Screening Techniques, Moiré In Four Color Printing.

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ABSTRACT

A survey is given of both rational and irrational tangent screening algorithms. Attention is given to the various ways to improve angular precision of rational tangent screens. A mathematical approach is presented to analyze moiré in the frequency domain. Both the moiré from the interaction between the cyan, magenta and black printers, and the moiré introduced by the yellow printer are explained.

1. Introduction.

Offset printing is a BINARY process. The press can either print INK or NO INK on a particular location of the paper.

In order to simulate the effect of different tones and colors, necessary for the reproduction of pictures, patterns of dots are used of which the SIZE is modulated. The process of rendering shades of tone and color by modulating dot sizes is called "halftoning" or "screening".

A halftone screen or raster is defined by the "angle" and "frequency" or "ruling" of the dot pattern, and by the way the shape of the dots changes as they grow from 0 to 100 percent coverage. The evolution of this shape is usually controlled by a "spot function".

In conventional color printing, four inks are used: cyan, magenta, yellow and black. Every printable color is rendered by overprinting a particular combination of dot percentages of these four inks.

The angles and rulings of the halftone screens of these four inks are chosen with the following considerations in mind:

1) In order to reduce the sensitivity of the color reproduction to registration errors, the relative position of the dots has to be (pseudo) randomized.
2) The dot patterns of the four inks should not give raise to disturbing moiré patterns.

In conventional technology, both of these requirements are satisfactorily met by using the same ruling for the rasters of the four printers, and by using the 0, 15, 135 and 75 degrees angle system.

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It can be shown that, with this combination of angles and rulings, the same relative position of the dots in the four rasters is never repeated, which meets the first requirement, while the "moiré" is a "micro moiré" (referred to as the "rosette"), which, at the commonly used rulings, is fine enough not to be disturbing.

2. Electronical Screening.

2.1. Basics of electronical screening.

Electronically generated screens are usually output on high resolution laser recorders. Typically the "grid" that defines the resolution at which the laser beam can be modulated ON or OFF has a pitch in the range of 1/2400 of an inch. It is the task of the digital screening algorithms to turn ON or OFF the micro dots on this grid, so that they form a pattern of clusters that together make up the halftone screen. The size of these clusters has to correspond to the local tone value in the original or in the separation.

Most electronical screening systems make use of a THRESHOLDING mechanism to convert the tone values of the pixels into halftone dots with a corresponding size. Figure 1 demonstrates by means of a one dimensional model how this thresholding mechanism works. The value of a SCREEN FUNCTION is COMPARED with the TONE VALUE of the corresponding pixel. Depending on the outcome of this result, the laser beam is modulated ON or OFF, which, in its turn will image a BLACK or a WHITE micro dot on the film. In this way, the tone values of the pixels are translated into contiguous series of black and white microdots.

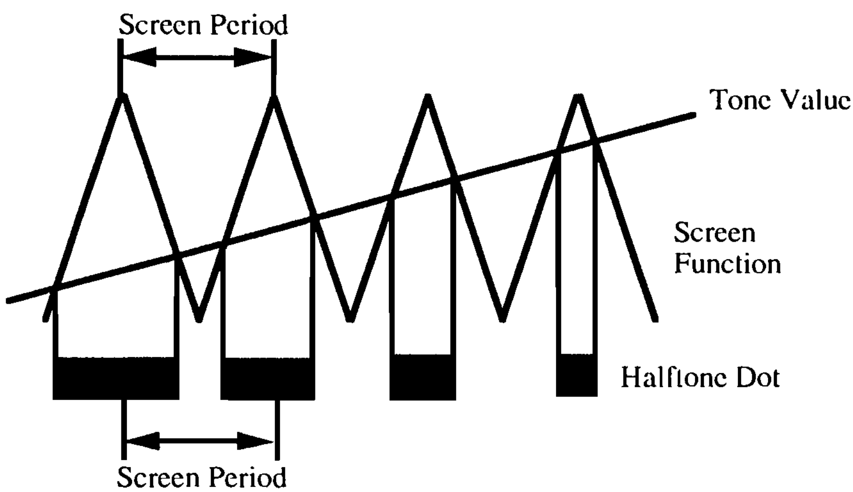


Figure 1 : One dimensional model of the thresholding mechanism to convert tone values in dot sizes.

Real screening is of course done in two dimensions. The tone values of the pixels in that case will form a two dimensional matrix, while the screen function will take the shape of a regular landscape with "mountains and valleys". The halftone dots that will result from the thresholding operation will be two dimensional clusters of microdots.

Figure 1 shows that the period of the halftone dot pattern is equal to the period of the screen function. In the two dimensional case, the same can also be said for the angle of the halftone dot pattern.

Figure 1 also shows that the "profile" of one screen function period determines how, for one series of microdots, the length depends on the tone value. Since a triangular waveform is used in this case, the relation will be linear. In the two dimensional case, the "profile" of one two dimensional period of the screen function will control how the SIZE and the SHAPE of the halftone dots will depend on the pixel values. It is the role of the "spot function" to characterize the profile of one two dimensional period of the screen function.

2.2. Practical implementation of digital screening.

Most digital screening algorithms generate their screen function values by means of the following two steps:

1) First the "periodical expansion" of the spot function is calculated (Figure 2);
2) Than this periodical expansion is sampled by an orthogonal grid with a specific angle and period in order to obtain the screen function values (Figure 2).

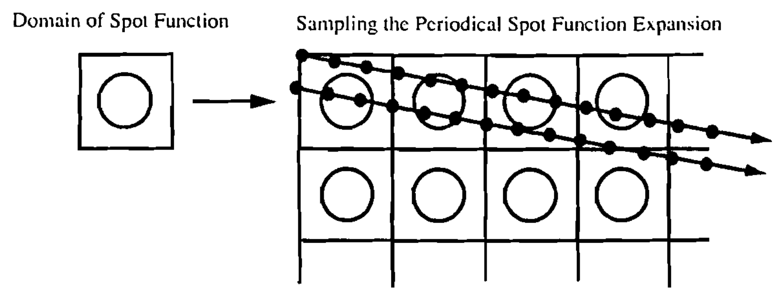


Figure 2 : Digital screening algorithms are usually based on a sampling operation of the periodical expansion of the spot function.

