Hybrid Color Halftoning

Ahmed Tausif* and Sasan Gooran*

Keywords: Color halftoning, hybrid halftoning, flexography, color screening

Abstract

Halftoning methods can be divided into two main categories, namely AM (amplitude modulated) and FM (frequency modulated). Some printing methods, such as flexography, are not able to produce sufficiently small dots in order to handle the highlights and the shadows of the original image by just using an AM halftoning method. The reason is that in order to reproduce the lighter tones the halftone dots should be smaller than the critical dot size in AM techniques, which the printing press is not able to produce. This will mean that the parts that are lighter than the tone corresponding to the critical dot size will be blank. In our previous works we proposed a hybrid halftoning method for grayscale images that incorporates AM and FM technologies in order to overcome this problem. The strategy was to use an FM method in the highlights (and the shadows) of the image and an AM method in the rest of the image.

In the case of color images, besides the problem related to the transition area between AM and FM, one should also consider other factors. One of the factors is where to start the FM technique in different color channels. For example, if the critical dot size corresponds to 12.5%, should the FM technique be used for tones lighter than 12.5% for all color channels? Or should it be used if any one of the channels is less than 12.5%? Or should the average of all the channels decide the FM starting point? In all of the above cases, parts of the image will be FM halftoned in one or several color channels and AM halftoned in the rest of the channels. How will the final image look like in these cases? These were only a few of many possible solutions to the problem.

In this paper we are going to try all possibilities of combining AM and FM in different color channels and investigate the results. We are then going to present a new approach for hybrid color halftoning, which does not only use the best solution of where FM should start in each channel but also places the different color dots in the highlights, as homogenously as possible.

Introduction

Halftoning is a process that transforms continuous-tone images to binary images through the use of dots, varying either in size or in spacing. Halftoning done by

---

*Department of Science and Technology, Linköping University, Sweden

variation in size of dot is called AM (amplitude modulated) halftoning. A single dot within the halftone cell grows larger as the tone value becomes darker and smaller when the tone value becomes lighter. When the spacing between the dots is varied and the size is kept constant then it is called FM (frequency modulated) halftoning. In conventional halftoning methods (either AM or FM), the quantity of micro dots within the halftone cell increases as the tone value becomes darker and decreases as the tone value becomes lighter. Different methodologies can be found in the literature for both type of halftoning techniques (Ulichney, 1987; Kang, 1999; Floyd, 1976; Analoui, 1992; and Gooran, 1996). Both, AM and FM, techniques have their own advantages and limitations. If the gray tones in the original image vary slowly, then a more homogenous binary image is produced using the AM halftoning methods. But when dealing with sharp transitions between the gray tones or heavy textures, then FM halftoning methods are far more superior. AM-halftoned images are also less affected by the optical dot gain as compared with the FM (Gustavson, S., 1997).

To get the best of both worlds these two techniques are combined to produce a method with none of the disadvantages. The combination is termed as "hybrid halftoning," which has a possible application in printing methods that are not able to produce sufficiently small dots, such as flexography. The challenge with AM screening is to print small dots, corresponding to lighter tones. Since in AM methods, lighter the tone, smaller the dot size and when printing methods are not able to produce dots sufficiently small enough, then the resulting image cannot have the exact tones, in highlights, as in the original image. Therefore, in flexography, AM halftoning fails to give a good perception of highlights and shadows. The possibility of combining these two technologies has been investigated for a long time (Barco), and for grayscale images Gooran (2005) has already described how to combine AM and FM methods to correctly handle the highlights and shadows of the original image. In this paper we have explored how the previously presented technique can be extended for color images.

For color images, we not only tried to solve the problem related to the transition area between AM and FM, but we also addressed a number of other problems like the starting point of the FM screening in different color channels and the effect of introducing angles in each of the color channels. We investigated a number of possibilities and the problems associated with each of them. These are discussed in detail in Section 3. Then we presented the best approach for finding the starting point of FM screening in each channel, and to further improve the results we used an FM method which controls the dot placement in each color channel. This FM method not only avoids the dot-on-dot printing but also places the colored dots as homogenously as possible. The FM and the AM method used have already been presented (Gooran, 2001; Kang, 1999) and described in a number of publications, but to get a quick review, the FM method is briefly discussed in Section 2.

