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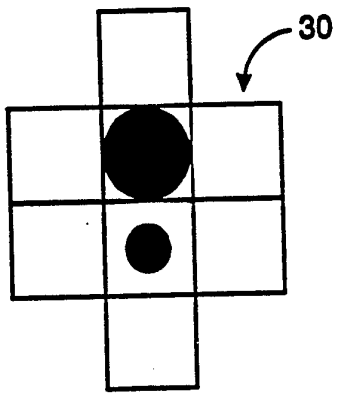

(57) Abstract

A printhead forms dots of variable dot sizes grouped into cells. For each increase in cell gray level, at least one dot in the cell forms a larger dot size. Cell growth patterns are described. In a further embodiment, a gray level printer forms dots in accordance with a template corresponding to increasing cell gray levels until a line structure is stable. In another embodiment, scanned pixel values are compared to a set of thresholding values that are defined by a 4-quadrant tone reproduction analysis using a dot template, selected bit depth and dot type structure. In another embodiment, the intensity values of some pixels are modified by introducing errors to intensity values of pixels at preferred locations such that pixels along screen lines have a greater likelihood to be printed with stable dots than pixels not at such preferred locations. Errors created by modifying the intensity values are diffused to neighboring pixels. In another embodiment, contour suppression is performed on the pixels of a text or half tone region. In another embodiment said regions are printed with a higher output screen frequency. In another embodiment a descreening filter iteratively reduces a specific frequency in the digitized image.

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METHOD AND APPARATUS FOR REPRODUCING AN IMAGE WITH GRAY LEVEL PRINTING

BACKGROUND OF THE INVENTION

The present invention relates to the field of encoding pictorial imagery for reproduction on display or printing systems, and more particularly to improvements in displays or printing apparatus that use gray level display/printing.

In the area of digital printing (the term "printing" is used to encompass both printing and displaying throughout), gray level has been achieved in a number of different manners. The representation of the intensity, i.e., the gray level, of a color by binary displays and printers has been the object of a variety of algorithms. Binary displays and printers are capable of making a mark, usually in the form of a dot, of a given, uniform size and at a specified resolution in marks per unit length, typically dots per inch. It has been common to place the marks according to a variety of geometrical patterns such that a group of marks when seen by the eye gives a rendition of an intermediate color tone between the color of the background (usually white paper stock) and total coverage, or solid density.

Continuous tone images contain an apparent continuum of gray levels. As an approximation to continuous tone images, pictorial imagery has been represented via binary halftone technologies. In order to record or display a halftone image with a scanning system, one picture element of the recording or display surface consists of a j x k matrix of sub-elements where j and k are positive integers. A halftone image is reproduced by printing the respective sub-elements or leaving them blank, in other words, by suitably distributing the printed marks.

Halftone image processing algorithms are evaluated in part, by their capability of delivering a complete gray scale at normal viewing distances. The capability of a particular process to reproduce high frequency rendition (fine detail) with high contrast modulation makes that procedure superior to one which reproduces such fine detail with lesser or no output contrast.

Another method of producing gray levels is provided by gray level printing. In such a method, each pixel has the capability to render several different dot sizes. The dot size for a pixel is a function of the exposure time provided an LED element (or other suitable printing device) corresponding to that pixel. The longer the exposure time, the more toner is attracted to that particular pixel.

There are two major concerns in rendering a continuous tone image for printing: (1) the resolution of image details, and (2) the reproduction of gray scales. In a binary halftone representation scheme, these two fundamental factors compete with each other. The more gray levels that are rendered, the larger is the halftone cell. Consequently, coarse halftone line screens are provided, with the attendant poor image appearance. Hence, a compromise is made in rendering between the selection of line resolution and gray scales in binary halftone printing. However, in gray level halftone printing, one can satisfy both resolution and gray level requirements. In gray level printing, the same number of addressable dots are present, and there is a choice of dot sizes from one dot-size of 1 bit/pixel to 16 different dot-sizes of 4 bits/pixel. An image could then be rendered with 133 line screens and 128 gray scales of higher quality image. Although providing higher image quality with respect to line resolution and tonal scales, gray level halftoning presents its own dot rendering issues.

In accordance with the invention, a number of different dot layouts are possible to build gray level dots from a cell template. These gray level dots are the digital representation of the gray level screening, and must be realized through a printing process. It is desirable in gray level screening to layout the dots with the printing process characteristics built into it such that the appearance of the dots are pleasing to the eye: less grainy, stable, less artifacts, less texture (i.e., visible screen and its microstructure).

There is a need for an apparatus and a method for providing a screen for gray scale rendering that establishes a

stable latent image structure, and renders more gray scales for an image, and with the process characteristics built into it so that the appearance of the dots are pleasing to the eye.

A problem also exists in the application of a gray level rendering technique to a document that contains different types of images: text, halftone, and continuous tone. These different types of images create different rendering problems, based on a trade-off between tone scales and detail resolution. For example, with text, the number of tone scales is not as important as providing a smooth text edge, whereas the opposite holds true for continuous tone images. Providing a single type of gray level halftone rendering technique to a document that contains two or more types of images may lead to the production of a document in which one or more of the different types of images are reproduced unsatisfactorily.

