GRAY COMPONENT REPLACEMENT: THE SCANNER CONNECTION

by
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ABSTRACT

Grey Component Replacement (GCR) is routinely available as an option on a variety of graphic arts color separation scanners made by several different manufacturers.

Many of the algorithms associated with the computation of GCR have been derived from the use of the Neugebauer [1] equations. However, as reported by Johnson [2] and Jung [3], each of the various scanner manufacturers utilize a different combination of approaches to produce their specific GCR effect. Questions have arisen concerning differences in the color and tone characteristics available from the different scanner sources, and how the differences, if any, are propagated through the reproduction chain. No single work is available comparing each of the various GCR/UCA scanner outputs with one another (film as well as resultant ink on paper images). The conventional 4 color output used a common input control transparency printed at the same time on the same press.

It is the object of this paper to review the results of data obtained by the author for the 3M Company from studies conducted independently and also under the auspices of the GCR Study Group of the Graphic Communications Association. This work represents an attempt to facilitate an understanding of the graphic arts halftone technique known generally as Grey Component Replacement.

BACKGROUND

Grey Component Replacement or GCR has been defined as a technique in color printing wherein the neutral or grey component of a three color image is replaced during reproduction with a corresponding level of black ink. The color components of that image are reduced by that level of removed grey.

Sigg [4] described GCR as a technique in color reproduction where in any given image location "the least predominant of the three primary printing inks is used to calculate a partial substitution for some or all of the primaries by black". A combination of this grey component into the black printer produces print images of near equivalent color result to conventional printing.

In a 4 color reproduction process a black printer is used for several purposes, among those to improve image definition and to extend the color gamut available, especially in the dark, saturated color image areas. Another reason to use the black printer is in a technique called Undercolor Removal (UCR) which allows for better ink trapping and drying.

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UCR does this by reduction of the colored ink levels at the upper portions of the tone reproduction curve and a replacement of this removed colored ink by increased black ink. Under the Sigg [4] definition and that of Yule [5] UCR is a subset of GCR.

In UCR however, this ink substitution technique ONLY occurs at the shoulder and Dmax levels of the neutral or grey tone reproduction curve. The resultant increased black image is of reduced range and sometimes called a "skeleton black".

GCR, as discussed in this paper, is differentiated from UCR by the fact that the colorimetric substitution of black ink for the grey replacement occurs throughout the image affecting grey and tertiary color images. Modern GCR is implemented with a scanning device which facilitates, during the halftone color separation step, the digitization and manipulation of color images at the smallest picture element or "pixel" stage. The black halftone separation that results from this technique is a full range black separation.

Early GCR images were judged to be commercially unacceptable as compared to those of the same image produced under conventional 4 color reproduction. Therefore, commercial acceptance of this technique diminished. The basic difficulty appeared to be an apparent lowered shoulder contrast in the GCR image. This condition is now eliminated or reduced by the practice of adding additional densities of each of the primary colors at the upper portion of their GCR tonal curve (in a ratio to ensure neutrality). This added density has been called Undercolor Addition or UCA. This difficulty appears to be due to a phenomenon called density additivity failure. Not withstanding the reason for UCA, GCR plus UCA has proven to be an effective team to ensure excellent color reproduction.

Questions concerning the color and tone reproduction characteristics of the different scanner output films through the reproduction chain have arisen. No definitive single work has appeared that compares the major scanner manufacturers outputs (GCR/UCA as well as conventional 4 color UCR) to each other for a common input on the same press run.

The Graphic Communication Association GCR Study Group provided a forum, with independent assessment by 3M Co., for scanner manufacturers to participate in such a study. This technical report will attempt to cover GCR studies by the 3M Company independently as well as part of that GCR Study Group.

APPENDIX 2 lists the membership of this GCR Study Group. Particular appreciation should be given to the scanner manufacturers as well as R. R. Donnelley, Torrance, CA. for the press time, ink, and paper as well as the labor and assistance.

For purposes of this report the various scanners involved will not be mentioned by brand name or model but only by letter.

OPERATIONAL DATA

The GCR test to date consists of 3 phases.

PHASE 1 INITIAL SET UP TEST

Since different ink sets have different secondary absorptions the GCR/UCA scanner set up must be custom adjusted to the ink being used. The use of standard ink colors such as SWOP (Specification Web Offset Publications) inks or Gravure Advertising Association Group VI inks simplifies the set up procedure.

PHASE 1 allowed the scanner manufacturers the opportunity to contact print their proprietary set up targets onto the plates to be used and obtain an ink on paper image from a press run at R. R. Donnelley, Torrence, Ca. This allowed them to fingerprint the inks, paper, and press. The derived data allowed the manufacturers themselves to set up optimum GCR adjustments for their own devices. Other in process test targets were included to provide process control for press consistency to the other phases of this study.

PHASE 2 SCANNER OUTPUT TESTING

Five scanner manufacturers were invited to use their data from Phase 1 to produce color separations from a custom 3M machine readable Ektachrome color transparency (details in APPENDIX 1)

The following operational instructions were given the scanner manufacturers for Phase 2:

1. Standard scanner linearization and control procedures were requested.
2. Since each scanner manufacturer provides a variety of output tone curves, the "normal" output curve was requested.
3. To standardize scanner input, a whitepoint and Dmax was specified for the 3M Scanner Grey Scale Target (A2)
4. An EK pictorial was included as a visual indication of GCR/UCA.
5. Each manufacturer was asked to produce a GCR/UCA set of 300% total area coverage color separations (at the manufacturers' selected UCA level appropriate for the GCR level chosen) covering the range of 100% to 50% GCR and a conventional (300% UCR total area coverage) separation. The GCR levels were specified at 100%, 85%, 75%, 65%, and 50%.

Unfortunately only 2 of the manufacturers chose to participate in this phase. These separations were quality checked at 3M using a Watchprint system then stripped up and again web printed at R. R. Donnelley at Torrence, Ca..

In the interest of accommodating the greatest scanner manufacturer participation, as well as provide a measure of data reliability, this full task was repeated twice-Phases 2 and 3. Experience being the greatest teacher some small changes in instruction were communicated to the manufacturers for phase 3.

PHASE 3 CHANGES

1. To ensure a specified input curve, the curve of the 3M transparency grey scale (A2) was additionally specified by detailing 25%, 50%, and 75% points as well as white point and Dmax.
2. A 3M practical transparency mated to the 3M Scanner Target was included in the test to be scanned under the same conditions as the Scanner Target.
3. The magnification of the 3M Target and practical was specified at 200%. This insured a final image size that could be analyzed by colorimetry.
4. The levels requested for Phase 3 were restricted to 50, 75, and 100% as well as the conventional (UCR 300% Total Area Coverage)
5. A request was made to produce GCR separations with and without UCA. This was to ascertain where UCA correction was applied.

A transparency formally used in a live advertisement was contributed by and included with the readable 3M Scanner Target.

EXPERIMENTAL PHASE 3 PRESS RUN Press and ink details

The following instructions were provided for the press runs of Phases 2 and 3.

1. The GCR/UCA and conventional separations were to be printed on the same plates side by side.
2. Information on which image came to an OK stage (GCR or Conventional) faster and makeready data was to be collected.
3. Selected sheets were to be sampled during the run.
4. Single color images of yellow, magenta, cyan and black were to be obtained.*
5. At the end of the press run the ink solid densities of only the cyan was to be changed by 0.50 density.*
6. At the end of the press run the ink solid density of only the magenta was to be hanged by 0.50 density.*

* Instructions apply only to Phase 3. Note 5 and 6 would be an indicator of the robustness of the GCR/UCA image as compared to the conventional image.

Unfortunately only 4 of the 5 scanner manufacturers fully participated. The levels of GCR delivered, however, were different than those requested. Nevertheless, some interesting truths were revealed.

