Review paper
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Development of FM screens

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Abstract:
What is a satisfactory quality when it comes to graphic arts industry? Acceptable quality of halftone image is become same as photographic picture. There are many different ways in which one can try to reach the desired quality. Different methods of halftoning (lpi and diferent methods of forming halftone dot), scanning, prepress, plate making are just some ways to influence the final printing result. Knowing the advantages and disadvantages of a certain halftoning technique will give us more ability to choose the right process path.

Keywords: First order FM, Second order FM, Quality, Colour Gamut.

Introduction

The quality of printed material is determined by three influential factors: printing technology, paper as a substrate to be printed and the method by which data is digitally transmitted to the final printing process on printing plate, i.e. transfer from digital to analog form. The transfer of image from analog to digital form of data which need to be printed is required due to limited technology of printing process. It can be concluded that it is necessary to know the technology of printing process in order to achieve best quality of print, or in other words, to achieve best possible image conversion from digital into analog form. Printing techniques and printing equipment depend on the physical and chemical laws that affect the quality of the prints. By adjusting the digital data according to output device provides the best possible quality that can be achieved in a given technique.

Need to print as close as possible to the original require different levels of brightness for each particular colour. Black and white photographs are made from all levels of light, because of the way that light illuminates the film. Film in the camera reacts to the incident light with the appropriate density which is in proportion to the incoming intensity of the light, i.e. light intensity that reaches the film through the lens or CCD chip, when it comes to digital photography. These different brightness levels or gray levels can not be reproduced as such in electro-photographic, ink-jet or offset devices. These kinds of gray levels can be generated on these devices through method called halftoning. Halftoning can be seen as a relation between the parts of an image that will not be covered with colour and those that will be covered. If one needs to produce a darker tone, the surface that will be covered with colour would be larger, and vice versa. This procedure is called subtractive colour synthesis. Subtractive colour processes work by blocking out parts of the spectrum. The idea of subtractive colour is to reduce the amount of undesired

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colour reaching the eye. If the surfaces that are covered in colour are small enough, the human visual system will not be able to recognize them as separate elements, but they will, in combination with a surface brightness, bee seen as a single colour.

Blue noise algorithms

Sophisticated mathematical algorithms define the means of transforming the image of continuous tone to image of discrete elements.

Halftoning mathematically can be represented as a process of converting images with high amplitude resolution to a smaller amplitude resolution of an image. The paper will present new generation of halftoning systems, based on the so-called nonlinear, aperiodic, stochastic method, which aims to deploy printing elements in that manner that the final product is as close as possible to the original, i.e. currently unattainable continuous tones images. (Hoffmann, 2006)

What impact has an improvement of halftoning process on the print industry and printing markets that is based on printing devices can bee seen analyzing the book of Robert Ulichney Digital Halftoning (Ulichney, 1987.) which has revolutionized the digital printing industry. At that time digital halftoning was done exclusively using amplitude modulated screen, where the dots are distributed on a grid with fixed positions, depending on the resolution. Different gray levels are achieved only by increasing or decreasing dot size in its fixed position. Ulichney analyzed frequency modulated halftoning which was introduced back in 1973 (Bayer, 1973), in which the different shades of gray are achieved with random distributed dots of same size. Result of this study was creation of new screening techniques, with ideal frequency modulated distribution of halftoning dots. One of the significant improvements in his work was the introduction of the “blue noise” algorithms (Ulichnery, 1988) that transform continuous tone image into a binary image using a single comparator operation. This simplicity as a result has a fast data processing and gets results without time-consuming and complicated algorithms, allowing its application for simple printing devices. In the printing industry, improvement introduced by Ulichney most affected the ability to create affordable four colour ink-jet printers. Negative sides that accompanies this type of halftoning, from the beginning, are variations in size and shape of the dots that deviate from the ideal distribution defined blue noise, and imperfections caused by the output device. It seems to be that the downside of “blue noise” is his perfection, and reliance on ideal conditions that are not achievable in commercial printing. Several different attempts have been made to adjust halftoning algorithms according to technical capabilities of output devices. In other words, finding an appropriate halftoning model for a particular printing system is the key to a successful implementation of new halftoning technologies.

