THE BLACK PRINTER

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Abstract: The choice of characteristics for the black printer of a 4 colour set of separations has often been quite arbitrary. Yet a black printer has a specific set of functions and these can be applied to lead to sound objective methods for its generation. UCR and GCR have theoretical advantages but only if the black printer is calculated correctly. GCR and conventional separations from four different makes of colour scanner have been compared in practical print trials. The results show there are still areas of weakness in the available systems which can be partly explained by the theory presented.

Functions of the black printer

(a) To make the control of the other three colours less critical as to ink balance.

(b) To produce better blacks and shadow detail than the other three colours alone can produce. This is probably the main reason why black printers are currently used. The improvement that results in a reproduction from using a good black printer is considerable.

(c) To substitute a relatively inexpensive black ink for a part of the more costly coloured inks.

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(d) In wet on wet printing, to avoid the piling up of several ink layers which do not print satisfactorily on top of each other and may give ink drying problems.

It is interesting to note that three of these functions can only be realised by using UCR or GCR. However, it is well recognised that applying large amounts of UCR in colour scanners often leads to problems. In particular, some colours change in hue and shadow detail often suffers. Also, UCR appears to be implemented on most scanners so that it acts on neutrals or near neturals only. There is no theoretical reason for this limitation and indeed GCR implementations appear far better in this respect.

The purpose of the work described in this paper was to examine black printers from a theoretical and practical viewpoint. The underlying principles of calculation of a black printer have been investigated and some observations on the printed results of GCR separations are presented.

Types of black printer

It is helpful to imagine that we are trying to reproduce an original which contains a grey scale. The different types of black printer will be discussed as various ways of reproducing that grey scale. Colours need separate consideration.

For the present, schematic graphs will be used to illustrate the different types of black printer. It is supposed that the objective in reproduction is a facsimile copy of the grey scale in the original. In the schematic graphs this is illustrated by a straight line at 45 degrees to the axis.

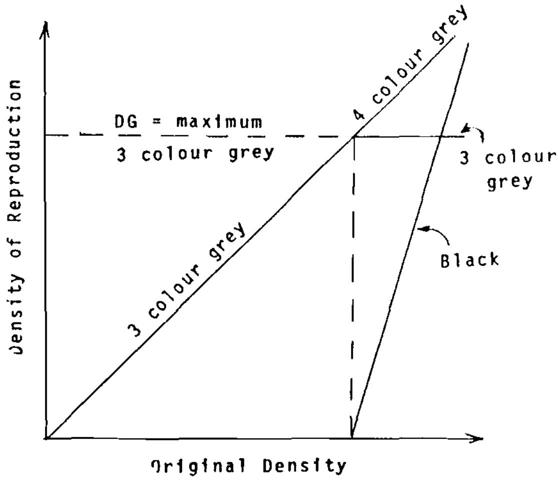
It is proposed that there are three basic types of black printer:

1 The use of the black printer simply to extend the maximum density of the reproduction beyond that which can be achieved using the three coloured inks.

2 An extension of the above to include the use of UCR. Greys up to some arbitrary density are produced using just three colours. Greys of greater density have the addition of black.

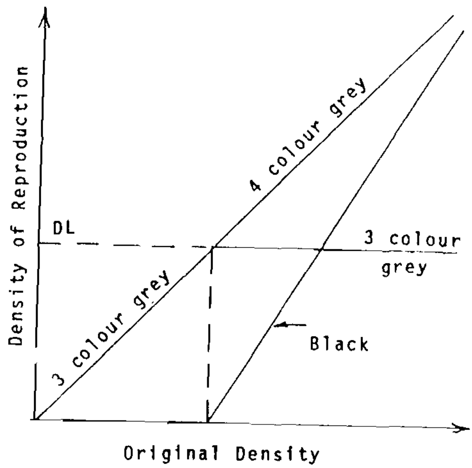
3 The full scale black printer. There are two versions of this depending on whether UCR/GCR is used or not.

These different approaches are illustrated in the following graphs. In fact type 2 was probably the commonest prior to the introduction of GCR and as will be shown is the worst from a theoretical point of view. Type 1 produces black printers which achieve one of the functions mentioned, so there are good reasons for examining type 3 in more detail.



