRACT

A comparative study was made of random dot printing and conventional halftone printing with respect to color characteristics.

Random dot printing is similar to continuous tone printing or very high frequency screen ruling and is capable of overcoming the limitatio of halftone printing. The randomly selected dots are achieved by the grain structure of the pre-sensitized printing plates. The advantages and the disadvantages of this process over conventional halftone printing process are discussed. The images and the test targets of both the processes were exposed to, and printed from a single plate for each process color so as to eliminate the ink and press variables.

The experimental steps and the criteria for the plate exposure and processing have been discussed. The design of the flat and a copy of the reproduction are also included.

For the purpose of objective evaluation of the color characteristics tone reproduction of both the processes and of each process color were studied. The hue error introduced by two different processes were measured. The proportionality of unwanted densities with the wanted density for each process color were derived and curves were plotted.

Further, the attributes of colors, such as lightness or brightness, saturation and dominant wavelength (hue) were compared by plotting the chromaticity diagram (CIE 1931). The chromaticity diagrams were plotted for two different standard light sources and the results were discussed. For a better representation of the data an enlarged chromaticity diagram was used.

The results may be interpreted to show that the random dot process allows a larger color gamut, produce brighter colors and shows less proportionality failure.

Abstract Approved Dr. J. L. Silver
Thesis Advisor

Title

6/9/81
Date

INTRODUCTION

The random dot offset printing process has been known for years. In 1969, at the Symposium on "Non-Silver Photographic Processes" a paper entitled "Screenless offset Printing Process Using Pre-sensitized Plates"[1] was presented by Dr. F. Uhlig, of Kalle AG., West Germany. Since then, there has been an increased emphasis on the development of pre-sensitized plates suitable for random dot printing by the pre-sensitized plate manufacturers. At present, conventional positive working pre-sensitized plates are found to be suitable for such printing, although pre-sensitized printing plates, specifically designed for random dot printing, will be available in the future. The nature of the random dot printing process has certain advantages - even compared to the very high frequency conventional halftone printing process. These advantages include enhanced rendition of lighter tones, better reproduction of brighter colors, higher resolution, absence of moire pattern and elimination of texture (which occurs in the conventional screened process when the pattern of an image interferes with halftone dot structure). It has been claimed by many authors[1,2] on this subject that random dot printing will reproduce better color than may be reproduced by the conventional halftone printing process.

A comparative study of the color characteristics of these two processes has not yet been reported. The present study is an attempt at comparing the color characteristics of the two processes by using measurements appropriate to graphic arts reproduction. The measurements include Hue Comparison, Per Cent Grayness in both processes, Comparison of bright Color Reproduction, Confirmation of Proportionality Law Failure and Comparison of Chromaticity Diagrams which exhibit Brightness and Saturation.

1. Uhlig, F., "Screenless offset printing process using presensitized printing plates", *The journal of photographic science*, volume 18, 1970

2. Lawson, E.L., "Tonal reproduction via unscreened positive printing plates", *The journal of photographic science*, volume 26, 1978

JUSTIFICATION OF THE STUDY

The advantages of random dot printing have been discussed in the Introduction. Like any other process it has disadvantages as well. But the advantages of the random dot process over conventional halftone printing process could very easily outweigh its disadvantages, so that this process could be practiced for better color reproduction - with some inconvenience. The advantages and disadvantages of random dot printing over conventional halftone printing are listed below.

Advantages

1. The absence of first order and second order moire patterns.
2. Elimination of the halftone screening steps.
3. Comparative ease in control over press with less variation in reproducing print quality.
4. Higher resolution, resulting in better image detail.
5. Ink prints with greater purity.
6. Tonal gradations of more accurate reproduction.
7. Line copy may be combined with continuous tone copy for reproduction with greater fidelity.
8. Economy of scanning, camera time and films.

Disadvantages

1. The contrast of the plate light sensitive layer is too high and the density range is short.
2. Newton rings must be carefully avoided.
3. Plate exposure and processing have to be very carefully controlled.
4. Registration is very critical.
5. Quality of reproduction of uniform density area is undesirable.

In order to work with this process, it is imperative to perform a study of its claimed advantages as mentioned above. At present, manufacturers of pre-sensitized random dot printing plates are also pursuing research to alleviate the disadvantages of the process, and thus in the future there is promise for use of the process for higher quality of color reproduction.

THEORETICAL BASIS

In a conventional halftone printing process the image is broken into a halftone dot pattern. This conversion degrades the image quality and introduces serious problems. The halftone process cannot resolve the fine details of the image because of the dot pattern.[1] The reproduction of critical colors is also restricted and the size of the reproduction as well.[2]

Random dot printing can be described as being very similar to a very high frequency halftone printing process. The "continuous tone" is reproduced owing to the grain of the plate, which causes distribution of the coating thickness according to the peak and valley structure of the grained plate.[3] The distribution of coating thickness will vary with the geometry of the grain. The randomly distributed spots of ink vary in size and are irreguar in shape. Their relative areas are changed to produce tones of color. A uniform increment of tonal gradation is achieved in this process. It is also possible that the random dot printing by this process varies the ink film thickness from highlight to shadow area of the reproduction. There is perhaps transfer of thinner ink films in the highlight area than in the shadow area of the reproduction. This rationale could be justified by the property of ink and water acceptibility of the pre-sensitized plate. In the highlight area, which is deeper into the valley of the grained plate, there will be transfer of less ink because of the greater amount of water present in that area than will be the case of the areas of the plate which have less exposure. Similarly, the shadow areas of the reproduction will transfer more ink, because of higher ink and water ratio.

On the other hand, it has been assumed by many that each halftone dot has the same density and transfers the same ink film thickness from the highlight to the shadow area of the reproduction. The dilution of the color on lighter tone areas is achieved by adding the density of the paper to the density of the ink. The different combinations of paper and ink density are obtained from the variation of area covered by ink, whereas the density of each single dot remains the same.[4] It becomes very difficult to reproduce strong colors. This is the main reason why halftone color reproduction is inferior to that of continuous tone originals.[5] The light tint could only be reproduced as well as in the continuous tone image with a thin enough ink film in the light tint area.

In the halftone printing process, the lighter tone area will suffer from a lack of brightness and in the darker tone area it may lack very fine image details. In the overprints area there will be the problem of color shifting and this will limit the range of color gamut. A uniform increment of tonal gradation cannot be achieved by the conventional halftone process.

The halftone pattern of the conventional printing process is also the most important cause of the proportionality failure. This can be predicted from the Murray-Davies equation;[6]

$$D = -\log [1 - a(1-10^{D_s})]$$

where D = density of the halftone tint,

a = dot area,

D_s = density of the solid area,

10^{-D_s} = reflectance of the solid

For a given solid ink patch, three complementary color filter readings may be measured. Then the densities for any dot area can be calculated from the Murray-Davies equation. A curve can be easily plotted from the calculated data. This calculated curve can be compared with the experimental curve to show the affect of the halftone pattern. The variation of the experimental curve from the calculated curve would exhibit the failure of proportionality introduced by the halftone pattern.

The finer screen ruling shows less proportionality failure. The light penetrates through the ink layer and then emerges through the paper or from between ink dot. Light also enters through the paper or an open area and reflects back through the ink layer. In the case of high frequency screen ruling the chances of light entering and emerging through an ink layer will be higher. The reason is an increased number of dots with higher frequency screen ruling. This characteristic create a situation very close to continuous tone imaging.

The degree of similarity depends on the screen ruling. The proportionality failure is more acute with coarser screen ruling than with finer screen ruling. The light tints will be corresondingly dirtier and consequently, the hue error of pale colors will be the highest. This indicates the possibilities of better color reproduction by random dot printing, as compared to a very high frequency halftone printing process.

HYPOTHESIS

It is hypothesized that if the random dot printing process varies the ink film thickness from the highlight to the shadow area and prints at a very close approximation to a very high frequency halftone printing process, then the random dot printing process should overcome the limitations of color reproduction by the conventional halftone printing process.

1. Pobboravsky, I., and Pearson, M., "Study of Screenless Lithography" TAGA Proceedings, May 1967.

2. Yule, A.C.J., Principle of Color Reproduction, John Wiley & Sons, Inc., New York, Pages 205-216.

3. Pobboravsky, I., and Pearson, M., "Study of Screenless Lithography" TAGA Proceedings, May 1967.

4. Strauss, Victor, The Printing Industry, Printing Industry of America, Washington, D.C., Pages 179188.

5. Yule, A.C.J., Principle of Color Reproduction, John Wiley & Sons, Inc., New York, Pages 205-216.

6. Ibid., Page 212.

METHODOLOGY

The intention of designing the experiment was to ensure simplicity. At first, a flow chart diagram of the experiment was drawn for better understanding of the process involved and the execution of the experimental steps, as shown below:

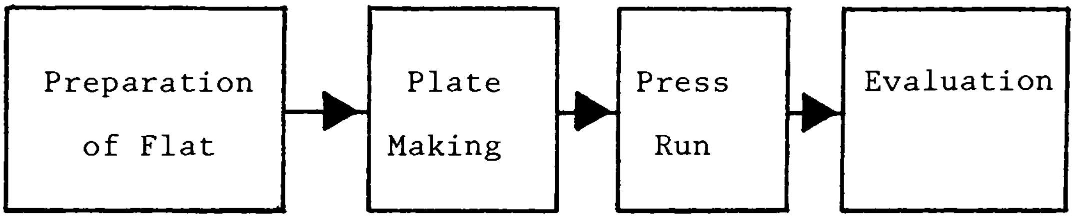


Figure 1

The pre-press work (preparation of flat and platemaking) and the press run for the experiment were done at Case-Hoyt Corp., Rochester, New York. Before the preparation of the flat, the plate characteristic curve of the printing plate, used in this experiment, was determined. Pre-sensitized positive working plates were exposed through a 21 step continuous tone stepwedge, as well as through a 150 line per inch screen tint, varying the dot area from 2 to 90 percent. The exposure and the processing steps of the plate were according to the manufacturer's recommendation. Three plates were exposed and processed similarly and were used to print the three process colors. Thus, reproduction of the two different stepwedges in the three different process colors were accomplished. The density reading of the continous tone stepwedge and the halftone stepwedge was easily determined with a reflection densitometer. The complementary color filters, for the three process colors were used for the densitometric measurements. A comparison of exposure of the random dot and the halftone processes was obtained by plotting the characteristic curve from the measured density readings. These data were helpful in finding the amount of exposure required to reproduce a density by continuous tone, which matched the densities obtained from the different dot areas of the halftone screen tint. This was done for all all three colors. The determination of the correct exposure of the continous tone was very critical.

A schematic of the flat used in this experiment is given below.

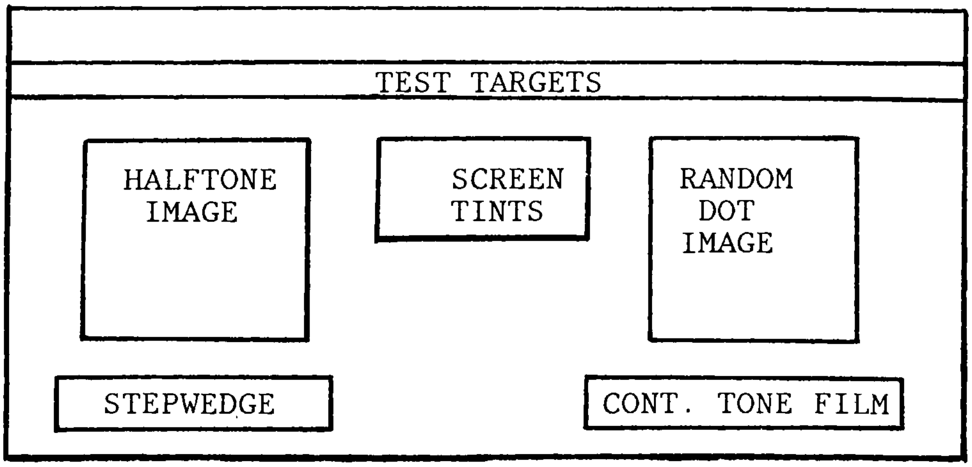


Figure 2

For subjective evaluation similar images were also printed by both processes. An identical color separation was made for this purpose, so that one reproduced by the random dot image and the other, by conventional halftone dot patterns. The frequency of the screen ruling was 150 line per inch. All test targets were stripped with the burn-out mask. The images were stripped into three different flats, used for three different process colors.

Platemaking

The manufacturer's recommendation was followed for the exposure and the processing of the plates. Since both the test targets were exposed to each plate, one plate was required for each color run. The exposure time and the development time were very carefully observed to ensure the least variability from plate to plate. Any deviation owing to exposure and processing steps would have effected both the random dot scale and the halftone scale simultaneously, in as much as the scales were exposed to the same plate. Positive working pre-sensitized Alympic Gold plates, manufactured by Hawson Alography was used because this plate is known to work very well for the random dot printing process as well as for the halftone printing process.

Press Runs

Both the random dot and the halftone images were run together on single plates as to eliminate ink and press condition variables. The press used was manufactured by Heidelberg Maschinen Fabrik, Heidelberg, West Germany, as a four unit offset press. The size of the press is 28" x 40". The press is equipped with conventional blankets and an alcohol dampening system. The stock used was 80 lb., coated and white in color. The standard process color inks were used. These inks are generally used for the production runs. The sequence of printing colors were magenta, cyan, black and yellow, since this was a standard procedure. The solid ink density across and along the cylinder was maintained uniformly, throughout the run. All throughout the printing, the thickness of the plate blanket, plate cylinder packing, blanket cylinder packing, ink viscosity, press speed and the fountain solution were maintained with as little deviation as possible.

During the press run no major problem was encountered. The roll-up and the overall performance of the plates were excellent.

EVALUATION

Case-Hoyt Corp.'s previous experience with the random dot printing process assured a very satisfactory press run. At the completion of the press run, randomly selected samples were taken. The samples were then subjected to color characteristics measurements.

The following color characteristics of the random dot process and the halftone process were evaluated for comparison.

1. Hue error of highlight, middletone and shadow area.
2. Grayness of the three process colors.
3. Proportionality Law failure
4. Comparison of brightness and saturation by plotting the chromaticity diagram (1931).

The measurement of all the color characteritics for this experiment was accomplished by measuring the continuous tone stepwedge and the halftone screen tint with the densitometer and with the spectrophotometer.

For the purpose of the densitometric measurement the reflection densitometer was used with the three complementary color filters, which are red, blue and green (Kodak Wratten Filter #26, 47, 58). The spectrophotometric measurements were done at Eastman Kodak Co., Rochester, New York. The spectrophotometer used for the measurements was manufactured by Zeiss Corp., West Germany, model # DMC 26. This instrument is capable of measuring a sample, which is very small in dimension. Other advantages of this instrument are discussed in the following chapter.

Tone Reproduction

For the purpose of comparing tone reproduction of the random dot printing process with the halftone printing process, a 150 line per inch screen with different per cent dot areas and a continuous tone stepwedge were printed. Three single color prints of both processes were measured to plot and compare the tone reproduction of each color generated from the two processes.

The densitometric measurements were obtained by using the complementary color filters of the three process color inks. Thus, six sets of data were recorded by reading two scales on three colors.

The densitometric readings (Table 1) were plotted against the respective densities of the positive film. The density of the positive films were measured with the transmission densitometer. The tone reproduction curves of the two different processes and of the same color were compared.

The tone reproduction of the magenta printer showed that the random dot process (See Figure 3) has a higher middle tone contrast than the halftone process (See Figure 4). Both processes did not compress the tonal range of the positive film, used to expose the plate.

The optimum tone reproduction for any process shouldbe 1:1. However, the halftone process showed an overall ratio higher than 1:1. On the other hand, the curve represented by the random dot process showed a ratio lower than 1:1, up till the middle tone, and then higher than 1:1 up to the shadow area.

The lower contrast, which is less than 1:1 ratio on the highlight of the random dot reproduction curve could be due to the overexposure of the plate. The procedure of the plate exposure has already been discussed in the chapter previous.