The distinction between most digital screening algorithms is based on variations in the "sampling" mechanism, and the use of more or less sophisticated spot functions.

Practically speaking, the periodical expansion of the spot function is obtained by applying a "modulo domain size" operation on the address values of the sampling points (Figure 3).

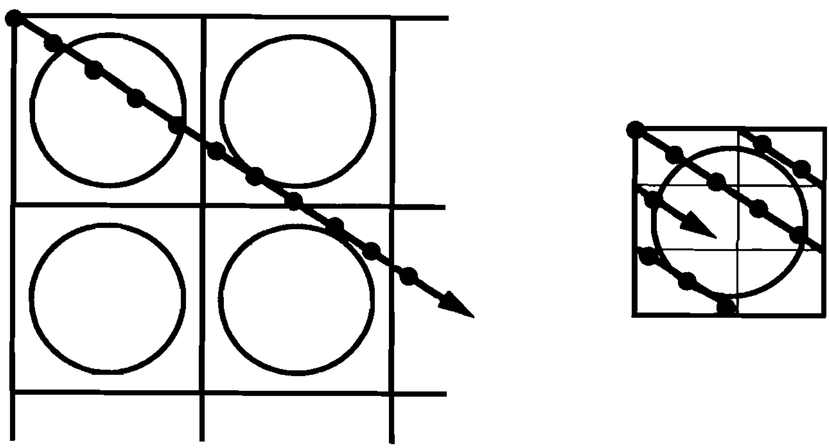


Figure 3 : Sampling the periodical expansion of the spot function corresponds to addressing the spot function "modulo domain size".

2.3. Overview of digital screening algorithms.

2.3.1. Rational tangent screening, first method.

In a first rational tangent method, the geometry of the grid that samples the spot function is chosen in a very particular relation to the domain of the spot function. This is demonstrated in Figure 4. As can be seen, the four corners of every period of the screen coincide exactly with points of the sampling grid. This means that the relative position of the sampling grid and the domain of the spot function will be the same for every dot.

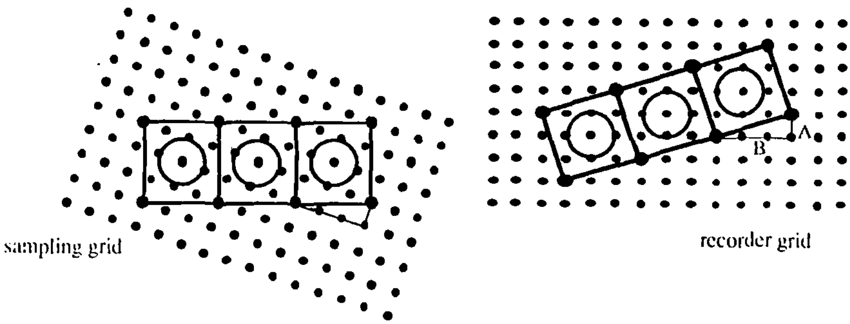
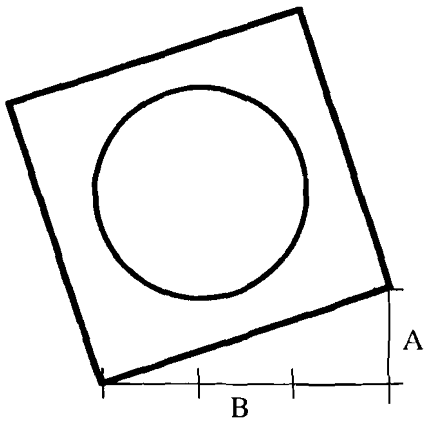


Figure 4 : With the first rational tangent method, the four corners of every screen period coincide with points of the sampling grid.

The important consequence of this is that the spot function needs to be sampled only once, and that the sampled values, when they are stored, can be used for all other dots. Since, for complex spot functions, the evaluation that is part of the sampling can be computationally intensive, it is certainly an advantage that this has to be done only for the samples of one screen period, instead of for all.

The internal two dimensional periodicity of the screen function values is a common property of all rational tangent screening methods. One such two dimensional period is often referred to as a halftone "cell".

Technically speaking, the first rational tangent method comes down to the calculation of one rotated halftone "cell" and its replication under the same angle on the recorder grid (Figure 5).



alfa=artan(A/B)

freq=res/sqrt(A*A+B*B)

Figure 5 : With the first rational tangent method, the spot function needs to be evaluated for only one screen period. It is then replicated on the recorder grid under a rational tangent angle.

One important limitation of this first rational tangent method is that, for a given recorder resolution, only a limited number of frequency and angle combinations are available. This is a problem when the screens are to be used for the reproduction of color images, since it makes difficult to find combinations of screen parameters that do not cause moiré problems on the press. A good angular approximation of the conventional 15 and 75 degree angles with this algorithm can only be achieved with large cells and correspondingly low screen frequencies (Figure 6).

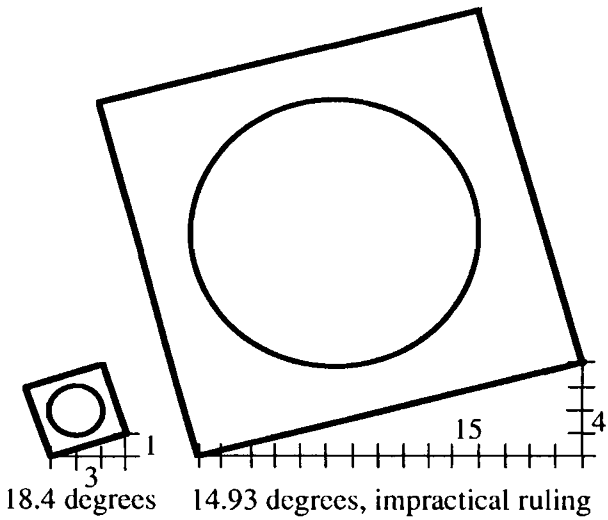


Figure 6 : Good angular accuracy can only be achieved with the first rational tangent method for large cell sizes, and thus correspondingly low screen frequencies.

