

METAMERISM IN THE GRAPHIC ARTS

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Abstract: If an original is processed to a printed image, and if a proof is made as an intermediate step, metameric color differences can occur between each of these three steps. To investigate the magnitude of metameric deviations, a computer program was written which calculates the delta E value between a color chosen as an original and its reproduction.

It is shown that metameric differences between originals and printed images can exceed delta E values of 5, whereas metamerism between printed images and off-press proofs is often negligible. This refers to a change of the illuminant from D50 to D65.

Where can metamerism occur?

If a yellow colored paper and a white paper are viewed under yellow light, both will appear the same. The phenomenon that they look identical is called metamerism.

It is common that object colors with different spectral curves look the same, if they are illuminated with colored light. This form of metamerism hardly causes problems in general practice. More critical are those cases where two object colors look similar under daylight, and, if the illuminant is slightly changed, become different.

However, metameric color deviations can only occur, if the colors to be compared have been produced with different colorants. In the graphic arts reproduction there are several cases where this applies.

The largest metameric color deviations occur, if colors are reproduced from non-photographic originals. Examples for this are textiles or metal surfaces. Watercolors are also sensitive to metamerism.

With photographic originals there is less danger of metameric color deviations, because both the color photograph and the four-color print base on primary colors which are similar. Metameric deviations are also possible between photographic off-press proofs and press proofs.

No metameric deviations, however, can occur between press proofs and production prints, because in both cases the primary colors have practically identical spectral properties.

There are mainly two cases where metameric color deviations can occur:

Case one:

An original is reproduced in such a way that the reproduction (which can be an off-press proof or a press proof) matches the original, if viewed under illuminant D50. If the reproduction and the original are then viewed under illuminant D50, metameric color deviations will occur (see fig. 1). (In this and the following case it is assumed that the original has been reproduced with primary colors having different spectral curves than the ink pigments.)

Case two:

An original is reproduced as an off-press proof in such a way that the off-press proof matches the original, if viewed under illuminant D50. Then a production print is reproduced from that off-press proof, and it is again assumed that an identity under illuminant D50 is achieved. In this case the production print is also an exact match of the original under illuminant D50.

If the off-press proof and the production print are then compared under illuminant D65, there will be a metameric color deviation (see fig. 2).

Determination of metameric color deviations

To determine metameric color deviations, four color measurements are required. The first two color measurements are to identify that an original matches its reproduction under a certain illuminant. The other two color measurements refer to a second illuminant from where the metameric color deviations are produced. Very often a reproduction fails to match its original at the chosen illuminant. If then the illuminant is changed, this color difference will be added to the metameric color deviation. To determine the pure metameric deviation, the color difference (measured under the first illuminant) has therefore to be eliminated mathematically. This is possible by correcting the color values measured under the second illuminant additively or multiplicatively.

In the present work the application of correction values has not been necessary, because the metameric color deviations had been determined by means of a computer program. The program works in such a way that first the colorimetrically identical reproduction of a given original color is computed for a certain illuminant. The next step is then to convert the color values of the original color and its reproduction to a second illuminant from where the metameric color deviations can be determined. The computer program is described in detail in the appendix.

In the present study the following illuminants have been included:

- illuminant D65 as the international standard illuminant for all color matching applications, except for photographic originals
- illuminant D50 as the matching illuminant for photographic originals
- illuminant A as the international standard tungsten light

If a general statement about the sensitivity of the graphic arts reproduction process to metamerism should be made, the question arises as to which colors should serve as representative examples. A useful selection of representative colors are the DIN test colors. It is a series of 17 colors defined by their spectral curves and also available as color samples for the purpose of color matching. As it is shown in table 1, these colors are taken from the everyday life, such as foliage green, skin tone, flesh tone etc.

For a general assessment of the magnitude of metameric color deviations, these 17 color samples are used: By means of a computer program developed at EMPA, an average metameric deviation is calculated and regarded as a measure for the metameric sensitivity of the reproduction process. It should be noted that any statement about the sensitivity of metamerism depends on the primary colors and the illuminants chosen for the reproduction process.

Metameric color deviations between an original and a press proof (or production print)

The metameric color deviations between an original and printed reproduction have been calculated for the case that an exact match of the original has been achieved under the illuminant D50 by using the European process inks.