MAGENTA PRINTER

HALFTONE PROCESS				RANDOM DOT PROCESS			
DENSITY OF SCREEN TINTS	DENSITY MEASURED THROUGH FILTER			DENSITY OF CONT. TONE STEPWEDGE	DENSITY MEASURED THROUGH FILTER		
	GREEN	RED	BLUE		GREEN	RED	BLUE
0.03	0.06	0.02	0.02	0.16	0.06	0.02	0.04
0.05	0.10	0.03	0.05	0.31	0.17	0.04	0.09
0.09	0.15	0.04	0.09	0.43	0.32	0.07	0.19
0.13	0.21	0.06	0.14	0.57	0.47	0.09	0.28
0.18	0.26	0.07	0.18	0.72	0.67	0.11	0.35
0.22	0.32	0.08	0.21	0.87	0.80	0.14	0.46
0.25	0.36	0.08	0.24	1.01	1.02	0.17	0.60
0.38	0.52	0.11	0.34	1.18	1.38	0.21	0.77
0.47	0.61	0.12	0.40	1.32	1.48	0.24	0.86
0.67	0.81	0.14	0.51	1.47	1.50	0.24	0.86
0.83	1.00	0.16	0.61				
1.04	1.16	0.17	0.67				

Table 1

TONE REPRODUCTION

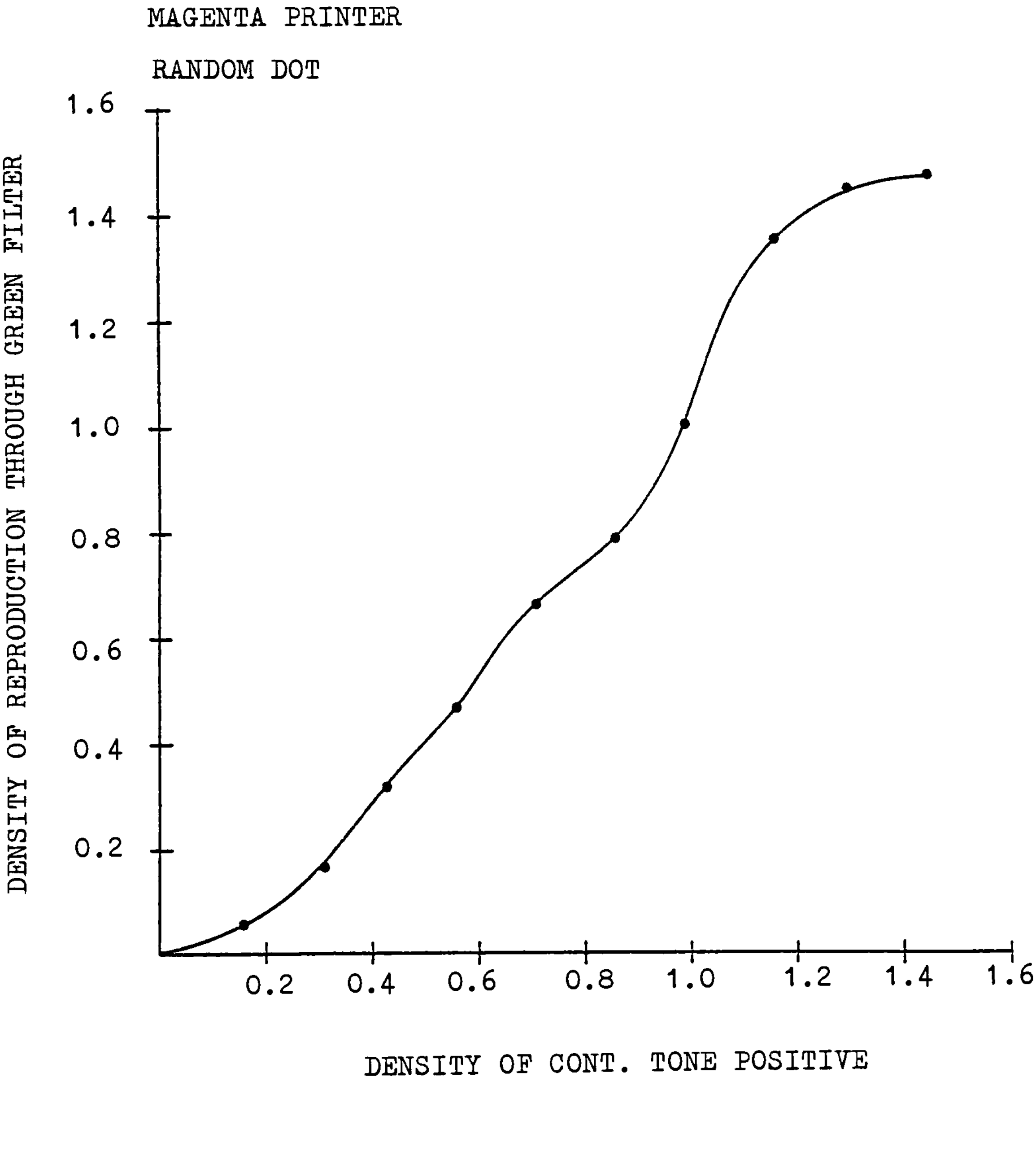


Figure 3

TONE REPRODUCTION

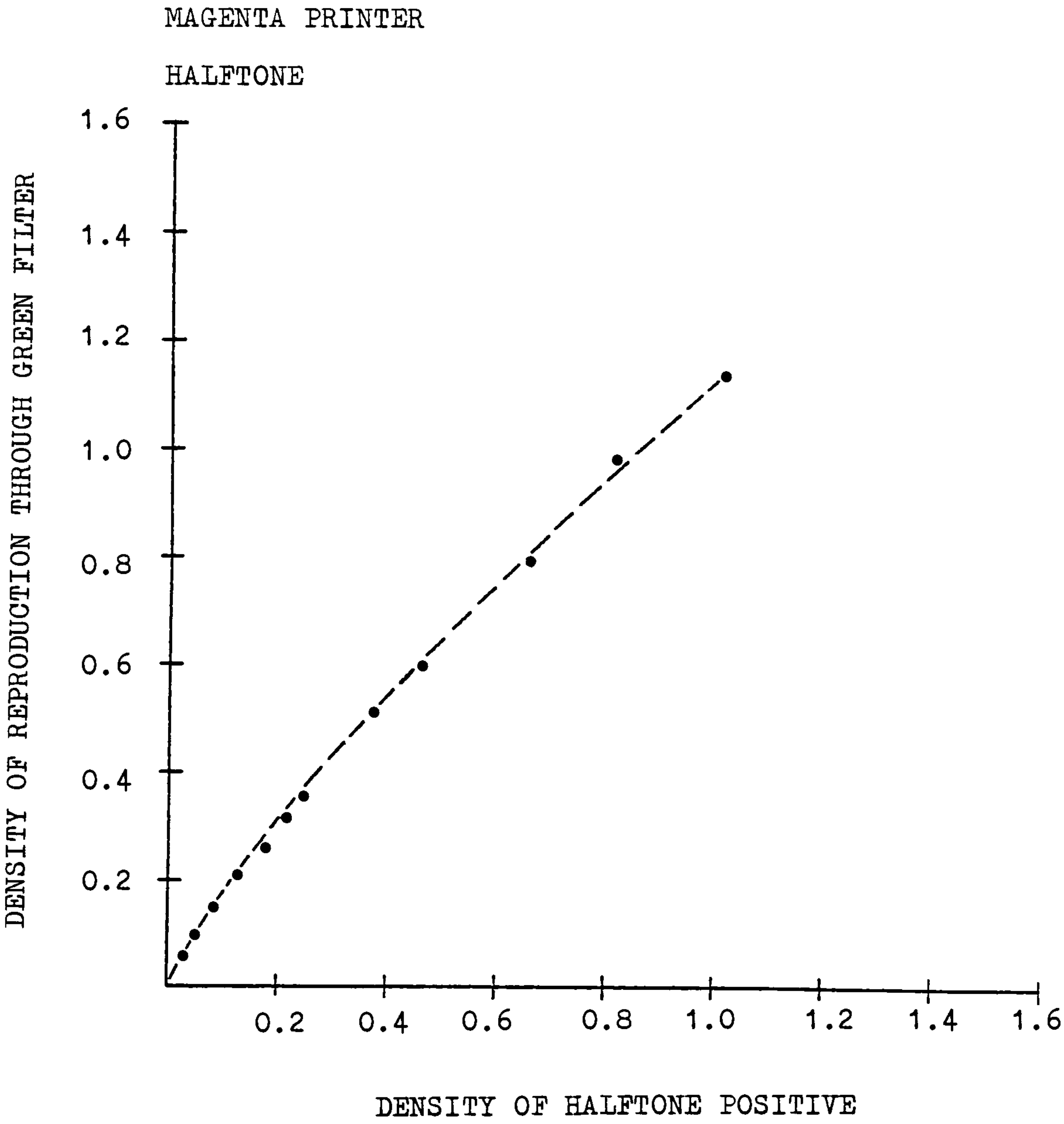


Figure 4

The tone reproduction curves for the yellow printer of both the half tone (See Figure 5) and the random dot processes (See Figure 6) showed a different characteristic from the tone reproduction curves produced by the magenta and cyan printers. The densitometric readings are listed in Table #2.

On the continuous tone curve the film density of 1.48 was compressed to 1.04 density above the paper. It represented a very flat curve, which was much lower than 1:1 reproduction. The reason for this behavior could be the solid ink density and the overexposure of the plate.

The half tone process yielded an overall higher than 1:1 reproduction, except in the shadow area where the cruve started to flatten out. This curve did not compress the tonal range or the density of the positive film. Since the desnity of the ink on paper is controlled by the percent dot area, the half tone system is less affected by the shift of exposure. It has a higher latitude of exposure than the continuous tone printing system. So, in this case, the half tone printing process produced a better tone reproduction curve than one reproduced by the random dot printing process.

The exposure of the printing plate is very critical[1] for the random dot printing process.

1. Lawson, E.L., "Tonal reproduction via unscreened positive printing plates", The journal of photographic science, volume 26, 1978.

YELLOW PRINTER

HALFTONE PROCESS				RANDOM DOT PROCESS			
DENSITY OF SCREEN TINT	DENSITY MEASURED THROUGH FILTER			DENSITY OF CONT. TONE STEPWEDGE	DENSITY MEASURED MEASURED THROUGH FILTER		
	BLUE	GREEN	RED		BLUE	GREEN	RED
0.03	0.03	0.02	0.02	0.16	0.03	0.02	0.02
0.05	0.06	0.02	0.02	0.31	0.12	0.02	0.02
0.09	0.12	0.03	0.02	0.43	0.22	0.03	0.02
0.13	0.16	0.03	0.02	0.57	0.30	0.04	0.02
0.18	0.22	0.04	0.02	0.72	0.40	0.05	0.02
0.22	0.27	0.04	0.02	0.87	0.50	0.07	0.03
0.25	0.32	0.05	0.02	1.01	0.59	0.08	0.04
0.38	0.50	0.06	0.02	1.18	0.72	0.10	0.04
0.47	0.65	0.08	0.03	1.32	0.81	0.10	0.04
0.67	0.89	0.09	0.03	1.47	0.89	0.10	0.04
0.83	0.98	0.10	0.04				
1.04	1.01	0.10	0.04				

Table 2

TONE REPRODUCTION

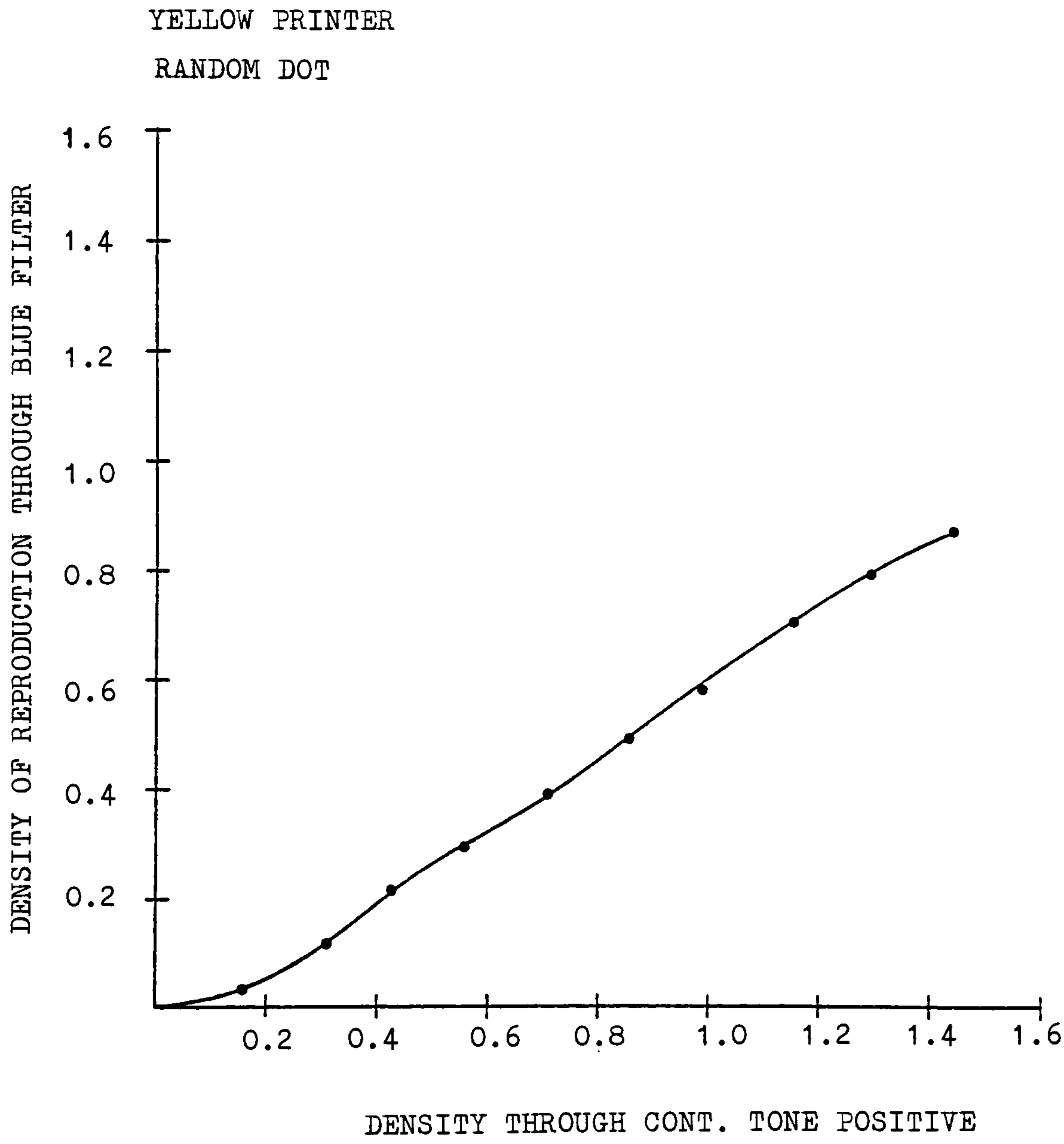


Figure 5

TONE REPRODUCTION

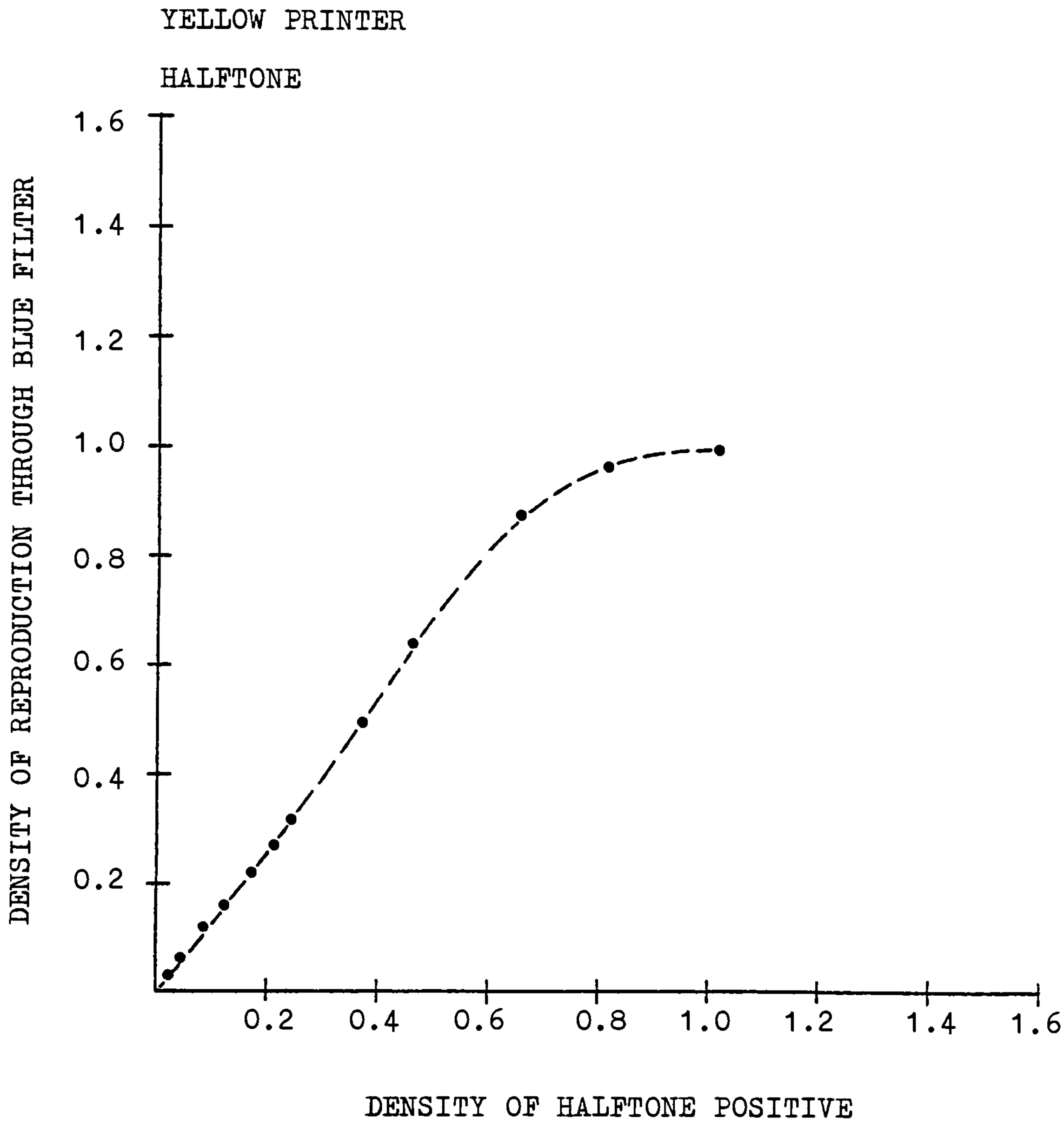


Figure 6

The cyan printer showed a tone reproduction very similar to one reproduced by the magenta printer. The half tone reproduced a tone reproduction curve almost identical with one obtained from the magenta printer. It has an overall higher than 1:1 reproduction. The tonal range of the reproduction was also extended. This result could be due to the high solid ink density.