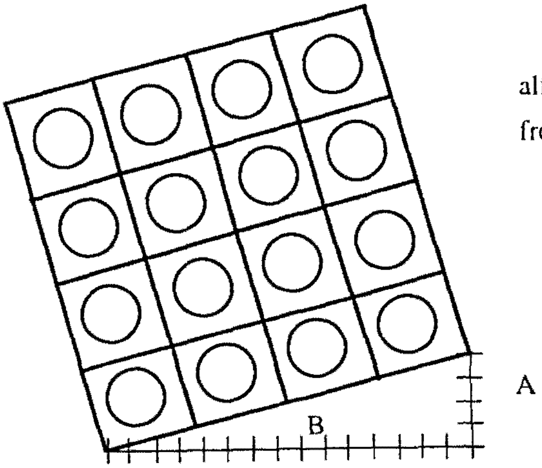
This can also be demonstrated by means of the formulas. The following table shows that, for a given resolution, increasingly better approximations of the conventional 15 degree angle also results in increasingly lower frequencies:

if resolution = 2400 dpi:

A	B	alfa	freq(dpi)
3	11	5.255	210.5
4	15	14.931	154.6
11	41	15.018	56.5
15	56	14.995	41.4
41	153	15.001	15.2

2.3.2. Rational tangent screening, second method.

The second rational tangent method is based on the first one but tries to cope with its limitations by using a "multiple dot" spot function. A multiple dot spot function creates "m" by "m" dots across its domain. that are lined up with the domain boundaries. The effect of this is that the resulting screen frequency is "m" times larger than would be expected based on the cell size. This is demonstrated by Figure 7. Cells that contain multiple dots are often referred to as "super cells".



alfa = artan(A/B)

freq = m*res/sqrt(A*A+B*B)

Figure 7 : By using a "multiple dot spot function", good angular accuracy can be combined with practical rulings. This forms the basis of a second rational tangent method.

2.3.3. Irrational tangent screening.

By relieving the constraint that the four corners of the domain of one spot function are to coincide with the sampling grid, the angle of this grid is allowed to have an irrational tangent. (See Figure 8). This is the principle behind the "irrational tangent" screening algorithms.

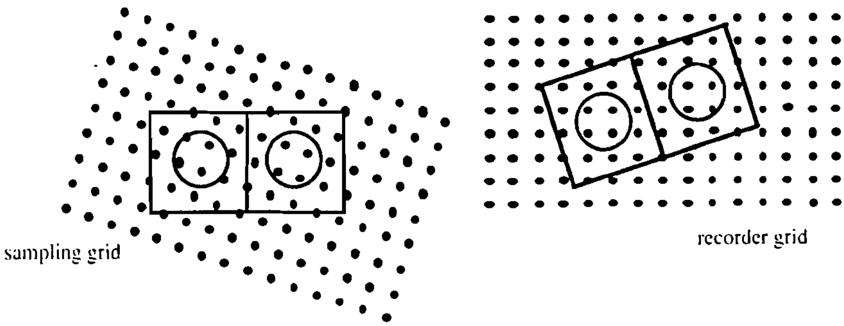


Figure 8 : Irrational tangent screens are obtained by sampling the periodical expansion of the spot function under an irrational tangent angle. If the angle is truly irrational, the spot function will never be evaluated twice at the same coordinates.

Removing this constraint has an implication on the amount of calculational work that needs to be done. Since for truly irrational tangent screens the relative geometry of every screen period with respect to the sampling grid is different, there is no equivalent of a repeating cell or supercell.

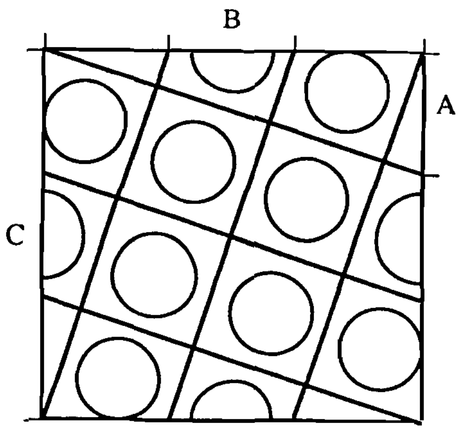
This means that for every point on the sampling grid the spot function needs to be evaluated. Since the evaluation of the analytical form of the spot function is usually too demanding for real time computation, a two dimensional look up table (with the spot function precalculated for, e.g. 128 by 128 combinations of x and y) in combination with interpolation is used instead.

Because of the limited resolution of the recorder grid, irrational tangent screens can have a tendency to "round off" locally to screens with a rational tangent angle. The positive and negative rounding off errors alternate, and this might be visible as "patterning". This patterning can be broken up by adding noise to the position coordinates of the sampling points.

The spot function in the irrational tangent method is usually (but not necessarily) a "single dot" spot function.

2.3.4. Rational tangent screening, third method.

In a third rational tangent screening method, the angle of the screen is obtained by using a "PREANGLED spot function" (Figure 9). The angle of the dots in one domain period always has a rational tangent. The four corners of one period of the spot function are locked to the sampling grid.



alfa = artan(A/B)

freq = res*sqrt(A*A + B*B)/C

Figure 9 : A third rational tangent technique is based on the use of a pre-angled spot function. As will be demonstrated, this will allow moiré free rastering of color images.