Full data is available for all the test images, film and printed images alike. Time and space does not permit a full discussion of all of these. Since yellow inks have excellent to good secondary absorptions, and black inks are vital to the GCR effect, much of the comments of this paper will highlight these two inks, as well as the separations and print images involved in their reproduction.

Figures 1a through 1d compare the conventional image percent dot area analysis of the yellow, magenta, cyan, and black separations of Participants A, B and C. There are differences between the scanner outputs. Although the separations from Participant A appear somewhat lower in speed and contrast the results are close. The results are however indicative of field practice.

Yellow Separations - Participants A, B & C

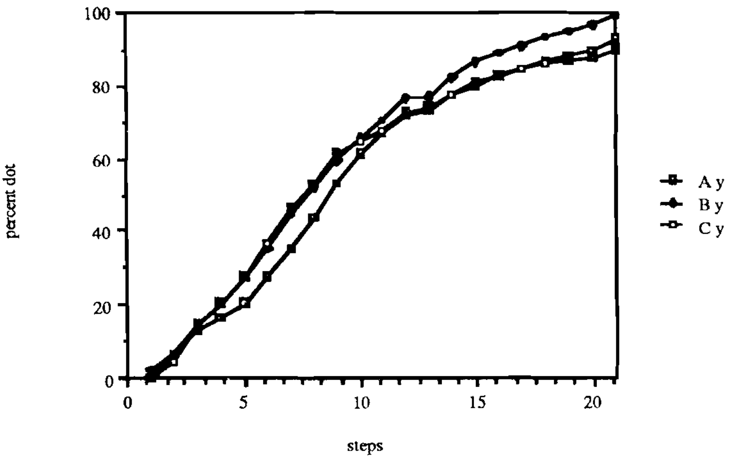

Figure 1a

Magenta Separations - Participants A, B & C

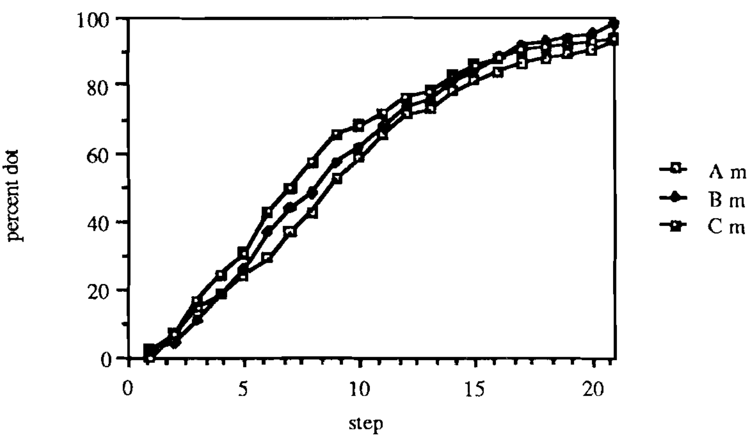

Figure 1b

Cyan Separations - Participants A, B & C

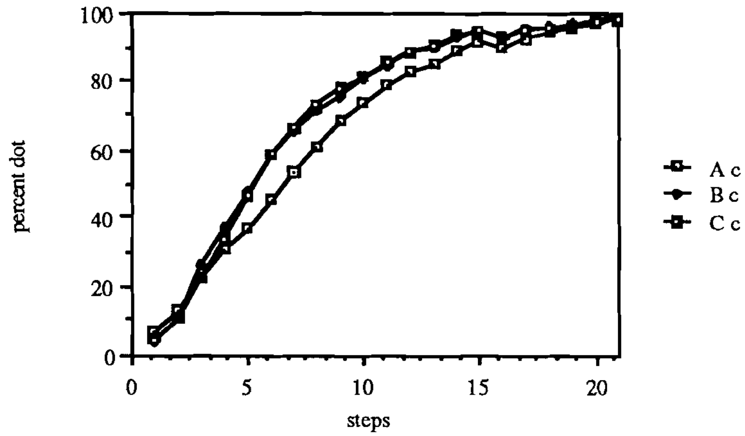

Figure 1c

Black Conventional Separations - Participants A, B & C

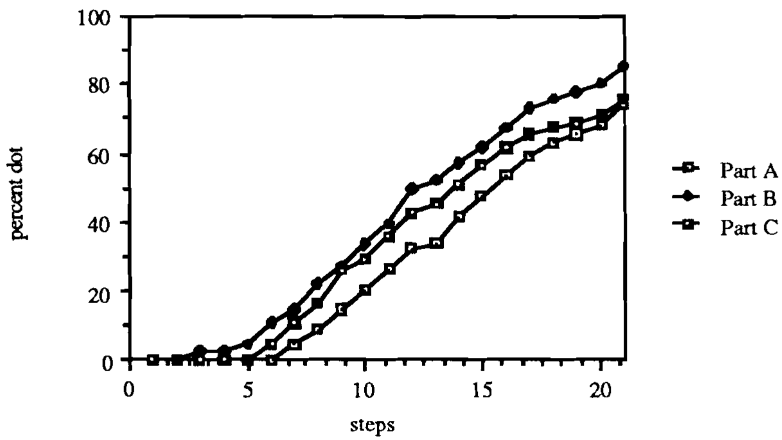

Figure 1d

Figure 2 compares the percent dot area analysis of the black sepration of the conventional UCR images as well as the 100% GCR/UCA images for Participants A and D. It appears that these Participants can produce conventional and 100% GCR/UCA images that closely match each other.

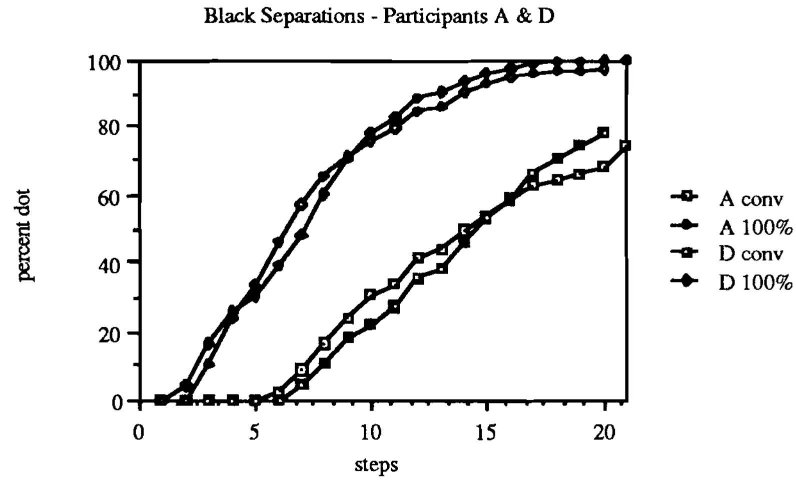

Figure 2

Figure 3 compares the black separation of the conventional UCR images as well as the 50% GCR/UCA images for Participants A and D. While these Participants can produce conventional and 100% GCR/UCA images that match each other,their 50% GCR/UCA levels differ.

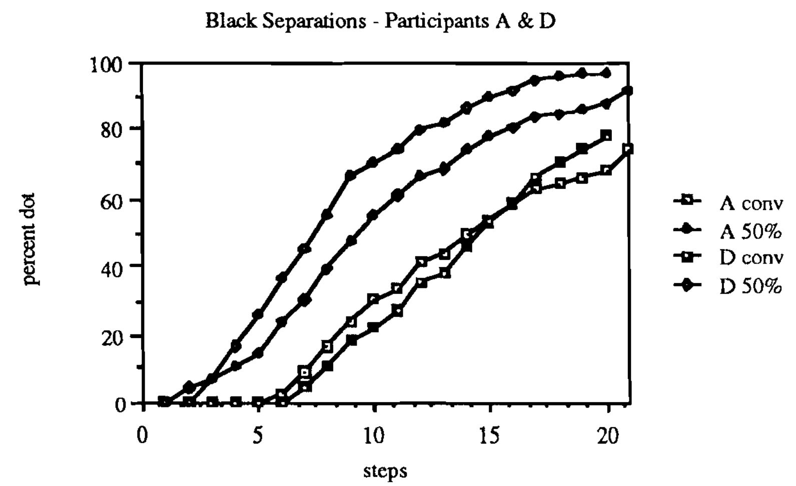

Figure 3

Figure 4 details the blue filter, yellow separation percent dot area analysis of the conventional image and changes in the GCR/UCA response for a 50 to 100% change for Participant A.