In theory it has been shown that metameric color deviations can only occur, if the spectral curves of the two object colors have at least three intersection points. This is illustrated in figure 3 with four DIN test colors.

However, it is not possible to derive the magnitude of metameric color deviations only from the differences of the spectral curves. In table 2 the metameric color deviations are compiled, if illuminant D50 is changed to A and D65 respectively.

A comparison of the obtained color deviations (see table 2) shows:

- The change from illuminant D50 to A produces higher deviations than the change from D50 to D65.
- The resulting metameric color deviations range from less than 0.5 units ΔE and to 5.0 units ΔE . In most cases the deviations are between 1.0 and 5.0 units ΔE . If it is considered that one unit ΔE corresponds to a change of dot area of about 1% in the mid-tones, it becomes apparent that the metameric color deviations are comparable with a dot area difference of 1 to 5%.
- Some rules can be derived as to which original colors tend to be sensitive to metamerism. Colors described as tertiary colors have a relatively strong sensitivity to metamerism, as for instance light brown, green, skin tone, foliage green. The same applies to chromatic colors such as grey. Less sensitive are light pastel colors, such as light blue, light purple etc. Saturated colors have the slightest sensitivity to metamerism, such as red, yellow, green and blue. There is a relationship between the dot area required for the reproduction of these colors and the sensitivity to metamerism. Colors with a relatively high dot area in C, M and Y are highly sensitive to metamerism. The sensitivity is small, if the dot area of the three primary colors is small. In case that only one or two primary colors are printed, there will be the slightest sensitivity to metamerism.

The change from illuminant D50 to D65 is important, if a customer uses the internationally recommended matching illuminant D65 for the judgement of graphic arts reproductions. The color deviations occurring in this case are hardly visible in most cases. Nevertheless it ought to be agreed with the customer that only the illuminant D50 should be used for the comparison of the original with its reproduction.

Metameric color deviations between an original and an off-press proof

When the off-press proofing systems were introduced, it was suspected that they were more sensitive to metamerism than printing inks. This suspicion, however, is unfounded, because off-press proofing systems have three primary colors being similar to those of the printing process.

To examine the metameric color deviations between an original and its off-press proof, the same proceeding was used as described in the preceding chapter. Instead of using the primary colors of the printing process those of the off-press proofing systems have been included in the calculations. It has been decided to investigate five off-press proofing systems, i. e. the three most common photomechanical processes, an electrographic

process and a digital proofing-process based on the silver halide photography. In particular the following process were included:

Photomechanical processes:

- Cromalin (Du Pont)
- Matchprint (3M)
- Color-Art (Fuji)

Electrophotographic:

- Stork Color Proofing (Stork)

Digital proofing process:

- Hell CP 403

In addition it was interesting to know to what extent some non-impact-printing systems can lead to metameric color deviations. For this purpose the primary colors of an ink jet printer (manufactured by Diablo) and of a thermal transfer printer (manufactured by Panasonic) were included. The metameric color deviations were again calculated for the 17 DIN colors. As can be seen from table 3, the metameric color deviations are larger when using printing inks than in most other cases. Especially the silver halide process is not critical with respect to metameric color deviations.

This explains why the conventional color photography produces only slight metameric color differences, if non-photographic originals are photographically reproduced.

Metameric color deviations between an off-press proof and the production print

It can be anticipated that the metameric deviations between an off-press proof and a production print are small, because both the off-press proofing system and the printing process base on primary colors whose spectral curves are quite similar.

The metameric deviations obtained with the various off-press proofing systems and the non-impact printing processes are shown in table 4. The procedure used in this case is described in fig. 2. As can be seen from table 4, the values are generally very low. It is interesting to note that the silver halide proofing process shows now the largest metameric color deviations, while it has produced the slightest deviations when compared with the original. This can be explained by the fact that the colorants used in photographic proofing systems show the largest spectral deviations from the process inks.

Conclusions

This investigation shows that basically two categories of metameric color deviations have to be distinguished in the graphic arts, namely the color deviations between the original and its reproduction and those between different reproductions, such as between a production print and an off-press proof.

Metameric color deviations can only be disturbing in the first case, and even this is only the case, if the original is based on non-photographic colors.