When scanning a document, image processing techniques have been applied to convert a gray scale image into an image representation which a printer can accept (either binary format or gray level format). In this scanning process, text areas, line drawing and halftone pictures are indistinguishable from each other, and all appear to be a gray scale image. An improper conversion process creates artifacts in the hardcopy such as a jagged boundary in the text area, or a Moire pattern in the halftone region. To overcome this, intelligent processes have been developed to segment the image into different regions of text, line drawing, and picture. Different conversion processes for the individual segments were then applied to these segments to restore the original document. However, these segmentation and conversion processes unduly complicate the digital copying process.

There is a need for a unified rendering method and apparatus using gray level printing that will satisfactorily reproduce an image that contains text, line drawing, halftone and/or continuous tone regions, with different gray dot representations selected for the specific regions. There

is a need for a method and apparatus which does this without a need to "know" where is the text region, the halftone region or the continuous tone region, and which overcomes artifacts such as a jagged text boundary or a Moire pattern in the halftone.

In accordanace with another aspect of the invention, it is desirable to provide an exposure time for the pixels such that there is an equal lightness change between steps in gray level halftone design. An example of a lightness vs. exposure time curve is shown in Figure 18. This exposure curve is that obtained for continuous tone, which is then normally used for halftone. Such a curve works well also for continuous tone output and gray level error diffusion as well as partial dot halftone. However, these methods have granularity limitations when the toner particles are relatively large (e.g. 12 microns volume diameter).

In gray level printing the exposure times are associated with different dot sizes. For example, with 3 bits/pixel, there can be 7 different exposure times (or intensity levels if intensity is varied rather than exposure duration), and thus 7 different dot sizes. A problem selecting the 7 exposure times from the continuous tone curve (which gives equal lightness change) can be recognized from Figure 19, which shows lightness of the overall gray level of a halftone vs. a step number of the halftone, for a mixed dot type halftone cell described later. As can be readily seen, there is a non-even lightness jump in some of the steps. If the unevenness of this lightness jump is too great, noticeable density contouring in the output print will occur.

The reason behind this lightness jump comes from the fact that pixels within a cell grow differently depending on their surroundings, so that the exposure time for a continuous type of system (when all surrounding pixels are on) cannot be simply selected and used for every pixel in a halftone cell employing a mixed dot type cell growth pattern.

There is thus also a need for a method and apparatus that reduces contouring by classifying pixels within a cell and

modifying the exposure of the pixels according to this classification.

As indicated earlier, continuous-tone pictures can only be printed in binary form through a halftoning process. The halftone process breaks the picture into dots via a screen-like structure. Through the integration of the human visual system, a sensation of gray shades is achieved. Normally, increasing the dot resolutions (for example, 2000 dots per inch (dpi) - 3000 dpi or higher) and making the dots smaller are the way to produce a high quality picture (a continuous-tone like picture). However, it is not necessary to present the continuous tone photographic quality picture in such high image resolutions. For example, 400 dpi or 500 dpi printing resolutions with 8-bit to 12-bit gray scales are adequate for true continuous tone photographic quality printing. Such continuous tone printing systems (for example, the photographic film based process and the dye sublimation thermal based process) are on the market now. These are very expensive exposure system controls which deliver 8-bit to 12-bit gray scales. Those printing devices and exposure system controls currently use two designs: a current modulating laser intensity system or a time modulating laser exposure system.

Through human visual system study, it has been discovered that the human eye can't distinguish the shade changes (i.e., it looks like a continuous shade) at medium resolutions around 400 dpi - 600 dpi range with multi-bit (4 bits or 5 bits) image pixel information.

There is a need for a design of dot patterns and the rendering of images into 4 bits or 5 bits image representation, such that when the rendered images are reconstructed through the gray scale printing, the restored structure looks like a continuous tone picture.

In electrophotography, the toning process is based on the differential electrostatic force generated by the charge potential on the latent image. A well (i.e. satisfactorily) formed cluster type of charge-potential-well is therefore

advantageous for developing a stable dot. Certain dot designs have a well formed potential well already built in, so that the rendered images will be less grainy. However, certain other dot designs will render a grainy image because there is no such well formed charge-potential-well for that dot structure on the latent image to stabilize the dot.

There is a need for an apparatus and method for providing a stable dot for a dot design that would normally not have a stable dot developed in the electrophotographic printing process.

SUMMARY OF THE INVENTION

In accordance with a first aspect of the invention, there is provided a method of producing a gray level image comprising controlling a gray level printhead such that the printhead forms dots of variable dot sizes on a recording medium at plural pixel locations, the pixel locations being grouped into cells having cell gray levels, wherein the dots of a cell are determined such that for each increase in cell gray level, a dot at at least one of said pixels in the cell forms a larger dot-size.

