Hybrid Screening, What It Will Do.

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Abstract: With conventional AM screening it is known that higher line rulings will render finer details. Because of the dots getting smaller, there is however the risk of losing highlights and shadows. With higher line rulings the number of AM dots increase, so the average size decreases. In the bright tones they might become that small that they can't be stable reproduced anymore. Hybrid screening can tackle this problem. When dots become too small to be reproduced, the screening algorithm automatically switches to FM screening. In this paper an overview will be given of the advantages and disadvantages of Hybrid screening. Although the algorithm will effectively counter the clipping in highlights and shadows, it might have effect on the overall image quality. Especially when the minimum reproducible dot size is rather large the FM part might look noisy. Also when using tile based screening, the replication of the tile will become visible because of the non-homogeneity introduced by the FM part.

Introduction

Although technology evolves incredible fast, most reproduction device are still not capable of reproducing a continuous range of tones. They can either print ink or not. Several techniques are developed to simulate continuous tones on this type of devices. Those simulated continuous tones are called halftones. Halftones are obtained by printing more or less black points in the same area on paper. A distinction can be made between two major classes of methods for distributing a given number of dots over the area. FM screening, stochastic screening or dot-dispersed screening tries to spread the printed dots as homogeneously as possible over the surface. AM screening or dot-clustered screening will group single printed dots together in larger dots. The darker the image is, the bigger those dots will be.

AM screening, or amplitude modulated screening, is still the most widely used halftoning type. Usually a fixed number of dots are placed on an orthogonal grid (figure 1). This grid is characterized by it's frequency (in graphics arts referred to as it's line ruling) and it's angle (screen angle). The different tones are obtained by modulating the

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amplitude (read the size) of the dots. Increasing the dot size results in darker tones, decreasing the dot size will render brighter tones.

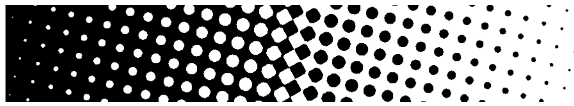

Figure 1. Vignette rendered with AM screening

This works well for black and white images. When printing color images a problem arises when placing the different color planes on top of each other. When merging geometrical patterns with similar frequencies and angles, very low frequent patterns called moiré patterns, might appear (left image of Figure 2).

When printing in 4 colors, there was found that printing the 3 most visible colors with a difference of 30° and the fourth color at a difference of 15° will give the least visible patterns (Figure 2, right image). Most commonly used is placing black at 45°, cyan at 15°, magenta at 75° and Yellow at 0°.

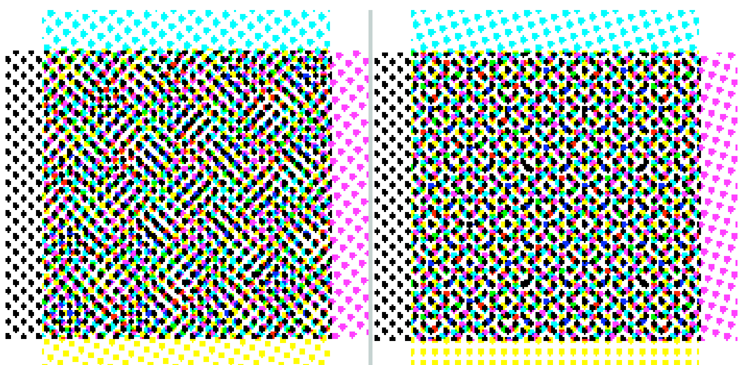

Figure 2. When different color planes are merged moiré patterns might appear. In the left image the angles of the screens are badly chosen. In the right image the conventional angles are applied.

Placing the screens 30° apart and using the same line ruling for all the planes was perfectly possible when the screen were made with analogue screening methods (Levy brothers' glass plates of crosshatched screens, already used in 1883 or Hephner's contact screens that were invented in 1953). A type of filter was placed between the continuous tone image and the photographic substrate. Those filters can be rotated over any angle and can be positioned very accurately.