Overview

To correctly understand the concept of halftoning and hybrid halftoning, we are presenting a brief review of a few terms, as they sometimes lead to confusion. The simplest way to halftone an image is to use an AM halftoning method, which divides it into small areas which are called "halftoned cells." Each of these small areas (each halftone cell) consists of a number of smaller dots, called "microdots." These microdots can either be filled with ink or remain blank (white). The fractional area of halftone cells covered by the ink represents the corresponding tone of the original image. Two 8×8 halftone cells are illustrated in Figure 1. The halftone dot on the left is covering 2×2 and thus represents the gray tone of 4/64, while the cell on the right is representing a tone of 44/64. Therefore, with an 8×8 halftone cell, it is possible to represent 65 (8^2+1) different tones.

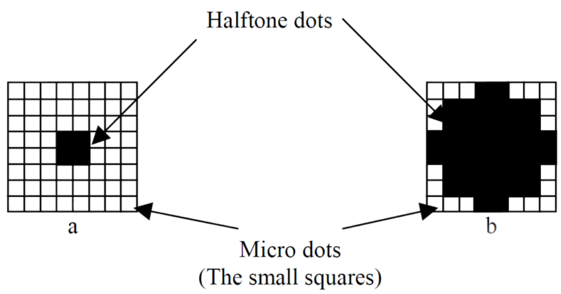

Figure 1. *Two halftone cells (left) a tone of 4/64 (Right) a tone of 44/64.*

The number of halftone cells per inch is called "line screen frequency," denoted by *lpi* (lines per inch), and the number of micro dots per inch is called the "print resolution" and is denoted by *dpi* (dots per inch). Therefore, it follows that the size of the halftone cell, and consequently the number of represented gray tones, can be determined by the following equation

$$GrayTones = \left(\frac{dpi}{lpi}\right)^2 + 1$$

As briefly discussed above, AM halftoning is done by varying the size of the halftone dot. In colored images, this size variation is done separately in each of the color channels of the image, which are mostly cyan, magenta, yellow, and black. Another important thing to take care with when (AM) halftoning colored images is the "screen angle," which is basically the angle at which the rows of halftone dots run in relation to the horizontal. AM halftoning of colored images can be done using the same screen angle, but misregistration during the printing process can cause some color shift and unwanted moiré pattern. In order to reduce the effect of misregistration, in practice, four different angles are used for cyan, magenta, yellow, and black.

Similarly, like AM halftoning of color images, the FM techniques can also be applied to the individual color channels of the image. Normally the color channels are halftoned independently, but the quality of the resulting image can be sufficiently improved by applying dependent halftoning algorithms to different color channels. It has also been shown that dependent color halftoning not only increases the print quality but also reduces the amount of ink needed to print the same image (Gooran, S. 2004). In this paper, initially, we placed the FM-halftoned dots freely in each of the color channels, but the results were greatly improved when we used the dependent FM halftoning technique applied to cyan and magenta channels. Since the yellow ink on a white paper is much less visible than cyan and magenta, we halftoned the yellow channel independent of the two others, without having a noticeable change in the result.

This dependent FM method is based on a successive assessment of the near optimum sequence of positions to render a halftone dot. The impact of each rendered position is then fed back to the process by a distribution function, thereby influencing subsequent evaluations. Our goal is to avoid the dot-on-dot printing as much as possible and place the C and M dots homogenously over the entire image. In this algorithm we begin by placing a dot at the position where the original image is darkest in either C or M channel. Since we assume that “1” and “0” represent black and white respectively, therefore, the algorithm finds the position of the largest density value (or the maximum) in either of the channel of the continuous-tone image and places a dot at that position in the binary image, which is totally white to begin with. The currently placed dot is then represented by a distribution function (filter) in both of the channels, which affects a neighboring region of the position of the maximum in the original image. After that, the algorithm looks for the next maximum density value position in both the channels and performs the same feedback process for that position. The algorithm is terminated when the difference between the mean value of the original and the halftoned image is minimized. The filter (distribution function) used within the algorithm plays a significant role in the appearance of the final image. By using a filter with an appropriate size, the dots can be placed homogeneously over the entire image (Gooran, 2004).