FM digital halftoning

The introduction of digital printers enabled the implementation of the idea to print an isolated pixel in order to reduce the visibility of the dots and patterns that dots create, especially in multicolour production runs. The possibility of recognizing isolated dot is a result of conventional amplitude modulated screen in which the dot is created by cluster of activated neighbor pixels. While not changing the size of printed dots, regardless to the gray level, i.e. keeping its size to the size of the single isolated pixels, new halftoning techniques are changing the distance between activated pixels, depending on the tonal values to be achieved. The first FM techniques introduced by Bayer and Bryngdalha (Bayer and Bryngdalh) used the ordered arrangement of isolated dots. These techniques, as well as AM dot schemes, were placeing each pixel independently of its neighbor pixels, according to a dither array, but on a limited number of thresholds, dispersed as much as possible. This means that these algorithms could not at once take into account all the pixels that need to be placed on the image. Image was divided into smaller areas and than in this arias algorithms was carried out, so that the image was eventually composed from the same size area over which the same algorithm was used. This resulted in problem which is shown that these early FM technique had, and it can be described as a tiling - the pattern, which occurs when the pixels in the same arrangement are repeated across an image.

A better approach to rasterization is given by Floyd and Steinberg (Floyd and Steinberg, 1976) who introduced a revolutionary expansion algorithm - Error diffusion. This algorithm integrated a statistical analysis of the position for each pixel. Position is determined by the input data for that pixel location and location of neighbor pixels. It can be said that this algorithm introduces an error in each dithering matrix and that error is passed to the next matrix, providing that no matrix is same and the same matrix are not repeated, thus giving the illusion of randomness. This randomness prevented moiré effect in pictures and gave an image much more natural look, but because of the added algorithm, it was muchmore demanding for calculation and execution.

Such improvements was first introduced by Ulichney Error-diffusion algorithm as a generator of “blue-noise”. Ulichney uses the term “blue” because the spectral content of the stochastic images are distributed exclusively through high-frequency spectral components, as the blue light is made entirely of high-frequency light waves of white light. Ulichney further found that the average distance between two same colour dot is directly related to the gray level in the picture before dithering. The problem with these types of screens are mostly reflected through the impossibility of maintaining consistent dot transmission to the surface, both in the pressrun or the sheet surface. Consequently the blue-noise and FM screening have been generally expensive, i.e. they needed very precise and expensive equipment for their use.

The introduction of FM halftoning in printing processes broke the limitations caused by screen angles and therefore enable the construction of a printer with more than four colours. The introduction of additional colours enable the increment of colour gamut that can be obtained by printing.

However, regardless of benefits introduced by this halftoning method, it remained applyed only in ink-jet technology. The reason is the inability of offset printing machines to print such a small isolated dot with sufficient consistency.

Green noise

When the technical capacity was acquired to achieve higher resolution of 1200 dpi, scientists have turned to the possibility of merging the individual pixels in a so-called clusters. This kind of merger enabled the creation of patterns that will be less visible to naked eye, with higher spacial resolution and still no periodic structure. With a certain amount of the merger, these clusters are much easier to print, i.e. enabling print without too much oscillation in the output tone. For four colour printing, grouping pixels in this manner, without the introduction of periodicity, can still successfully avoid the appearance of moare effect. Nowadays, these are often called second generation FM halftones, or hybrid XM screens depending on the way clusters are formed. (Lau et al., 1998)

One of the way that will allow usage of random dots on the devices that are not entirely reliable, and enable them to maintain consistency as in the standard AM halfton was found in Levien (Levien, 1992) “Output dependent feedback in error diffusion halftoning” method. This method is based on the error diffusion algorithm dependent on the output device. Here, the increased amount of pixels obtained previously is used to obtain a threshold quantization matrix of the resulting structure. This structure is composed of randomly assembled clusters of different shapes and different sizes. This system gives good results but led to problems due to excessive computational complexity.

Its on the researchers to seek a way in which will the advantages of FM screens fit the market demand resulting in better quality than the conventional periodic halftoning. Attention was diverted into the algorithms that will be able to group certain colours pixel together in a random fashion, to obtain the structure of the halftone, which will be able to print with more consistency, from sheet to sheet, without fear of moare.

As the blue-noise is high-frequency component of white-noise, green noise is component with mid-frequency of white noise, and also with aperiodic structure of blue-noise. It also needs to avoid the low-frequency structure that is responsible for the appearance of grainy pattern. But unlike blue-noise which is composed of an isolated pixel, the green-noise pixels are grouped together and create random clusters. The reason for using green-noise is a combination of disperse blue-noise components with the AM method of forming the dots, with the added possibility of controlling the degree of clustering. (Lau et al., 1998) The reason is the possibility of creating a halftone structure that will be able to define the level of clustering of dots depending on the quality and reliability of the output device. In usage of a higher quality output devices one can reduce the level of clustering of pixels and thus get smaller clusters whose structure is less visible to the naked eye. For devices whose reliability in transfering dots is small, clustering of pixels can be increased and so that can provide a sufficiently large clusters which can be transferred without major fluctuations. Therefore, the usage of FM halftone is possible with the most sophisticated offset machines and also with large web-offset.