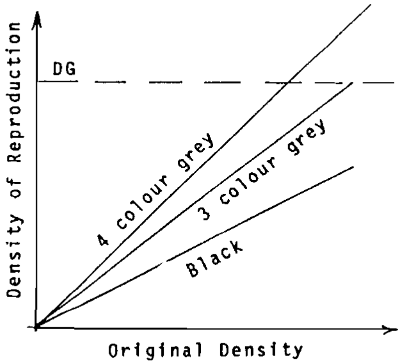
Graph showing reproduction of grey scale using a type 1 black printer

Figure 1



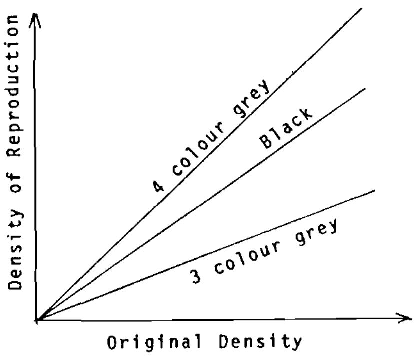
Graph showing the method of reproducing the grey scale in a type 2 situation

Figure 2



Type 3 black printer with no UCR

Figure 3



Type 3 black printer with UCR

Figure 4

A special case arises when either a type 2 or type 3 situation is taken to extremes. That is, all the 3 colour grey is removed and the grey scale is printed using the black printer only.

This may or may not be a desirable thing to do but any system of calculating the black printer and modifying the colour printers to suit must be able to cope with this requirement in order to demonstrate that it is theoretically sound.

In order to develop further the principles involved in generating a black printer a program was developed on a microcomputer which modelled the action of an ideal scanner.

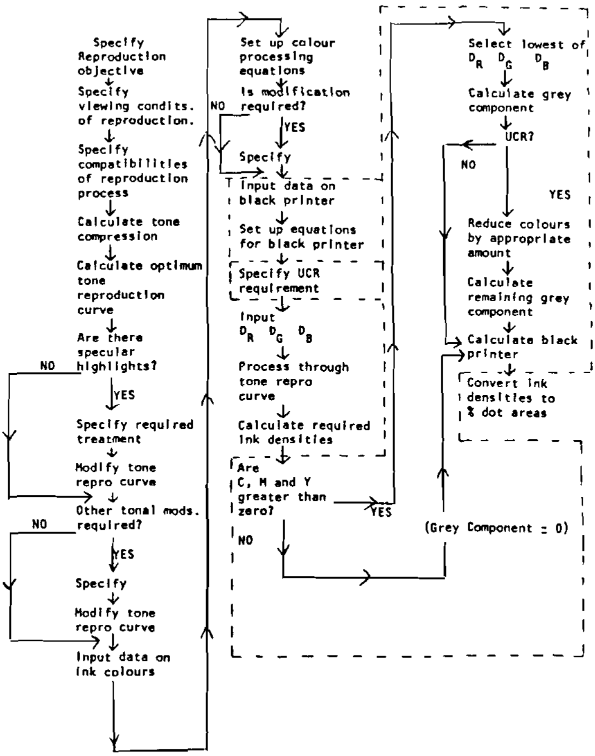


Figure 5 : The model colour scanner. The overall flow chart for the model scanner is shown in the diagram

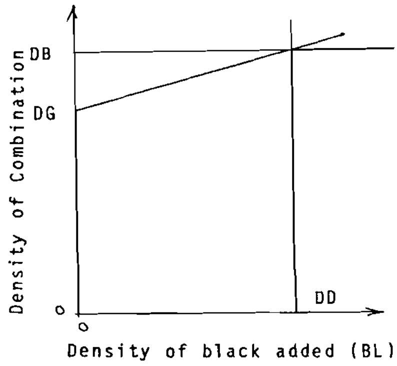


Figure 6 : Additivity diagram

The black printer is calculated from an additivity diagram. A full explanation of this diagram can be found in Yule.

The necessary data consists of:

(a) The maximum 3 colour grey equals DG
(b) The maximum 4 colour density equals DB
(c) The density of black ink required to raise DG to DB equals DD

Thus, for example, if DB is produced by printing a 70 per cent black dot over a three colour grey of density DG, then DD is the density of a 70 per cent black tint.

From this information the line in the additivity diagram can be drawn and its equation worked out.

The equation for the line is:

$$\text{BL equals } \frac{\text{DD}}{\text{DB minus DG}} \text{ times (DC minus DG)}$$

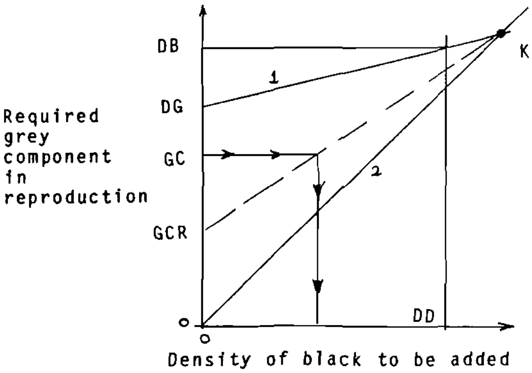


Figure 7: Additivity diagram for calculating black to be added

To calculate black printers with UCR/GCR a more general additivity diagram is needed. Firstly, the position of K, the rotation point is calculated. This can be found from an examination of boundary conditions, and a general expression derived:

$$\text{K equals } \frac{\text{DG times D}}{\text{(DD minus DB plus DG)}}$$

where DG equals maximum 3 col grey
DB equals maximum 4 col black
DD equals density of black to be overprinted on DG to achieve DB

The grey component (GC) of a colour is now calculated for an accurate reproduction in the three process colours (in fact, we have used second order masking equations with additional corrections for proportionality failure which give reasonable results, although improvement is certainly possible).