It is interesting to note that reproduction processes based on the primary colors of the silver halide photography (such as the off-press proofing system Hell CP 403) produce significantly slighter metameric color deviations than the reproduction with printing inks (or with primary colors similar to printing inks).

In the second category the metameric color deviations are necessarily small. As this investigation has shown, no disturbing metameric color deviations occur in this case. This

applies if illuminant D50 is changed to illuminant D65 (or vice versa). Hence, it is admitted to compare an original with an off-press proof under illuminant D50, and subsequently compare the production print with the off-press proof under illuminant D65. There are certain differences within the off-press proofing systems (and non-impact processes), because some processes have primary colors being similar to the printing inks, while others use primary colors being closer to the silver halide photography. The first category (as for instance Matchprint) produce very slight metameric deviations, while the latter lead to somewhat larger deviations.

Fig. 1 Occurrence of metameric color deviations in the graphic arts: case1

*)The statement "reproduced under D50" means that there are no color deviations between the original and the reproduction under this illuminant.

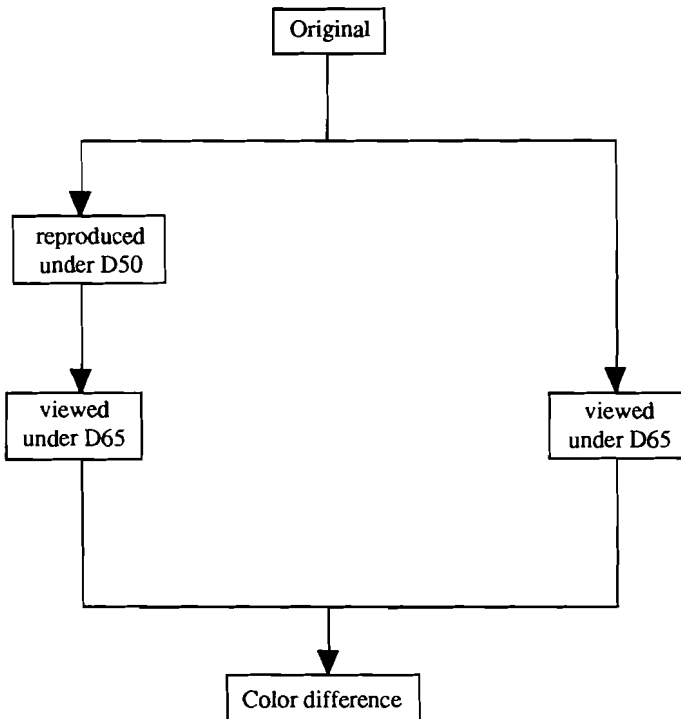


Fig. 2 Occurrence of metameric color deviations in the graphic arts: case 2

Note:
If the off-press proofing system and the printing process work with primary colors having the same spectral curves, no metameric deviations can occur.

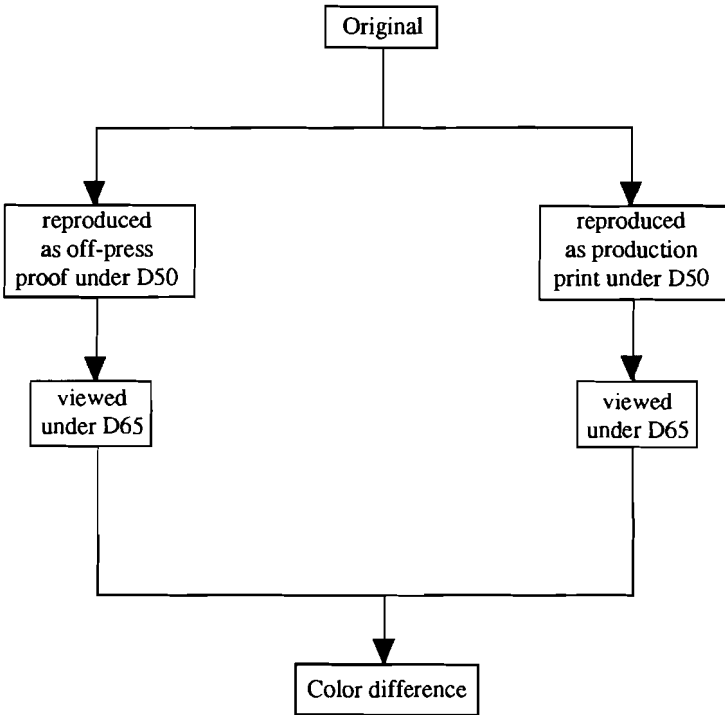


Fig.3
Four DIN Test Colors and their colorimetrically identical reproduction
obtained with the European process inks under illuminant D50