This third rational tangent method is one of the principles behind the Agfa Balanced Screening technology and it combines the advantages of the previous screening methods (rational and irrational tangent):

1) As with the irrational tangent algorithms, this method can provide screening systems that are visually AND mathematically moiré free, and that have a rosette structure that is indistinguishable from the traditional one.

2) Preangled spot functions can be used with many dots in one cell (up to several thousands in the Agfa Balanced Screening technology). By allowing the individual dots in one cell to have slightly different sizes, and by controlling their AVERAGE size, it becomes possible to SIMULATE dot sizes that are normally not available. This technique, which is called dithering, INCREASES the NUMBER of available SHADES at low recorder resolutions. However, at least as important, and this even at high recorder resolutions, is that the dithering technique provides a UNIFORM DISTRIBUTION of the available SHADES. This allows the smoothest and most continuous rendering of degrades at a given resolution.

3) The spot function in the Agfa Balanced Screening technology is designed to explicitly control both the "CENTER OF GRAVITY", AND the "MOMENT OF INERTIA" of the clusters of microdots that make up the halftone dots. The first condition minimizes the "harmonic distortions" of the created halftone pattern. The second condition minimizes the circumference of the dot clusters, producing the most "compact" halftone dots, and the sharpest edge definition. This level of optimization is practically impossible with the irrational tangent techniques, because of the amount of calculational work it would require on the fly.

2.3.5. Rational tangent screening, fourth method.

There is of course no reason why the principles of the "first" and "third" rational tangent algorithms could not be combined. This was the reasoning when a fourth rational tangent algorithm was developed, which combines the angled replication of a cell with the use of preangled spot function (Figure 10). The principle advantage of the fourth method is that, since more degrees of freedom are available to control the screening angle, the advantages of the third method can be combined with very fine control over the screening angle.

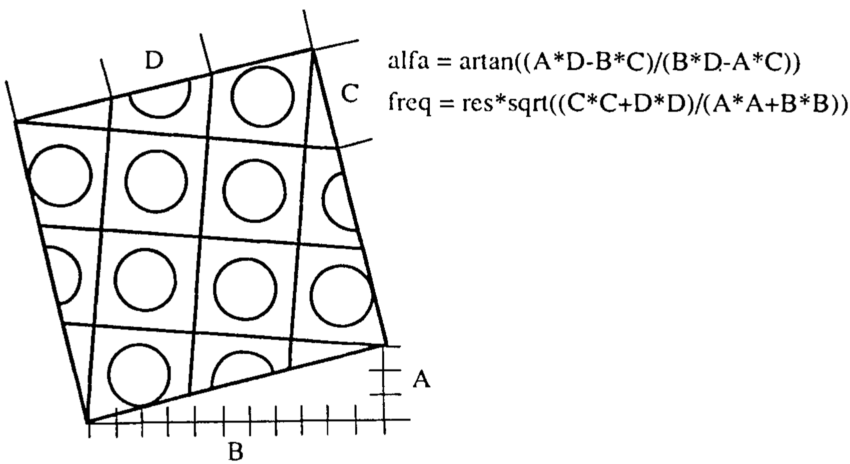


Figure 10 : In a fourth rational tangent technique, a preangled cell is replicated under a rational tangent angle.

3. Moiré in color printing.

Moiré refers to the geometrical interactions between patterns.

In the case of color printing, the patterns are the rasters of the four printers. Interaction can only occur between rasters that have overlapping absorption bands. These absorption bands can be the "main absorptions" of the inks, but also the "side absorptions". An important example of the latter are the interactions between the yellow ink and the unwanted side absorptions in the blue of the cyan and magenta inks.

3.1. Introduction to moiré analysis in the frequency domain.

Moiré analysis of rasters can best be done in the "frequency domain". A qualitative analysis is possible by means of graphical representations of the "frequency components" of the rasters. If also a quantitative analysis is required, the corresponding analytical formulas can be used.

The frequency representation of a line screen is a vector, perpendicularly oriented to the direction of the lines themselves, and with a length that is inversely proportional to the line period (Figure 11 left).

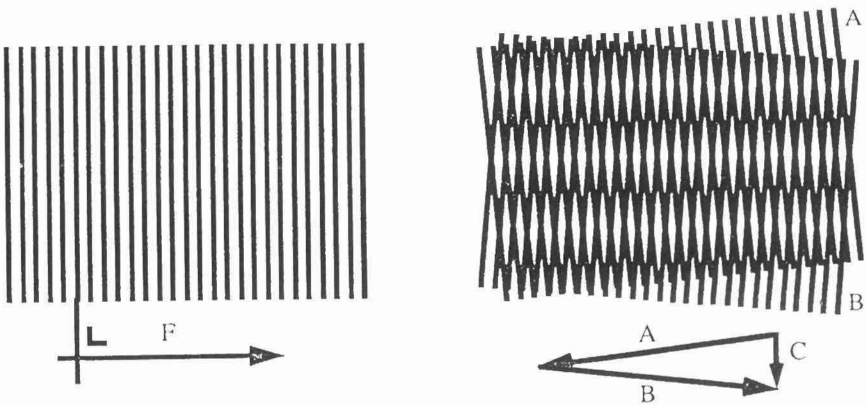


Figure 11 : The interactions between line screens can conveniently be represented in the "frequency domain".

Using this representation, it is possible to predict the interaction between two line screens (Figure 11, right). The vector C corresponds to the line pattern that results from the interaction between the line patterns A and B.

The frequency representation of a square raster can conveniently be represented by a set of two perpendicular vectors.

Besides by their frequency and angle, patterns are also characterized by a phase with respect to an arbitrarily chosen reference.

Most moiré phenomena will be strongest when the primary patterns have a coverage around 50%.

In certain cases, the interactions between the harmonics of halftone rasters have to be included in the moiré analysis.

From a mathematical viewpoint it makes sense to split up the moiré analysis in four color printing into two parts. The first part handles the geometrical interactions between the cyan, magenta and black rasters. The second part discusses the moiré introduced by the yellow printer.

