STOCHASTIC HALFTONE SCREENING

New Technology Simplifies Halftone Reproduction

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Introduction

During the last 12 months there has been a great deal of development in a new type of halftone known as Frequency Modulated (FM) or random dot. It is also known as Stochastic Screening because it uses a randomly applied variable in the halftone generating algorithm. Most of the information published about this new type of halftoning has been vague and limited. Calls to major suppliers have resulted in little, if any, useful information as it applies to screen printing.

This new type of halftone offers considerable advantages to screen printers over conventional halftones. Among these advantages are reduction or elimination of moiré, controlled dot gain, no midtone jump, increased detail and definition of the reproduced image, and a wide range of printing meshes.

Among the disadvantages are limited availability, surface texturing of large uniform tone areas, and the tendency toward the generation of "artifacts" at certain tonal positions. With the early experience to date, the advantages seem to far outweigh the limitations.

It is the intention here to provide you with a historical perspective of FM halftone screening and how we can apply it to screen printing applications. There is still a great deal of development going on in this area, and you should expect to see significant news releases over the coming months as more and more suppliers bring FM models forward and make them available to the industry.

History of development

The concept of random dot halftone screening has been around for a long time. There have been conventional halftone contact screens available for at least 20 years. To understand how this concept works we should study development of the halftone screen.

The concept of a halftone was developed and patented by Frederick E. Ives of Philadelphia in 1873 and utilized two glass plates with scribed lines that were perpendicular to each other. This created a grid that effectively diffused the continuous tone image that was projected onto its surface. The resulting diffraction created dots of varying size and based on the amount of reflected light. For many years during early development of halftone engraving this was the only way to create halftones.

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The natural extension of the glass halftone screen was the flexible contact screen. This was a film-based halftone screen, still oriented on a grid, that allowed the halftone image to be produced when the contact screen was held in place against unexposed film on the camera back. The contact screen was much easier and safer to use than the fragile and expensive glass contact screens. It is still in wide use today as either a grey or magenta screen in a designated line ruling and predetermined angle.

As the plastic contact screen gained popularity, there were other versions developed based on special effects. The most notable was the common mezzotint that was based on the reticulated grain pattern that could be produced during the processing of conventional photographic film. The mezzotint pattern was used primarily as a special effect texture screen because the image generated by this pattern tended to be "wormy" and was quite coarse.

An extension of the mezzotint was the first true random grain halftone screen. It was generated using the enlarged grain of the photographic film itself. If you have ever done any black and white photography and enlarging, you will remember the "grainy" appearance that resulted from using fast photographic emulsions with an ISO speed over 400. This appearance was the result of the enlargement of actual silver halide crystals of the film emulsion. Halftone screens using this method were available in Europe during the 1960's from Polichrome of Italy and are still available today. This random grain contact screen was available in coarse and fine designations and were used primarily for special effects.

During the early 1970s there were a number of individuals in Germany who were working on a method of electronically generating a random grain halftone dot. At this time electronic scanners were just beginning to appear in the prepress market and were limited to the very largest companies because of their extreme cost. Development was limited primarily to the mathematics of the randomization algorithms and experimentation was limited because of the high cost of computing power. For all practical purposes there was little, if any, commercial application of the algorithms as an electronic dot generating mechanism.

During the 1980s things began to change as electronic scanners began to proliferate and the cost of computing horsepower began to decline. The first patents for practical application of random dot were issued to Hell Graphic Systems about 12 years ago. Random dot generation has been available on a commercial basis in Europe since 1988 or 1989.

It has been only the last two or three years where extensive development of stochastic screening has gained industry attention. While it has been widely known in academic industry circles, it has found only limited application until the widespread use of Adobe Postscript® as the electronic page description language of the desktop publisher. As more and more laser imagesetters began to appear in the graphic arts marketplace, the problems associated with the generation of fine line halftones became more and more apparent. The majority of imagesetters on the market did not possess the quality of electronic dot generation that the high-end scanners do. This is understandable because they cost much less and the limitations of the programming language place significant limits on the ability to electronically generate a halftone dot. In an effort to improve the fine line capability of the imagesetter, electronic halftone designers came up against increasingly

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complex moiré problems as the halftone dot count got finer and finer. Hence, in an effort to minimize the mathematics of these complex halftone models, designers turned to the stochastic or FM dot as a possible way to minimize or eliminate the moiré common to imagesetter-based halftone generation. This came at a particularly good time as the cost of computing had dropped dramatically since the introduction of the first stochastic algorithms.