The random dot process (See Figure 7) exhibited a lower than 1:1 reproduction, although the middletone to shadow contrast was higher than one experienced from the half tone process (See Figure 8). There was no sign of tone compression on the reproduction. The lower contrast on the highlight area could, very possibly, be due to the overexposure of the plate.

CYAN PRINTER

HALFTONE PROCESS				RANDOM DOT PROCESS			
DENSITY OF SCREEN TINT	DENSITY MEASURED THROUGH FILTER			DENSITY OF CONT. TONE STEPWEDGE	DENSITY MEASURED THROUGH FILTER		
	RED	GREEN	BLUE		RED	GREEN	BLUE
0.03	0.05	0.03	0.03	0.16	0.06	0.03	0.03
0.05	0.08	0.04	0.03	0.31	0.18	0.07	0.04
0.09	0.14	0.07	0.03	0.43	0.30	0.11	0.05
0.13	0.19	0.09	0.04	0.57	0.45	0.16	0.07
0.18	0.25	0.12	0.05	0.72	0.58	0.21	0.08
0.22	0.30	0.14	0.06	0.87	0.72	0.24	0.09
0.25	0.35	0.16	0.07	1.01	0.86	0.28	0.10
0.38	0.50	0.22	0.09	1.18	1.10	0.34	0.12
0.47	0.59	0.25	0.10	1.32	1.24	0.39	0.15
0.67	0.79	0.31	0.11	1.47	1.43	0.39	0.15
0.83	0.97	0.35	0.13				
1.04	1.16	0.38	0.13				

Table 3

TONE REPRODUCTION

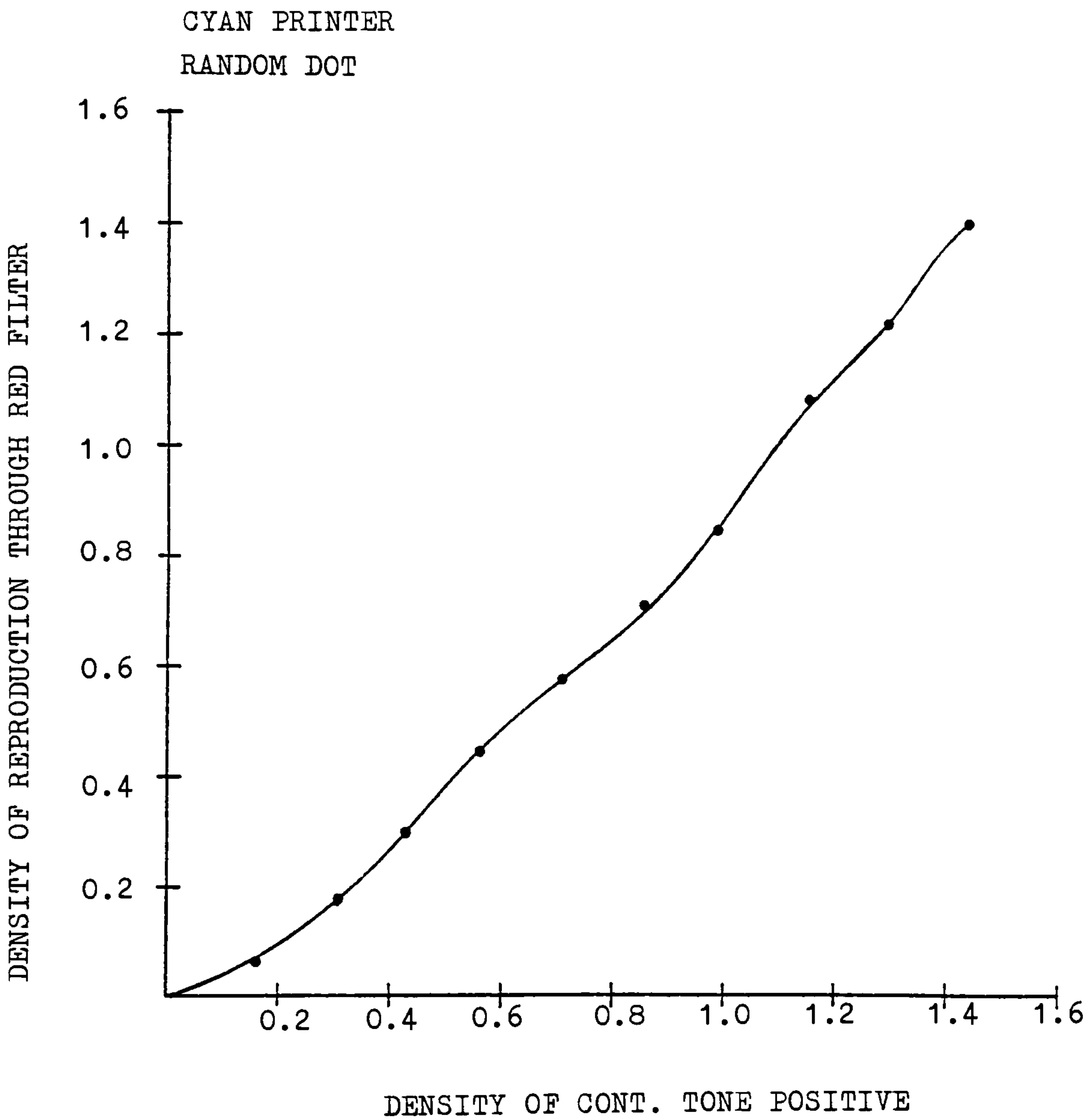


Figure 7

TONE REPRODUCTION

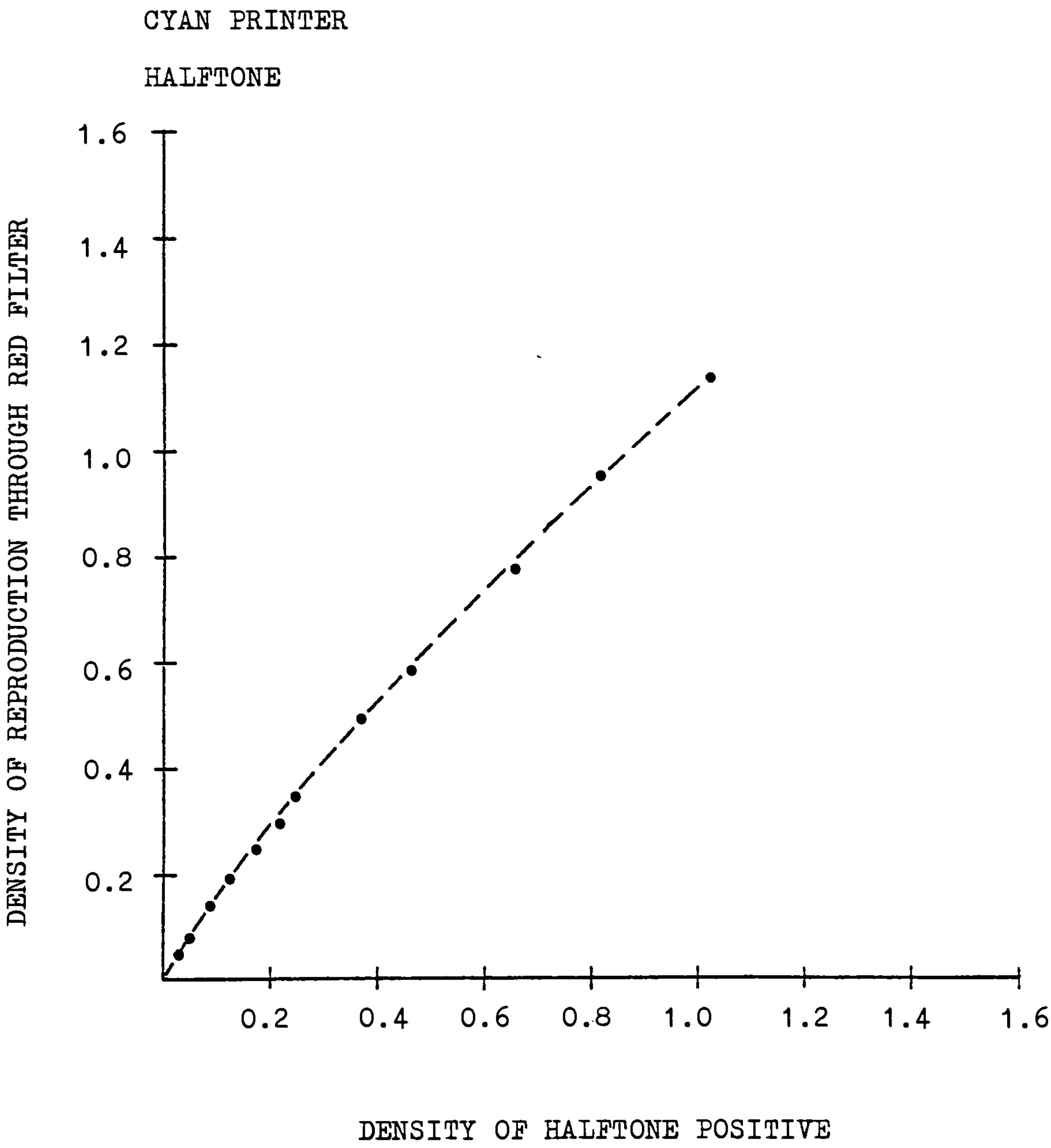


Figure 8

Hue Error

The hue error of the inks is obtained by measuring the density of each ink through the three complementary color separation filters. An ideal ink would give a high density through one filter and zero density through the other two filters. In reality, such inks do not exist. The hue error of the inks are based on the difference between the two unwanted densities. The less the hue error the better is the reproduction. The hue error of an individual ink is always in the same direction, whereas the two and three color overlaps vary widely and may cause hue error in various directions. The variation depends on the strength of the ink, ink film thickness or the solid ink density, as well as on the area covered by the ink. In this experiment the inks were the same for both the processes and both were printed from the same plate.

The random dot printing process showed less hue error in the lighter or highlight area of the scale.

The hue error curves (See Figures 9, 10, 11) were plotted to show this behavior of the two different processes and for three different process colors. The three complementary color separation filter reading of the continuous tone stepwedge and the halftone screen tint of different dot area were measured for three single process colors. The density readings were used in the equation[1] to determine the per cent hue error associated with corresponding wanted or highest density.

$$\text{Per Cent Hue Error} = 100\,\frac{M - L}{H - L}$$

Then the percent hue error were plotted against the highest density of the corresponding patch being measured. The curve generated from this plotting represents the errors introduced by unwanted densities for respective wanted density. The wanted density is the highest density of an ink when density is measured only with the complementary color filter of that specific ink. The hue error curve of all three colors showed less per cent error in the random dot printing process.

1. Yule, A.C.J., Principle of color reproduction, John Wiley & Sons, Inc., New York, pages 160-162.

PER CENT HUE ERROR

CYAN PRINTER

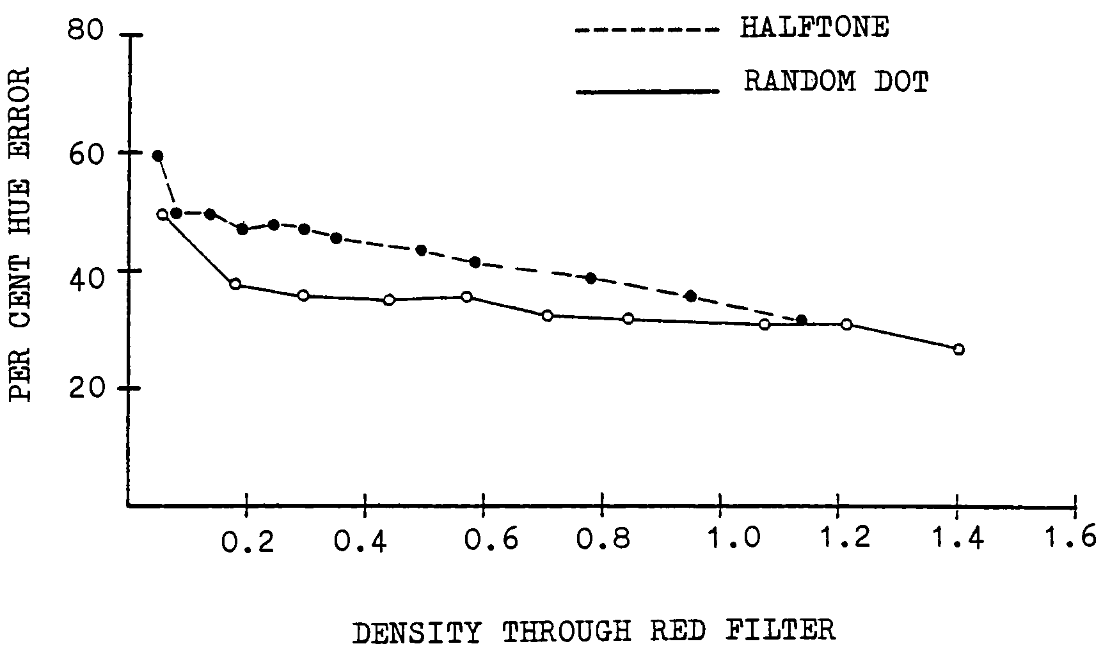


Figure 9

PER CENT HUE ERROR

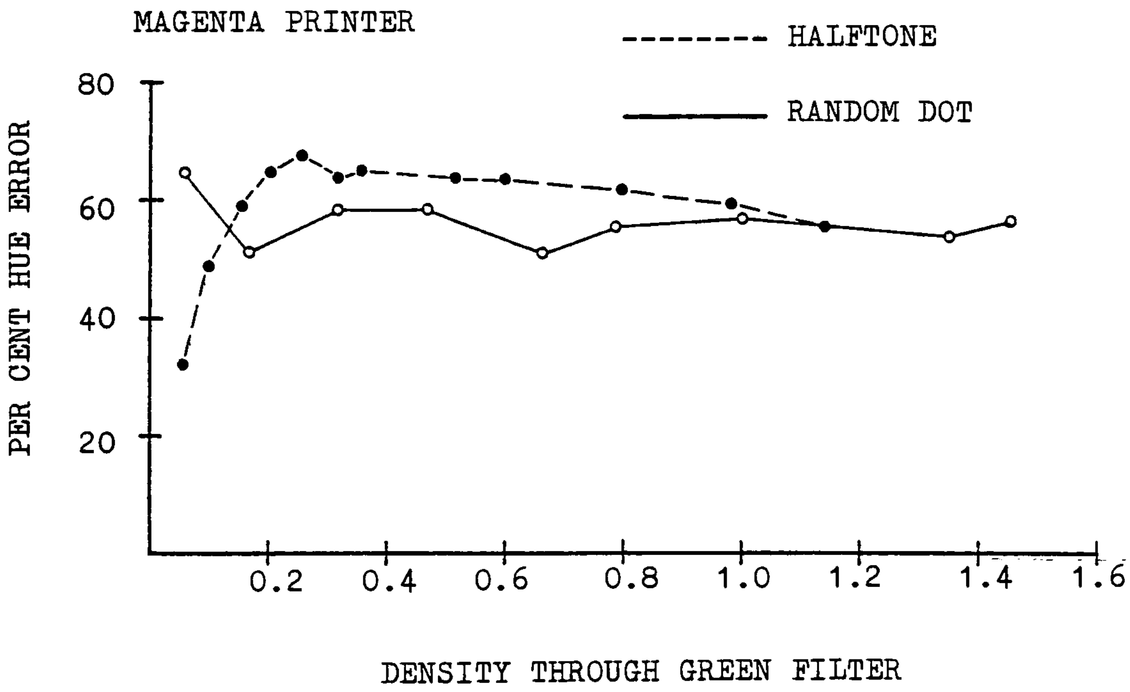


Figure 10

PER CENT HUE ERROR

YELLOW PRINTER

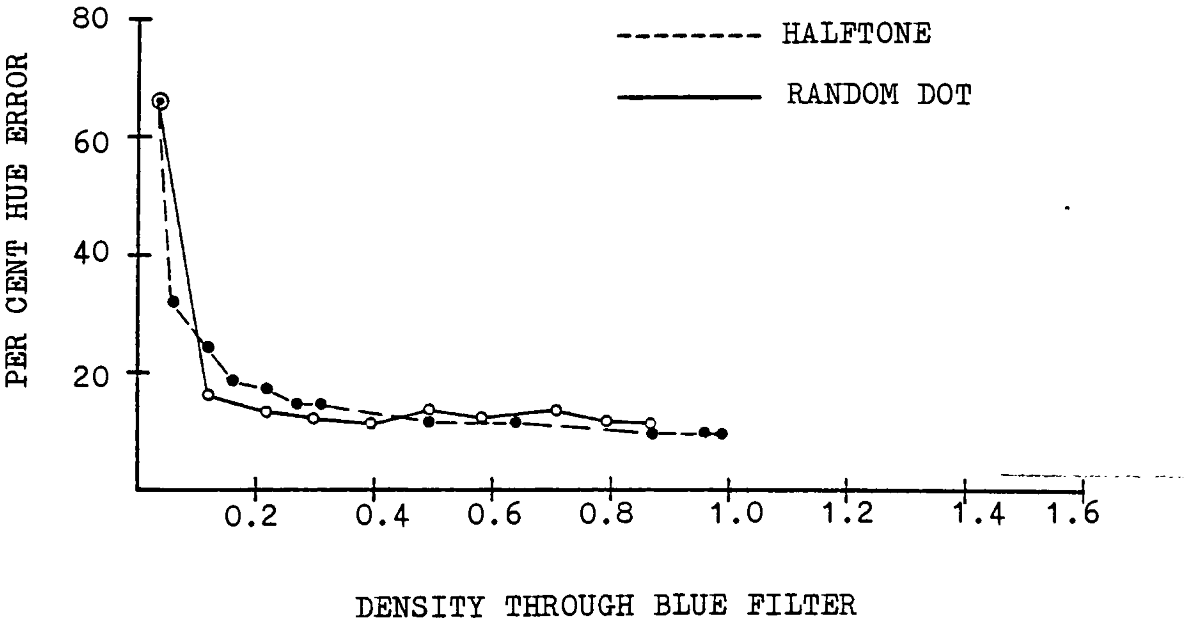


Figure 11

Grayness

The measurement of grayness also required the density measurement of the individual ink through the three complementary color separation filters. Unlike hue error, grayness is based on the highest density reading and on the lowest unwanted density reading.[1]

$$\text{Per Cent Grayness} = 100\ \frac{\text{Lowest unwanted density}}{\text{Highest density}}$$