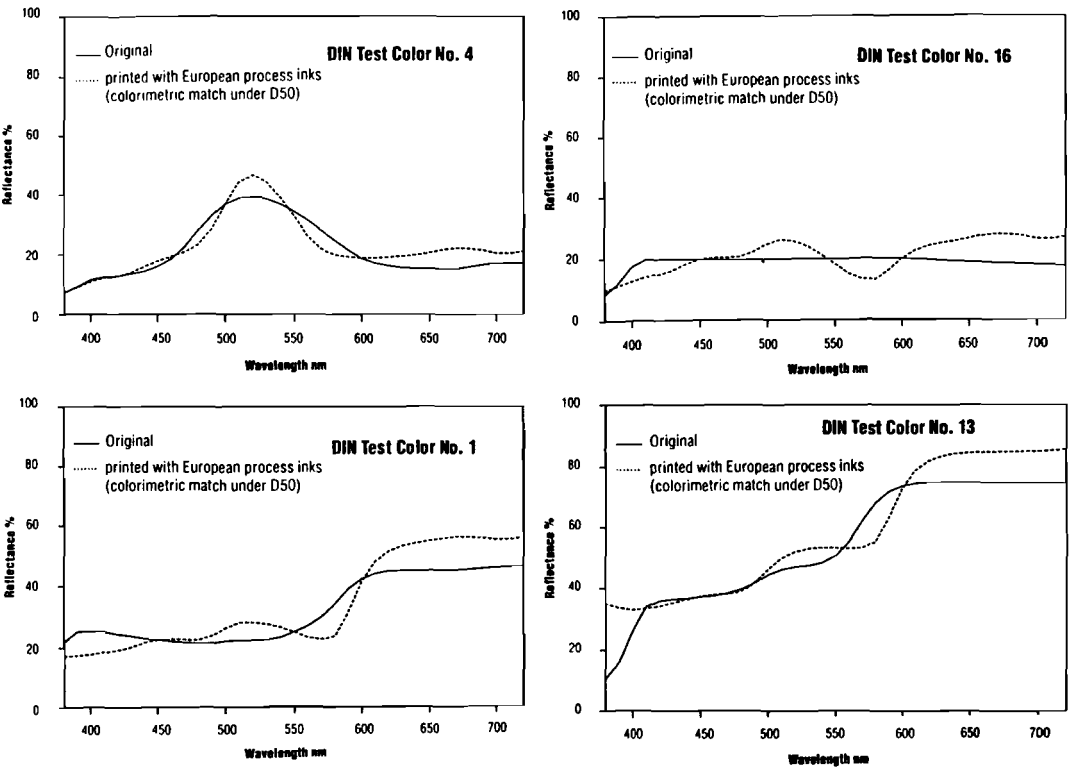


Table 1: DIN 6169 Test Colors

Test color No.	Color name
1	flesh tone
2	light brown
3	yellow-green
4	green
5	blue-green
6	light blue
7	light purple
8	red-purple
9	saturated red
10	saturated yellow
11	saturated green
12	saturated blue
13	skin tone
14	foliage green
15	dark grey
16	medium grey
17	light grey

Table 2: Metameric color deviations (ΔE , CIELAB) between an original and a three-color print under illuminant A and D65, if the print is a match of the original under illuminant D50.

DIN	ΔE (CIELAB) under	
	colorilluminant A	illuminant D65
1	3.74	0.77
2	4.08	1.55
3	5.34	2.10
4	3.09	0.91
5	3.62	1.23
6	2.02	0.83
7	2.51	1.30
8	0.98	0.71
9	1.51	0.59
10	2.88	1.11
11	2.18	0.79
12	1.90	1.62
13	2.38	0.82
14	6.72	2.63
15	5.59	2.25
16	4.84	1.90
17	0.74	0.26
Mean value	3.18	1.26

Table 3: Metameric color deviations (ΔE , CIELAB) between an original and an off-press proof under illuminant A and D65, if the off-press proof is a match of the original under illuminant D50

Process	ΔE (CIELAB) *) under	
	illuminant A	illuminant D65
Matchprint	3.13	1.31
Cromalin	2.46	0.92
Color-Art	2.61	0.93
Stork	2.10	0.78
Hell CP 403	1.09	0.47
Ink jet (Diablo)	2.56	1.01
Thermal transfer (Panasonic)	2.38	0.93
Four-color print	3.18	1.26

*) Mean value obtained from 17 test colors

Table 4: Metameric color deviations (ΔE , CIELAB) between an off-press proof and a production print under illuminant D65, if the production print is a match of the off-press proof under illuminant D50.