In April 1993 both Agfa and Linotype-Hell announced the release of stochastic halftone screening for their imagesetters. There was a flurry of interest and attention centered on this early announcement. Unfortunately, implementation of the announced versions have some serious limitations that have not been totally overcome. Subsequent to the Agfa/ Linotype-Hell announcement a number of other companies have released different models for different imagesetters. Scitex is among them, and Crosfield is about to release its version for their high-end scanners and imagesetters. Interest still remains high as more of the market finds out about the advantages of this type of halftone screening.

Characteristics and comparisons

Before we can begin to understand differences between conventional halftones and FM halftones, we need to clarify some terms. This can be very confusing. Conventional halftone screening works on the principle of ordered rows of dots, aligned to a grid of a specific ruling in lines per inch or lines per centimeter. This is called the halftone frequency. A traditional 150 line halftone is a halftone with a frequency of 150 halftone dots per inch.

This grid is usually aligned at some predetermined angle set, commonly 15° (105°), 45°, 75°, 90° (0°) for lithographic separations. The dot size varies with the tone value that is being reproduced. The halftone dot is generated from the center of the halftone cell out toward the edges and increases until 100% of the area is covered, representing solid coverage. The smallest addressable spot used to image the individual halftone cell is known as a pixel.

The laser spot is the smallest size that the imaging laser can be focused to produce the pixels. The laser spot, also called dots per inch (dpi), can be considerably smaller than the pixel, depending on the frequency of the halftone. This is the case as the halftone dot becomes coarser. For very fine halftones (200 lines per inch and above), the pixel size approaches the laser spot size. Common laser spot sizes are 1200, 2400, 3600 dpi, and are typically 20, 14, and 7 microns in size, respectively.

The laser spot is the smallest area that the imaging laser can be focused to produce the pixels that make up the individual halftone. The laser spot is also measured in dots per inch (dpi), as in 1270 dpi. The laser spot can be considerably smaller than the halftone pixel, depending on the frequency of the halftone. This is the case as the halftone dot becomes coarser. For very fine halftones (200 lines per inch and above,) the pixel size approaches the laser spot size. Common laser spot sizes are 1200, 2400, and 3600 dpi, and are typically 20, 14, and 7 microns in size, respectively.

The FM dot is one uniform size. It works on the principle that the halftone cell is covered with many smaller pixels until the equivalent area is covered. The arrangement of these pixels varies randomly within each cell, with no two cells being identical. Because of this randomization, there is very little chance of developing a color to color moiré due to angular interference.

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Advanced FM algorithms can have multiple sized spots. If all of the pixels are the same size, the halftone is said to be "first order." If there are two different sizes, the halftone is "second order." The ability to have two different sized pixels aids in smoothness of the tonal reproduction. Random intermixing of differing dot sizes helps to break up the apparent "graininess" of the rendered surface. Currently most FM algorithms are first order in nature.

Resolution and detail

Conventional halftones are generated from the center of the halftone cell outward. This is known as a "dot centered cluster array." With Postscript®, the smallest dot that can be generated is .4%, and tonal steps increase in multiples of .4%. Since the dots are generated outward from the center of the cell, there is a physical limitation to the level of detail that can be rendered at any given line count. This detail is governed by the dot density which increases geometrically as line count increases. For instance the dot density of a 65 line halftone is 65 x 65 or 4225 dots per square inch. An 85 line halftone has a dot density of 85^2, or 7225 dots per square inch. The ability to resolve detail is further limited by the fact that halftone dots are generated on predetermined centers.

Stochastic halftones are limited only by the size of the pixel that is defined. With current lithographic FM software this pixel size happens to correspond to the laser spot size. This is usually 7, 14, or 20 microns in diameter. A 20 micron dot is slightly smaller than .001" in diameter (.001" = 25.4 microns). With lithographic printing the dot size is limited by the ability of a aluminum litho plate to image and physically hold these very small dots. As far as screen printing is concerned, this limitation is not one of ability of the emulsion to resolve the detail. The problem comes from the mesh threads blocking the halftone dot. With typical 390 mesh, the thread diameter can range between 27 to 34 microns in diameter. We can easily see that there is the possibility for total halftone blockage, or total halftone fidelity, depending on where the halftone hits the thread of the mesh. The smaller the halftone dot becomes, the greater the chances of thread interference. This is the main reason it is so difficult to print high line counts (over 120) with conventional halftones.