3.2. Moiré from the interaction between the cyan, magenta and black rasters.

The most important common absorption band of the cyan, magenta and black rasters lies in the green part of the spectrum. Green corresponds to one of the main absorptions of the black, to the main absorption of the magenta, and to the first side absorption of the cyan ink. Therefore the moiré between these three rasters will mainly be visible as a periodical shift in the green absorption band (causing a periodical shift in color balance from too green to too magenta) in colors that are printed with these three inks.

3.2.1. Mathematical analysis of the conventional screening system.

The key to understand how the different "new" screening technologies work with respect to moiré is to understand how the "conventional" screening system works.

Figure 12 shows the vector diagram that corresponds to the cyan, magenta and black components of the conventional screening system, with proper registration. The reason why this screening system works as well as it does is:

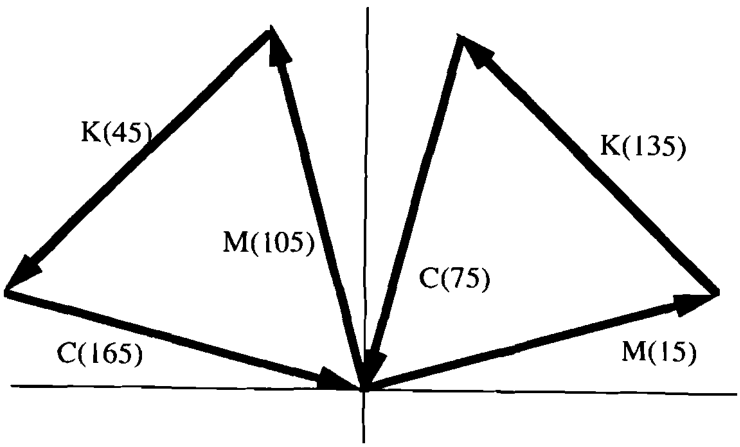


Figure 12 : Vector diagram of the conventional screening system. The triangles "close", and there is no moiré.

1) Because the SUM of the magenta component at 15 degrees PLUS the black component at 135 degrees PLUS the cyan component at 75 degrees IS EQUAL to a moiré with ZERO frequency (and hence an infinite period);
2) AND because the SUM of the cyan component at 165 degrees PLUS the black component at 45 degrees PLUS the magenta component at 105 degrees IS EQUAL to a moiré with ZERO frequency (and hence an infinite period);

Figure 13 shows what happens when the 75 degree cyan screen is out of register:

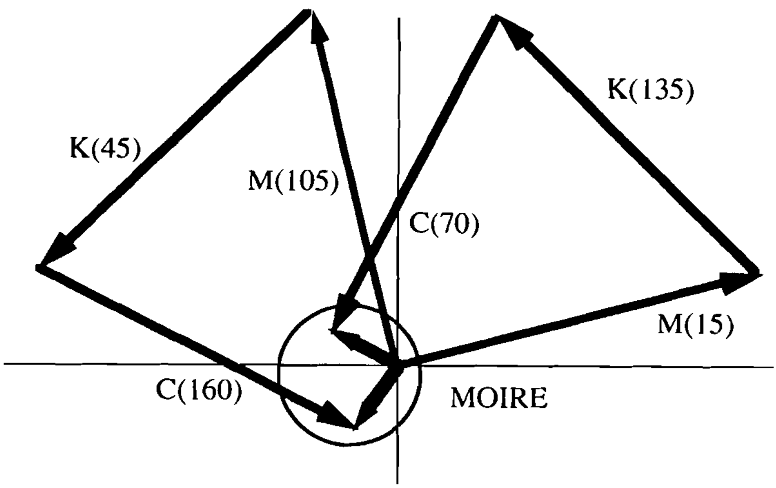


Figure 13 : Vector diagram of a screening system when the cyan raster is off register. The triangles do not close, and there will be moiré.

1) The SUM of the magenta component at 15 degrees PLUS the black component at 135 degrees PLUS the cyan component at 75 degrees IS NOT EQUAL to a moiré with ZERO frequency (and hence this moiré has a finite period);
2) AND the SUM of the cyan component at 165 degrees PLUS the black component at 45 degrees PLUS the magenta component at

105 degrees IS NOT EQUAL to a moiré with ZERO frequency (and hence this moiré has a finite period);

The moiré that results from this misregistration will be visible as a periodical shift in the green absorption band. The angle and period of the moiré are predicted by the diagram.

If the screens are orthogonally symmetrical, the moiré analysis can be limited to only one "triangle". A closing triangle will correspond to the absence of moiré. An open triangle will predict the angle and period of a moiré.

3.2.2. Moiré and the rosette structure.

It was already mentioned that, a complete description of the interactions between patterns should also include the effect of their relative "phase". In the case of the interaction between the black, cyan, and magenta rasters, the relative phase is going to determine the nature of the "rosette" that will be produced. The rosette can be "clear centered", "dot centered", or anything in between. Both rosette types are each others phase opposite. This means for example that a clear centered rosette is converted into a dot centered rosette when a (negative) contact copy is made and vice versa.

The "clear centered" rosette is considered more desirable, since it is less noticeable in the highlights and midtones (including the critical skin tones). It also allows better gradation control on the press in the shadow areas (Figure 14).

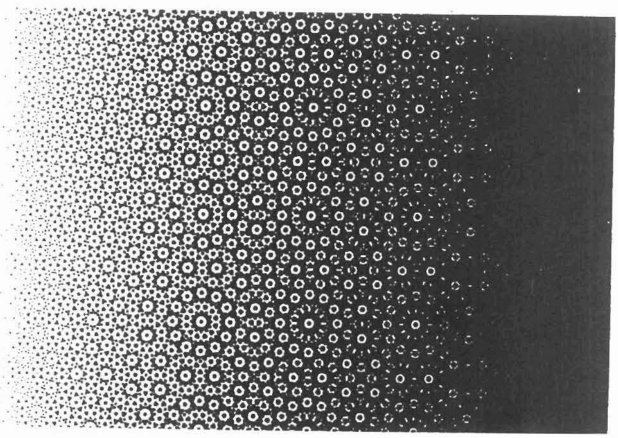


Figure 14a : An image created by the superposition of three degrades from 0% tot 90%, rastered at 15, 45 and 75 degrees with identical rulings. There is no moiré. The rosette is consistently dot centered.