Process	ΔE (CIELAB) under illuminant D65 *)
Matchprint	0.07
Cromalin	0.45
Color-Art	0.36
Stork	0.70
Hell CP 403	1.12
Ink jet (Diablo)	0.53
Thermal transfer (Panasonic)	0.49
Mean value	0.53

*) obtained from 17 test colors

Appendix

Calculation of metameric color deviations by means of the Neugebauer equations

To calculate metameric color deviations between an original and its reproduction, it is necessary to know their spectral curves. Then the color values for two different illuminants and the resulting color difference ΔE can be calculated.

The spectral curve of an original color is available by measurement with a spectrophotometer.

The spectral curve of its reproduction can be calculated by means of the Neugebauer equations which, however, have to be modified for this purpose.

In program 1 is illustrated how the calculation works when the Neugebauer equations are used.

To calculate the spectral curves of a printed three-color overlap, it is necessary to convert the Neugebauer equations into the so-called "spectral" Neugebauer equations. Other than in the conventional Neugebauer equations where the tristimulus values X, Y, Z of the 8 primary colors are used, the spectral values are utilized. From those and the fractional dot area of each primary color the spectral values of the three-color overlap can be calculated (see chart B). This process is somewhat complicated, because 35 spectral values ranging 380 nm to 720nm have to be calculated.

The calculation process is illustrated in program 2. To improve the accuracy, a correction exponent can also be used.

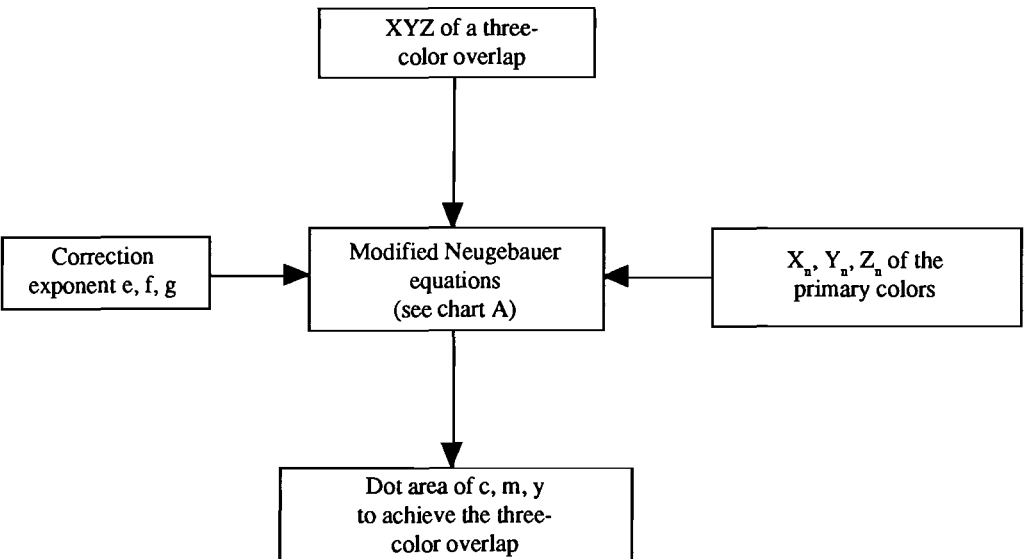
If the tristimulus values of a three-color overlap are given, and the corresponding spectral curve is wanted, the programs 1 and 2 can be connected (see program 3). As the spectral Neugebauer equations and the modified Neugebauer equations produce different results, an additional iteration is necessary in program 3.

Program 3 is then the starting point for all metamerism calculations.