Yellow Separations - Participant A

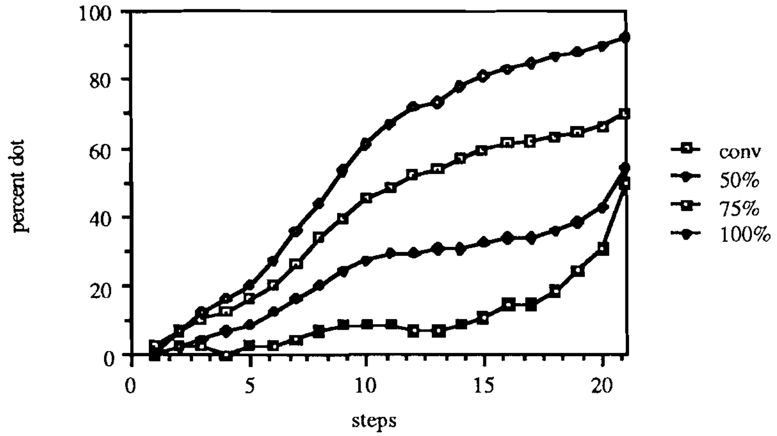

Figure 4

Figure 5 details the green filter, magenta separation of the conventional image and changes in the GCR/UCA response for a 50 to 100%.GCR change for Participant A.

Magenta Separations - Participant A

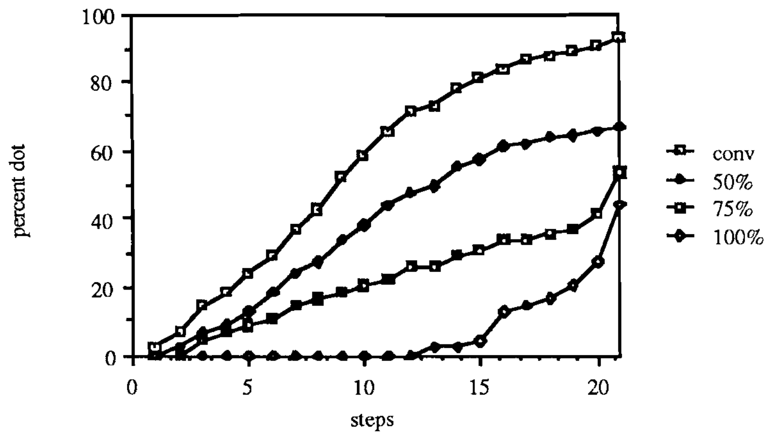

Figure 5

Figure 6 details the red filter, cyan separation of the conventional image and changes in the GCR/UCA tone response for a 50 to 100% GCR change for Participant A.

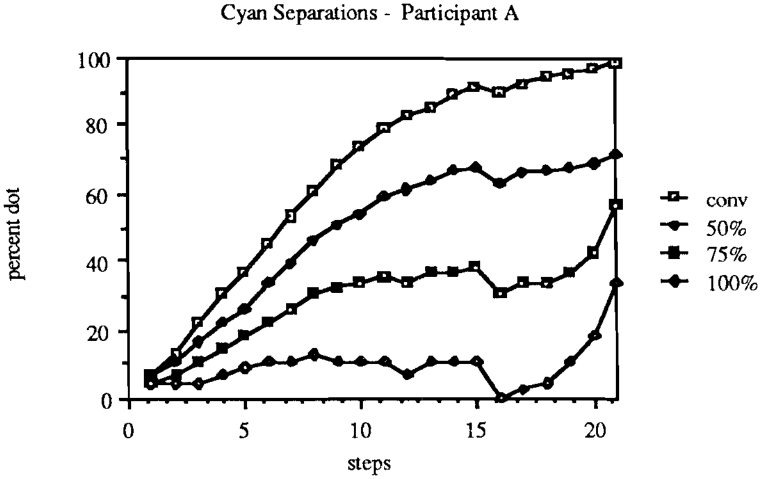

Figure 6

Figure 7 details the black separation of the conventional image and changes in the GCR/UCA response for a 50 to 100% GCR change for Participant A.

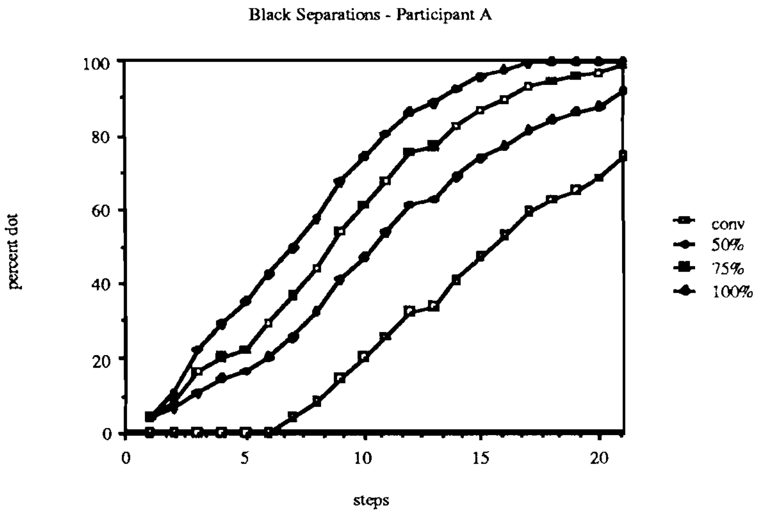

Figure 7

Note the deliberate smooth transition between the conventional and the different levels of GCR.

Figure 8 details percent dot area analysis of the black separation of the conventional image and gradual changes in the GCR/UCA response for a 70 to 100% GCR change for Part.B.

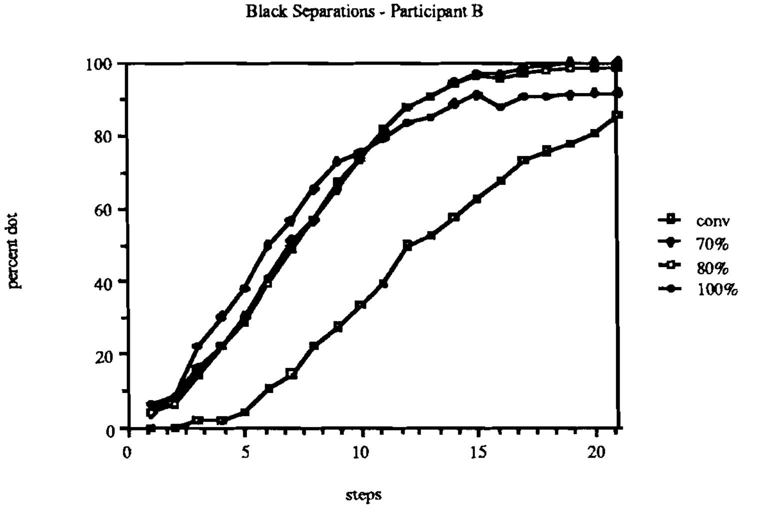

Figure 8

Participant B could not deliver a 50% level. Levels "B" called 70, 80, and 100% percent were provided. The change in black printer response over this range is dramatic. Compression, not differentiation is evidenced between the 70, 80, and 100 % levels.

Figures 9a and 9b detail the blue filter, yellow separation film response for the various GCR/UCA levels from Participant A and the same GCR/UCA levels from Participant D.