Different Hybrid Color Halftoning Techniques

As indicated in Section 1, one of the possible applications of this method is in flexography, which is a modified form of letterpress printing that is commonly used in the packaging industry for printing on the most varied materials. The print quality in flexography is lower as compared to offset printing. On the other hand, flexography is the only printing method that can print on very thin flexible and solid films, thick cardboards, rough-surface packaging materials, and fabrics (Klipphan, 2001). As indicated earlier, one of the problems with flexographic printing is that it can not produce sufficiently small dots in order to handle the very light and dark parts of the original image by just using AM method. Experience in AM and FM methods showed that both technologies have their advantages and drawbacks in flexographic printing. AM technologies are especially usable in the midtones because the dot gain is lower compared to the FM technology. FM methods, on the other hand, perform very well in the highlights where the optimized dot positioning and the choice of the minimum dot size allow for a perfect match to the technical limitations of the printing process.

One of the biggest challenges in combining the two technologies is handling the transition area between the AM-halftoned and the FM-halftoned parts. Another problem, when dealing with color images, is to define the starting point of the FM method in different color channels. To illustrate these problems and their possible solutions, we will use a simple ramp shown in Figure 2.

Figure 2. *Ramp used as a test image consisting of only cyan and magenta.*

For simplicity this ramp is made up of just two color channels, cyan and magenta, and is divided into three regions: left, middle, and right. In the left region both cyan and magenta are less than 12.5%, in the middle cyan is less than 12.5% but magenta is greater, and in the right region both are greater than 12.5%. The division of our test image is based on the assumption that the printing method in use is not able to produce dots less than 12.5%. Therefore, parts of the image that are less than or equal to this threshold value, in their respective color channels, will be totally clear. To illustrate this, the test ramp is first halftoned using the AM method, result of which is shown in Figure 3.

As can be seen, the dots corresponding to tones less than 12.5% are cleared during the printing process; only dots greater than the threshold value are visible. A possible solution to this problem is to change the spacing of the dots in the respective color channel instead of decreasing the size. This is basically what an FM method does. This leads to another problem of having areas in an image where one color channel halftoned in FM and the other halftoned in AM.

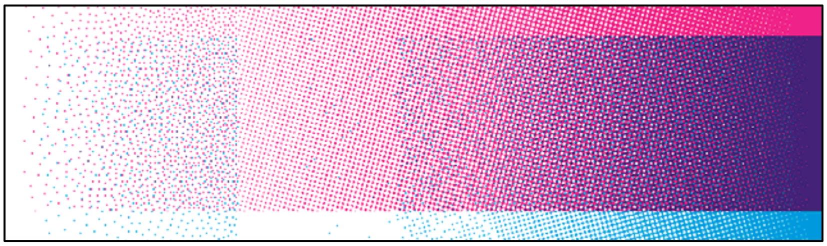

Figure 3. *AM-halftoned test ramp. Printing method is assumed not to print dots corresponding to tones less than 12.5% in each channel.*

To find asolution to this problem, we are going to present, step by step, six different ways for combining the two methods in all ofthe color channels, of an image. Every method has its own limitations and drawbacks which are discussed below in detail. Each of these limitations drived us to explore the next method until we reached to the one that produced the best results.

After reading the image, the first step in all of the six methods is the generation of a mask that will mark the starting point of the FM. But the criterion for mask generation is different in every method. After that AM and FM halftoning is done in every color channel of the image, based on the mask. In the last step, AM- and FM-halftoned portions of the image are merged together to form a hybrid halftone image. During the merging process there may be some unwanted dots at the transition that are below the critical dot size; those are removed using the method, with some amendments, proposed by Gooran (2005). These steps are illustrated in Figure 4.

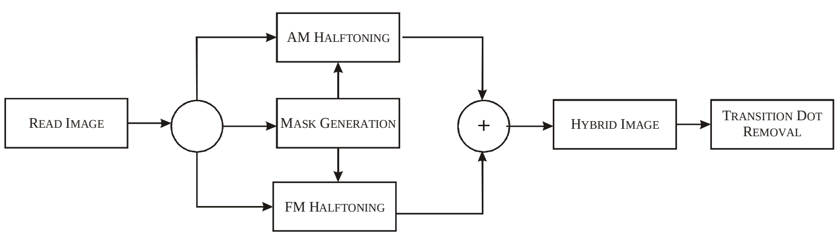

Figure 4. *Generalized flow diagram of the hybrid halftoning method.*

Hybrid Technique 1: In this technique a mask is generated such that the image is FM halftoned in areas where all the channels have values less than the critical threshold value and the rest of the image is AM halftoned. In the left region of the ramp where cyan and magenta both are less than 12.5% the image is FM halftoned while the rest of the image is AM halftoned. As can be seen clearly in

Figure 5, the middle region of the ramp will have smaller dots (less than 12.5%) in the cyan channel that will be removed during the unwanted dot removal step, hence changing the resulting color of the halftoned image. Another problem with this technique is the visibility of a clear boundary between the transition of AM and FM. This is because the unwanted dot removal, which leaves behind a relatively larger dot size so the transition jumps suddenly from a bit higher percentage in AM to FM.