Application of previous research

Choice of FM dot shape is very important, because it influences the choice of printing plates, CTP devices, the aesthetic appearance of printed material as well as the behavior of the printing press during print run. There is a greater variety of FM halftone dots shapes than is the case with AM dots.

First generation of FM halftones

In FM screens every dot is forming inside halftone cell, which consists a grid of up to16 x 16 pixels. Pixels within each cell are activated in pseudo random order to form the FM cell surface or full tone. Then the cells are connected to each other, like a mosaic, to form an image.

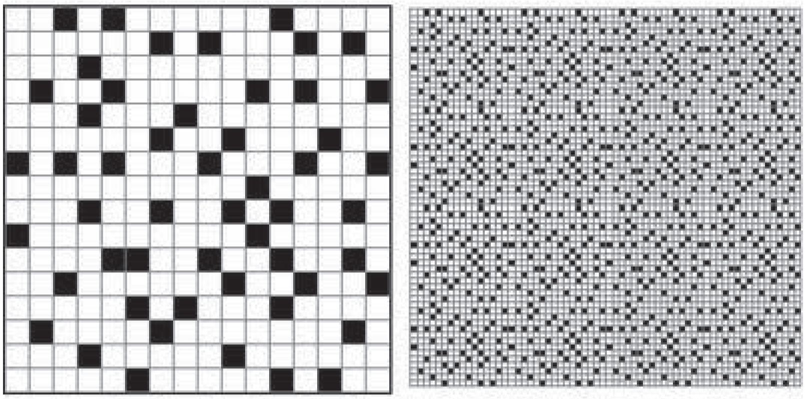


Figure 1.
a) One halftone cell with 16x16 pixels
b) identical cells arranged in 4x4

Figure 1 shows one enlarged cell, composed from 16x16 pixels with some of them activated. On the right side it can bee seen area filled with sixteen of the 16x16 cells.

Repeating the same cell, in this case, 16 times, one can come to the conclusion that the visible pattern occurs within the halftone surface, which is more or less recognizable to eye. Consequently it violates one of the great advantages of FM screens compared to the AM halftones and that is certainly aperiodic nature. Grainy appearance become evident, the inconsistent structure that emphasizes the uneven colour. Small physical size of dots makes printing very inconsistent, unables even transfer from first to last sheet during the press run, and over the surface of a sheet.

Because of the very small printing elements, which are positioned on the printing plate,often came to losing them in the printing process, consequently reducing the number of impression that can be achieved.

Certainly the advantages like extremly small screening dot, even looking at printing element through magnifying glass, often enabled usage of this type of halftoning for art reproductions. Due the fact that positive sides was greatly outnumbered by negative side, this way of halftoning is kept only in highly specialized workshops.

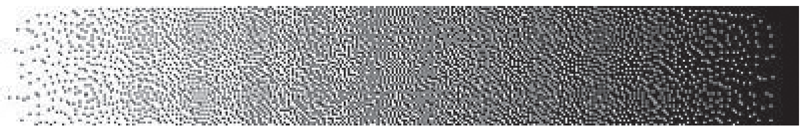
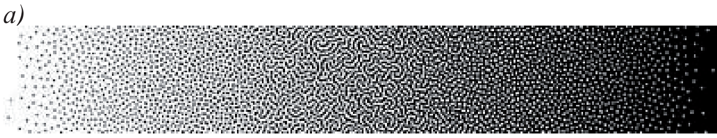


Figure 2 First generation FM screen

Second generation FM screen

Second generation FM screen greatly nullified any negative effects that occurred in the first generation FM screen. As such, it has become standard in today's printing industry. This type of halftoning increases halftone dot as a way of increasing tonal values. Growth of halftone dot can be carried out in one direction, forming a worms resembling structure shapes, as is the case with Kodak Stacato FM screen or halftone dot may be increased in both directions, forming a dot which then resembles a conventional halftone dot, like Screen Spekta FM screen. In this section, it must be noted that various manufacturers of CTP devices, equipped theres CTPs with varius types of algorithms, improved them, adapting them according to their technology, so on the market, one can find different versions of second generation FM screens. So that depending on the manufacturer, some shortcomings of the first generation are more or less successfully overcome. One of the major shortcomings of the first generation was uneven tones, especially towhen it comes to mid tones. Remaining shortcomings, when it comes to the first example, is the need for high resolution, because the dot can be formed only from one or two pixels. Frequent deficiencies in second examples are related to consistency due to changes in the shape of halftone dots in shadow area.