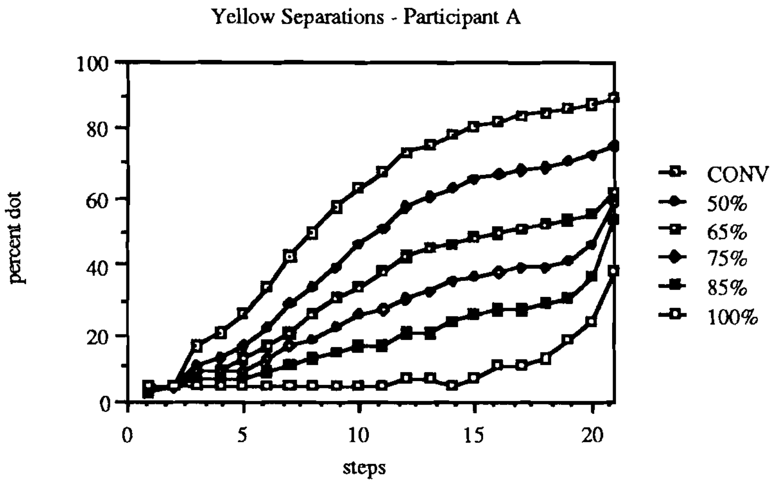

Figure 9a

Yellow Separations - Participant D

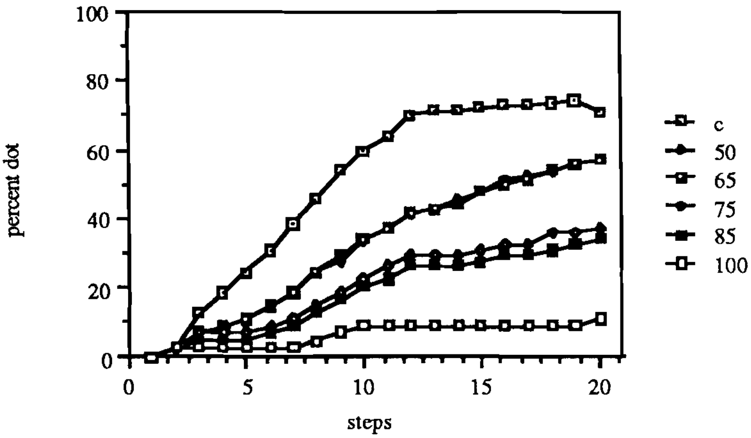

Figure 9b

It is evident that both Participants can produce GCR/UCA results that cover the same range, but Participant D tonal values for 50 and 65% GCR/UCA levels are the same. The tonal values of the 75% and 85% levels are also equal for this Participant.

This evidence indicates that the nomenclature "percent GCR" is deceptive since not all the scanners available produce the same response for a specified percent GCR input. Also, not all the scanners produce the same range of GCR.

Figure 10 depicts the differences between Participants B and C for the percent dot area for the blue filter, yellow separation at a 100% GCR/UCA level. A set of conventional UCR containing blue filter, yellow separation curves for both Participants is included. Speed and contrast differences appear to exist between the B and C GCR/UCA separations.

Yellow Separations - participants B & C

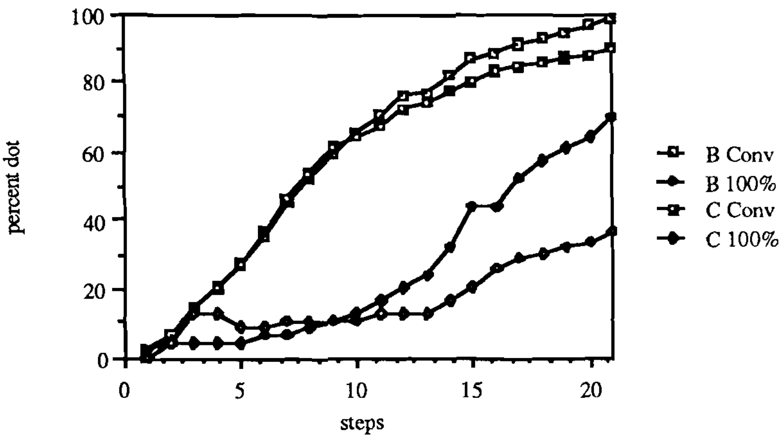

Figure 10

However, separations with and without UCA were provided by Participant C. Examination of the plus and minus UCA curves of Participant C to the reproduction curve of Participant B (Figure 11) ndicates that the difference between the curves may be due to the point at which the UCA effect becomes operative and the level of UCA provided.

Yellow Separations with & without UCA - Part B & C

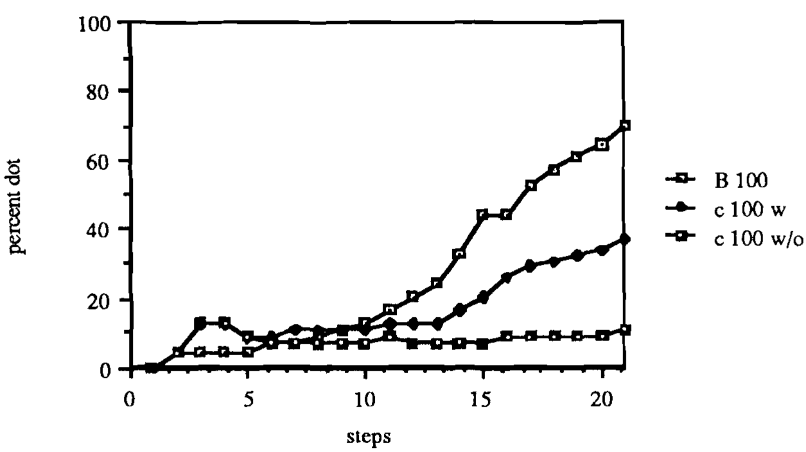

Figure 11

There appear to be program related differences between devices concerning the tonal point at which the UCA effect begins. Since many of the scanning devices have no controls that enable the operator to effect the point where UCA becomes operative, this presents a difficulty. The amount or level of the UCA effect is adjustable, but the evidence seems to indicate differences between the values of UCA. A standard operating procedure covering the point at which UCA becomes operative as well as how best to determine the UCA level is needed.

Figures 12a and 12b compare the percent dot area curves available from the analysis of the blue filter, yellow color separation films (right image) to the final 4 color ink on paper composite gray images made from those films (left image). These are for conventional as well as all levels of GCR for Participant A.

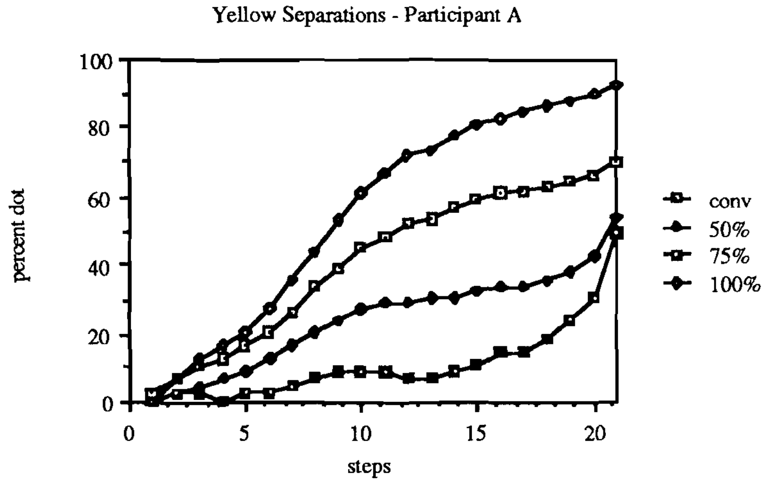

Figure 12a

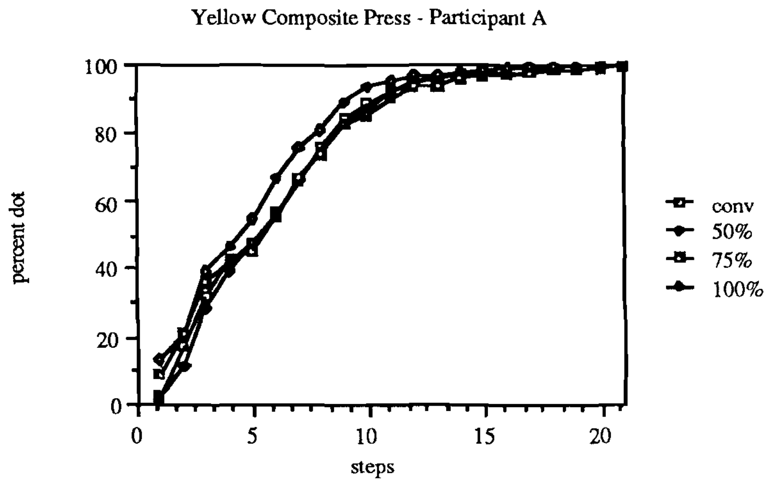

Figure 12b

The difference in the curve shapes of the right and left images are due to the inability of integral densitometry to separate the yellow density contributions of the primary yellow image from the yellow density produced as a result of the yellow contributions of the magenta, cyan, and black ink images.