The specified amount of under colour removal refers to the proportion of this grey component to be removed. The appropriate amount is subtracted from each ink density and a new grey component calculated on the basis of the remaining ink densities (GCR). To calculate the black printer it is necessary to add black to the grey component remaining to an extent that restores the grey component to its original value.

This is effectively done by setting the line in the additivity diagram such that it meets the vertical axis at GCR and passes through K (dotted line in figure 7). The density of black required is found by locating the original grey component (GC) on the vertical axis, running horizontally to the dotted line and down onto the 'BL' axis.

Expressed as an equation this is:

$$BL \text{ equals } \frac{K \text{ times } (GC \text{ minus } GCR)}{(K \text{ minus } GCR)}$$

Three points should be noted:

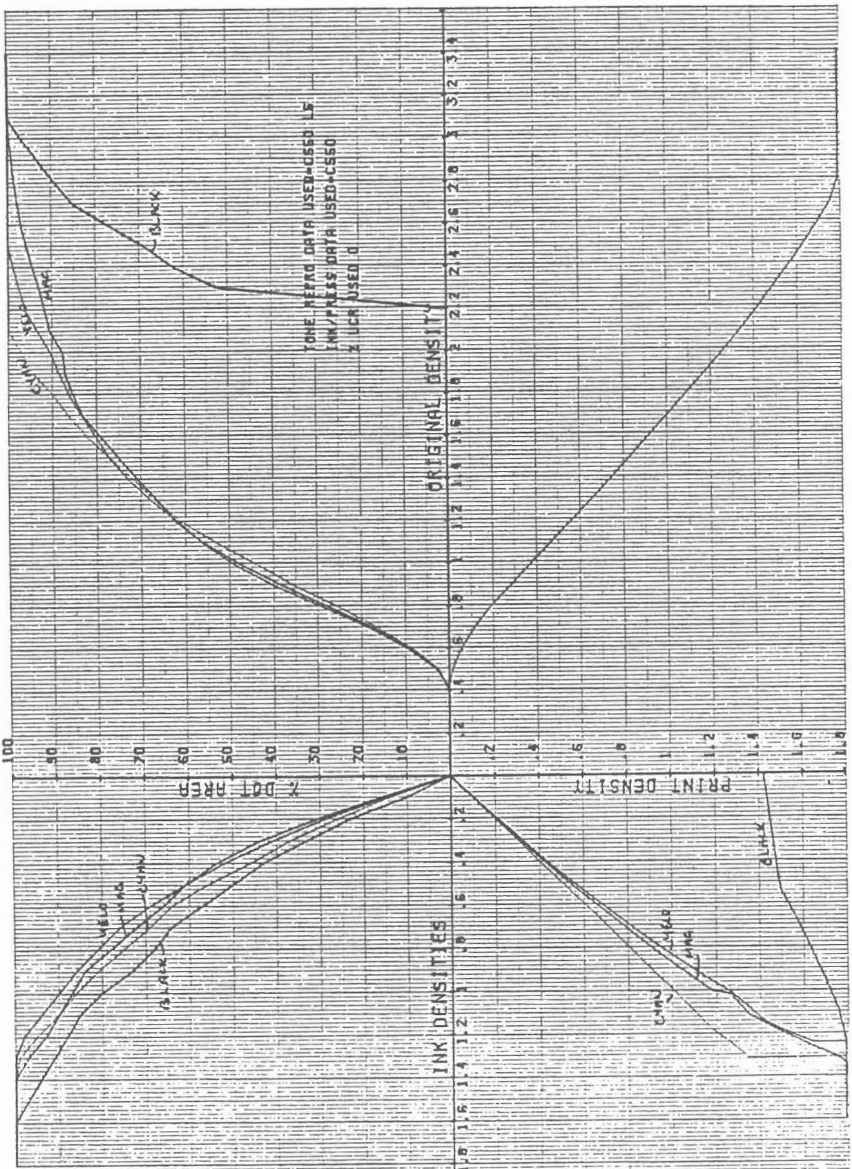
1 An upper limit is set for GCR equal to DG (since this is the maximum grey component which can be produced with the three process colours). This is shown by line 1 in the figure and it will be seen that this corresponds to the no UCR case discussed previously - a type 1 black printer.