a)



b)

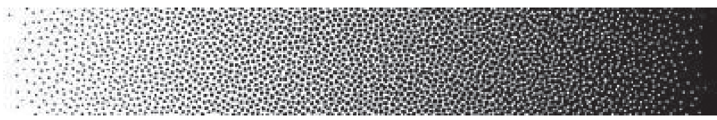


Figure 3 Two different ways of forming a cluster) in one direction, b) in two directions

At this stage it should be noted that one can not generally speak about FM halftones, as halftones that givesa grainy structure. The quality of FM halftone depend heavily on the implementation of algorithms in manufacturers CTP devices.

FM gamut

One of the major advantages attributed to FM screen is expanded colour gamut that can be obtained by applying a dispersed dithering type.

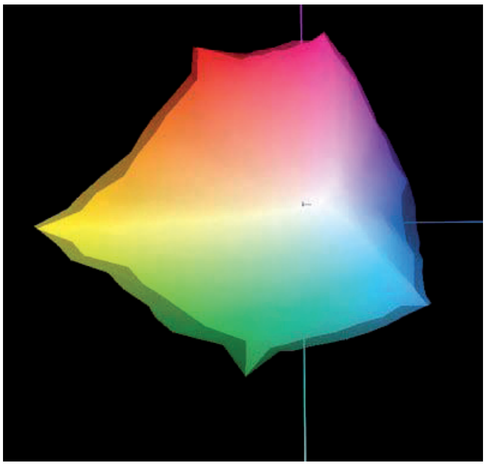


Figure 4. Colour gamut AM (fill) and FM screen (transparent)

The picture shows the colour gamut obtained with 20 micron Kodak Staccato FM halftone, shown as transparent, and within this range colour gamut obtained by 175 line AM screen. GRACoL 7 test chart was used as a test form and special linearization is applied when illuminating FM screens. What can be clearly seen is that the FM colour gamut is larger than gamut obtained by raster AM. However, the difference will eventually become visible in one or two colours and in the areas of 10% to 90% tonal value. Since the two colour bitmap is not common, the difference in gamuts, (AM and FM gamut) may not be visible in reproduction.

The increase in gamut can be explained as a result of the smaller dots of the FM screen, which cover a larger surface of paper area compared to conventional AM halftone at the same reproduced tone value. This means that if the frequencyof the AM increased to about 350 lpi would lead to an identical increase in the gamut that can be seen in the 20 micron FM raster. FM screen does not increase the gamut that can be obtained, instead it is more accurate to say that FM reduces potential colour gamut less than it is the case with the AM. The function of the ink colour is to filter white light and when that happens it can be seen colour depending on what part of the spectrum is filtered in this way.

Part of the light passes through a ink layer on the surface of paper and is filtered by ink and than reflected from the surface. A certain amount of light gets scatter inside the substrate beneath layers of ink, thus contributing to the optical dot gain. Finally, part of the light bounces off the surface of the substrate with no ink and as such returns to the observer. The unfiltered light is than mixed with filtered light and affect its purity, contaminating it. FM halftone dots largely cover the substrate surface, consequently they are causing more optical dot gain, outcome is greater amount of light that is filtered by the ink comparing to the light that bounced off the substrate without filtering. Between AM dots there is much more empty space from which light will be reflect, without filtering. An example can be seen in in Figure 5. where the areas with 15% and 40% coverage are displayed as for the AM and FM.