When moving to digital imaging, as is done almost always nowadays, this is not the case anymore. The images are produced by a computer that is connected to an imager. A digital image can be considered as a large matrix with rows and columns. The imager scans the photographic substrate in the horizontal and the vertical direction. The data stored in the binary digital image is transferred to the imager. When the imager gets a 1, the laser beam is switched on. When it gets a 0, the beam is switched off.

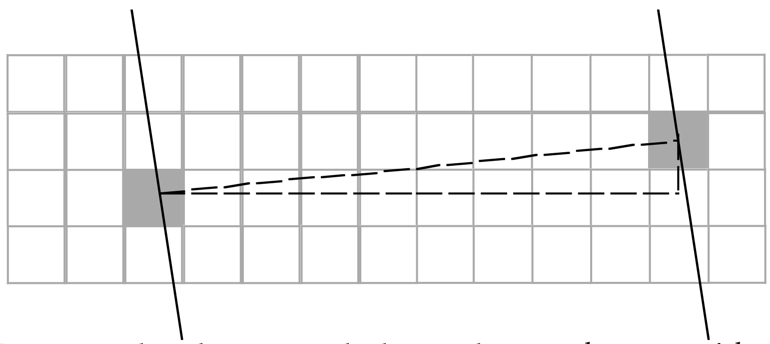

Figure 3. In digital imaging only dots can be set at the centre of the image pixels. So the distance between two successive screen lines and the angle of the screen can only have specific values.

The accuracy with which the screen angles can be rendered depends on the resolution of the imager. The higher the resolution (addressability) the more accurate the grid can be written. If we have an imager operating at 1200 dpi and we want to apply an AM screen with a line ruling of 120 lpi the distance between the dots is 10 image pixels. Let's consider a screen to be generated at 15°. If we have a triangle of which the slanting side is 10 pixels and one angle is 15° it can easily be calculated that the other sides will be 2.59 and 9.66. If you put the first dot at one image pixel and you want to put the other dot at an image pixel at a distance of 10 pixels you can not go 2.59 up and 9.66 left. You have to choose, either go 2 or 3 and either 9 or 10. The angles you will get will not be exactly 15° and also the line ruling will not be 100 lpi. An overview of the really obtained values is shown in Table 1.

Vertical	Horizontal	Angle	Ruling
2	9	12°31′	130.1
2	9	11°18′	117.7
3	10	18°26′	126.5
3	10	16°42′	114.9

Table 1: Angle and line ruling as function of the horizontal and vertical displacements over an integer number of pixels for an imager at 1200 dpi.

If the imager has a higher resolution, lets take 2400, then the quantization error is less and the line ruling and angle can be more accurately rendered (Table 2).

Vertical	Horizontal	Angle	Ruling
5	19	14°45′	122.1
5	19	14°02′	116.4
6	20	17°31′	120.5
6	20	16°42′	114.9

Table 2: Angle and line ruling as function of the horizontal and vertical displacements over an integer number of pixels for an imager at 2400 dpi.

As you can see in the above tables can the difference of the obtained angles and line ruling with the requested ones become rather large on a digital imager. As is known with geometrical structures can those very small differences lead to very disturbing patterns that will make the images unacceptable. Different techniques can be applied to reduce the quantization noise (super cell, …).

Better than trying to map the rulings and angles as close as possible to the conventional values, is generating a set screens that will have no color moiré at all by it's design. How this can be done is beyond the scope of this paper but is described in detail in [3]. This method is the base of Agfa Balanced Screening (ABS) and will give the best moiré free digital AM screens available at the market.

Frequency modulated screening (FM) will at the contrary modulate the number of dots. So all dots will have the same size. This size will be as small as possible on the target imager and press. Some tests have to be done to investigate what dot size still holds stable on the press [7].