This perceived difficulty prompted the author to request single color ink images of all the color and black separations for the Phase 3 press run.

Figure 13 depicts the color density matrix available from a densitometric analysis of all the colors and black from the ink set used in this test.

	V	R	G	B
Yellow	0.17	0.16	0.21	0.91
Magenta	0.74	0.28	1.21	0.71
Cyan	0.80	1.36	0.51	0.28
Black	1.62	1.65	1.60	1.55

Figure 13

Figure 14 is a synthetic curve derived from the addition of the densities of yellow secondary and primary contributions of the inks used to make the composite. The additive curve matchs that of the final curve and demonstrates the effect.

Synthetic and Actual Yellow Conventional

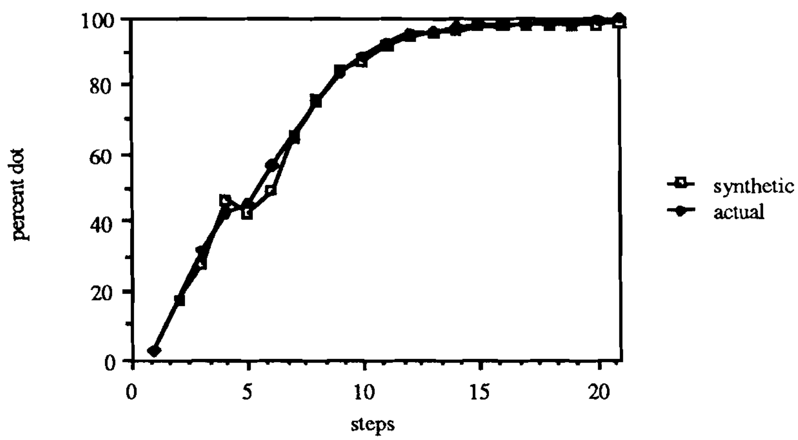

Figure 14

Figures 15a through 15h depict the single color images of each of the individual film separations for each color and compares them to the corresponding single ink on paper separation. The differences between the film and single color ink images relates to the dot gain on press.