The higher the grayness the less saturated the color becomes. The high grayness value is a result of an increasing amount of lowest unwanted density. The grayness and the hue error also determine the strength of the mask required to correct the unwanted densities of the individual ink. The higher the hue error and the grayness, the higher is the masking strength required.

It has been found from this experiment that per cent grayness is influenced by the frequency of the screen ruling. The random dot printing, which is synonymous with high frequency printing, introduced less per cent grayness from highlight to the middletone than that by conventional halftone printing. This property is attributed to cleaner and brighter low densities or light color reproduction.

The per cent grayness curves were plotted (See Figures 12, 13, 14) for three process colors - cyan, magenta and yellow as well as for the two different processes. Since grayness is based on the highest density reading, the percent grayness values were plotted against corresponding highest density of the measured patch.

1. Yule, A.C.J., Principle of color reproduction, John Wiley & Sons, Inc., New York, pages 160-163.

PER CENT GRAYNESS

CYAN PRINTER

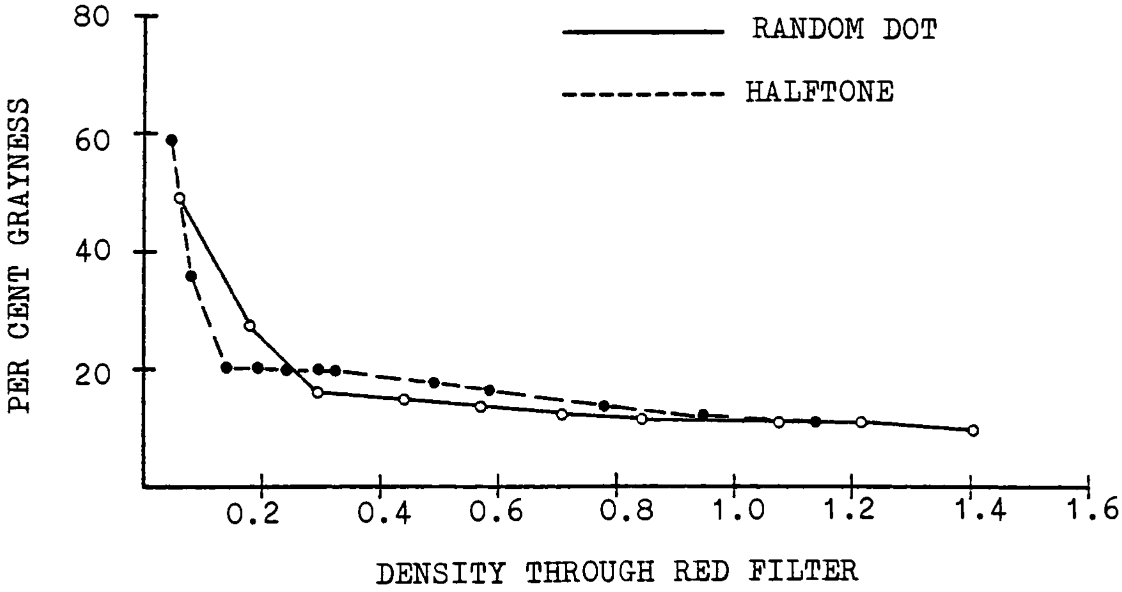


Figure 12

PER CENT GRAYNESS

MAGENTA PRINTER

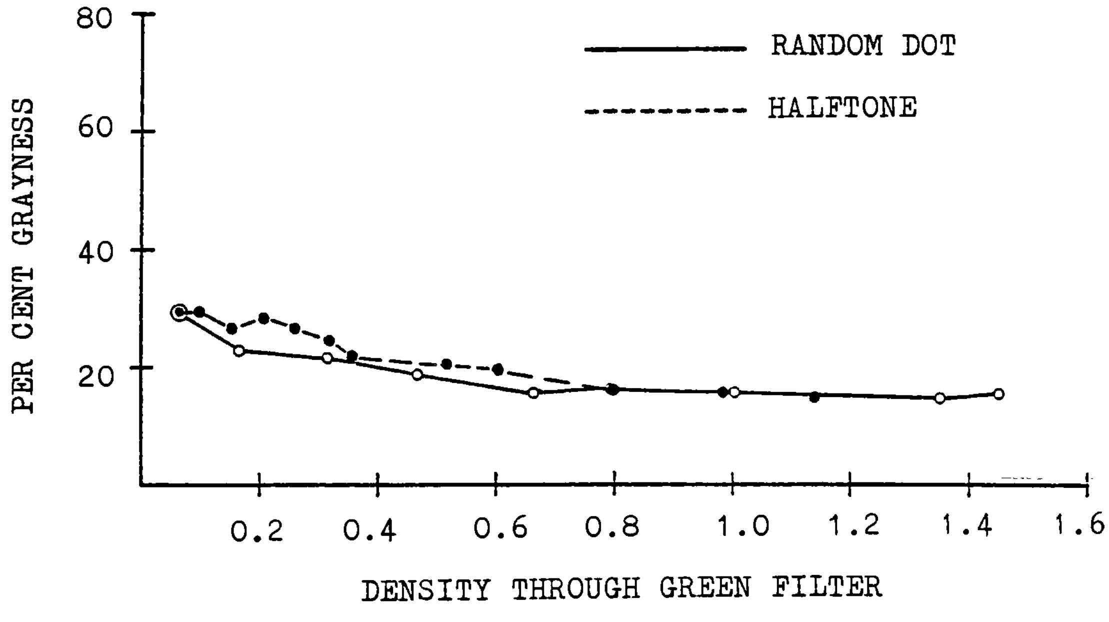


Figure 13

PER CENT GRAYNESS

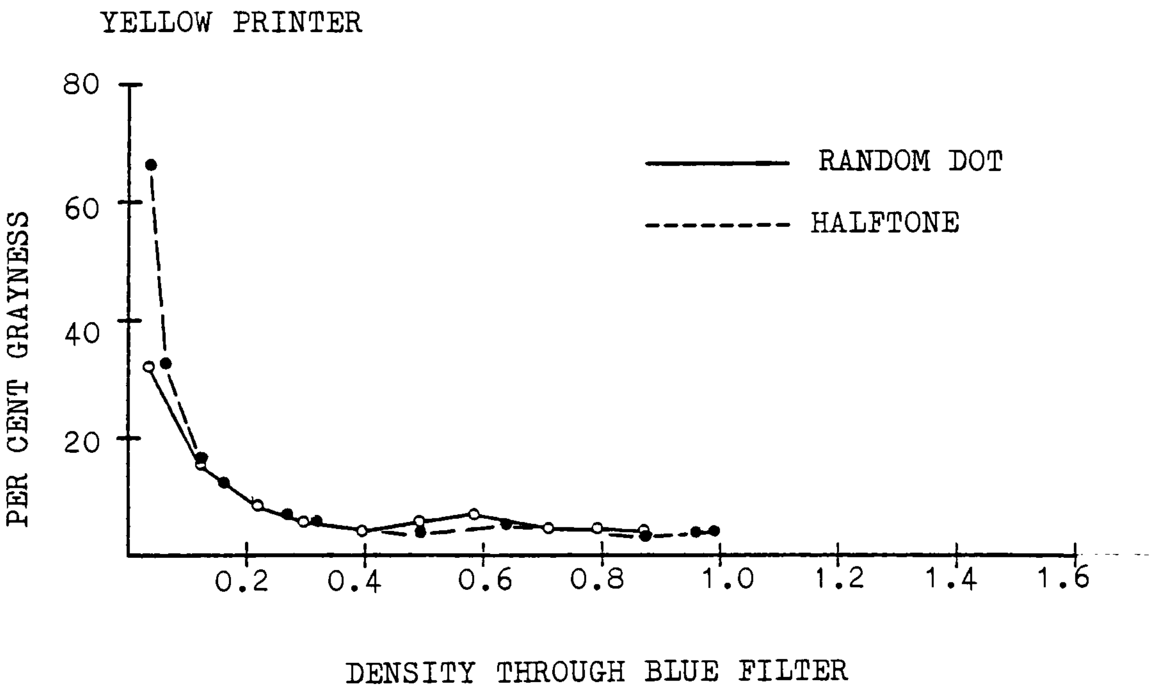


Figure 14

<u>Proportionality of Densities</u>

The eye's response to color is additive. In photomechanical halftone printing this additivity is accomplished by spatial fusion.[1] This is where the individual color elements are too small to be resolved by normal human vision. Therefore the perception is the integrated response of all the colors. The attributes of color, such as lightness or darkness, saturation and hue are achieved by different sizes of halftone dots or areas covered by ink and by changing the solid ink density or ink film thickness. Consequently, the amount of light reflected back and the spectral distribution of that reflected light will vary with the dot area and the solid ink density of individual colors. The three complementary color filter readings of the individual color should remain proportional to each other (from highlight to shadow area of the scale) as the area covered by ink and the thickness of the ink film increase. This property is generally known as the proportionality rule.[2] A color reproduction printed by halftone dot does not obey this rule strictly. This behavior introduces problems in color reproduction. The shadow area of the reproduction appears cleaner than the highlight area. However, less proportionality failure is assumed when finer or higher frequency screen rulings are employed.

Since random dot printing is compared to very high frequency screen ruling printing, it should confirm less proportionality failure than the conventional halftone printing process. As a result, the random dot process will print cleaner light tints and increase the gammut of light colors reproduction, which cannot be reproduced by the halftone process.

For the purpose of this evaluation three process colors were printed. The curves have been plotted from the data (See Figures 15-20). In this instance, the random dot process indicated less proportionality failure than the conventional halftone process, as had been predicted.

The test targets of both the processes were reproduced by three process colors. The densitometric measurements for this purpose were obtained by measuring both targets of every single color with three complementary color filters. Thus, every color patch of the targets had three density readings. The highest density of each patch was obtained by measuring it with the complementary color filter. The other two density readings of each color patch are designated as "unwanted density". Among the unwanted density readings, the one with the higher value is called the highest unwanted density, and the other is called the lowest unwanted density. For each process color two curves were plotted. One of them was to exhibit the proportionality of the wanted density to the highest unwanted density from highlight to shadow area of the scale, and the other was to show wanted or highest density VS lowest unwanted density.

The ideal curve confirming proportionality rule will be a straight line indicating a constant proportion of unwanted density over the whole range of the highest densities.