Figure 4. Vignette rendered with FM screening

Different methods are designed to define where to position the changing number of dots: error diffusion, stochastic screeining, blue noise masks, Bayer algorithm, …

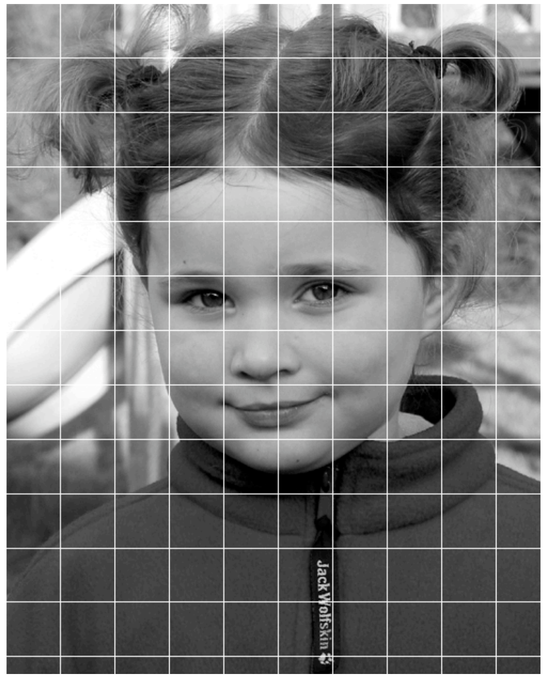

Figure 5. A tile (mask) with threshold values is placed over the image and repeated in horizontal and vertical direction allowing a very fast rendering.

With error diffusion the image will be scanned from left to right and from top to bottom. One can either set a dot or no dot. Setting a dot means value 100 and setting no dot means value 0. Those values 0 or 100 differ from the continuous tone image value and so by putting or not putting a dot on the paper one makes an error. This error is propagated to the neighbor pixels. If a dot will be set depends on the value of the continuous tone image and of the current error. The most famous algorithm is the Floyd and Steinberg algorithm. Many researchers have found improvements of this algorithm that will reduce the artifacts.

Although the algorithm is rather slow, 'Error Diffusion' is almost always used in inkjet printers. Because ink jet printer apply the ink by scanning the paper by a printing head, they are rather slow themselves and the calculation time of the algorithm is no obstacle anymore.

This is not the case for imagers used in the graphic arts used to make the printing plates. Those printing plates can be very large and need to be imaged in such a short time that other algorithms have to be used to render the halftones.

Many devices interact with the computer via a Postscript™ interface. In order to handle high resolutions Postscript™ is equipped with a tile based mechanism that can render a continuous tone image into a halftone matrix in a very effective way. A tile is a set of thresholds to which the continuous tone values of the image are compared [1]. If the continuous tone value is smaller than the threshold, the pixel is made black. In the other case the pixel remains white. This tile is repeated in the horizontal and the vertical direction so that the whole image is covered (figure 5).

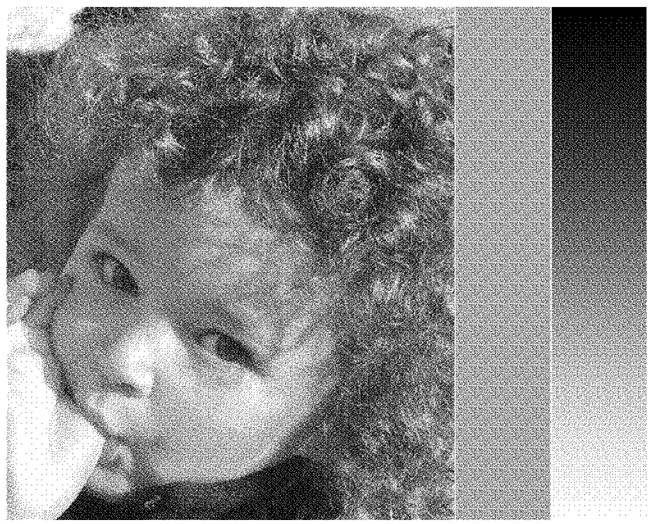

Figure 6. When the FM mask is badly designed the tile replication becomes clearly visible. Especially in vignettes and flat tones the patterning will become unacceptable.

When designing a tile one should care that the next expected row of the bottom row is the top row and the next expected column for the right column is the left column. When repeating the tile over the image the seam should not be visible.