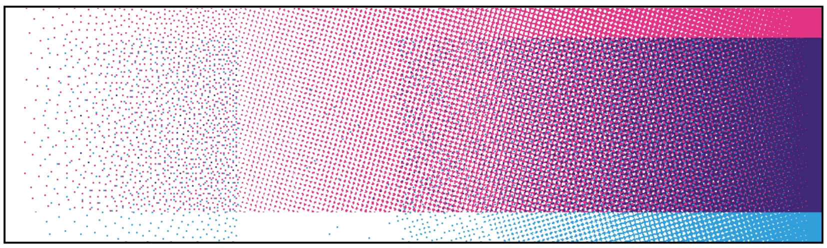

Figure 5: *Hybrid Technique 1 applied to the test ramp.*

Hybrid Technique 2: The mask for this technique is generated such that the image is FM halftoned in areas where any of the color channels have values less than the critical threshold value, and the rest of the image is AM halftoned. In the case of our test ramp, the left and the middle regions, where either cyan or magenta are less than 12.5%, are FM halftoned while the rest of the image, where all of the channels have values greater than the threshold value (12.5%), is AM halftoned. This is shown in Figure 6. The problem with this technique is that most of the image will be FM halftoned and in most real-life images at least one of the channels will have highlights in it. Due to which the problems associated with FM, like optical dot gain, will be seen in the resulting image. Here also you can see the boundary at the transition between the two methods, but it's better than the previous.

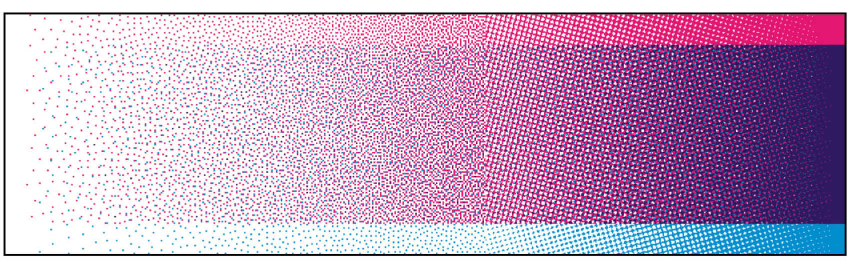

Figure 6. *Hybrid Technique 2 applied to the test ramp.*

Hybrid Technique 3: In this technique a mask is generated by taking the mean (grayscale) value of all of the color channels. Areas of the image in which all of the channels have value less than the mean value are FM halftoned while the areas above the mean value are AM halftoned. The resulting image created with this technique will have a similar problem as Technique 1. After halftoning, any of the channels can have dots smaller than the critical dot size, as the mean value can be larger than the threshold value. As can be seen in Figure 7, the mean value of our test ramp lies somewhere in the middle of the image, which means there will still be areas in the cyan channel that will have value less than the threshold value (12.5%). Those dots, when AM halftoned, will be removed in the unwanted dot removal step of our algorithm. Also note that the transition between the two methods is not smooth.

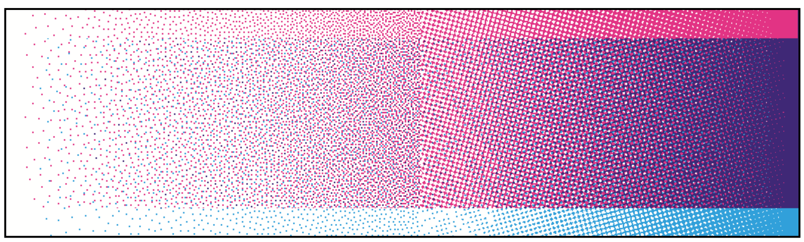

Figure 7. *Hybrid Technique 3 applied to the test ramp.*

Hybrid Technique 4: In this technique a mask is generated independently in all of the channels. That is, in each channel of an image, areas less than the threshold value will be FM halftoned, and areas having value greater than the threshold will be AM halftoned. This means that in the resulting halftoned image there will be areas that will have AM halftoning in one channel and FM in the other. When such an image is printed it will cause some unwanted moiré effect, and the resulting quality will be distorted. The results of this technique applied to our test ramp can be seen in Figure 8, which shows that in both channels, the left region will be FM and the right region will be AM; while in the middle region the cyan channel will be FM and magenta will be AM, which may give rise to unwanted noise patterns.