The key to understanding the advantages of detail reproduction with FM halftones is that we must compare them to conventional halftones for some correlation. FM halftones are of one size only. We simply define the size of the pixel and the software does the rest. Much smaller dots are printable without thread interference because the pixels are not locked to predetermined grid based centers. The tendency is for smaller FM dots to follow the detail. If you are familiar with the art technique known as pointillism or stippling, you can easily visualize how the FM dot concentrates along the edges of the detail in the image. Depending on the resolution of the dot that is selected, the detail carrying capacity of FM compared to conventional can be three to ten times greater!

Reduction in moiré

Moiré is probably the number one problem of screen printed halftones. There are many causes of moiré, and many of them are unique to the screen printing process. Moiré can be controlled on a limited basis when using conventional halftone reproduction. The success is greatest at the lower line counts (below 100 lines per inch). Even experienced halftone printers are faced with surprise moiré. This is what makes it so frustrating.

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No matter how careful you are, circumstances beyond your control will lead to the localized generation of a moiré pattern in the image.

Moiré is nothing more than repetitive interference patterns. To eliminate them, we must eliminate the interference or eliminate the repetition. This is where stochastic halftoning really has an advantage. Since dots are randomly distributed, there is very little chance that a regular pattern will form. We essentially eliminate repetition of the dot patterns. We cannot completely eliminate interference of the mesh with the dot, but we can eliminate the repetition. This effectively cancels the formation of the moiré. The randomness of the dot generation neutralizes mesh-to-dot, dot-to-dot, dot-to-substrate, and printed-dot-to-printed-dot (cross moiré in UV) moiré.

Placement of the halftone image on the screen is not critical. Unlike conventional halftones where halftone angle is of primary concern, stochastic halftones are not sensitive to positioning on the mesh. If anything, the only angle that they are sensitive to is 0º or 90º. This relieves the screen maker of the responsibility of precise placement on the mesh. Likewise, there is no need to consider biasing the screen mesh to the frame.

While it may appear that it is possible to completely eliminate moiré with stochastic screening, this is not entirely true. We must remember that all digital imaging is conducted on the X-Y grid axis of the laser imagesetter. No matter how random the appearance of the halftone generated, the imagesetter grid is still there. In controlled tests we have been able to make random dot halftones moiré at specific dot sizes on specific mesh counts. This is very useful because the moiré is always "global", meaning that it is everywhere. You either get it or you don't. It also helps the halftone designer avoid specific relationships that will cause a problem. It is now possible to "engineer" a halftone solution to a specific mesh with a very high probability (greater than 99.9%) of moiré-free imaging.

Limitations

Stochastic halftones are not free of limitations. Like most processes involved with screen printing, it is a series of compromises. These compromises simply help to define when and where to use this type of halftone method. Most of these considerations will diminish with time as further development continues.

Currently the size of the stochastic dot is a problem. At this time I am aware of only one product that allows for specific selection of the size of the stochastic dot. All of the other products use the laser spot size as the governing method for the generation of halftone dot size. This limits the dot size to 7, 14, or 20 microns. Virtually all of the stochastic halftone programs are geared for lithographic and gravure printing. Even at that, printers are having difficulty handling these very small dots. By the time you read this, there may very well be other products that will work for screen printing.

The halftoning takes place at the Raster Image Processing (RIP) stage. The RIP may be either hardware-based or software-based. The greatest availability of FM halftoning is imagesetter specific. This means that Agfa software must run on Agfa equipment and a Linotype product must run on Linotronic imagesetters. This is because of the intensive calculations that must be optimized to keep the RIP processing time at a reasonable minimum.

To afford the luxury of working with any imagesetter, stochastic halftoning would need to be done on a software RIP.

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This is very slow as you are limited to the speed of the processor of the computer that the software RIP is resident in. With a hardware-based RIP, the processor is very, very fast and is optimized to handle up to several hundred million processing instructions per second. If we move the very intensive task of processing these millions of halftones to a slow processor like a 486DX66 or a 68040 33 Mhz, you may wait hours for an image to process or crash. This means that a relatively large image (30" x 40") could take half a day or longer to process. The resulting bit-mapped files can also be very very large (in excess of 250 megabytes). Clearly this is not acceptable in order to keep the cost of the separations down and the productivity of the computer workstations up.

Another major limitation of the stochastic halftone is one of image quality when generating large areas of detail-free tone. The very nature of the FM halftone is that it is patterned after the random grain of photographic silver halide. Depending on the algorithm used to generate the randomization, the image can have a distinctly "grainy" texture. This can be very bad for certain types of artwork. If you have large areas of smooth tone, such as a chrome bumper on a car, the added graininess can seriously degrade the quality of the image. To be successful, the size of the grain or pixel must be so small as to not impart a pattern or texture to the surface that you are trying to render. Unfortunately, this is below the size of dot that screen printing can easily handle. As a result, FM halftoning works best on areas of extreme detail, and works marginally well on large flat areas. This is a decision that you and your customer will have to decide together. The FM prints so much easier that you may be willing to sacrifice some of the image quality for the reduction in moiré and the increased quality of detail rendition.