1. Pearson, M., Color Reproduction, Rochester, N.Y.

2. Yule, A.C.J., Principle of color reproduction, John Wiley & Sons, Inc., New York, pages 205-216.

PROPORTIONALITY OF DENSITIES

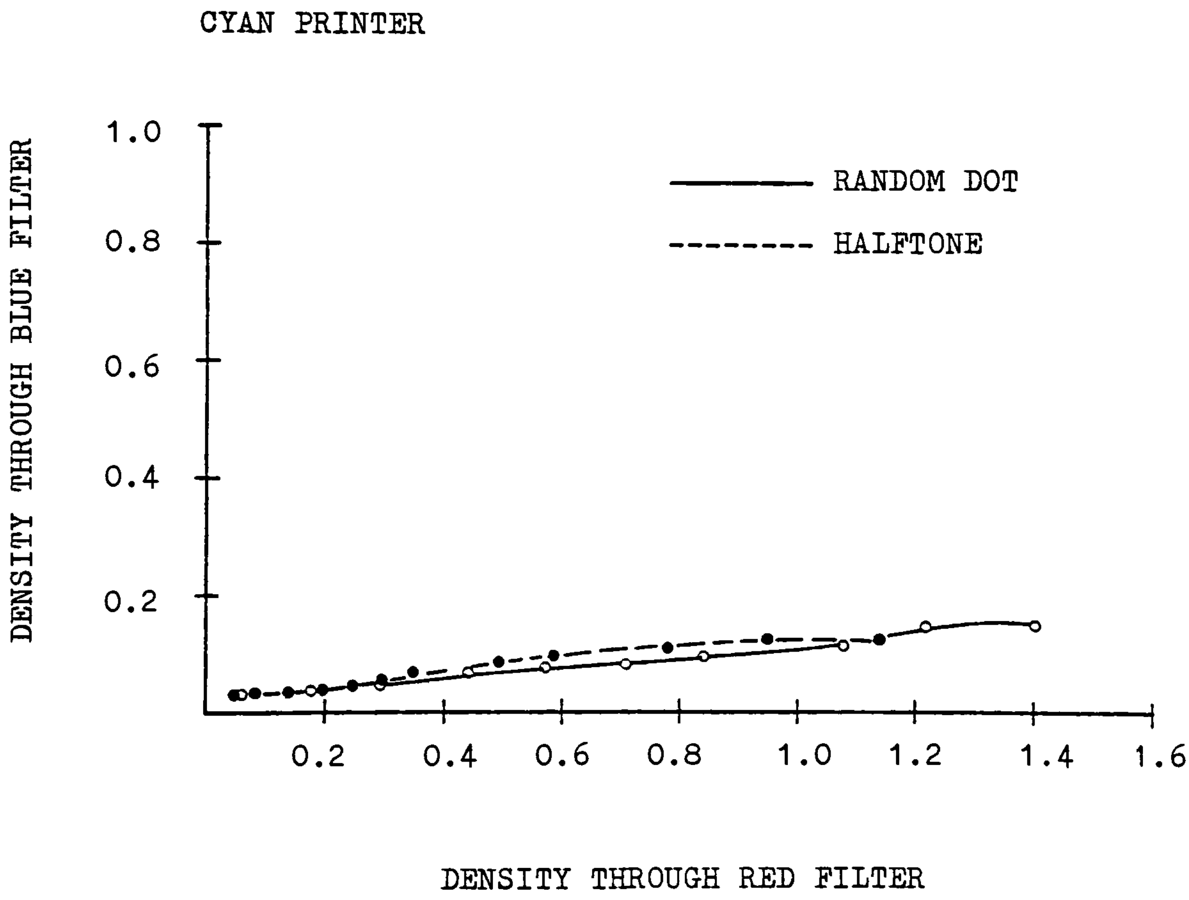


Figure 15

PROPORTIONALITY OF DENSITIES

CYAN PRINTER

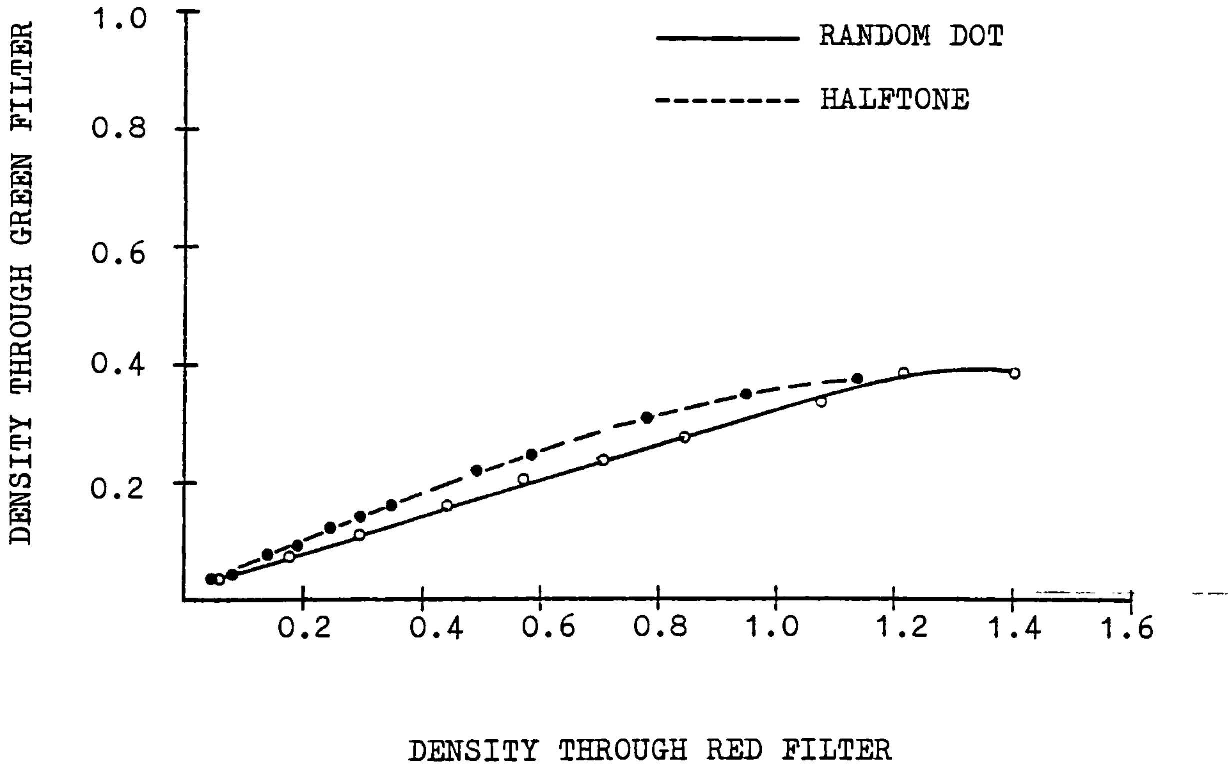


Figure 16

PROPORTIONALITY OF DENSITIES

MAGENTA PRINTER

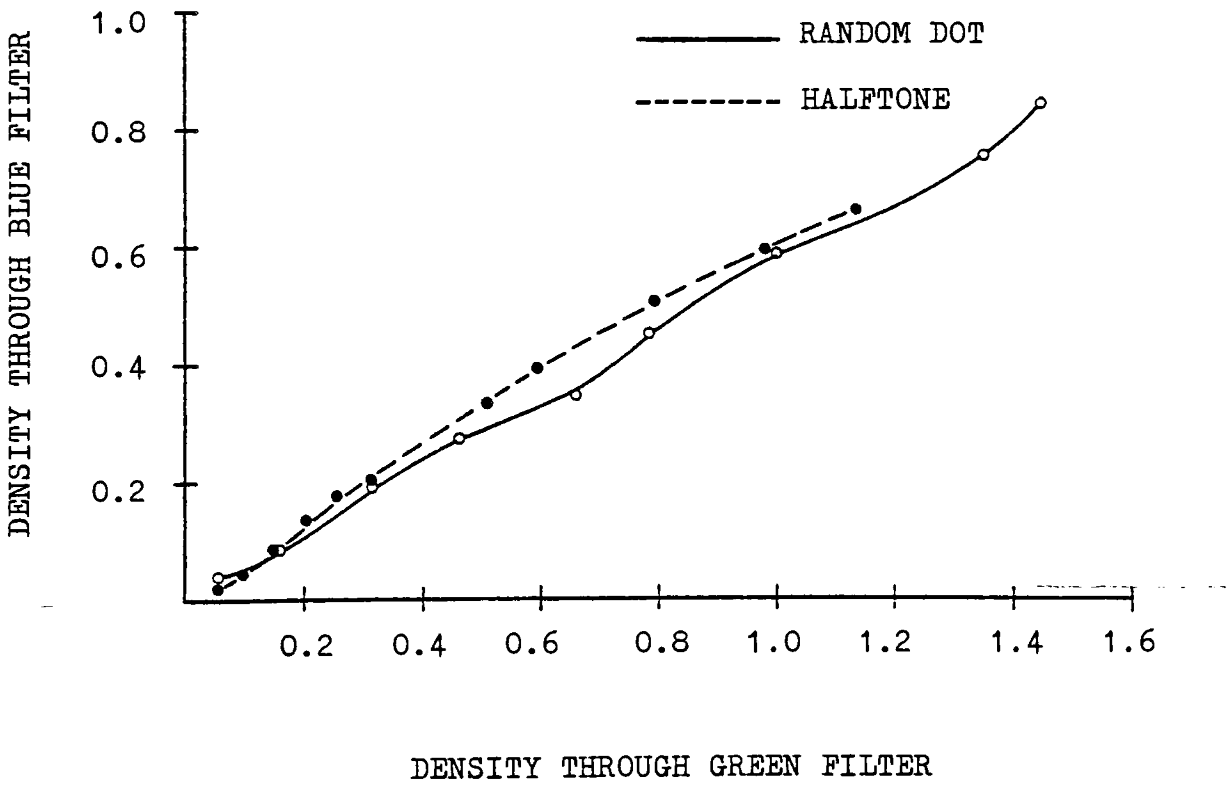


Figure 17

PROPORTIONALITY OF DENSITIES

MAGENTA PRINTER

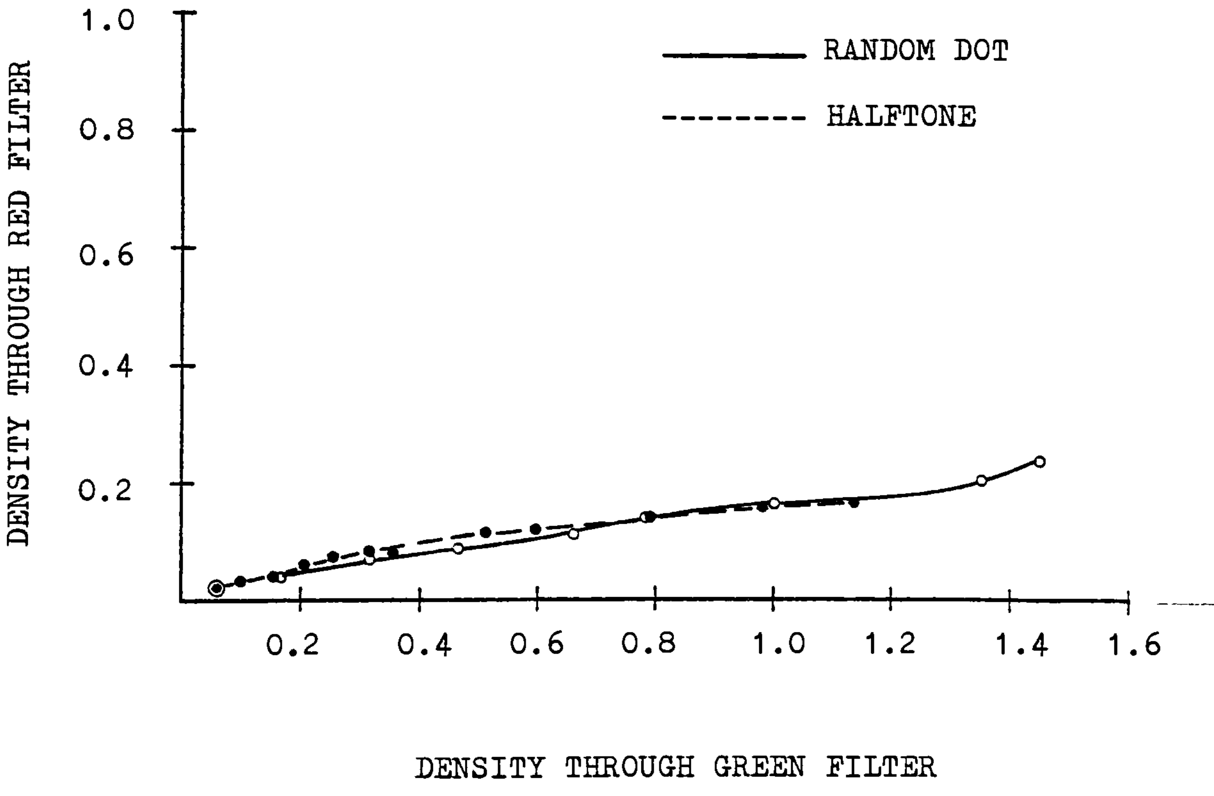


Figure 18

PROPORTIONALITY OF DENSITIES

YELLOW PRINTER

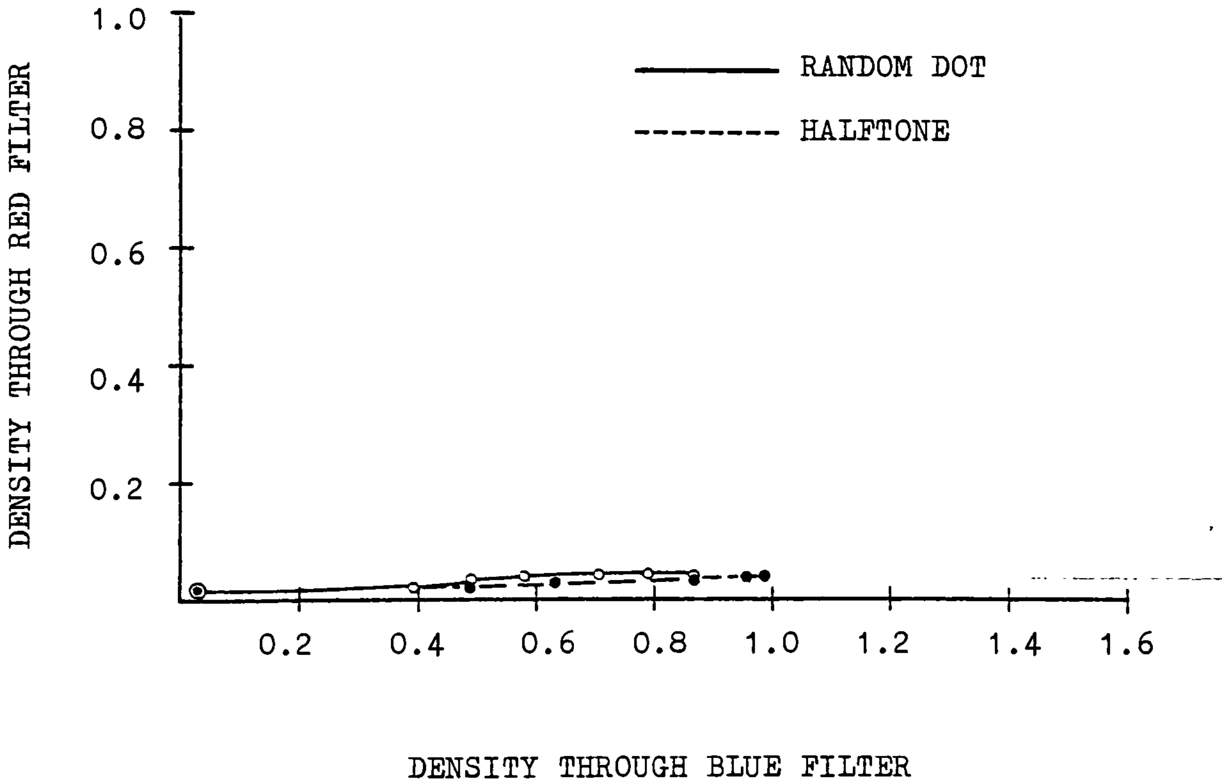


Figure 19

PROPORTIONALITY OF DENSITIES

YELLOW PRINTER

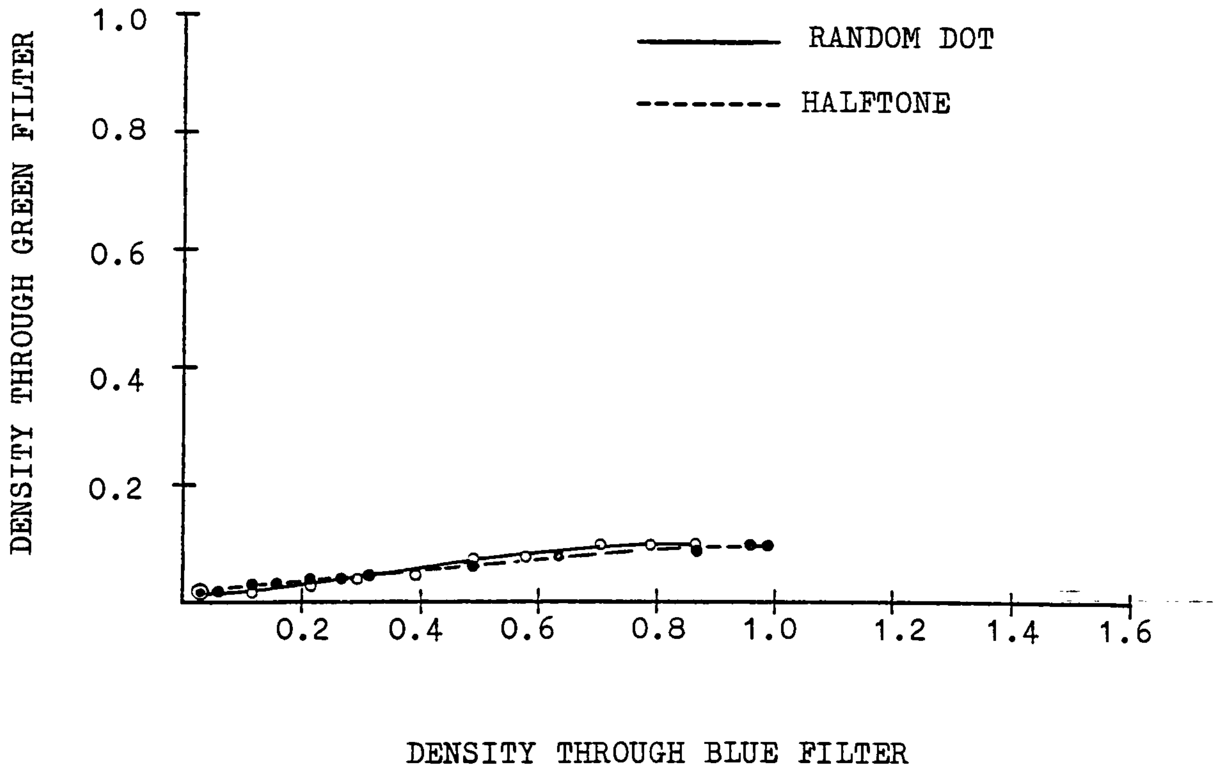


Figure 20

Chromaticity Diagrams

The measurement of color is generally divided into two problems. First the measurement of luminance and second, the measurement of chromaticity. A diagram in which each point represents the chromaticity independent of luminance of a color is called a chromaticity diagram.

The densitometric measurement of a color or ink will only indicate the luminance or luminous reflectance of the object, but it would not provide any information about the visual aspects of hue and saturation of the color.

The CIE chromaticity diagram is a psychophysical space system.[1] It does not represent equal visual perception differences. However, this system provides precise and accurate color specification. The three important components of color specification involve - a source of radiant energy or light (source), an illuminated object (attenuator) and an observor (detector).

In order to decribe the color of an object, the CIE system requires and provides both a standard light source and a standard observer. The incandescent light, noon sunlight and overcast-sky day light are fairly matched by the CIE standard sources A, B and C, respectively. The 1931 CIE standard observer is a numerical description of the response to color of the normal human eye to the color as expressed by the color matching functions $\bar{x}$, $\bar{y}$ and $\bar{z}$. The CIE system describes the color of the objects which are illuminated by the CIE standard sources and viewed by the CIE standard observers.

The CIE tristimulus values X, Y and Z are the objective specification of what the color is; and any color could be described by such a set. These are the standard coordinates of the 1931 CIE system. The tristimulus values of a color are obtained by multiplying together the relative energy E of a CIE standard source, the per cent reflectance or absorbance the object and the color matching functions.[2] The products are summed up for every ten wavelength or otherwise as mentioned in the visible or specified wavelength - to give the tristimulus values of the object. The percent reflectance or absorbance R of the object is obtained from the spectrophotometric curve. The curve, generated from reading the object in a spectrophotometer represents the spectral distribution of the object at the visible or specified wavelength of the standard source used.

$$X = E\ R\ x$$

$$Y = E\ R\ y$$

$$Z = E\ R\ z$$

The Y value represents the relative luminous reflectance of the object with respect to the intensity or the luminance of the standard source used for this experiment.