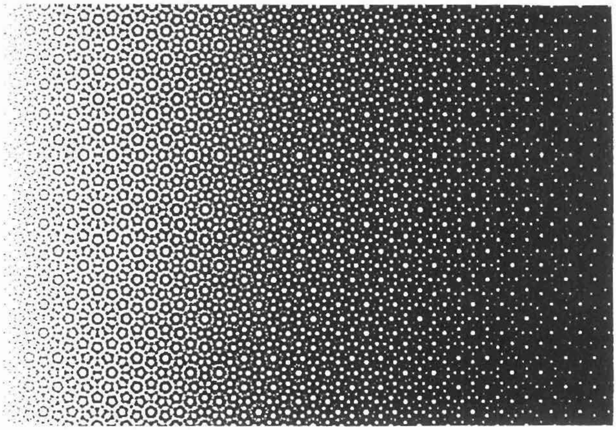


Figure 14b : Same as Figure 14a, but by having offset the 45 degree raster over half a period, the rosette is now clear centered. The clear centered rosette looks less coarse to the eye in the mid tones, and preserves the gradation better in the dark tones than the dot centered rosette.

This is a good place to point to the fact that the "strength" of the rosette structure is also depending on the separation technique. The more black is used in highlights and midtones for example (when a a high GCR level is used), the more pronounced the rosette structure will be. Inversely, the lesser cyan and magenta are used in the shadows (when a high UCR level is used), the lesser visible the rosette structure will be.

One interpretation of moiré in context of rosettes is to see it as a periodically changing rosette structure (Figure 15). The moiré angle and period correspond to the shortest line that connects two places with an identical rosette structure.

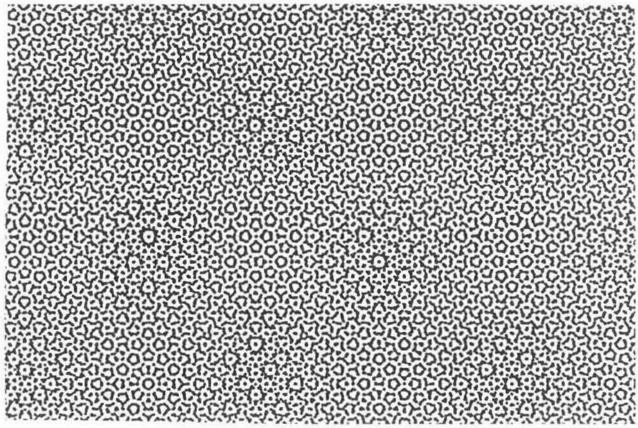


Figure 15 : Moiré can be seen as a periodically shifting "phase relation" between the cyan, magenta and black rasters, causing a periodically shifting rosette.

3.2.3. Moiré analysis of the first and second rational tangent methods.

Moiré analysis of screens generated with the first or second rational tangent method reveals that the moiré period can be made larger (the rosette structure stable over a longer distance) by improving the angular accuracy of the 15 and 75 degree screens. Only in the limit however becomes the moiré period infinitely large. We will proof this for the most logical case, namely for a set of three screens that are defined by two integer numbers as follows:

Given: A, B, m, and res.

screen1: alfa1 = arctan(A/B); F1 = m*res/sqrt(A*A + B*B);
screen2: alfa2 = arctan(1.0); F2 = m*res/sqrt((A-B)*(A-B)+(A-B)*(A-B));
screen3: alfa3 = arctan(B/A); F3 = m*res/sqrt(B*B + A*A);

An example of such a screen set is:

A = 15, B = 56, m = 4, res = 2400 dpi.

screen1: alfa1 = 14.995 degrees; F1 = 165.59 lpi.
screen2: alfa2 = 135.000 degrees; F2 = 165.57 lpi.
screen3: alfa3 = 75.005 degrees; F3 = 165.59 lpi.

The endpoints of the vectors that correspond to screen1 and screen3 are:

endpoint screen1: (x0,y0) = (F1*cos(alfa1),F1*sin(alfa1));
endpoint screen3: (x1,y1) = (F3*sin(alfa1),F3*cos(alfa1));

In order to have no moiré, the angle of the "ideal" frequency vector F2' should be 135.0 degrees, and its length should be the distance between the endpoints of screen1 and screen3:

F2' = sqrt((x0-x1)*(x0-x1) + (y0-y1*(y0-y1))
= F1*sqrt(2 - 4*cos(alfa1)*sin(alfa1))
= F1*sqrt(2 - 4*A*A/(A*A+B*B))
= F1*sqrt(2*A*A + 2*B*B - 4*A*B)/(A*A+B*B)

The length of the frequency vector F2 however is:

F2 = res/sqrt((A-B)*(A-B)+(A-B)*(A-B));
= F1*sqrt(A*A+B*B)/sqrt((A-B)*(A-B)+(A-B)*(A-B));
= F1*sqrt((A*A+B*B)/(2*A*A+2*B*B-4*A*B)).

The frequency of the moiré will be F2-F2'. In the given example it would be 14 inches. In order to have no second order moiré (moiré period infinitely large), it would be required that F2=F2'. We will calculate now under which conditions this is possible:

F2 = F2'

By working out this equation, the following condition is found:

3*z*z*z*z-16*z*z*z+22*z*z-16*z+4=0;

with: z=A/B.