The tiling mechanism can be used for both AM screening and FM screening. In literature this tiling mechanism is often referred to as stacking algorithm and the tile being used is often called the mask. A disadvantage of FM screening applied by tiles is the fact that the dots are never distributed homogenously over tile and that the repeating of some unbalance may result in patterning (that can be compared to patterns on wall paper) (shown in figure 6). Several researchers have designed algorithms to produce FM tiles in a way that the least patterning occurs when the tile is repeated over the image. But also here the overview goes beyond the scope of this paper but can easily be found in literature [4, 5, 6].

Figure 7. The same image rendered with FM screening (top) and AM screening (bottom). The FM screen will better keep the sharp details of the curly hair while the AM screen gives less noisy skintones.

The advantage of the tiling mechanism is that the algorithm to generate to most perfect tile may take hours, days, months or more to calculate. Once the tiles are generated, they can be applied in a very short time.

Both AM screening and FM screening have their advantages and disadvantages.

FM screening will in general render better the higher frequencies in the image. If we compare both images of figure 7 we see that the curly hair looks much sharper on the FM image than on the AM image.

In order to be able to render higher frequencies using AM screening, one can increase the line ruling. Those high lineruling screens will be able to render both the high frequencies and the flat tones. But this only applies for the midtones. The size of the dots depends on the number of dots. The higher the number, the lower the size must be to render the same tone. This number increases when the line ruling increases. When rendering highlights the dots might become that small that they are too small to be reproduced. Table 3 gives the diameter of circular dots and the size of square dots needed for rendering a 5% tone as a function of line ruling.

Lpi	Round	Square
150	43μ	38μ
200	32μ	28μ
280	23μ	20μ
340	19μ	17μ
425	15μ	13μ

Table 3: Diameter of round dots and size of square dots rendering a 5% tone as a function of line ruling.

Because dots (or holes) become too small, they will not print and clipping will take place.

Figure 8. When applying a high line ruling AM screen to the left image, the bright spots in the supporting color (cyan: center top, black: center bottom) of the skin tone will clip. This will make break lines (fake contours) showing up (right image).

The AM screens on the other hand look much less noisy. Although the dots are much larger than with FM screening, the dots are nicely ordered in a regular grid that is easily accepted by the human eye and hence are filtered out. Flat tones rendered with AM screening look much softer and less grainy. This is especially important for skin tones. If we look at the FM image of figure 7 the skin is sharp but rather noisy. The AM image has a rough grid, but this grid is less disturbing than the grainy skin in the FM image.

FM screening is not composed out of overlaying geometrical patterns. This makes that there is no risk for color moiré (interference between the different color planes). In Agfa Balanced screen the color moiré is eliminated between the most visible colors (C, M, K) and minimized for the interference with yellow [3]. But still some colors will have minor moiré patterning.

The average dot size in FM screening is much smaller than with AM screening. FM screening will almost always use the smallest printable dot. This means that the printing process is much more unstable and needs much more attention of the printer (regularly check of plate setter, press, …). The dot gain is much larger than with AM screening and hence needs appropriate transfer curves. Also the printing dots are not that strong and will have smaller run lengths.

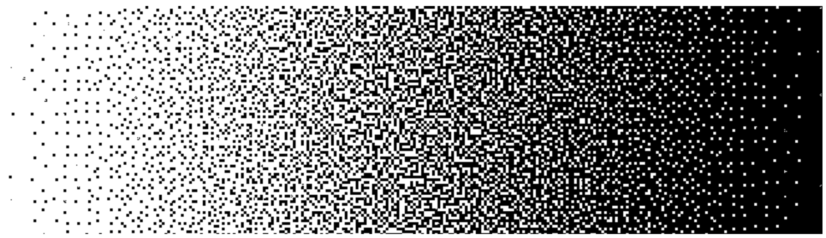

Figure 9. Agfa's Cristal Raster applied to a grey vignette. Around the 30% too many dots have to be placed to keep them apart. So some dots will start clustering. This amplifies the graininess of the FM screen.

A last disadvantage of FM screening is that it is rather uncontrollable how the dots cluster when the number of dots become too large to keep them apart. At a certain level dot start connecting which can lead to non-pleasing midtones. Figure 9 shows an enlargement of a vignette rendered with Agfa Cristal Raster. In the midtones rather rough clusters appear.