2 If the upper limit to GCR is set at some lower level than DG, then a type 2 printer is produced.

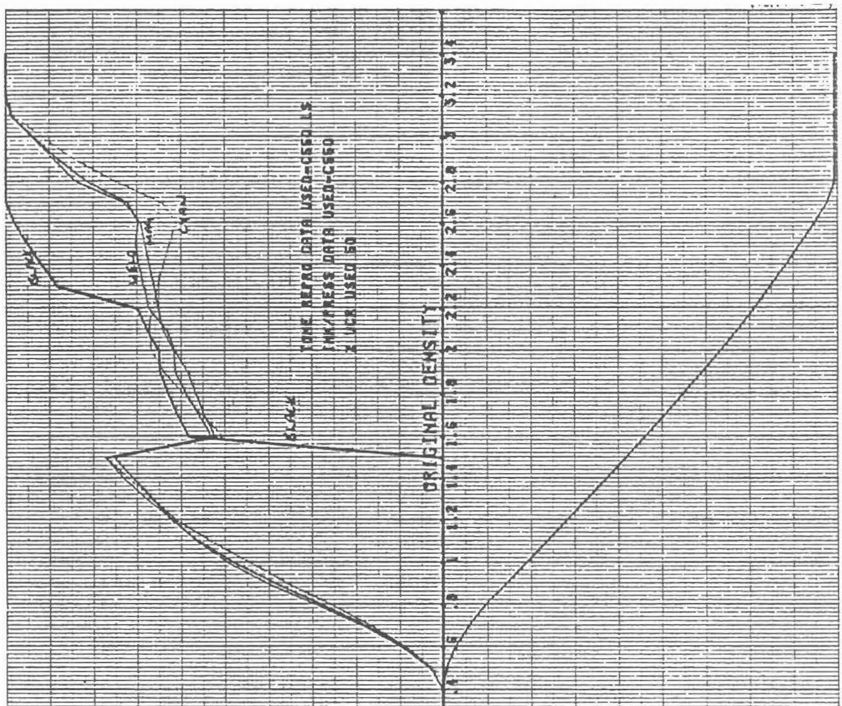
3 If the value of GCR is allowed to vary between 0 and DG then a type 3 black printer is produced.

The above calculations are built into the model colour scanner program. The latter is tested by using as an original, prints made up from known dot areas. A densitometer is used to provide red, green and blue input densities to the program. The measure of accuracy is how close the program calculates the known dot areas of the original. Results are not perfect but certainly as good as real colour scanners achieve. Some typical results are presented in the following three graphs, which show a type 1, 2 and 3 black printer respectively.

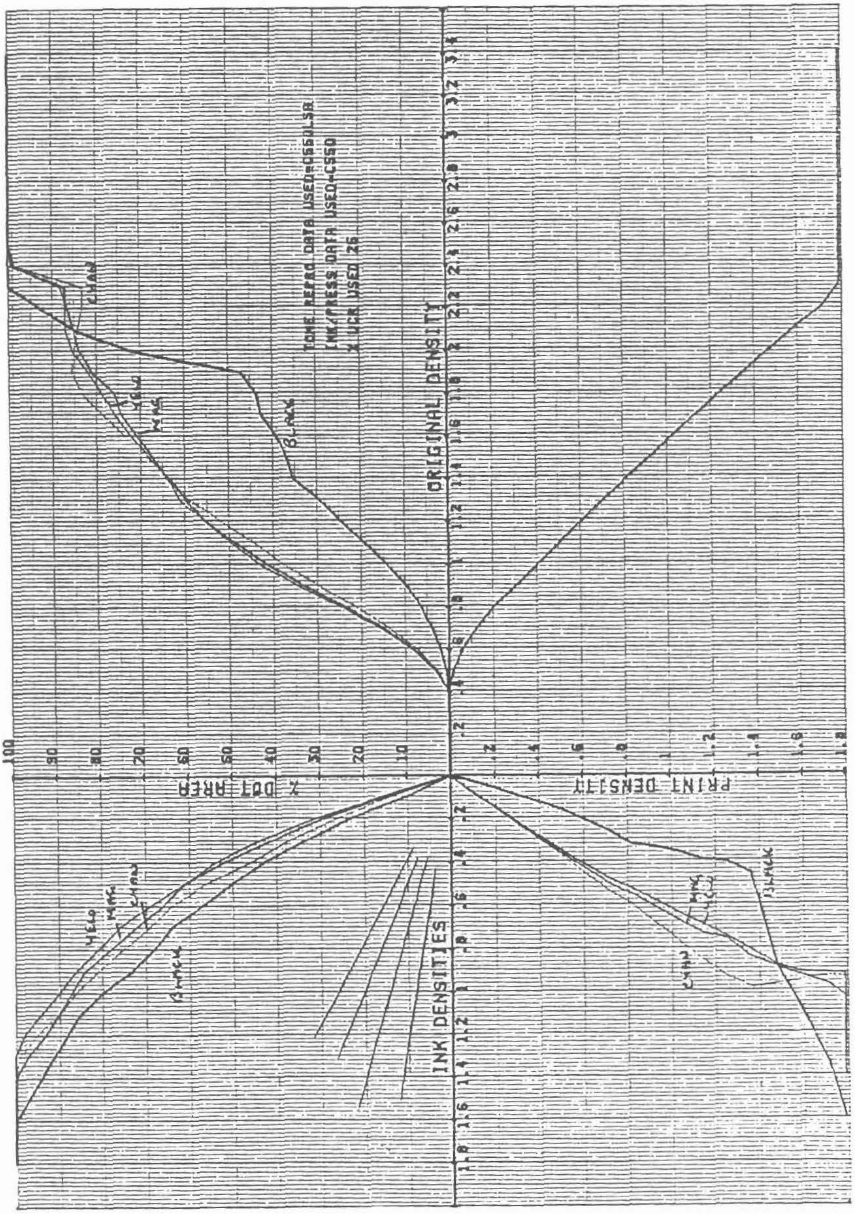
The second graph with a type 2 black printer shows very undesirable discontinuities in the various graphs which arise from the quite arbitrary constraints that are imposed with this type.