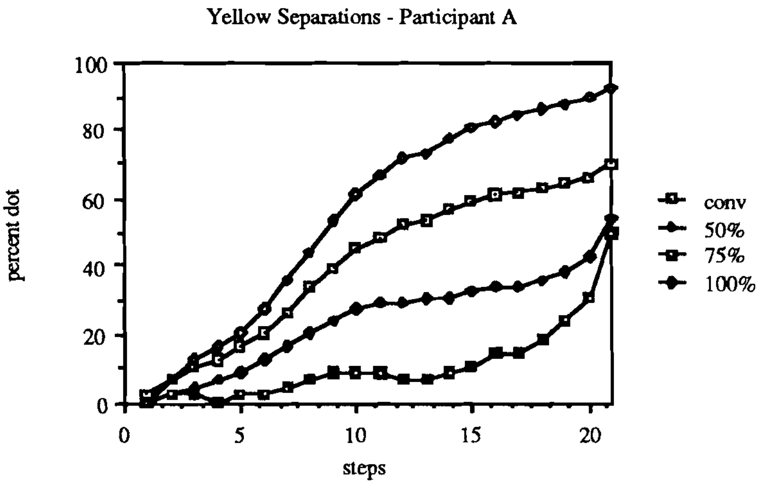

Figure 15a

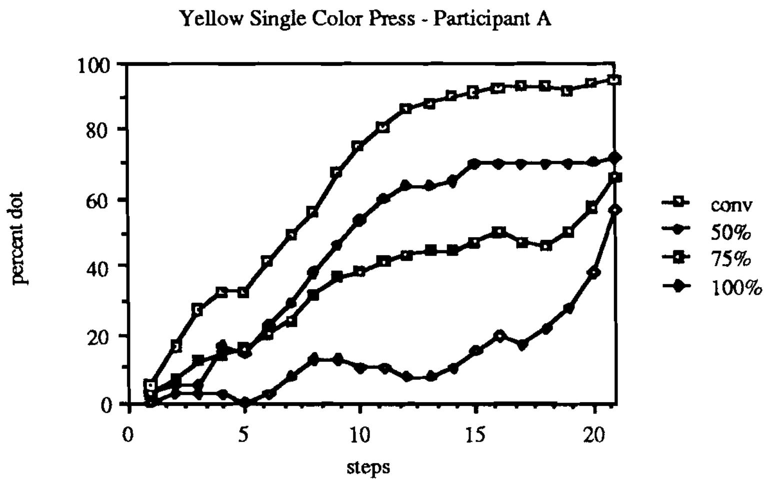

Figure 15b

Magenta Separations - Participant A

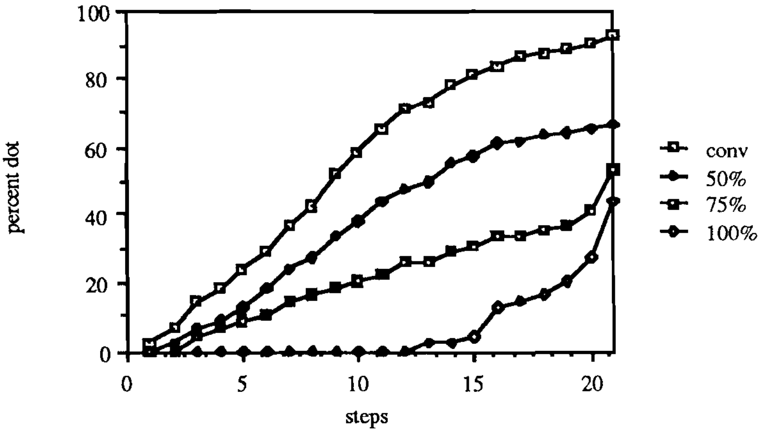

Figure 15c

Magenta Single Color Press - Participant A

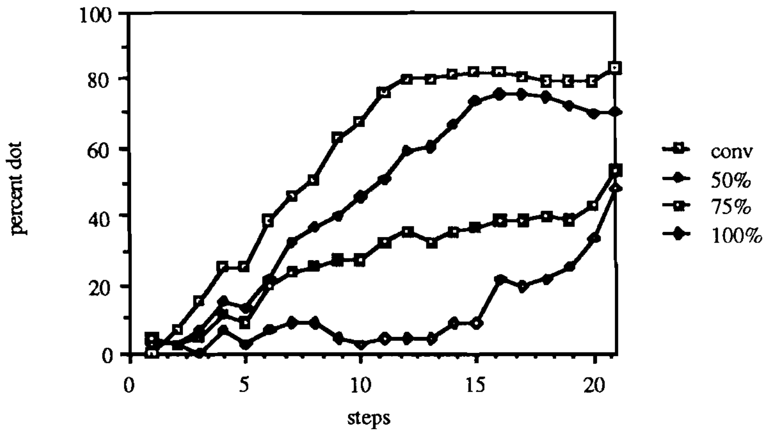

Figure 15d

Cyan Separations - Participant A

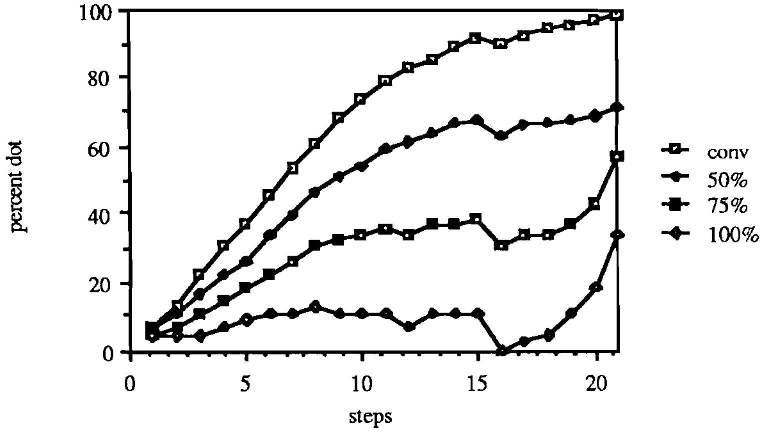

Figure 15e

Cyan Single Color Press - Participant A

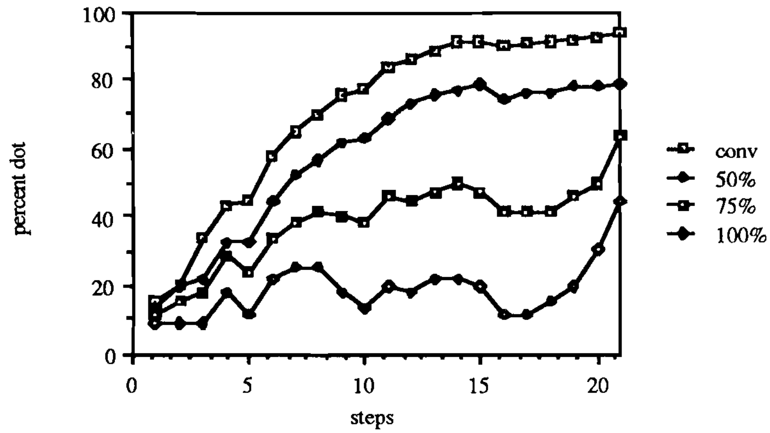

Figure 15f

Black Separations - Participant A

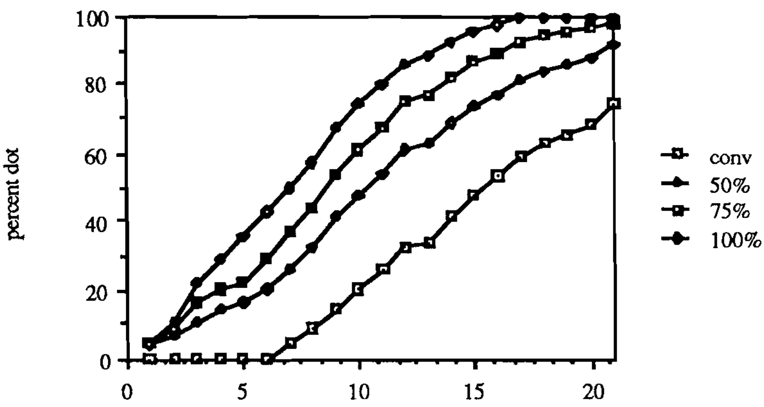

Figure 15g

Black Single Color Press - Participant A

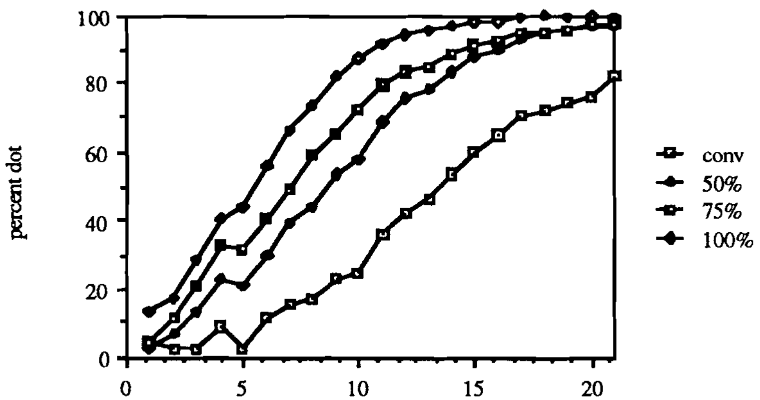

Figure 15h

Such a detailed image train allows one to construct a Jones type diagram of the conventional and GCR offset printing systems.

COLOR PATCH (B2) Analysis

Any analysis of a GCR/UCA system would not be complete without a study of the color produced. The 3M target included a range of color images selected to fall around the peripheral of three dimensional color space at three different levels of chroma. These have been called bright, normal, and dark.

Figure 16 depicts the status A red, green, and blue density readings of the "normal" or middle color patch target. A comparative percent dot area analysis of the separations produced by each of the scanners will indicate how each of them respond to the same input color range. From that data one can get an appreciation of how the various scanners see and reproduce the same Ektachrome colors.

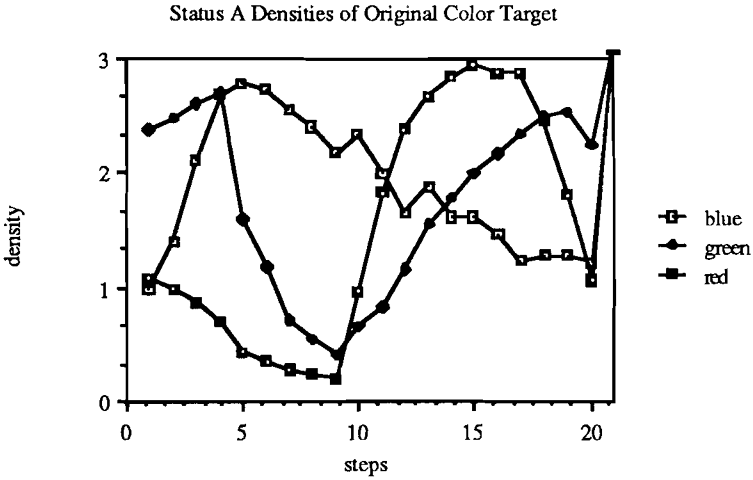

Figure 16

Figures 17a through 17c compare percent dot area analysis of the blue, green, and red color separations of Participants A, B, and C from the "bright" or highest chroma (saturation) color patches for the 4-color conventional UCR containing separations.