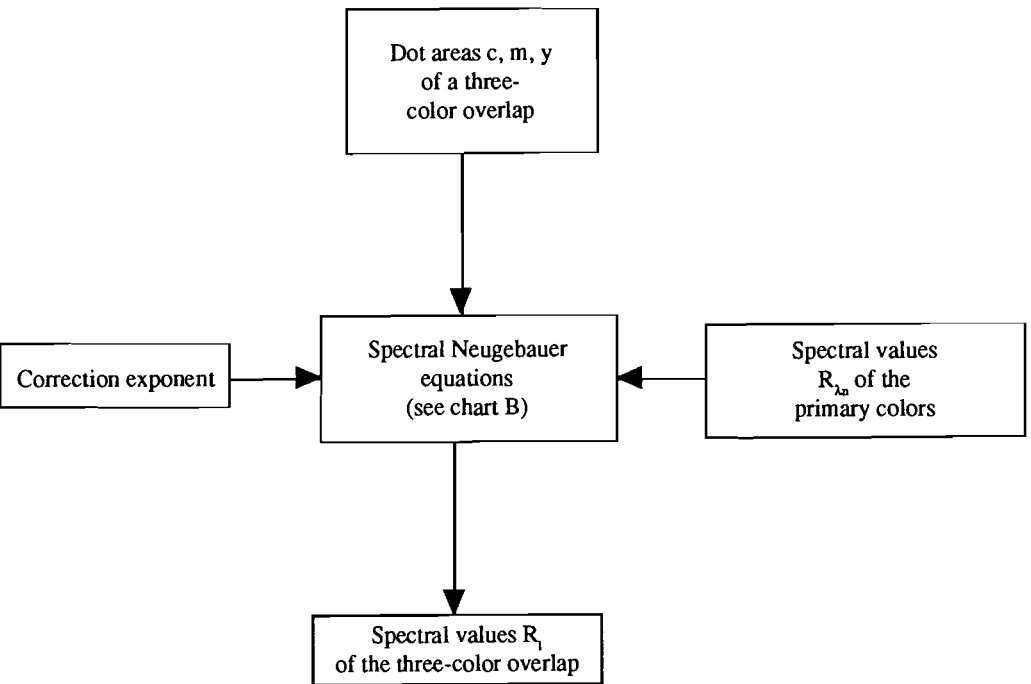
For the two cases of metamerism discussed in this report, the programs 4 and 5 were developed based of program 3.

The illuminants D_1 and D_2 specified in the programs can be chosen freely. In most cases for D_1 illuminant D50 and for D_2 illuminant D65 was chosen.

Program 1:
Calculation of the dot areas c , m , y of a three-color overlap, if the tristimulus values XYZ of the primary colors are given.