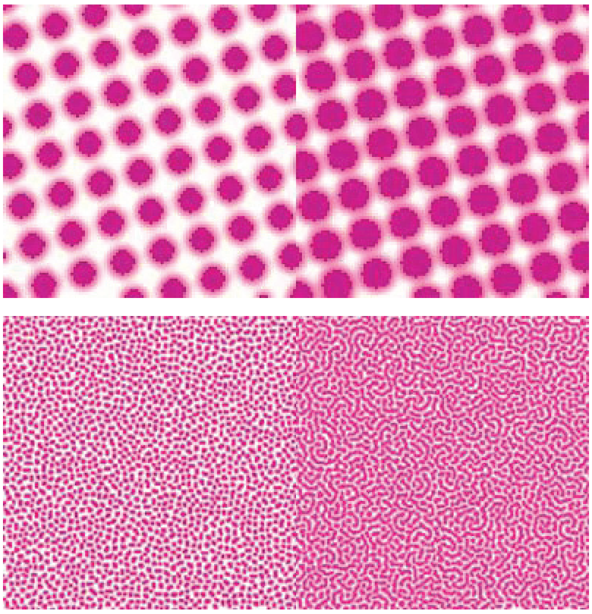


Figure 5 Comparison between amounts of white space in two types of halftoning

It can be clearly seen that the surface coverage with FM screens is higher and thus the more likely it will filter the light. As a result, fewer white light will appear and consequently there will be less loss in the colour gamut.

There is another factor which is responsible for the existence of a larger gamut of FM screens. The thicker layer of ink on the surface it is, it becomes less efficient filter for light. Instead, light is reflected from the surface of ink. FM screens have a uniform film of ink on the substrate and lower film thickenss, i.e. thinner layer of ink is on top of the surface, when compared to AM screens.

Figure 6 shows the AM and FM raster fields of magenta. Both fields have the same tone value. The different, increased densities across the surface of each AM dot reduces ink filtering ability.

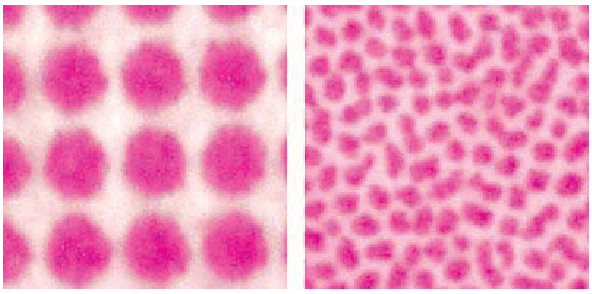


Figure 6 Comparison the colour of the layer thickness

Finally, FM screens, because of the thin film of ink on the surface,tend to dry faster than the thicker AM ink film. This allows them to dry faster and hance over-printing.

Resolution

The great advantage of FM is its high screen resolution, which, in theory, should allow a lot more detail on images than is possible with AM halftone techniques. Certainly the benefits of such large screen resolution, can be seen in the finest details of images such as pictures with glossy surfaces with colour transitions or fabric,where the FM screen can prevent the moarea occurrence.

Print contrast

Images printed with AM halftone will have higher contrast than the images printed with a stochastic halftone. It can be explained with larger areas of white papir that can be seen and that these areas has increased the image contrast. Due to the increase in tone values of the stochastic samples, print contrast can be lowered.

Market trends

Years of research in the area of halftonign techniques, enabled the obtaining of a large number of patents, over 1300 which in its abstract with the word halftone. Although many papers have been written on this subject, there is still many improvement in ahead of us related to transition of continuous tone image to an image that can be printed in sufficient quality, financially efficient.

In the printing industry, the most significant discoveries in halftoning techniques soon found their way into commercial applications. Most vendors did not want to fall behind when it comes to advanced halftonign techniques. They implement different varieties of FM screen into their RIP. Already in 1990 the first commercial FM screens appeared on the market. They were presented by Agfa Miles, Inc. With its drastically different approach to halftoning, than previously used conventional AM, immediately attracted attention. However, fine, small dots that were unattainable dream come true of continuous tone image, soon became a nightmare, filled with uncontrollable dot gain, grainy patterns and decreased gamut, due to congestion in shadow areas of image. FM screen has since than been marked as “ uncontrollable”.

Thanks to the improvement in CTP technology and printing plates performance, FM screen began, at the end of the nineties, his comeback to everyday use in printing industry.

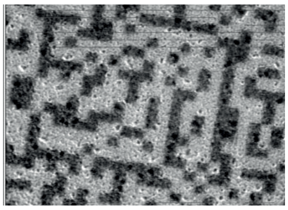
Today, there are about a dozen manufacturers that offer stochastic and hybrid screens. Each vendor has several FM modulation, depending on the size of the dots, algorithms used for layout of dots and even shapes of halftone dots.

Conclusion

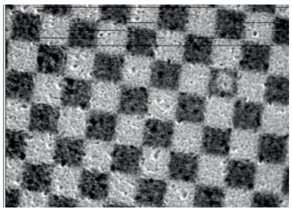
This paper presents significant developments of stochastic screening techniques in conversion of continuous tone images to binary data. Each technique has its advantages and disadvantages. Getting familiar with these advantages and disadvantages holds a key of successful implementation of frequency modulated screening techniques into print process.