The chromaticity of the object is also described by the ratios of the tristimulus values of their sum[3].

$$\bar{x} = \frac{x}{x+y+z}$$

$$\bar{y} = \frac{y}{x+y+z}$$

$$\bar{z} = \frac{z}{x+y+z}$$

These ratios are known as the chromaticity coordinates $\bar{x}$, $\bar{y}$ and $\bar{z}$. The chromaticity coordinates are plotted on the chromaticity diagram (1931).[4] Of these coordinates $\bar{x}$, $\bar{y}$ are plotted and required to describe the color. The tristimulus value of Y must be separately described. The chromaticity coordinates $\bar{x}$ and $\bar{y}$ correspond to the sensation of hue and color saturation of the object. The CIE standard source or the illuminant point is also required to be designated in the chromaticity diagram. The dominant wavelength and the purity or saturation of the color are determined only with respect to the illuminant point. The dominant wavelength and the saturation correlate with the visual aspects of hue and chroma. However, the CIE chromaticity diagram (1931) is non linear to the visual color perception.

For the purpose of this experiment, the spectrophotometric readings of the selected samples were obtained by using a spectrophotometer which is capable of measuring a sample of very small dimension. This spectrophotometer was available at the Eastman Kodak Company, Rochester, New York. The spectrophotometer plotted the per cent reflectance curve of the sample and printed out this value at an interval of 10nm wavelength over the spectral distribution of the light source. The CIE standard sources used for this experiment were source A (incandescent light - 3400°K) and source D (average daylight - 6500°K). A computer calculates the tristimulus values and the chromaticity coordinates and prints out this data with respective reading of spectral reflectance of the sample. These $\bar{x}$ and $\bar{y}$ coordinates were then plotted in the chromaticity diagram (see Figures 21-24). The chromaticity diagrams were further studied for comparing the color characteristics of the random dot printing process vis a vis the halftone printing process.

The chromaticity diagrams were plotted for two different light sources and for the two different processes. The diagrams of identical light source and of the two different processes were compared. (Colorimetric data are all listed in Tables 4, 5, 6, 7.)

Beginning with the CIE standard source A, the chromaticity coordinates of the halftone process (See Figure 21) for each single color represented fairly close to a straight line compared to the coordinates of the random dot process (See Figure 22) which were curved. This behaviour was also apparent for the CIE standard source D (6500°K) (see Figures

23 and 24). The reason for the curvature of the line representing the chromaticity coordinates could be ascribed to various factors. The Munsell constant-hue lines in the CIE (1931) chromaticity diagram are generally curved - with the exception of one (10Y) in the yellow region and one (between 5) and .5P) in the purple region. The Bezold-Brucke phenomenon (Bezold, 1873; Purdy, 1937)[5] has indicated that most color stimuli change their hue with luminance.

A better depiction of the line joining the chromaticity coordinates of each single color was not possible to obtain from this chromaticity diagram, because it could precisely plot only up to two decimal points. It was however, attained through plotting the data on an extended scale - to three decimal points by using a different graph paper (see Figures 25-30). An indication of the curvature of the lines joining the coordinates of the halftone process was found. However, the curvature of the line was less noticeable than the one representing the random dot process. The difference of curvature was higher for the color cyan and magenta than for the color yellow. This could be due to the fact that the yellow ink was printed with minimum ink film thickness or solid ink density, and the yellow ink was found to have the least unwanted densities among the three process colors which were used in this experiment.

For a given density, the random dot printing process exhibited higher brightness than the corresponding halftone process. The chroma was the same or even higher. The difference in chroma for a set of coordinates of these two processes could not be expressed quantitatively because of the instrument's limit of accuracy. The effect of higher brightness (see Figures 25-30) makes for supporting the hypothesis that the random dot printing process varied the ink film thickness from the highlight to the shadow area of the scale, which helps to overcome the limitation of bright color reproduction.

1. Billmeyer, F.W., and Saltzman, M., Principles of Color Technology, John Wiley & Sons, Inc., New York, 1st Edition.

2. Ibid., pages 31-38.

3. Ibid., pages 38-45.

4. Judd, B.D., and Wyszecki, G., Color in Business, Science and Industry, John Wiley & Sons, Inc., New York, 3rd Edition 1975, pages 129-134.

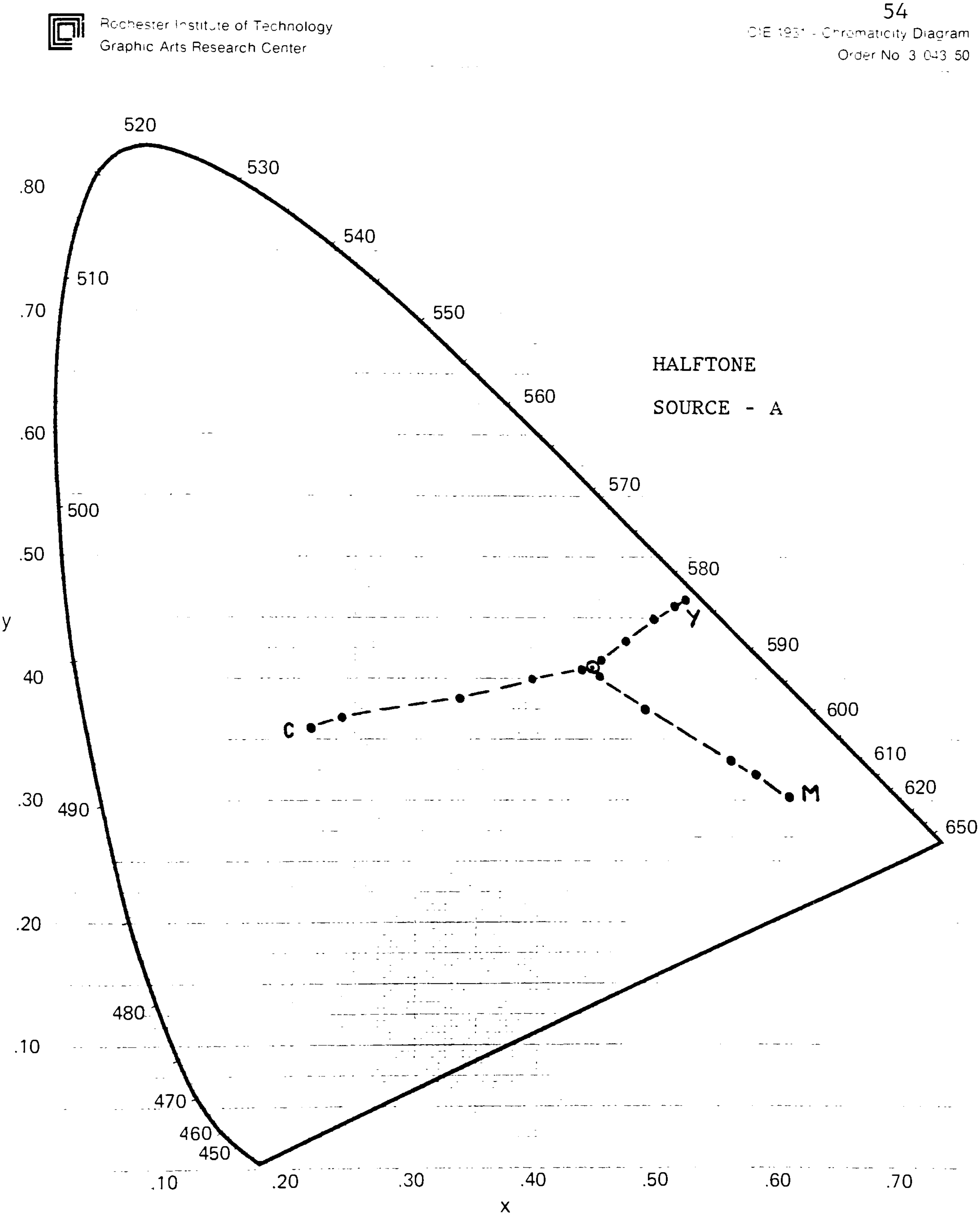
5. Ibid., pages 258-266.

CIE - STANDARD SOURCE A

HALFTONE PRINTING PROCESS

COLOR PATCH	DENSITY MEASURED THROUGH FILTER	CHROMATICITY COORDINATES		TRI-STIMULUS VALUE
CYAN	RED	x	y	Y
1	0.05	.4367	.4051	78.48
2	0.30	.3968	.3992	54.64
3	0.59	.3377	.3879	35.75
4	1.16	.2412	.3652	21.24
5	1.52	.2149	.3581	18.86
MAGENTA	GREEN			
1	0.06	.4532	.3991	77.11
2	0.32	.4900	.3733	52.47
3	0.81	.5614	.3310	29.36
4	1.00	.5816	.3200	25.76
5	1.50	.6098	.3029	22.15
YELLOW	BLUE			
1	0.03	.4524	.4120	85.91
2	0.22	.4741	.4320	81.52
3	0.50	.4977	.4485	79.06
4	0.89	.5158	.4602	76.30
5	1.04	.5190	.4635	75.20

Table 4


Rochester Institute of Technology
Graphic Arts Research Center
CIE 1931 - Chromaticity Diagram
Order No 3 043 50
HALFTONE
SOURCE - A
520
530
540
550
560
570
580
590
600
610
620
650
510
500
490
480
470
460
450
.80
.70
.60
.50
40
.30
.20
.10
y
.10
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.30
.40
.50
.60
.70
x
C
Y
M

Figure 21

COLOR PATCH	DENSITY MEASURED THROUGH FILTER	CHROMATICITY COORDINATES		TRI - STIMULUS VALUE
CYAN	RED	x	y	Y
1	0.06	.4366	.4058	79.91
2	0.30	.3876	.4035	55.76
3	0.58	.3382	.3975	40.66
4	1.10	.2507	.3735	23.91
5	1.52	.2149	.3581	18.86
MAGENTA	GREEN			
1	0.06	.4523	.3979	78.42
2	0.32	.4875	.3661	53.58
3	0.81	.5468	.3289	33.14
4	1.02	.5739	.3170	27.34
5	1.50	.6098	.3029	22.15
YELLOW	BLUE			
1	0.03	.4503	.4108	86.46
2	0.22	.4722	.4313	83.66
3	0.50	.4937	.4483	79.96
4	0.89	.5147	.4603	76.13
5	1.04	.5190	.4635	75.20

Table 5

Rochester Institute of Technology
Graphic Arts Research Center

CIE 1931 - Chromaticity Diagram
Order No. 3 043 50

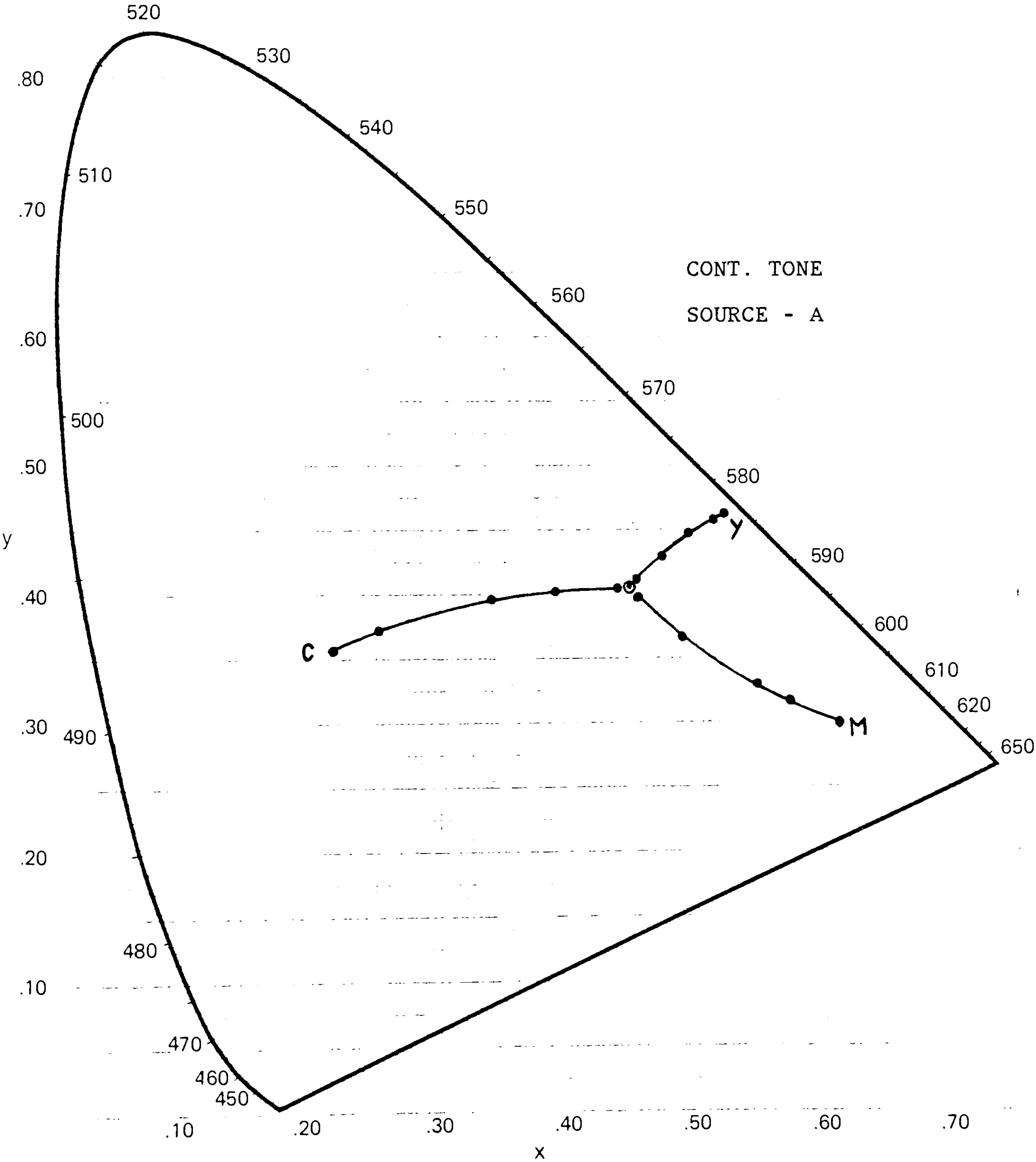


Figure 22

CIE - STANDARD ILLUMINANT D (6500 K)

HALFTONE PRINTING PROCESS

COLOR PATCH	DENSITY MEASURED THROUGH FILTER	CHROMATICITY COORDINATES		TRI - STIMULUS VALUE
CYAN	RED	x	y	Y
1	0.05	.3013	.3206	79.59
2	0.30	.2653	.2988	58.55
3	0.59	.2234	.2715	41.50
4	1.16	.1744	.2369	28.06
5	1.52	.1640	.2288	25.82
MAGENTA	GREEN			
1	0.06	.3143	.3194	76.39
2	0.32	.3381	.2986	49.10
3	0.81	.3993	.2639	23.80
4	1.00	.4209	.2539	19.85
5	1.50	.4534	.2344	15.64
YELLOW	BLUE			
1	0.03	.3196	.3390	85.52
2	0.22	.3533	.3857	79.56
3	0.50	.3984	.4457	75.53
4	0.89	.4397	.4961	71.64
5	1.04	.4493	.5058	70.37