Closely related to the surface texture issue is that of artifact generation. Some of the less sophisticated algorithms used in generating stochastic dots tend to create very undesirable patterns at certain tonal points. They are particularly noticeable in the highlights as "orphan dots," "worms," and in the midtones as "mezzo patterns." If the level of detail is great, the creation of artifacts is not too much of a problem. With large areas of flat tone, they can have a significant effect on an quality of the image. The generation of artifacts is the major determinant in the quality of the FM algorithm. The fewer artifacts, the more sophisticated and time-consuming the processing required. You must determine what you are willing to settle for.

Prepress considerations

The prepress aspects of stochastic halftones offer many advantages and few limitations compared to conventional halftones. Let's begin with the selection of mesh. Conventional halftones generally are limited to 305 and higher mesh counts. The most common for textiles are 305 and 355. For graphics, 305 and 390. The choice of mesh is closely tied to the line count of the halftone we are using to minimize the impact of localized and global moiré. When printing UV inks, the thread diameter and total mesh thickness come into play as well.

With FM halftoning, the selection of meshes is much less critical. Since there is very little interference and no repetition, there are no tricky formulas to remember. With no angles, there is no need to worry about biasing the mesh. There is no need for special handling of films to precisely position the halftone to the mesh. In fact, small angle variations may actually aid in minimizing even the slight potential that still exists for moiré! Depending on what your ink deposit requirements are, a typical set of positives for screen printing

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application can be successfully imaged on 230, 245, 255, 265, N272, 280, N300, 305, 330, 355, N366, N380, 390, 420, and 465. The only limitation will be in a slight increase in dot gain on the lower meshes. For mesh counts 280 and above, there will be no appreciable differences. This is good news for solvent and waterbased graphics printers. This remarkable range of meshes is the result of having only one size dot to contend with.

Vacuum contact for FM is critical. With only one dot size, perfect contact is essential. Any undercutting of the image will have serious effects on the quality of the image. Unlike conventional halftones, where undercutting starts in the highlight areas and spreads toward the midtones, FM halftone dots must be considered to be all highlight in size. This means that undercutting will affect the entire tone range of the image, not just the lightest portions.

Carefully inspect your vacuum frame for good seals and good even draw down. Make a test image with 10% halftone dots of whatever line count you are currently using. Place nine of these images in your frame in a 3" x 3" grid to make sure that exposure and vacuum are even. After exposure and development, print the screen and measure the resulting test areas with a densitometer to be sure that all areas of your frame are working properly. With stochastic images, uneven vacuum can have catastrophic effects on your print quality. Common items that cause unevenness are localized seal of the inlet line to the glass, insufficient bleeder lines, weak vacuum, broken vacuum beading, and holes in the vacuum blanket.

The surface of the vacuum glass must also be in very good condition. Since the halftone dot is smaller and of only one size, it is much more sensitive to dirt, scratches, emulsions, water marks, and other surface flaws. Defects in the imaged screen are much more difficult to touch up after development. If your glass is scratched, you can get extra life out of it by flipping it in the frame. With scratches on the outside of the frame, there is little problem. The light will refract around them and the shadow that is cast onto the positive surface will have little effect on the exposure and image quality. Screen makers will have to be even more diligent in the future to avoid scratching and nicking the glass.

Cleanliness in the screen area is also very critical. Dust and small blobs of dirt, ink, emulsion, tape adhesive, etc. are all very critical to the image. Because the FM halftones are all one size, and smaller than conventional halftone dots, any dirt is a bigger problem than you may be used to. Static build-up on the positives and vacuum glass attract and hold dust and dirt. Careful attention to cleaning the glass after every exposure will help to guarantee successful results. Anti-static sprays and coatings are a good idea to help in reducing the build-up of static. Wiping each positive with anti-static film cleaner also helps. Don't overlook the vacuum blanket as a source of contamination.

Exposure of film positives is also somewhat different than conventional halftones. Because the dots are all one size, the exposure latitude is significantly larger. We recently conducted tests with 100 micron dots (similar to 65 line halftone dots), and were able to achieve a 100% variation in our exposure with no negative loss of dots between 3% and 97%. For instance, if a normal exposure would be 60 units, your acceptable latitude with FM would be 120 units. You do not have partial undercutting of the image. It will either all be there or it will all be gone. This is particularly important in maintaining fine highlight detail. It is very easy to maintain 1%-2% tone in light pastel areas.