Yellow Separations - Bright Color Patch

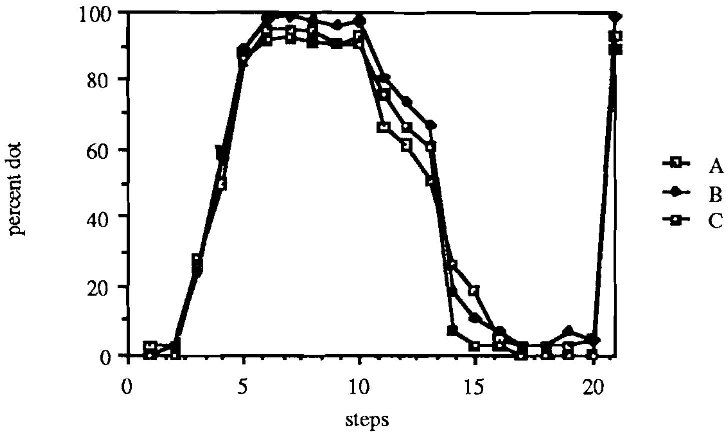

Figure 17a

Magenta Separations - Bright Color Patch

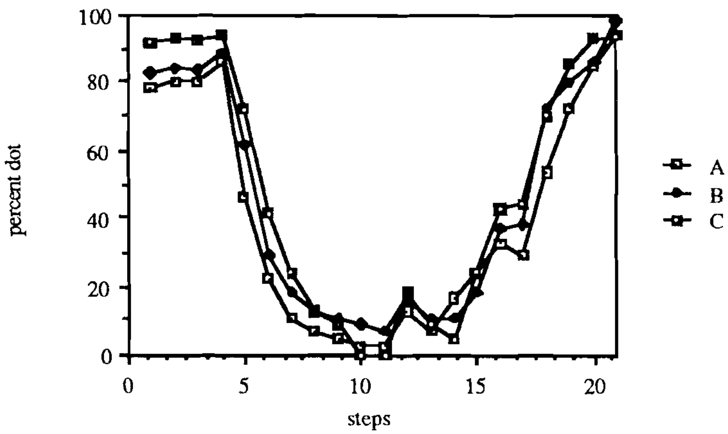

Figure 17b

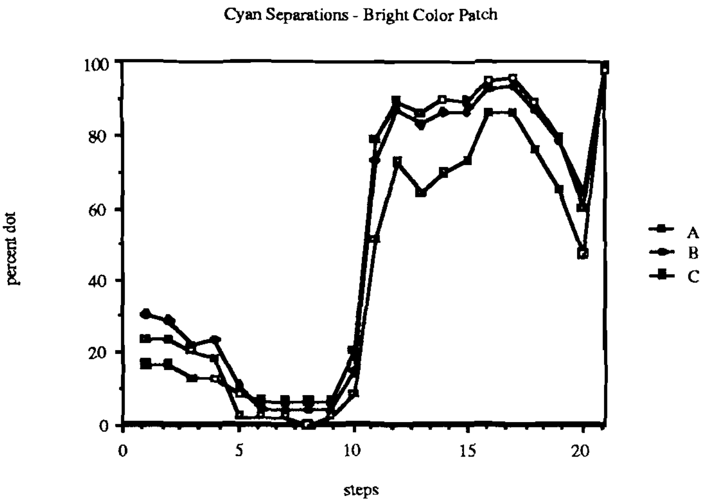

Figure 17c

Each of the devices are significantly different from each other for all 3 colors. This is not surprising, since each uses different photosensors, filters, and proprietary analysis systems.

Such deficiencies indicate the same original Ektachrome colors will be reproduced differently by each of the scanners. This indicates the futility of trying to compare either conventional or GCR color reproduction between scanners. Color rendition between conventional and GCR images produced by the same device is, however, possible.

Figure 18 indicates only the Status A blue density readings for the middle or normal chroma level of the color patches in the 3M Test Transparency .

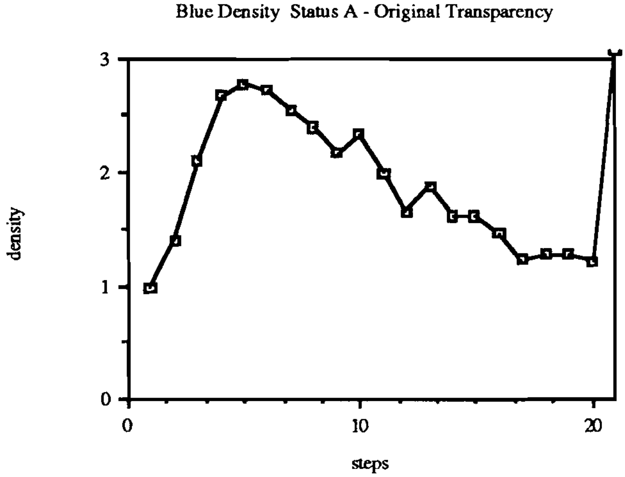

Figure 18

Figures 19a and 19b represent the blue filter density analysis of the single color yellow ink image changes over a range of from 50 to 100% GCR/UCA as well as a conventional 4 color UCR control for both the "bright" and "normal" chroma levels for Participant A.

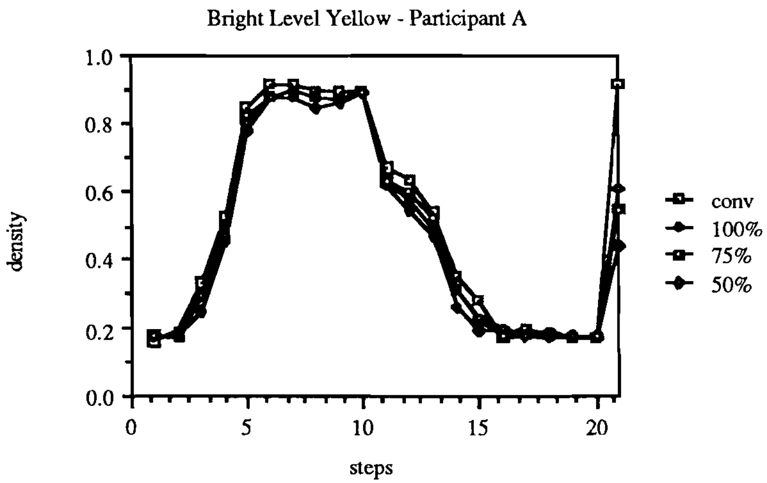

Figure 19a

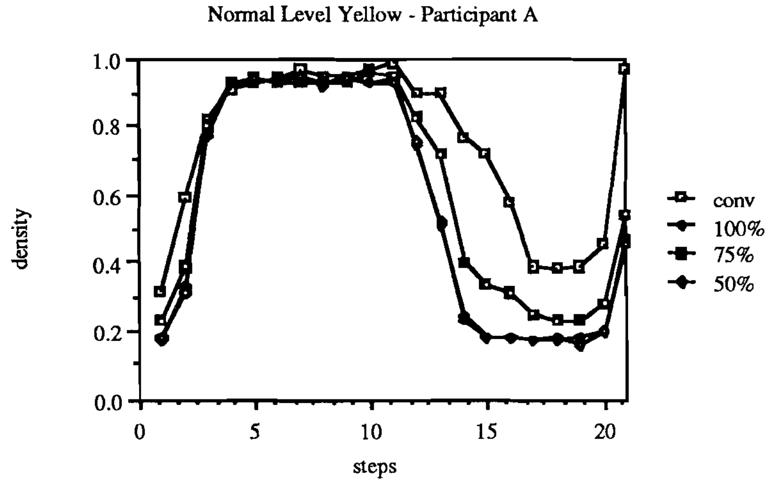

Figure 19b

It is evident the most saturated colors, even tertiary colors (those of the "bright" level), are reproduced with considerably less GCR/UCA correction then those for the "normal" saturation levels.

Having seen that one can compare only one scanner to itself for GCR versus conventional color rendering and knowing that densitometry can not provide information on how one might perceive color, the color patches were analyzed by colorimetry.

Figure 20 presents the CIE L*a*b* color space data from the "normal" chroma color patches using the full color ink on paper images. The data is displayed in a type of color gamut. The conventional and the various GCR/UCA image changes for Participant B are included in the same graph. Reflection colorimeteric conditions include 0/45 geometry, a color temperature of 6500 Kelvin and the 2 degree CIE 1931 Standard Observer.

Normal Color Patch - a* vs b* - Participant B

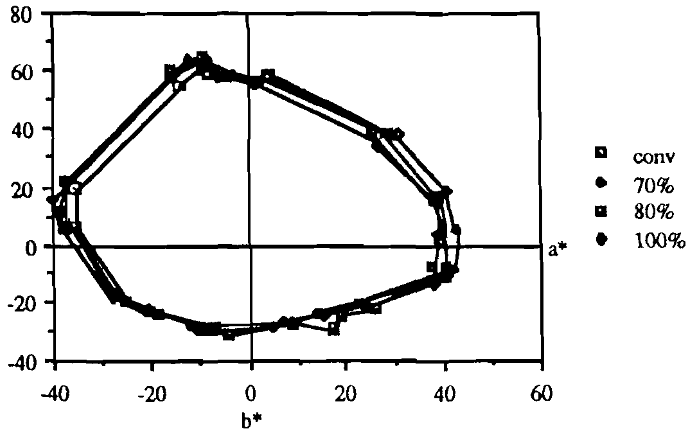

Figure 20

Figure 21presents the CIE L*a*b* color space data from the "normal" chroma color patches for Participant A. Note the differences between the conventional and the 50% GCR/UCA from the rest of the GCR/UCA color data. This change may be indicative of trapping differences or a lower than optimum black printer level for both of these separation sets. Such a lower level (Yule [8]) can restrict color gamut.