Table 6

Rochester Institute of Technology
Graphic Arts Research Center

CIE 1931 - Chromaticity Diagram
Order No 3 043 50

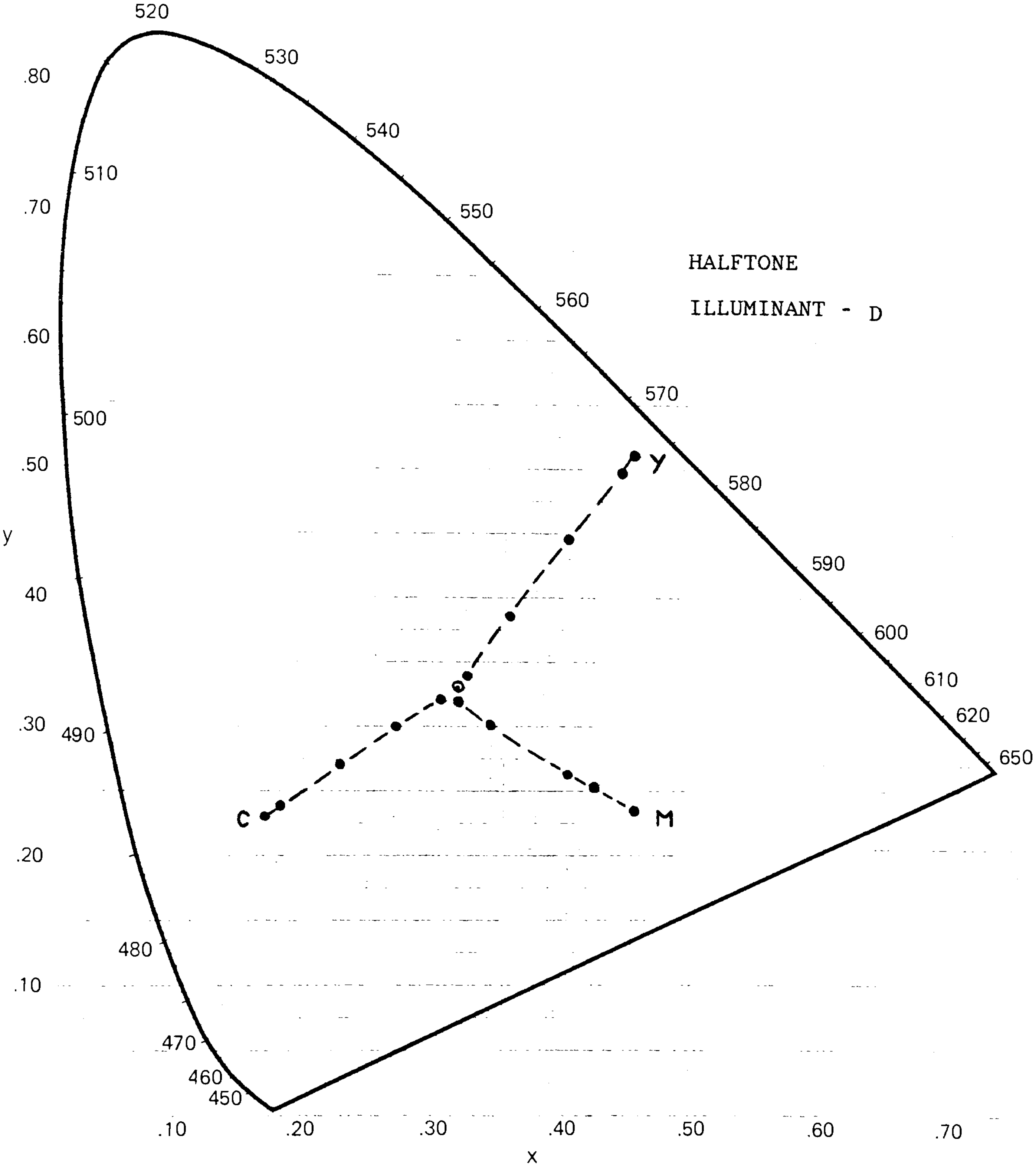


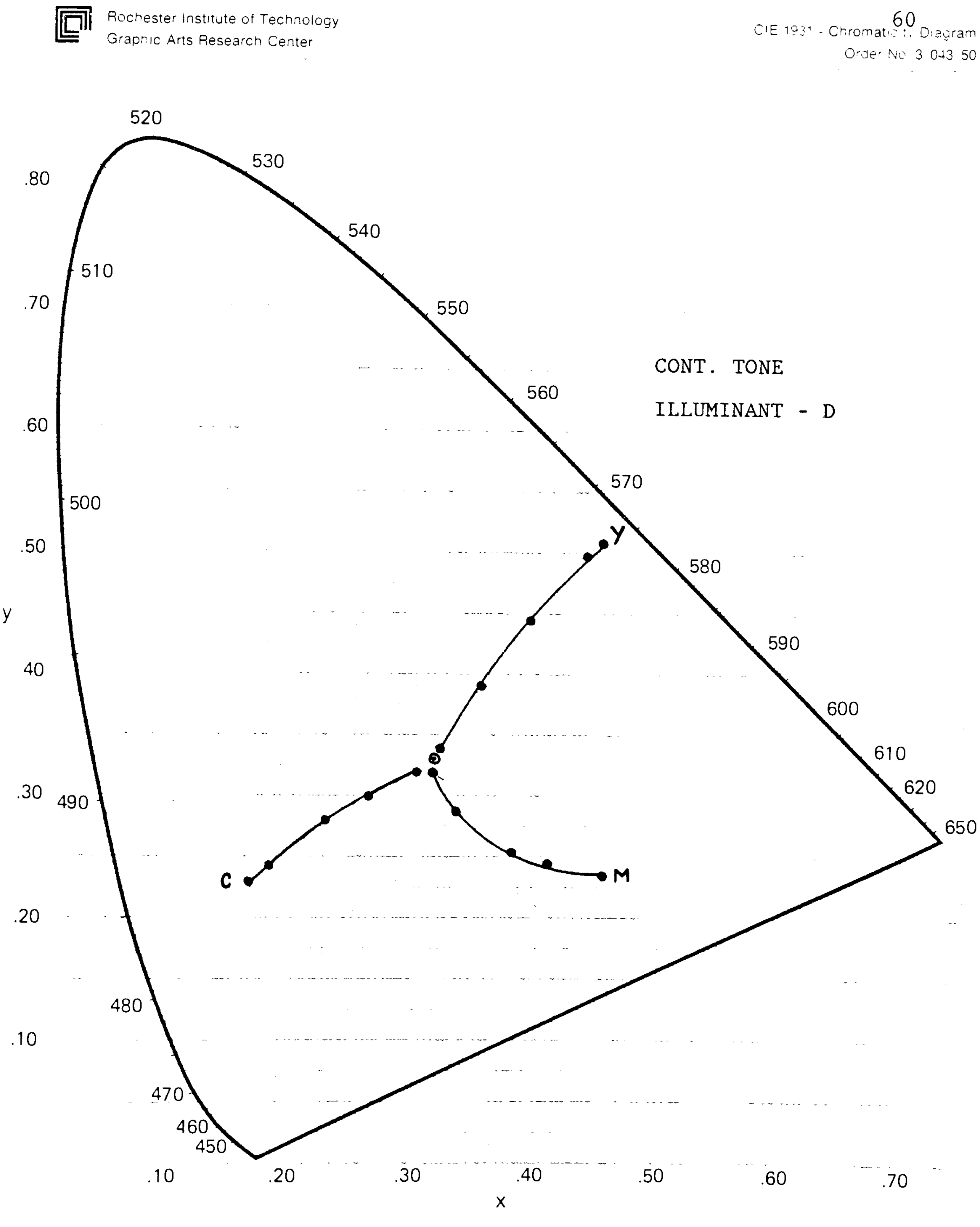
Figure 23

CIE - STANDARD ILLUMINANT D (6500 K)

RANDOM DOT PRINTING PROCESS

COLOR PATCH	DENSITY MEASURED THROUGH FILTER	CHROMATICITY COORDINATES		TRI - STIMULUS VALUE
CYAN	RED	x	y	Y
1	0.06	.3015	.3215	81.06
2	0.30	.2598	.3009	60.48
3	0.58	.2258	.2813	47.08
4	1.10	.1792	.2944	31.10
5	1.52	.1640	.2288	25.82
MAGENTA	GREEN			
1	0.06	.3129	.3170	77.76
2	0.32	.3320	.2863	50.12
3	0.81	.3785	.2535	27.47
4	1.02	.4072	.2449	21.26
5	1.50	.4534	.2344	15.64
YELLOW	BLUE			
1	0.03	.3170	.3363	86.29
2	0.22	.3513	.3886	82.07
3	0.50	.3917	.4444	77.00
4	0.89	.4374	.4970	71.71
5	1.04	.4493	.5085	70.37

Table 7


Rochester Institute of Technology
Graphic Arts Research Center
CIE 1931 - Chromaticity Diagram
Order No. 3 043 50
CONT. TONE
ILLUMINANT - D
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.70
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.50
40
.30
.20
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y
x
.10
.20
.30
.40
.50
.60
.70
Y
C
M