Graph 1 Type 1 Black Printer



Graph 2 Type 2 Black Printer



Graph 3 Type 3 Black Printer

The third graph shows a type 3 printer with black printing throughout the tone scale - this corresponds most closely to the GCR approach. Two points are worth noting:

(a) the three colours flatten off at a certain point, as a result of the amount of GCR which has been specified. There is a sharp increase in the amount of black being added at this point in order that the required tonal gradation can be maintained.

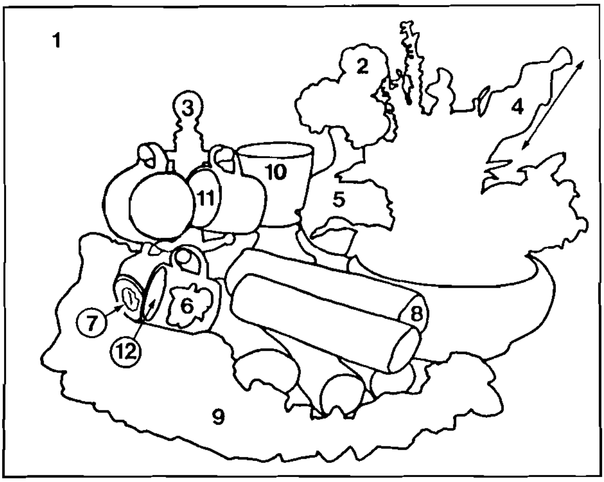
(b) At the point where the black reaches 100 per cent, there is a sharp rise in the 3 colour grey to maintain the required tonal gradation.

These points are important in relation to some of the errors seen in some GCR reproductions.

The concepts developed in the model colour scanner are now being used in a type of pre-scan analysis system.

Assessment of GCR separations

This assessment is based upon separations produced from the same original transparency, by four major scanner manufacturers. The transparency was specifically designed to highlight areas where differences, between conventional and GCR separations were anticipated. Details of the original are shown in the diagram.



Area	Description	Purpose
One	Neutral vignette	To assess the ability of the G.C R. system to reproduce smooth tonal transition with possibly only one ink
Two	Bright, pure colour with definite detail placed against a neutral background	To check for any increase in registration difficulties with pure colours against neutrals, & to ascertain if any particular unsharp masking treatment is required under these image circumstances
Three	An even area of pure bright colour with specular highlights	As area two but with a lower density background, less drawing and areas of catchlight & highlight detail
Four	Natural, saturated greens against a neutral vignette	Similar to two & three with good highlight & mid-tone detail
Five	Non-neutral, deep shadow with distinct detail	To check for loss of colour in areas which may be confused with neutrals & to monitor the reproduction of detail in areas where a high degree of G C R. could be anticipated
Six	Neutral line design against white	We suspected that this type of image may be enhanced over a conventional reproduction because of the single ink in use
Seven	Fine detail against a non-neutral, even tone	As a direct control and comparison for area six.
Eight	Fine detail in a tertiary midtone	To provide a range of identifiable areas for comparison, which relate to illustrative originals rather than flat areas of a test form
Nine	Large area of neutral shadow	This large area of deep, matt shadow has a great deal of fine detail and is included to check for the G C R system's ability to maintain maximum density, without affecting detail.
Ten	Pastel colour against white	As eight
Eleven	Strong colour with gradation to black	An excellent area to see the full effect of G.C.R. in the 3 colour overprint (Examples A, B, C & D.)
Twelve	Tertiary green with limited gradation	As area eight

Figure 8 : Details of test original

To enable an assessment of the separations to be made, and to provide some practical experience of printing with GCR, they were printed at Pira on a four colour sheet-fed litho press. This practical asessment has also been supplemented by discussions with printers who have some experience of GCR. Our assessment has been restricted to lithographic reproduction, but many of the comments could also apply to other processes, such as flexography.