Normal Color Patch - a* vs b* - Participant A

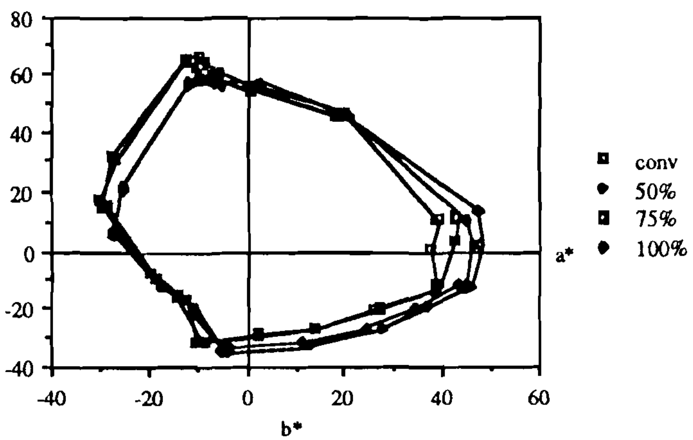

Figure 21

CONCLUSIONS

CONCLUSIONS CONCERNING THE PRODUCTION ANALYSIS OF THE PRINTING PHASE 3 AS REPORTED BY B. TRAVER, V.P. PRODUCTION OF R. R. DONNELLY, TORRENCE, CA.

1. 18% decrease in makeready time for GCR.
2. 24% decrease in waste.
3. 0.5 density increases in cyan or magenta ink solid density when the process was at equilibrium produced a less visible change in GCR/UCA production images than did the same change in 4 color conventional images run side by side. This indicated the GCR images may be more robust to press ink density changes.

CONCLUSIONS FROM PHASE 2 and 3 WORK
TEST IMAGE ANALYSIS

1. The conventional (UCR) tone reproductions of the scanners tested, as measured by the separations, are close to one another.
2. There are differences in what each scanner manufacturer labels a given GCR/UCA effect.
3. Changes in the total ranges covered between different scanners was disclosed.
4. Incremental changes within a scanners GCR range are not the same between all the scanners. Each of the Participant's responses were different. There is no uniformity in where on the tone reproduction curve the UCA effect should or does occur and no uniformity in the level of UCA exists.
5. In order to fully investigate ink on paper, color reproduction single color images are needed.
6. Differences are evident between the colors reproduced by different scanners, due to separation filter or color computer setting differences.
7. The color rendering within a scanner for 4 color conventional and GCR/UCA differences are close. The differences are primarily a result of GCR not by GCR itself. These differences are possibly due to trapping and black separation levels.

The author would like to express his appreciation to the 3M Company for sponsoring this work, and to acknowledge a special appreciation to Sharon Bartels of that company.

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APPENDIX 1

TARGET INFORMATION

PHASE 1 Targets

These targets were proprietary separation films supplied by each of the scanner manufacturers. They consisted of a series of halftone values covering a full range of tonal value for the primary colors, secondary colors, and specific overprints.

A UCA target of the type described by Otschik [9] consisting of a lattice formed by a series of black tonal images covering a range of from 2 to 100% dot levels. Each level was overprinted at right angles with a different level of combined yellow, magenta, and cyan separations (at a ratio to ensure neutrality). Proofing and printing targets were also included to compare the printing at this phase of the test to correlate to other PHASE test runs.

PHASE 2 and 3 Targets

THE 3M SCANNER TRANSPARENCY TARGET

A 3M custom made 4x5 Ektachrome transparency was used as a scanner target. The following scales of that target were used for the color and tone GCR/ UCA and conventional image analysis.

SCALE A - A linear scale of visual grey densities covering a range of from to Status A densities.

SCALE A1 - The A Scale in a continuous mode.

SCALE A2 - The A Scale in a 21 step mode.

Figure 22 depicts the relationship between the Status A densities and the 21 grey scale steps of the A2 scale.

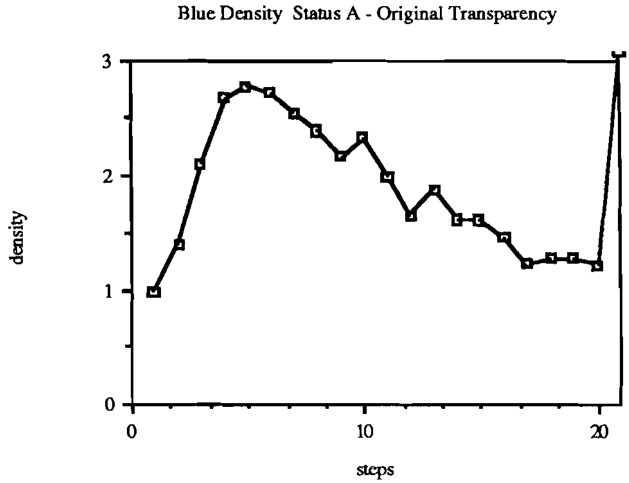

Figure 22

SCALE B
A series of color blended patches wherein a near constant level of cyan is overprinted with a combination of magenta is changed by increasing quantities of yellow until a yellow maximum density is achieved, and then that yellow with an increasing amount of cyan until a maximum cyan density is achieved, and then at that cyan level increasing amounts of magenta density is achieved.
SCALE B1 - These color patches at a minimum color brightness level.
SCALE B2 - These color patches at a medium brightness level.
SCALE B3 - These color patches at a high brightness level.
Figure 3 depicts the STATUS A, red, green, and blue filter density readings.

SCALE C - Individual 11 step scales of yellow, magenta, cyan, red, green, blue and black colors.

APPENDIX 2

List of GCA/GCR Study Group

Generous contributions of time and materials for GCR Phase I, II, III and the PC/UCA Study have been made by:

Arcata Graphics/Baird-Ward; Black Dot Graphics; Brown Printing; Bureau of Engraving; William Byrd Press; Champion International; Collier/Wright Co.; Collins, Miller & Hutchings/Techtron; Colour Graphics; Conde Nast Publications; Coulter Systems; Crosfield Electronics; D. S. America; Danbury Printing & Litho; E. I. DuPont de Nemours Co., Inc.; Eastman Kodak Company; Editors Press; Eikonix; Enco Printing Products; Fuji Photo Film USA; General Printing Ink; G. S. Imaging Services/Techtron; HELL Graphic Systems; Horan Engraving; Hughes Printing; Jordan & Horn/Techtron;

Judd's Incorporated/Shenandoah Valley Press; Kwik International; LDS Church Printing Services; Liberty Engraving; 3M Company; Mack Printing; McGraw-Hill Publications; Modern Imaging/Techtron; Mundercolor; NCL Graphics; Newsweek; Oakland National Engraving; Penn Well Printing Company; Potomac Graphic Industries Inc.; R. R. Donnelley & Sons/Torrence; Reader's Digest Association; Ronalds Printing/Vancouver; Rosos International; Saatchi Saatchi Compton; Sage Technologies; Scitex America; T & R Engraving; Time Inc.; Toppan Printing Company, Inc.; U.S. News & World Report; Walker Graphics/Techtron; Walker Prismatic Engraving Corp.; Waverly Press; Web Offset Publications; Webcraft Technologies; Williams Printing Corp.; Williamson Printing Corporation; Wisconsin Cuneo Press; World Color Press; and World Color Press.