This is a fourth degree polynomial in A/B. The equation has four real roots:

z0 = +(2.0 - sqrt(3.0));
z1 = -(2.0 - sqrt(3.0));
z2 = +(2.0 + sqrt(3.0));
z3 = -(2.0 + sqrt(3.0));

Both are irrational numbers, so no two integer numbers A and B exist that can make the moiré frequency zero. This proofs our point.
It is interesting to see that roots correspond to the tangent values of +/-15.0 and +/-75.0 degrees.
This confirms that there is almost a "continuous" transition from "rational" to "irrational tangent" screening, as the arctangent of the A/B value approximates better the 15 degree angle.

3.2.4. Moiré analysis of "RT screening".

The early digital screening techniques, were based on the first rational tangent screening method. Since attempts to simulate the conventional screening systems were not successful, an alternative screening system was pioneered in the seventies by Dr. Rudolf Hell GMBH, This alternative screening system, called "RT Screening", uses rational tangent screens of 18.4 and 71.6 degrees, in combination with a 135 degree screen so that the HARMONICS of the primary components are "locked" with respect to each other. The moiré in that case will be a micro moiré. There are a couple of sets of these RT screen systems in use:

(the equations are to be interpreted as vector equations)
set1: (C + M) = 2*K;
set2: 2*(C + M) = 3*K;
set3: 3*(C + M) = 4*K.

The corresponding frequency diagrams are found on Figure 16.

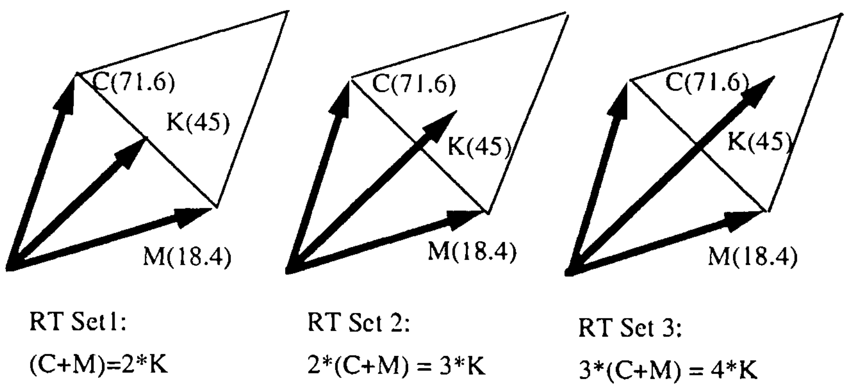


Figure 16 : Frequency diagrams for three sets of "RT Screening". These sets try to optimize the relations between the "harmonics" of the fundamental rasters.

The RT screen sets work well, but have also a number of drawbacks:

1) The rulings of the three rasters is not the same, which can give raise to printability problems for the screen with the highest ruling.
2) The color reproduction is more dependent on registration, because the relative position of the dots of the different rasters is not as well "randomized" as with the conventional angles.
3) They are "different" from the conventional screening systems.
4) The micro moiré of sets 2 and 3 more noticeable than the rosette structure obtained with the conventional screening systems.

3.2.4.1. Moiré analysis for the third of fourth rational tangent algorithm.

It will be shown here that, with the third rational tangent method, it is possible to design screen sets, that cancel out the second order moiré in exactly the same way as the conventional screening system does, and hence produce a rosette structure that is indistinguishable from the conventional rosette structure.

One set of screens that meet this requirement is:

screen1: alfa1 = arctan(C/D); F1 = res*sqrt(C*C + D*D)/B;
screen2: alfa2 = arctan(1.0); F2 = res*sqrt((C-D)*(C-D)+(C-D)*(C-D))/B;
screen3: alfa3 = arctan(D/C); F3 = res*sqrt(D*D + C*C)/B;

An example of such a screen set is:

A = 0, B = 795, C = 15, D = 56, res = 2400 dpi.

screen1: alfa1 = 14.995 degrees; F1 = 175.02 lpi.
screen2: alfa2 = 135.000 degrees; F2 = 175.04 lpi.
screen3: alfa3 = 75.005 degrees; F3 = 175.02 lpi.

The endpoints of the vectors that correspond to screen1 and screen3 are:

endpoint screen1: (x0,y0) = (F1*cos(alfa1),F1*sin(alfa1));
endpoint screen3: (x1,y1) = (F3*sin(alfa1),F3*cos(alfa1));

In order to have no moiré, the angle of the "ideal" frequency vector F2' should be 135.0 degrees, and its length should be the distance between the endpoints of screen1 and screen3.

F2' = sqrt((x0-x1)*(x0-x1) + (y0-y1*(y0-y1))
= F1*sqrt(2 - 4*cos(alfa1)*sin(alfa1))
= F1*sqrt(2 - 4*C*D/(C*C + D*D))
= F1*sqrt((2*C*C + 2*D*D - 4*C*D)/(C*C + D*D))

The length of the frequency vector F2 is:

F2 = res*sqrt((C-D)*(C-D) + (C-D)*(C-D))/B;
= F1*sqrt((C-D)*(C-D) + (C-D)*(C-D))/(C*C + D*D);
= F1*sqrt((2*C*C + 2*D*D - 4*C*D)/(C*A + D*D)).

Hence we have found that F2 = F2', and that the second order moiré has a zero frequency. What has happened is that the small angular offset caused by the rational tangent approximation of the 15 and 75 degree screens, has been EXACTLY offset by the small difference between the ruling of the 135 degree screen and the 15 and 75 degree screens.

3.3. Moiré from interactions with the yellow raster.

The yellow ink absorbs only in the blue part of the spectrum. Interaction is therefore possible with:
1) The main absorption of blue by the black ink;
2) The first side absorption of blue by the magenta ink;
3) The second side absorption of blue by the cyan ink.

First an moiré analysis for the yellow raster is made for the conventional screening system. This analysis will allow to understand the improvements that were incorporated in the Agfa Balanced Screening Technology.