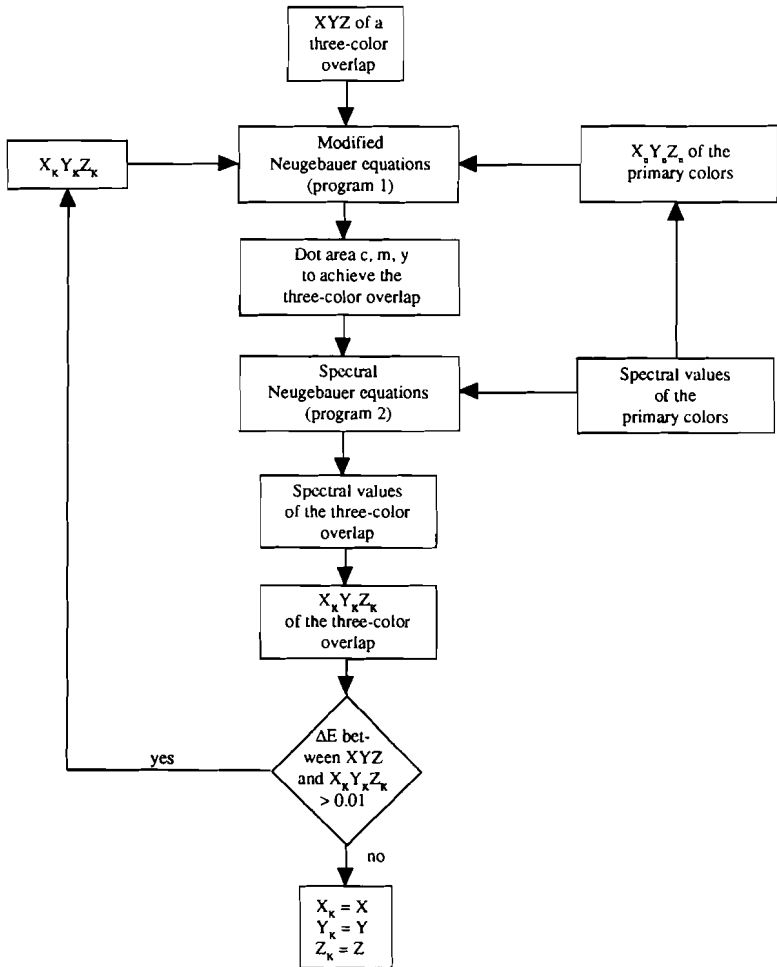


Program 2:
Calculation of the spectral values of a three-color overlap, if the dot areas of the three-color overlap and the spectral values of the primary colors are given.



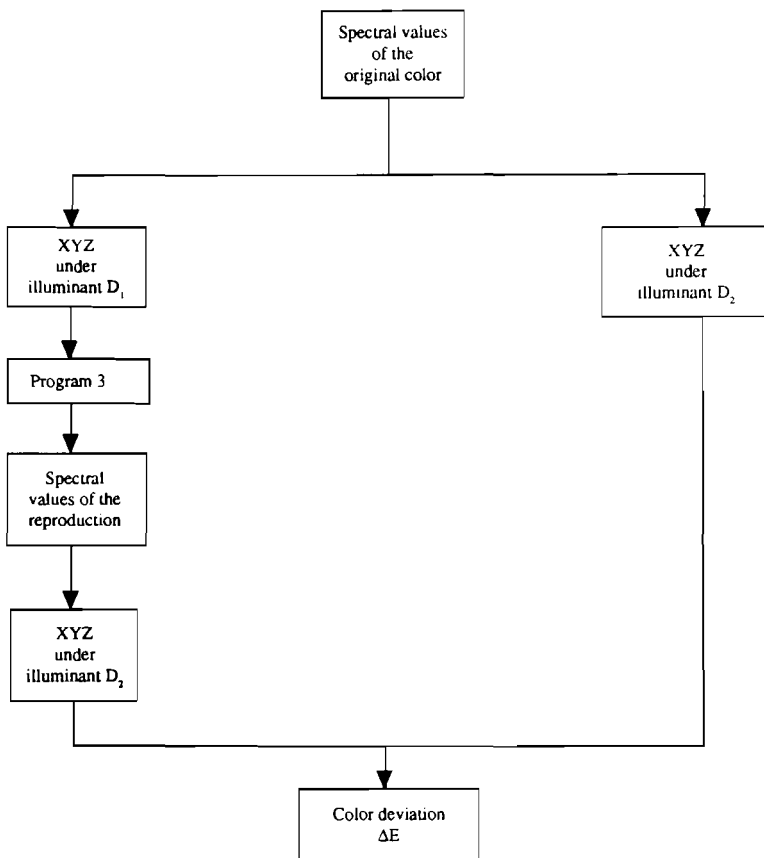
Program 3:

Calculation of the spectral values of a three-color overlap, if the tristimulus values XYZ are given.



Program 4:

Calculation of the metameric color deviations between an original color and its reproduction under illuminant D_2 , if the reproduction is a match of the original under illuminant D_1 .



Program 5:

Calculation of the metameric color deviations between an off-press proof and a production print under illuminant D_2 , if the production print is a match of the off-press proof under illuminant D_1 .