Figure 24

ENLARGED CHROMATICITY DIAGRAM

CYAN PRINTER

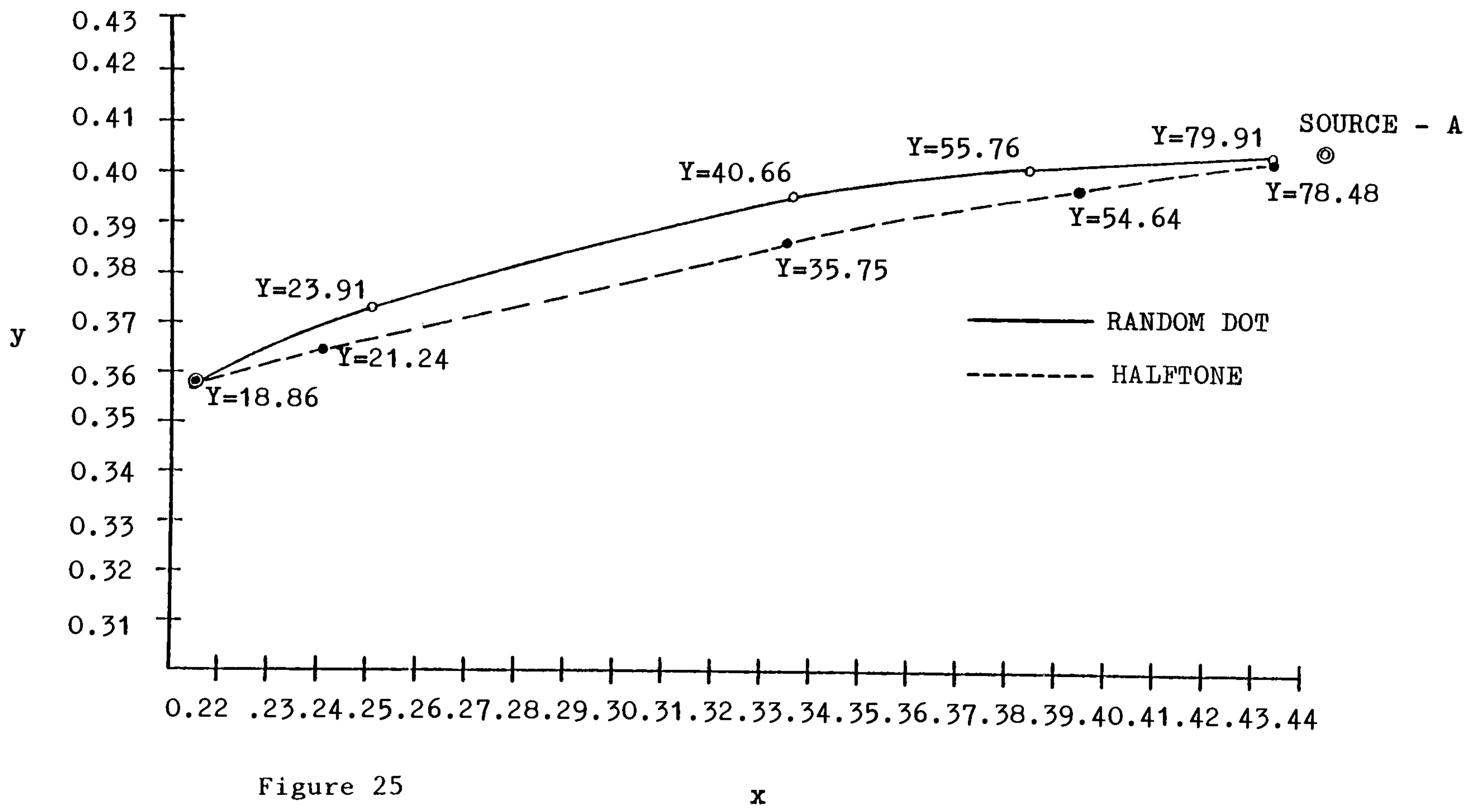

Figure 25

ENLARGED CHROMATICITY DIAGRAM

MAGENTA PRINTER

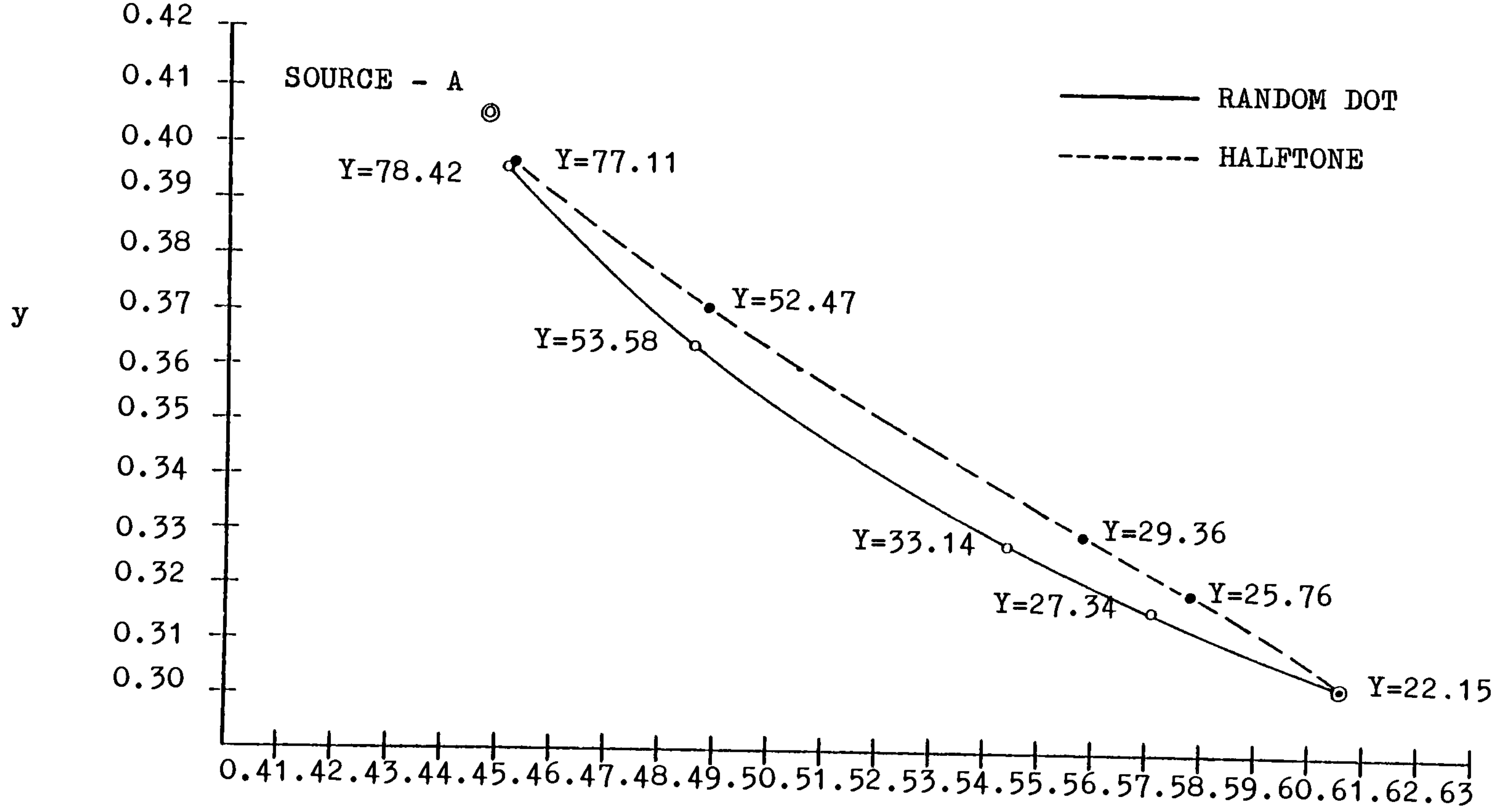

Figure 26

ENLARGED CHROMATICITY DIAGRAM

YELLOW PRINTER

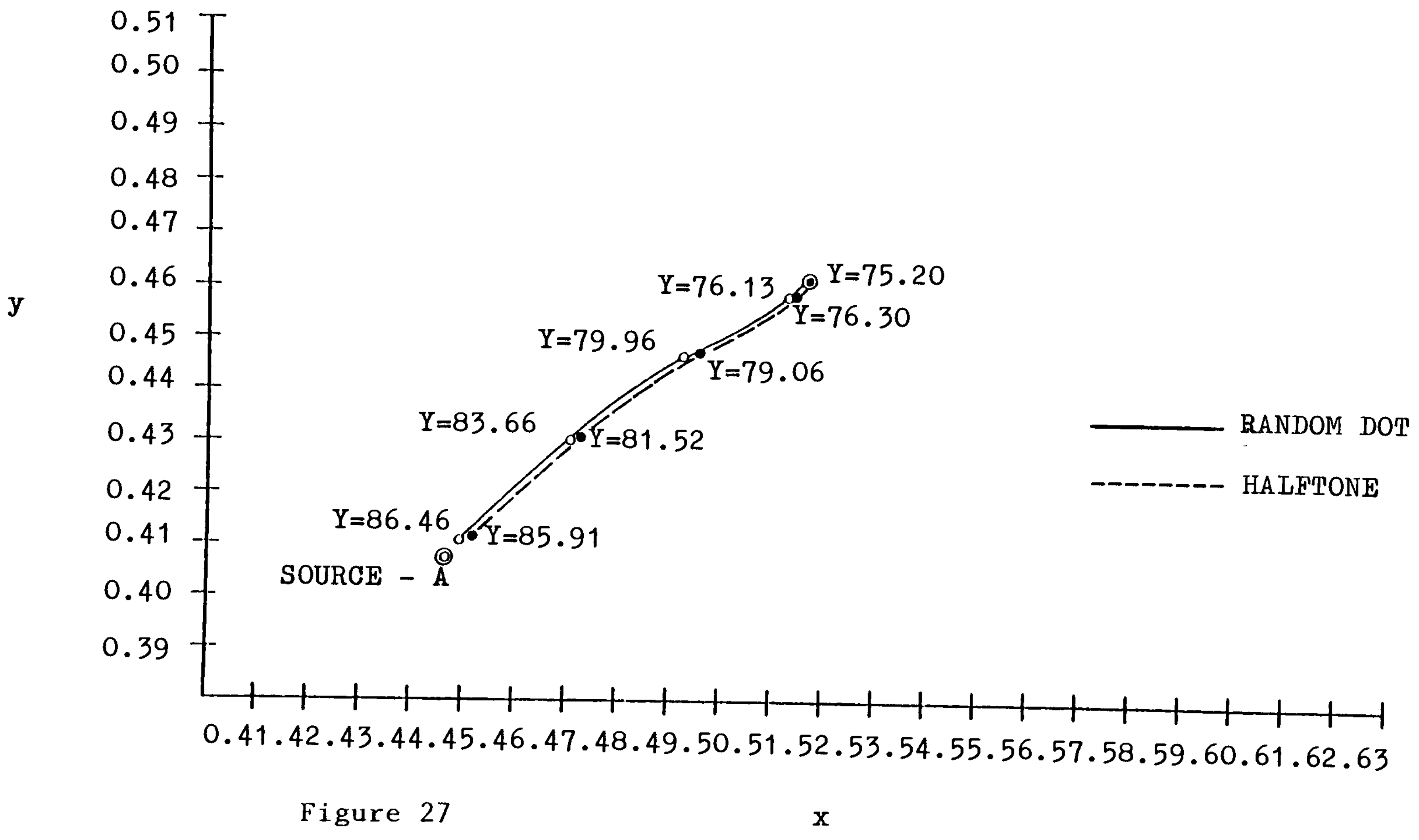

Figure 27

ENLARGED CHROMATICITY DIAGRAM

CYAN PRINTER

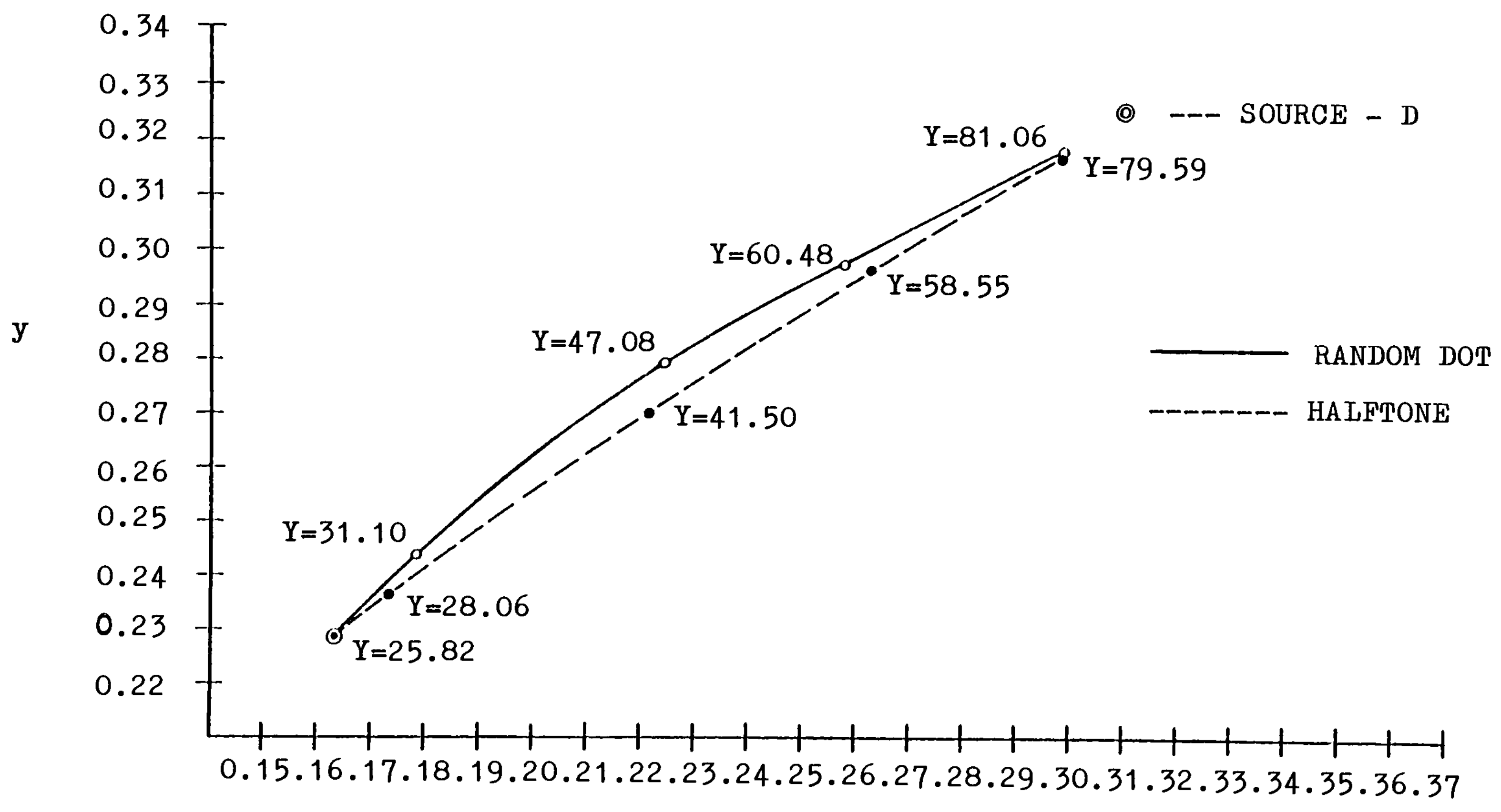

Figure 28

ENLARGED CHROMATICITY DIAGRAM

MAGENTA PRINTER

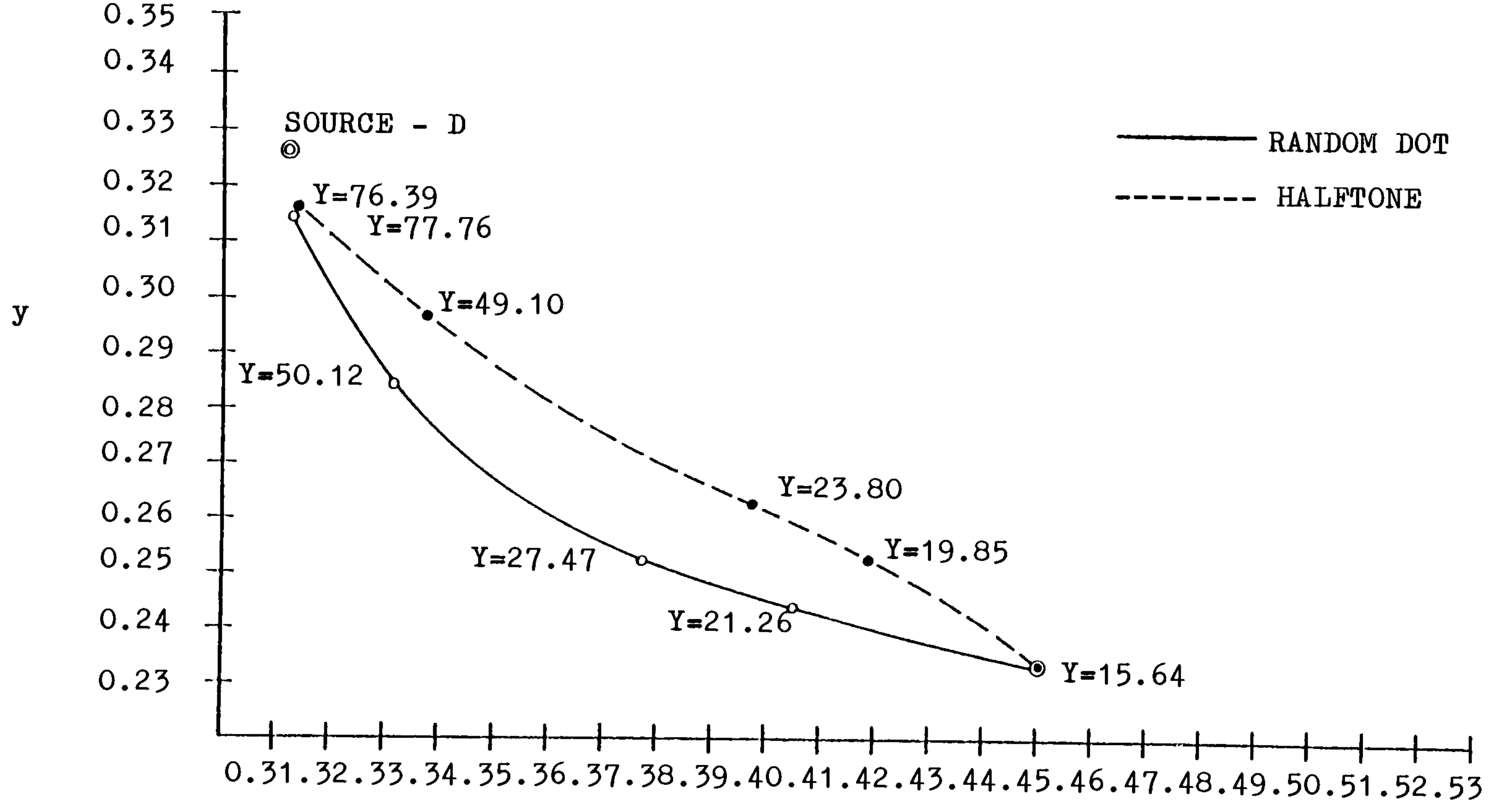

Figure 29

ENLARGED CHROMATICITY DIAGRAM

YELLOW PRINTER

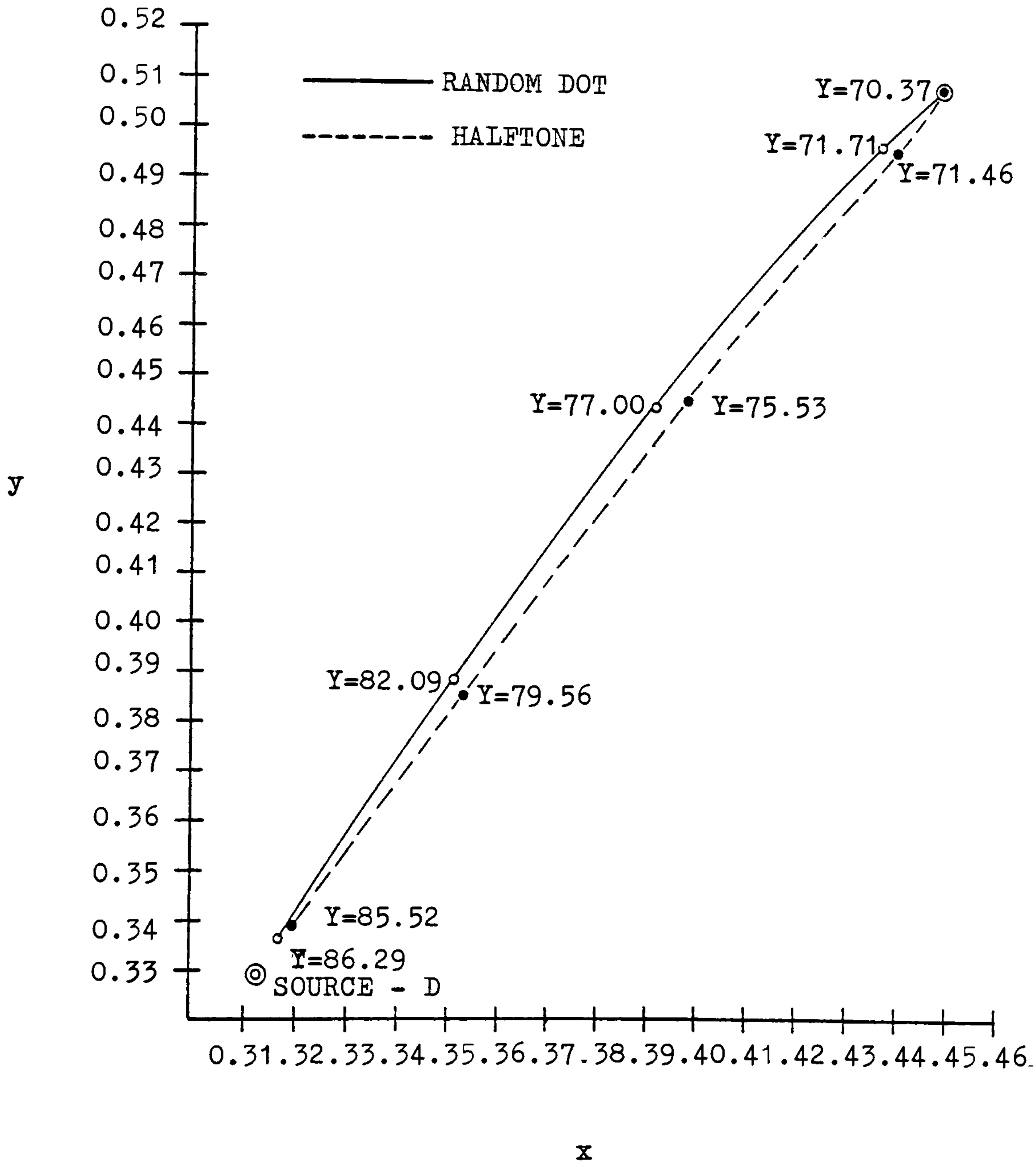

Figure 30

CONCLUSIONS

The result of comparison of color characterstics reproduced by two different processes was discussed. The color characteristics evaluated were hue error, per cent grayness, proportionality failure and comparison of brightness and saturation.

Tone Reproduction

The tone reproduction of the random dot printing process is primarily a function of the grain structure of the printing plate. The exposure and processing of the plate also effect the shape of the characteristic curve. This is true for both the processes, but it is very critical for the random dot process. The difficulties of determining the right plate exposure are due to the lack of proper test targets.

The tone reproduction curves generated by both the processes do not resemble the optimum curves. Nevertheless, the halftone process yielded better results than the random dot process.

Hue Error

The cyan printer showed overall less per cent hue error for random dot printing.

The magenta printer had one point in the high light area which indicated higher hue error than the corresponding point reproduced by halftone printing system. The points, except for the above mentioned one, showed less per cent hue error by random dot printing process.

The yellow printers, being printed with the lowest solid ink density, exhibited almost identical curves. The random dot process had a little per cent hue error in the highlight or the lighter tone area.

Per Cent Grayness

The magenta printer showed less per cent grayness in the highlight area, when printed by the random dot process. In the higher density area, per cent grayness was very similar in both processes.

The cyan printer, in the random dot process, had one point higher than the corresponding point reproduced by the halftone process. All other points of the random dot process had a lower per cent grayness.

The yellow printer, in both processes, had the same curves - except for the density area of 0.5 to 0.6. The random dot process indicates a little higher per cent grayness in that area.

Proportionality Rule

Both the processes exhibited failure of the proportionality rule. The failure was less severe for the yellow printer, and both processes indicated the same behaviour. In the case of the other two colors, the relative failure was less for the random dot printing process.

Chromaticity Diagram

The chromaticity coordinates, derived from the experimental data of the random dot process, had higher brightness, whereas the saturation of the patches of equal densities were the same and sometimes higher. The higher brightness of the lower density area may be a consequence of lesser ink film thicknesses on those area.

The curvature of the line representing the coordinates of the random dot process may be due to one or more reasons. It is very likely that the curvature of the line simulates the curve customarily generated by equal visual perception of Munsell system on the CIE (1931) chromaticity diagram. Another reason could be the scattering of the light by the dot structure of the random dot process.

One may also speculate that the line joining any two of the three primary colors or representing the combination of any two primary colors would also be curved. The result will be a triangle of larger area than the area of the triangle reproduced by the halftone process. The triangle of larger area means a larger gamut of reproducible colors by the set of process colors used.

Based on the result of this study, it is assumed that the hypothesis is valid. This states that if the random dot printing process varies the ink film thickness from the highlight to the shadow area and prints at a very close approximation to a very high frequency halftone printing process, then the random dot printing process should overcome the limitations of color reproduction by the conventional halftone printing process.

RECOMMENDATION

Further studies in this area are essential. The characteristics of the random dot printing process will be understood only with future research.

It has been noticed that the plate exposure for the random dot process is very critical. Confirmation of the right exposure was not possible without a roll up on the press - a procedure that is very cumbersome. Therefore, a test target should be developed to overcome this problem.

A comparative study of these two processes would require similar characteristic curves for tone reproduction.

It is also necessary to study the gamut of color reproduction. The color gamut chart should be printed by both the processes and their exact reproduction should be judged by plotting the chromaticity coordinates of each color on the chromaticity diagram. It is important to be aware of the size of color patches on the color gamut chart and the aperture of the spectrophotometer. Each color patch has to be large enough to cover the aperture of the spectrophotometer, otherwise the situation would introduce error to the readings.

Last but not least, the effect of ink tack on the gamut of color reproduction and on the range of the tone reproduction curves should be investigated.

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