Table 4 gives an overview of the pros and cons of AM and FM screening.

	AM	FM
Rendering of fine details	-	+
Grainyness of flat tones	+	-
Dot gain	+	-
Press stability	+	-
Color Moiré	-	+
Subject Moiré	-	+
Aliasing	=	=
Run length	+	-
Clipping in highlights	-	+
Rendering of midtones	+	-
Closing in shadows	-	+

Table 4. Overview of pros and cons of AM and FM screening.

Hybrid screening

Recently new screening techniques have been developed that are a mixture of FM screening and AM screening. That's why they are called Hybrid screens.

One approach is to divide the images in parts that better can be rendered by FM screens (high frequent parts) and other parts for which AM screening is preferable used (flat tones).

One can easily try this using Adobe PhotoShop. If we take the image of figure 7 and apply the following filters to it:

- Find Edges
- Gaussian smooth with radius 3
- Threshold with a threshold that gives you an nice segmentation

You will get the binary image at the top of figure 10. Now we can choose to render the smooth tones (skin tones, …) (shown in white) with AM screening and the high frequency part with error diffusion (shown in black). The resulting image is the bottom image of figure 10.

Although the different parts are rendered with the most appropriate screening techniques the border between the different screening techniques is clearly visible. One can reduce this by smoothing the segmentation mask, but it will be almost impossible to eliminate it completely. Another major problem for this technique is the needed calculation time to apply the different filters. This type of hybrid screening will never be applicable in high productive workflows.

A better approach to improve the rendering of high frequencies and still have soft flat tones, is finding a mixed screening that allows higher line rulings of AM screening without loss of highlights or shadows.

This can be done by applying a similar segmentation mask as we did before. In this case the mask is created by applying a threshold algorithm to the image of figure 11. Here two thresholds are used. The pixels with a tone value in between the thresholds are rendered with AM screening, the others are rendered with FM screening. The result can be seen in figure 8.

The AM screen guaranties soft rendering and because of it's high line ruling it is still showing the finest details. The FM screen makes that the dots will not become smaller than what can become reproduced on the imager and press. Instead of dots going smaller the number of dots is reduced. But here again the intersection between FM and AM becomes clearly visible.

Figure 10. Hybrid screening by applying AM to soft tones and FM to high frequent parts of the image (bottom). The segmentation of the original image (top) is obtained by some filtering in PhotoShop.

Figure 11. Hybrid screened image (bottom) obtained by applying AM to midtones (10% - 90%, white in top image) and FM in highlight and shadows (black in top image).

Figure 12. The same image rendered with Agfa's Sublima screening.
Here the AM screening evolves smoothly to FM screening.

To improve this type of hybrid screening we have to find a screen that smoothly evolves from AM to FM. This can be done by putting the FM dots right on the place were the AM dots will start growing. Or to describe it the other way, the AM dots become smaller when rendering bright tones till the moment that the minimum dot size is reached. From that moment on dots are withdrawn out of the grid. A similar approach can be taken for the shadows. Figure 12 shows the same image rendered with this type of screening. As can be seen, the screen smoothly evolves from the one screening type to the other without a visible intersection showing up. As this screening type can be embedded in a screening mask it can be applied as fast as any conventional AM or FM tile based screening. We think that this type of hybrid screening combines the advantages of both screening classes as much as possible and has the capabilities to become the standard in graphic arts in a very short time. This is also why we have chosen it for our recently released Sublima Screening.

Things to be aware of when using hybrid screening

Although hybrid screening combines the advantages of both screening classes, it also takes some of the weak points. It is important to have those little shortcomings in mind when designing and fine tuning the images to be rendered. This will make the result at the end even better.

Depending on the minimum dot size the AM screen will go at some level over in FM screen. From that moment on the image might appear a little bit noisy. The hybrid mechanism works really well for the image of figure 8 to prevent a supporting color from clipping. Here the graininess of the FM part is covered by the AM screen of the main color. But when the bright tone appears in a single color it might become visible. Especially in vignettes it might be disturbing when the minimum dot size is rather large. In this case it could be better trying to make the vignette residing in the AM part alone.