Screen pattern

The rosette pattern is more obvious on all of the GCR separations, when a direct comparison is made with a matching conventional result. This creates the impression that the GCR sets have been produced with a coarser screen ruling, when in fact it is the same as the conventional sets. It is not quite clear why this should be so, but it appears to be due to the lower image coverage allowing more white paper to be seen through the dots.

Brightness and cleanliness of colours

Saturated colours on the GCR separations are brighter and cleaner in appearance when a comprison is made with the same colours on the conventional separations. It is particularly apparent in the bright reds, greens and blues of the original (test subject areas 2, 3, 4 and 11). This should be particularly advantageous when printing on substrates which have very poor brightness, such as newsprint and other uncoated papers.

Shadow detail and gradation

The detail and gradation in dark shadows of all the GCR sets are inferior to the conventional. It is particularly noticeable that none of the GCR sets have been able to retain the same level of detail in the vase (test subject area 5), that is apparent on the equivalent conventional separation. The gradation achieved in the charcoal (test subject area 9) is also noticeably inferior to that on the conventional sets and the detail is further reduced by the obtrusive rosette pattern. This is not so on one of the samples, however, because the tone reproduction of the black printer is such that most areas of the charcoal are printing with solid black. The gradation in this area is primarily being achieved by the underlying three-colour grey. This has resulted in a smooth gradation in the charcoal but it has resulted in a very coarse transition from dark to light in the netural vignette background.

Achieving a smooth gradation through from solid to light tones is always difficult when printing in a single colour, because of the jump that occurs when dots join. Any original, which contains a neutral vignette is likely to present some difficulties, and is less suited to being reproduced by GCR.

Stability of print quality during production run

During the print run this was assessed by deliberately introducing changes in solid density and dot gain (of the magenta printer).

With GCR separations the predominant printer in the neutral areas is black and variations in density or dot gain of the process colours did not therefore have a noticeble affect on the neturality of these areas. Tertiary colours were also more stable. Variation in density and dot gain obviously affect the saturation and apearance of colours but it was apparent from the prints produced that this is much less detracting than the shift that occurred in the neutral tones of the conventional separations.

Although GCR separations achieve a stable result, even if variations in the ink levels of colours occur, the reverse is true if variations occur with black.

Controlling the printing characteristics of the black printer is much more important when printing with GCR. Variations do not, however, lead to colour shifts, but cause changes to occur in the 'contrast' of the print.

Ink consumption

It was clear from the GCR separations produced that the image areas of cyan, magenta and yellow were noticeably less than the corresponding areas in the conventional separations, and vice versa with the black. The extent of this depends of course to some degree on the original subject but mainly on the level of GCR that has been applied. Illustrations that are predominantly grey will show more reduction, for the same degree of GCR, than those with large areas of pure colour. The paper type will also have some influence, because when printing dark colours or greys on uncoated papers, the black printer requires a greater contribution from the colours, to achieve an acceptable maximum density, than might have been necessary when printing the same subject on coated paper.

A measurement of the ink coverage for the image used was made using a Heidelberg CPC3 plate scanner. The comparison of the GCR sets with conventional sets is shown overleaf.

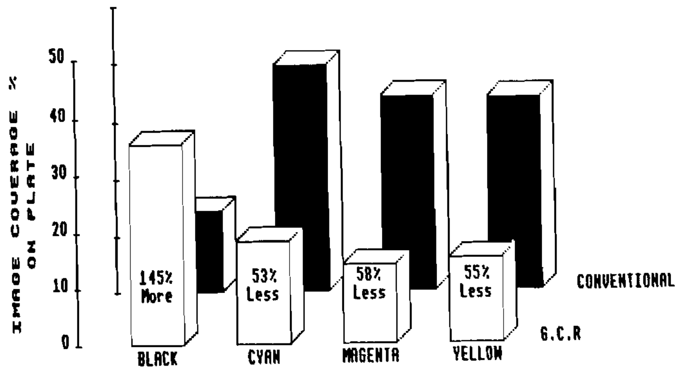


Figure 9 : Comparison of the image coverage of each colour between conventional and GCR separations