3.3.1. Analysis of the conventional screening system.

In the "conventional" screening technology, the following angles are used:

yellow: 0 degrees.
magenta: 15 degrees;
black: 45 degrees;
cyan: 75 degrees;
and all the rulings are equal to each other.

The 0 degree component of the yellow raster gives raise to the following moiré components (see Figure 17):

1) A low frequency moiré component from the interaction with the 15 degree magenta raster component. The frequency of this moiré is 0.26 times the screen frequency. This moiré will primarily be visible in orange colors with magenta and yellow raster values around 50%.
2) A high frequency moiré component from the interaction with the 135 degree black raster component. The frequency of this moiré is 0.76 times the screen frequency. This moiré will not be disturbing because of its high frequency.
3) A low frequency moiré component from the interaction with the -15 degree cyan raster component. The frequency of this moiré is 0.26 times the screen frequency. This moiré will primarily be visible in light green colors with cyan and yellow raster values around 50%.
4) A second order moiré from the interaction with the sum of the previous moirés in point 1) and 3). This moiré has a frequency of ONLY 0.07 times the screen frequency. It occurs in colors with cyan, magenta and yellow rasters values around 50% (tan). It is also very visible when the corresponding film separations are overlaid.
5) A second order moiré from the interaction with the sum of the 45 and 135 degree black rasters components. This moiré has a frequency of 0.41 times the screen frequency.
6) A third order moiré between the previous second order moirés.

A similar set of moiré components can of course also be found for the interactions with the 90 degree component of the yellow raster.

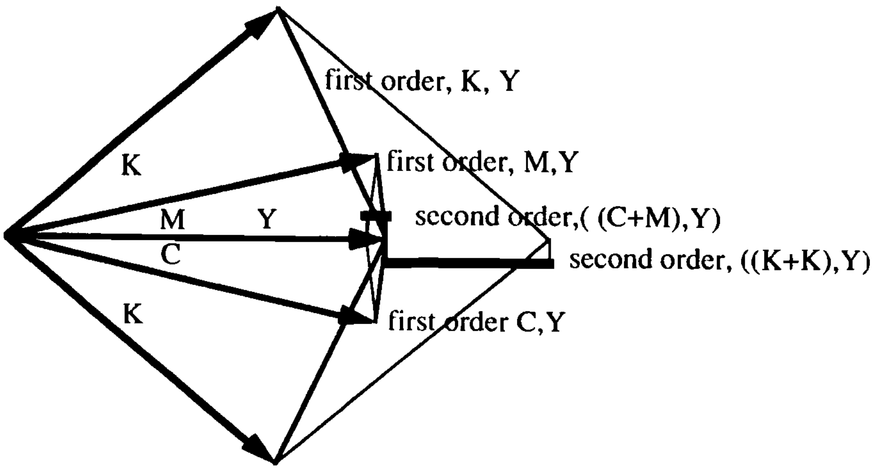


Figure 17 : Analysis of the interactions of the yellow raster with other the rasters in four color printing. See text for explanation.

3.3.2. Methods to reduce moiré caused by the yellow printer.

3.3.1.1. Use of clean inks.

By using inks with less unwanted side absorptions, the interactions due to these side absorptions can be reduced.

Unwanted side absorptions can also be the result of cross contamination of the inks when they are ran on the press. This cross contamination has to be limited as much as possible.

3.3.2.2. Swapping the angles of two of the cyan, magenta and black rasters.

By swapping the angles of the black and the magenta rasters, the moiré frequency of the interaction between the magenta and yellow raster becomes 0.76 times instead of 0.26 times the screen frequency, and this will greatly reduce its visibility. In a similar fashion, the angles of the cyan and black rasters can be swapped to reduce the moiré in the light green colors. It is impossible however to find a combination of angle swappings that will eliminate the moiré for both the orange AND light green colors.

3.3.2.3. Changing the frequency of the yellow separation.

Instead of swapping angles of the other rasters, it is also possible to change the frequency of the yellow screen to reduce moiré. Figure 18 shows a plot in which, of all 6 interactions that were described, always the lowest moiré frequency was plotted versus a range of yellow frequencies.

The frequency scale was normalized with the screen frequency of the cyan, magenta and black rasters being the unity.

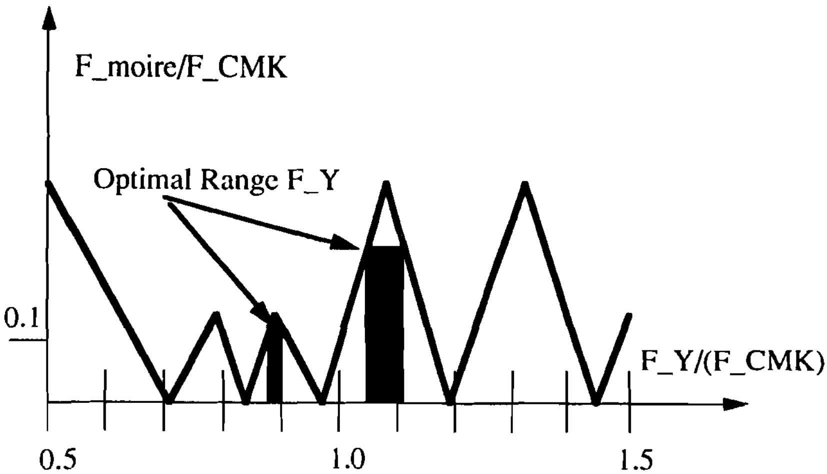


Figure 18 : Plot of normalized moiré frequencies caused by the interactions with the yellow raster. The optimal frequency for the yellow raster lies around 1.11 times the frequency of the cyan, magenta and black rasters.

If ones takes the approach that the frequency of the moiré caused by the yellow printer has to be as high as possible in order to minimize its visibility, the plot demonstrates that making the frequency of the yellow raster equal to the the frequency of the three other rasters is not optimal. The optimal lies around 1.11 times the CMK raster frequency. This has been experimentally verified.