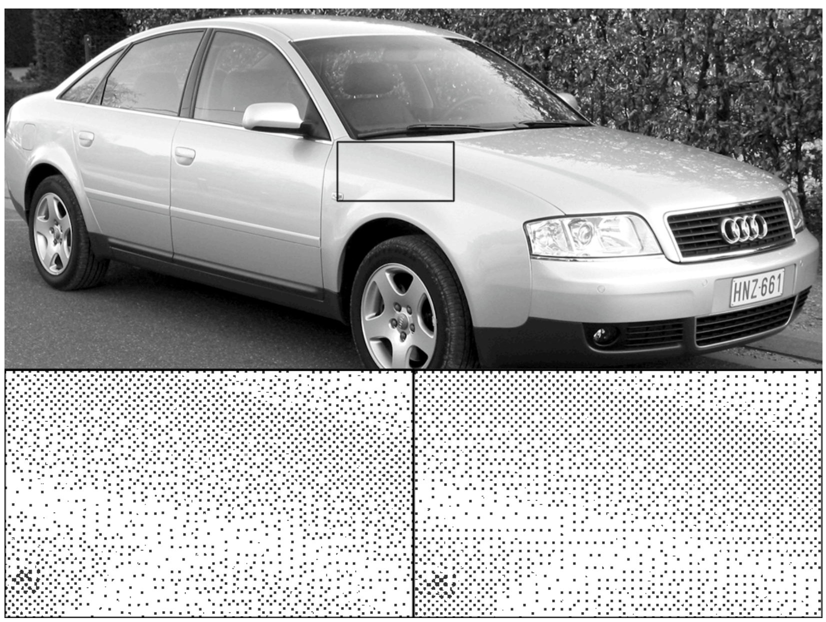

Figure 13. The algorithm that decides in what order AM dots have to withdrawn is very important. Two screens are compared for the rendering of a bright car. As can seen is the algorithm of the bottom left much better than the one for the image on the right.

The algorithm that decides in what order AM dots have to be withdrawn is very important. A detailed discussion is given in [2]. Figure 13 compares two different dot order withdrawal methods applied on the image of a car. When the algorithm is not well designed the patterns might become really disturbing (as is the case for the bottom right image).

AM screening has the advantage over FM screening that it is a more stable process. This stability decreases when the line ruling increases. The capability of rendering high frequencies behaves the opposite. We can put conventional AM screen at a lower line ruling at one side and FM screening at the other side. Hybrid screens make the bridge between both. A wide range of stability – quality combinations is made possible by hybrid screening.

In order to be able to render the higher frequencies, the higher frequencies need to be present in the image. This means that if we are using higher line rulings, we need more detailed input images. What can lead to higher storage needs and longer transfer rates at the input side.

The same holds for the bitmap images going to the imager. Because hybrid screened images contain more information, they will be compressed with lower compression ratios when applying lossless algorithms. This will increase storage needs and transfer times at the output side.

A last thing that often surprises people when checking the bitmaps made with a tile based hybrid screen, is the fact that some dots are smaller than the minimum dot size. This is because of the working of the tile based algorithm in the PostScript page description language. A pixel with a tone value of 100% will always get ink, a tone value of 0% will stay blank. The algorithm compares the input image with the thresholds in the tile. The input image is therefore resampled to the resolution of the imager. If the resampled image contains a hairline of tickness one, the output will be a hairline of tickness one. If it would be a 1 by 1 checkerboard the output would be a one by one checkerboard regardless of what screening type is embedded in the tile, be it a 5 lpi AM screen, a FM screen or a 340 lpi hybrid screen. The minimum dot is only granted for flat tones. But because the original input image is normally at a much lower resolution than the resolution of the imager the resampled image will change smoothly making that almost all dots will have the mimimum dot size.

Conclusion

In this paper a detailed overview is given of the advantages and disadvantages of both AM and FM screening. There is shown how advantages of both can be combined in hybrid screening that will be the screening technology of the future.

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