All those who have a tendency to use these new screening techniques must be aware that is necessary to constantly monitor all parameters of the printing process, in order to obtain an appropriate outcome. Creating an appropriate analysis model is the best way to eliminate any outside influences that can affect print quality. Too often one can witness that printing sheets do not contain control strips; control devices that should help in obtaining the desired quality are often unused. Each of the devices must be regularly serviced and calibrated to give relevant measurement.

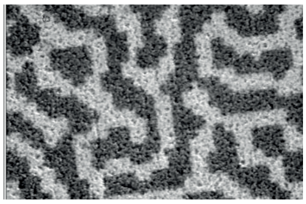
In order to successfully implement a stochastic halftoning, it is necessary to fully acquire knowledge about the printing process. Process control must be an integral part of printing. It consists of an initial image quality analysis and colour separation, then the imposition and creation of pdf or ps files. Selecting the appropriate RIP option is next step in preparation of printing plates. It is necessary to apply a compensation curve, which will be used by RIP. Most importantly, it is necessary to provide identical working conditions for offset printing machines from day to day. This implies the standardization of the process, which will be best achieved by creating model of analysis.



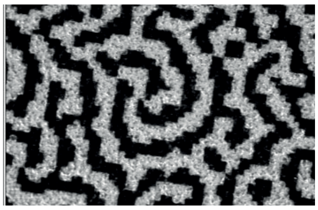
Agfa CrystalRaster - is Agfa choice of FM screening. It is designed for high-quality offset machines with the highest resolution output devices.



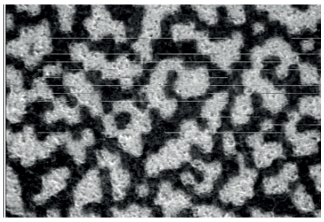
Agfa Sublima - is hybrid halftone or XM (Cross-Modulation)-based on Agfa Balanced Screening technology, AM in medium tones, to circumvent the frequent errors that may appear in the press with FM screens



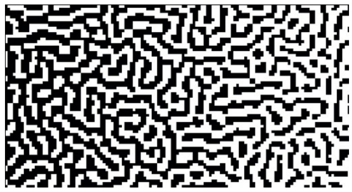
basysPrint FM screen is composed of second-generation algorithms that form a pattern wormy like.



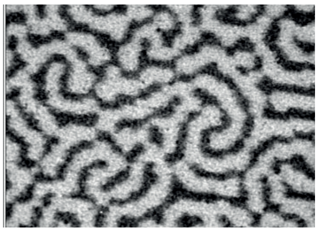
Kodak Staccato 20 μm allows printing equivalent with 340 line AM screen. Kodak has assumed this screen from Creo and continued its production



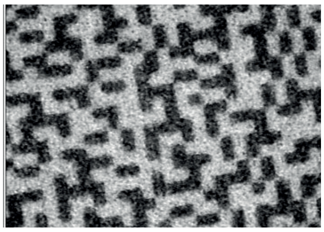
Heidelberg Satin Screen created in 2003, replaced with Prinect Stochastic screen



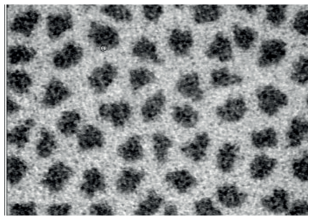
Prinect Stochastic Screening II is the second generation of Prinect Heidelberg stochastic screens with improved algorithms.



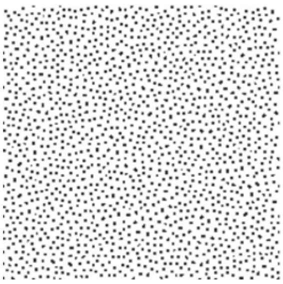
Luscher Harlequin HDS Coarse which proved to be extremely easy to print /Pinćjer, 2010/

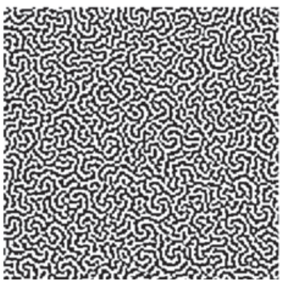


Screen 2400-dpi RanDot is the first generation of RanDot screen, replaced with RanDot X with green noise algorithms



Screen Spekta is hybrid screen. Consistency of halftone dot is achived by incresing its size in two dimension. In this way it creates various shapes of raster dots.





RanDot X with 20% 60% and 80% halftone

Figure 7. Some of the best known FM screens

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