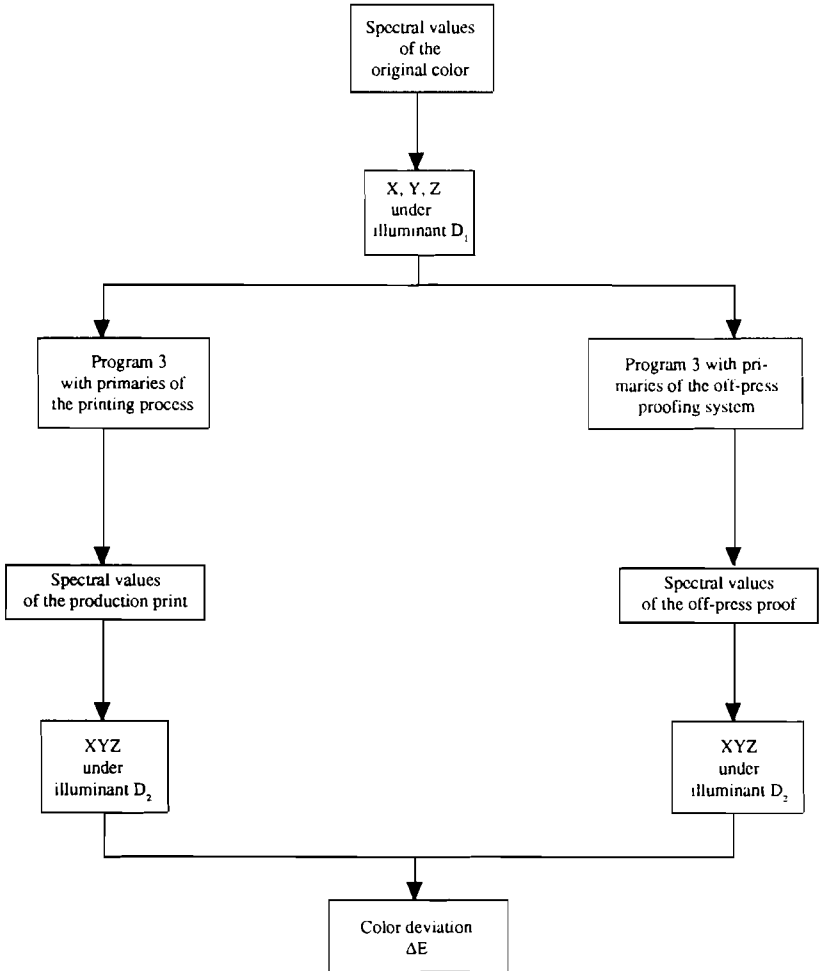


Chart A: Modified Neugebauer equations

$$\begin{pmatrix} X^e \\ Y^f \\ Z^g \end{pmatrix} = \sum_{n=1}^{n=8} f_n \cdot \begin{pmatrix} X_n^e \\ Y_n^f \\ Z_n^g \end{pmatrix}$$

Primary colors n

$f_1 = (1-c) (1-m) (1-y)$	n = 1	Paper white
$f_2 = c (1-m) (1-y)$	2	Cyan (C)
$f_3 = m (1-c) (1-y)$	3	Magenta (M)
$f_4 = y (1-c) (1-m)$	4	Yellow (Y)
$f_5 = c \cdot m (1-y)$	5	C + M
$f_6 = m \cdot y (1-c)$	6	M + Y
$f_7 = c \cdot y (1-m)$	7	C + Y
$f_8 = c \cdot m \cdot y$	8	C + M + Y

I.e.:

X, Y, Z	Tristimulus values of a three-color overlap
X_n, Y_n, Z_n	Tristimulus values of the primary colors n
f_n	Fractional dot areas (of the primary colors n)
c, m, y	Dot area of CMY
e, f, g	Correction exponents

Chart B: Spectral Neugebauer equations

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \sum_{n=1}^{n=8} R_{\lambda} \cdot \begin{pmatrix} X_{\lambda} \\ Y_{\lambda} \\ Z_{\lambda} \end{pmatrix}$$

$$R_{\lambda}^h = \sum_{n=1}^{n=8} f_n \cdot R_n^h$$

$$R_1 = R_w$$

$$R_2 = R_c$$

$$R_3 = R_m$$

$$R_4 = R_y$$

$$R_5 = R_c \cdot R_m$$

$$R_6 = R_m \cdot R_y$$

$$R_7 = R_c \cdot R_y$$

$$R_8 = R_c \cdot R_m \cdot R_y$$

X, Y, Z Tristimulus values of a three-color overlap

R_l Spectral reflection value of a three-color overlap for wavelength l

$x_{\lambda}, y_{\lambda}, z_{\lambda}$ Spectral tristimulus values

f_n Fractional dot area of the primary color n

R_n Spectral reflection value of the primary color n

h Correction exponent

R_c, R_m, R_y, R_w Spectral reflection values of the primary colors CMY and of the paper white