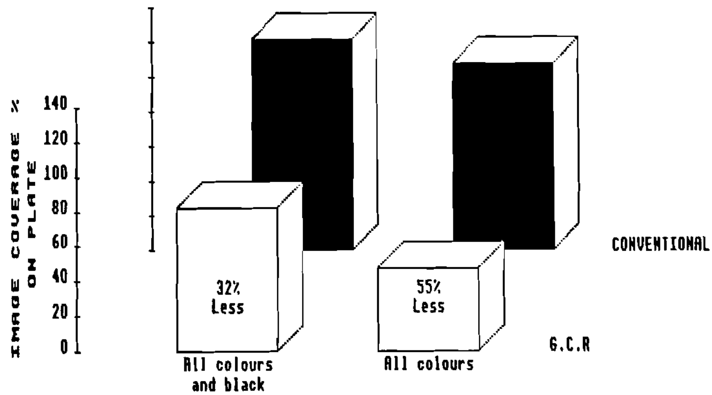


Figure 10 : Comparison of the combined image coverage of all colours between conventional and GCR separations

Register

In areas where dark, fine detail occurs on a light background (test subject area 6) the GCR separations were less sensitive to slight errors in fit or register, because the detail is predominantly achieved by the black printer. The GCR separations were, however, more sensitive to misfit or misregister in areas where a saturated colour is surrounded by a netural (test subject areas 2, 3 and 4) due to the very low levels of three colour grey in the background. In effect a 100 per cent GCR neutral, printing with virtually a single ink, will leave a white window into which the saturated colour must fit. Slight misregister in this area results in a light fringe around the saturated colour. This can be further accentuated by the unsharp masking border particularly if the dominant colour of the masking coincides with the saturated colour of the subject.

Paper dust and debris

An advantage of printing conventional separations in the normal sequence of black, cyan, magenta and yellow is that any paper dust that builds up on the first blanket does not have a significant effect on the print. This is true so long as the black is a skeleton key, typical on conventional separations. It was noticeable when printing GCR and conventional separations together, in a normal sequence for conventional separations, that paper dust and debris was much more apparent on the GCR set, due to the greater coverage of the black printer. This effect can be overcome by moving the black from the first unit and it is another good reason for altering the sequence of printing when the majority of separations are GCR.

Three colour neutral support under the black printer

We have seen a number of printed examples of GCR separations where the maximum black density was abnormally low. In some cases this problem appeared to be related to the paper used for printing. We have therefore carried out some printing tests on a number of different materials to establish how the separating requirement might differ for these materials.

In conventional reproduction, areas of maximum density typically comprise 100 per cent cyan, 80 per cent yellow, 80 per cent magenta and 70 per cent black. When producing separations with under colour removal, or GCR, it is clearly not possible to remove all the grey component of dark colours or greys and replace with black, while still achieving the maximum density achieved on conventional separations. Conventional process black ink is not sufficiently dense to reproduce, alone, the equivalent of the 330 per cent four colour coverage mentioned above.

So the maximum shadow density in a reproduction should still be made up from all four of the printing colours, as was explained earlier in this paper.

To assess the different levels of black support required, test prints were produced on six different materials. The test image consisted of an area of normal coverage for maximum density on conventional separations, next to an area of solid black, overprinted with varying levels of three-colour grey.

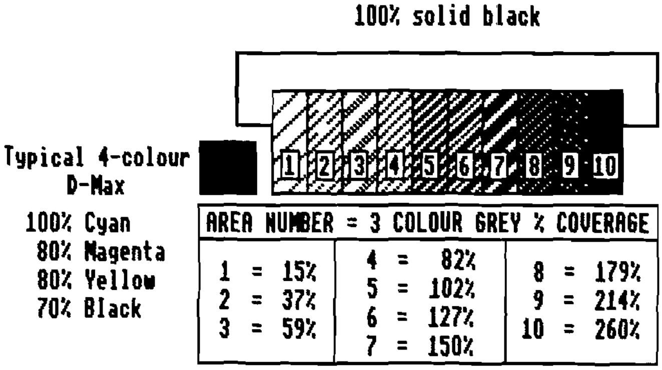
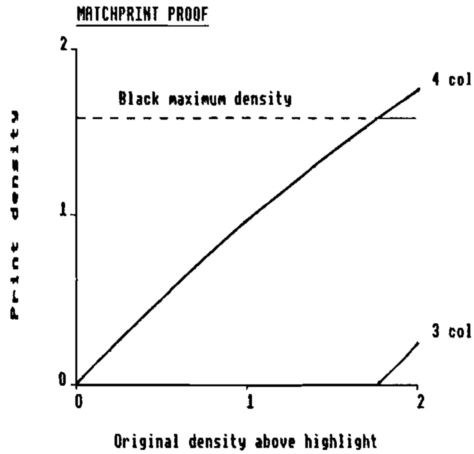


Figure 11: Test object to determine black support required

A comparison has been made of the amount of three colour grey required to raise the 100 per cent black density to be comparable with the typical four-colour maximum density of the conventional separations. The results are shown below:


MATCHPRINT PROOF
Print density
Black maximum density
4 col
3 col
2
1
0
0
1
2
Original density above highlight

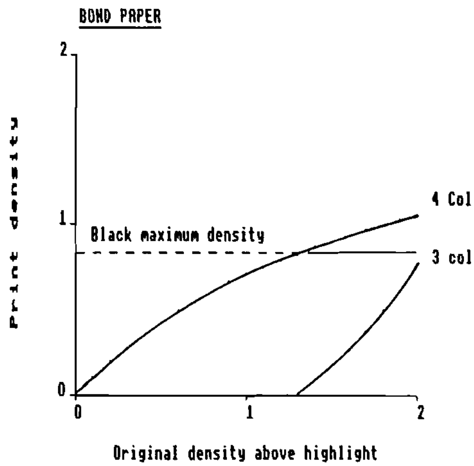
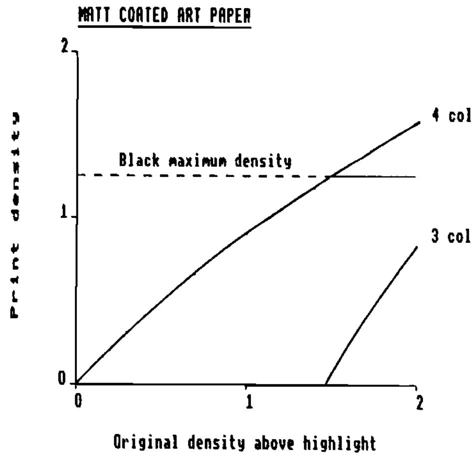

BOND PAPER
Print density
Black maximum density
4 Col
3 col
2
1
0
0
1
2
Original density above highlight

Figure 12



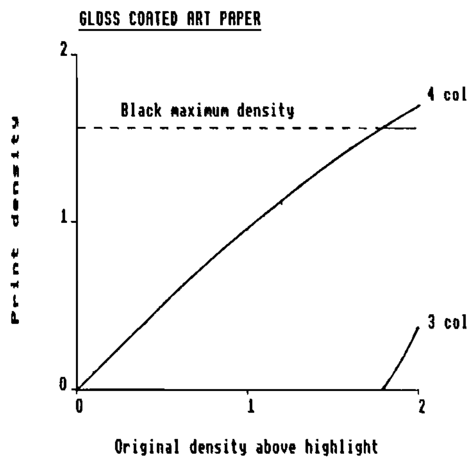


Figure 12 contd.

In these tests, the ink film thickness for all colours and black was kept constant. It would clearly be possible to adjust the ink film thickness of the black to raise the density but this would increase the dot gain the control of which becomes more critical with GCR sets.

From the results of these tests it can be seen that a GCR set of separations, produced with a level of black support that provides acceptable results on gloss coated paper might be unacceptable on uncoated, as the shadows would be lacking density. A similar effect has been observed between photomechanical proofs and printed sheets. In this instance the Cromalin proof had a black solid density greater than that achieved with the conventional four-colour black, consequently it required no additional support. The photomechanical proof produced an acceptable result but the production print was unacceptable due to low density shadows.

On some papers, particularly matt coated, the gloss of the ink on paper increases significantly when multiple layers of heavy coverage are applied on top of each other. Polarised densitometers minimise the apparent increased density due to the higher gloss. The overall effect is to reduce the density difference between the normal four-colour density and solid black. This consequently affects the determination of the amount of grey required under black. In these cases, non-polarised instruments have been found to more closely reflect the visual appearance of the prints.

Conclusion

A theoretical approach to the calculation of the black printer has been presented which caters in a systematic fashion for any of the different types of black printer which might be required. The principles can be used in a computer program that models a colour scanner and are a useful aid to setting the scanner correctly.

It can also be used to explain the tonal gradation problems sometimes present in GCR sets of colour separations.

Separations produced using GCR by any of the four major scanner manufacturers, do not provide any significant benefit, in terms of quality of reproduction, to that achieved with conventional techniques. There is some improvement in brightness and cleanness of colours, when the results are compared with those of conventional separations, but the rosette pattern is more apparent and the gradation, smoothness and detail in dark tones is inferior.

The major benefit to be gained from the use of GCR separations comes from the more stable results that are achieved on the press during production and the corresponding reduction that results in waste material and time. There are other less significant benefits to be gained, such as savings in ink, and a reduction in problems associated with tracking.

GCR separations for printing on newsprint and other uncoated papers require a higher level of black support than on coated paper, this will reduce the benefit of reduced ink consumption but benefit will still be gained from the cleaner colours and the more stable result.

References

Principles of colour reproduction, Yule J A C
John Wiley & Sons 1967, Chapter 11