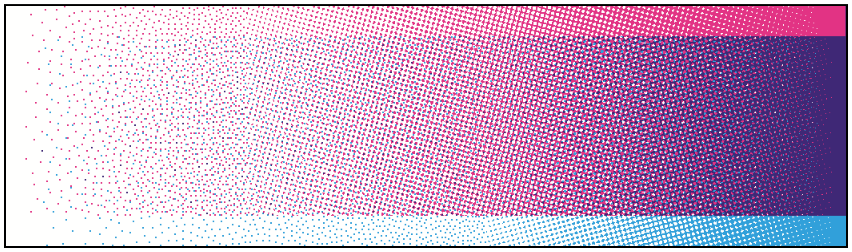

Figure 8. *Hybrid Technique 4 applied to the test ramp.*

Hybrid Technique 5: To understand this technique we first introduce another concept of halftoning, which basically superimposes FM over AM. This method is illustrated in Figure 9 using a simple grey ramp with a threshold value of 25%. In this method, areas in the image that are lighter than the threshold value (25%) are first FM halftoned with an FM dot size equal to the AM halftone cell size. Then each of the FM dots are assigned the threshold value (25% here) and added to the above threshold area of the original image (Non Black area in Figure 9b). This combined image (Figure 9c) is then AM halftoned. We call the resulting image a superimposed FM halftoned image. It can be seen clearly in the final image (9d) that the dots in the highlight area are not exactly free FM. The dots are placed at a regular interval as in AM, but only a few of them are removed, giving an effect of FM. The resulting image quality can be made better by using free FM in the highlights area.

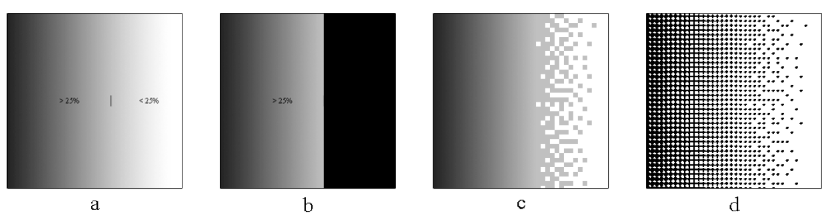

Figure 9. *Superimposed FM in which FM halftoning is superimposed on AM technique.*

In the fifth hybrid halftoning technique we used the concept of this superimposed FM and combined it with the conventional freely placed FM. Two masks are generated, one indicating areas for free FM and the other indicating areas for superimposed FM. Results of this technique applied to the test ramp can be seen in Figure 10. We have used free FM in areas where all the color channels have a value below the threshold (12.5%), so the left region of our ramp will be free FM halftoned. Areas where any of the color channels has value less than the threshold, we use superimposed FM. So the middle region of our test ramp, where cyan is less than the threshold and magenta is higher, the cyan channel will be halftoned using the superimposed FM technique, while magenta will be halftoned using AM technique and the rest of the image is AM halftoned where both the color channels have values greater than the threshold. This method produces much smoother transition between the AM and FM methods.

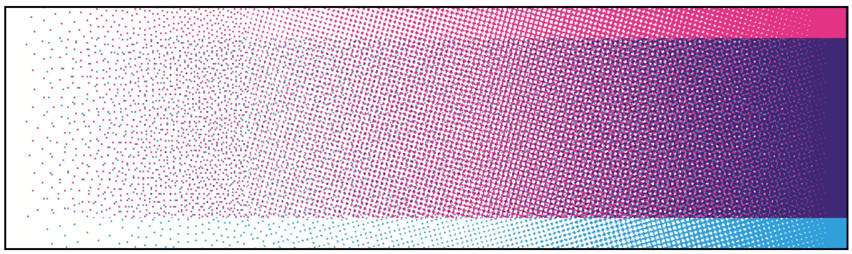

Figure 10. *Hybrid Technique 5 applied to the test ramp.*

Hybrid Technique 6: This technique is similar to the above, except that instead of placing the FM-halftoned dots freely and independently, they are placed dependently, depending on the other color channel. This method is proposed by Sasan (2004), which controls the dot placement over the entire color image and avoids the dot-on-dot printing as much as possible. This FM method is briefly described in Section 2. The results of this technique applied to our test ramp can be seen in Figure 11, as you can see that the dots are more homogenously placed in the left region of our image.