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This is especially important for reproduction of very light beiges and greys.

Depending on how fine the dot is that you are printing, the exposure range will vary. For general purposes lower line counts (equivalent to 100 lpi and below), a latitude of 50%-100% is common. Above the equivalent of 100 lpi an increased range of 25%-50% is easily attainable. Depending on the color of your mesh, color of emulsion, light source, light intensity, and vacuum efficiency, increased latitude in excess of these generalized ranges is possible.

Increased latitude is extremely important for large format (fleet graphics and outdoor advertising) because it helps to minimize the effect of edge-to-edge light fall-off on large frames. Because exposure uniformity is governed by the inverse square law, a wider latitude significantly improves side-to-side exposure of very large frames.

Another key item with increased exposure range is that you can use the same exposure for a number of different meshes, thereby further eliminating more variables to the process color equation. While I admit that you may not be optimizing the exposure, as along as it is within the zone of process acceptability, eliminate as many of the other exposure choices as you can to keep it simple for your operators. For instance, if the screen maker knows that he has to use 75 units of exposure for FM halftones regardless of the mesh that he is using, you eliminate confusion and save time.

Press characteristics

On press the major difference that you will see is in dot gain. Next to moiré this is the most difficult item to control when printing halftones. What makes it such a problem is that with conventional halftones the dot changes size as tone increases. It reaches its greatest size at the 50% dot, and begins decreasing in a negative version until it closes up. If we were to plot the rate of dot gain we would see that it follows the increase in dot size fairly closely. It peaks in the midtones, and declines as it approaches the solid coverage. The reason for this is that dot gain occurs around the perimeter of the dot. As the perimeter of the dot increases, so does the amount of available border that can experience dot gain.

With stochastic halftoning, the rate of dot gain is different. Since all dots are the same size, the rate of dot gain is more or less constant. This is true as long as the total borderline of the covered tonal area is equal to the borderline of the conventional dot. For instance, if the border of a conventional dot is 300 microns, the dot gain will be similar as long as the total borderline of the smaller FM dots making up that tonal area does not exceed 300 microns. Calculations for border dot gain should be left up to the separator to create the optimum dot for your printing application. Dot gain for textile will be significantly different than for vinyl or fine art paper.

Aside from the prospect of more controllable dot gain, there is another great significance. There is no midtone jump. The typical problem of magenta fleshtones with conventional halftones is a thing of the past. Critical color reproduction of reference color and memory color is much easier to print and maintain over long runs.

More controllable gain also means that it will be much easier to maintain neutral greys and beiges. It has been extremely difficult to achieve very light beiges and greys with halftone frequencies above 100 lines. In the highlight areas a neutral grey is typically made up of a ratio of yellow, magenta, and cyan of 6:6:9. To obtain a

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neutral grey in a watercolor wash of 3% would require 1% yellow, 1% magenta, and 3% cyan. With conventional halftones this would be impossible due to thread eclipsing and moiré for halftone rulings above 35 lpi. This is the reason that light neutral greys often appear blue as the yellow and magenta components of the grey are clipped by the threads of the mesh. The key again lies in the fact that the stochastic halftone is made up of only one size dot. Since we are adjusting only the frequency of where we are placing that dot, we can obtain almost any tone that we desire.

Since the smaller FM dots are less prone to noticeable gain, the images you print will look cleaner and more stable for longer periods of time. The greatest impact on gain will now be due to declining mesh tension over the run length. If you can minimize your off contact and peel settings, it is easily possible to maintain a ± 1% tone value over several thousand press sheets over a full tone range of 3%-97% for even the very finest halftones. This level of consistency has been almost unattainable until now.

Conclusions

The introduction of stochastic halftoning to screen printing opens the door to greatly improved tone reproduction. As process color continues to increase in popularity and demand, the ability to successfully deliver to our customers printed images that meet or exceed their expectations will determine the life of our process. New generations of electronic imaging devices challenge the economic viability of screen printing, but the versatility and durability of the screen printed image will be hard to duplicate. Every serious quality printer will need to print four-color process with consistency and repeatability to survive. Stochastic halftoning will make that possible. As development continues in this area, even greater possibilities exist beyond what I have discussed here. I am very excited and enthusiastic about the opportunities that this new tone reproduction option offers our industry.

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