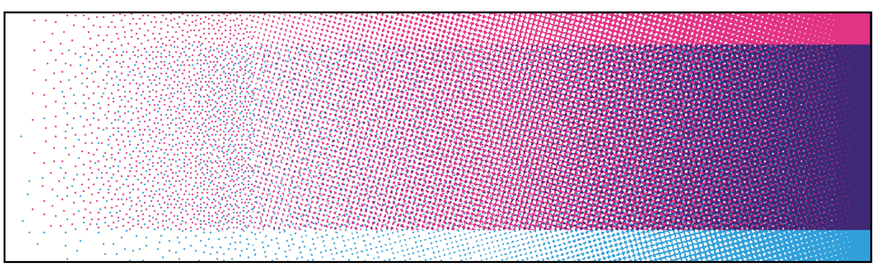

Figure 11. *Hybrid Technique 6 applied to the test ramp.*

Conclusion

It has already been demonstrated in previous research that using the FM method in the highlights and the AM method in the rest of the original image is a necessity in printing processes like flexography. By investigating the results of different hybrid techniques described above, it can be concluded that best results are achieved when FM halftoning is combined with the superimposed FM method described above and using the conventional AM in rest of the image. This combination also produces a smooth transition between the AM and FM parts of the resulting image.

It can also be concluded that the type (dependent or independent) of FM method used in the above-proposed technique can affect the quality of the resulting image. The resulting ramp image from the final hybrid technique seems to be smoother, compared to the results from hybrid Technique 5. The underlying dependent FM method used has already been proven to give rise to satisfying results. In Gooran (2004), this FM method is described in detail. The test image example illustrated in this paper uses FM dots having a square shape, but it is fully possible to use any shape, which depends on the AM method and also on the threshold color tone for less than which the FM method is used.

References

Analoui, M. J.P. Allebach. 1992. "Model-based Halftoning Using Direct Binary Search," *Proceedings of the 1992 SPIE/IS&T Symposium on Electronic Imaging Science and Technology,* Vol 1666, San Jose, CA, 1992, pp. 96–108.

Barco Graphics. "SambaFlex Screens," User Manual, Partcode: 4913710.

Floyd, R.W. and L. Steinberg. 1976. "An adaptive algorithm for spatial grey scale." *Proc. SID,* Vol 17/2, 1976, pp. 75–77.

Gooran, S., M. Österberg, and B. Kruse. 1996. "Hybrid Halftoning—A Novel Algorithm for Using Multiple Halftoning Technologies," *Proc. IS&T Int. Conf. on Digital Printing Technologies* (NIP12), Oct. 1996, pp. 79–86.

Gooran S. 2001. "High Quality Frequency Modulated Halftoning," Ph.D. Thesis No. 668, Linköping Studies in Science and Technology, Jan. 2001, ISBN 91-7219-913-X

———. 2004. "Dependent Color Halftoning, Better Quality with Less Ink," *Journal of Imaging Science & Technology,* Volume 48, Number 4, pp. 354–362.

———. 2005. "Hybrid Halftoning, A Useful Technique for Flexography," *Journal of Imaging Science & Technology,* Volume 49, Number 1, pp. 85–95.

———. 2006. "In Dependent Color Halftoning, Yellow Matters," *Journal of Imaging Science & Technology,* Volume 50, Number 5, pp. 448–457.

Gustavson, S. 1997. “Dot Gain in Colour Halftones,” Thesis, Linköping University, Linköping, Sweden.

Kang, H.R. 1999. “Digital Color Halftoning,” SPIE/IEEE series on Imaging Science & Engineering.

Klipphan, H. 2001. *Handbook of Print Media,* ISBN 3-540-67326-1.

Ulichney R.A. 1987. *Digital Halftoning,* MIT Press, 1987.