In accordance with a second aspect of the invention, there is provided an apparatus for reproducing an original image, comprising a scanner which scans and digitizes the original image into pixels ; a controller means coupled to the scanner to receive the digitized original image, and which produces a first signal corresponding to a gray level halftoned representation of the digitized original image; and a printer coupled to the controller to receive said first signal and which produces a gray level halftoned reproduction of the original image wherein the controller means groups the pixels into cells that each have a determined cell gray level, and controls the formation of dots within the pixels of an individual cell by the printer such that for each increase in cell gray level, a dot at at least one of said pixels in the cell forms to a larger dot-size.

In accordance with a third aspect of the invention, an apparatus for reproducing an original image, comprising a scanner which scans the original image and generates first signals representing said original image as pixels of different gray level values; a controller coupled to the scanner and responsive to the first signals, and which generates second signals corresponding to a gray level halftoned representation of the original image; and a printer coupled to the controller to receive said second signals and which produces a gray level halftoned reproduction of the original image; and wherein the controller includes means for defining a criteria for stable pixel locations in accordance with a screen frequency and screen angle of the image to be reproduced and for determining in accordance with said criteria whether or not there is to be a stable dot at a current pixel and if the current pixel is determined to be at a location meeting said criteria for a stable pixel location, alters a gray level value of the current pixel to increase the density of the current pixel for stabilizing said pixel at said location and diffuses error introduced by increasing the density of the current pixel to pixels that neighbor the current pixel.

In accordance with a fourth aspect of the invention, a method of reproducing an original image comprises the steps of generating first signals representing an original image divided into pixels of varying intensity values; in accordance with a criterion based on screen frequency, identifying a current pixel as being a preferred pixel for forming of a stable dot if the current pixel meets said criterion; in response to a current pixel being identified as a preferred pixel introducing an error to adjust the intensity value of the current pixel to form a modified intensity value; comparing the modified intensity value with a threshold value; and as a result of said comparing step defining a grey level value for printing the current pixel; and distributing the error to adjust intensity values of pixels neighboring a preferred pixel that are not preferred pixels.

In accordance with a fifth aspect of the invention, a method of reproducing an original image that contains at least one of a text region or a halftone region, comprises scanning said original image to produce a signal representing a digitized original image; determining that a region of said original image contains either a text region or a halftone region; and performing contour suppression on every pixel of said digitized original image; controlling a gray level printer to print the digitized original image after contour suppression has been performed.

In accordance with a sixth aspect of the invention, a method of reproducing an original image that contains at least one of a text region or a halftone region, comprises scanning said original image to produce a signal representing a digitized original image, said original image having a screen frequency; determining that a region of said original image contains either a text region or a halftone region; and controlling a gray level printer to print the digitized original image with an output screen frequency higher in screen frequency than the screen frequency of the original image.

In accordance with a seventh aspect of the invention, a method of reproducing an original image, comprises

scanning an original image to produce a digitized image; performing a local structure analysis of the digitized image; selectively applying a descreening filter to a region of the digitized image based on the results of the local structure analysis to remove a specific frequency of the digitized image caused by halftone screens; bypassing the descreening filter with regions of the digitized image such that said bypassed regions remain unfiltered by said descreening filter; printing said filtered regions and said bypassed regions as a single , unified reproduction of the original image; and wherein the step of performing the local structure analysis includes the steps of establishing a moving window for the digitized image around a central pixel; determining if the moving window is a low contrast window or a high contrast window; determining if there is a consistent transition in the

moving window around the central pixel; and causing the application of the descreening filter to the moving window when the moving window is a high contrast window and there is not consistent transition in the moving window around the central pixel.

In accordance with an eighth aspect of the invention, there is provided a method and apparatus of reproducing an original image, comprising scanning an original image to produce a digitized image; performing a local structure analysis of the digitized image; selectively applying a descreening filter to a region of the digitized image based on the results of the local structure analysis to remove a specific frequency of the digitized image caused by halftone screens; bypassing the descreening filter with regions of the digitized image such that bypassed regions remain unfiltered by said descreening filter; printing filtered regions and bypassed regions as a single, unified reproduction of the original image; and wherein in the descreening filter the image is transformed to a frequency spectrum and the strength at a certain frequency is reduced and the modified image transformed into the spatial domain, and there is feedback between the spatial domain and the frequency domain to iteratively reduce to a minimum the certain screen frequency.

In accordance with a a ninth aspect of the invention, there is a provided an apparatus for reproducing an original image, comprising means for scanning and digitizing the original image into pixels; controller means for producing a first signal corresponding to a gray level halftoned representation of the original image; and a gray level printer means coupled to the controller means and responsive to said first signal for producing at least three gray level dot sizes to form a gray level halftoned reproduction of the original image; wherein the controller means includes first means for processing the pixels by cells, each of plural pixels, and for controlling the printer means to form dots of variable size in a cell along lines in accordance with at least one template, such that a first line structure is formed that is stable before

beginning formation of additional lines within the cell corresponding to increasing cell gray levels.

Other objects, advantages and novel features of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a block diagram of an apparatus for reproducing an image, constructed in accordance with an embodiment of the present invention.

Figure 2 shows an example of a 4x4 cell with indications of gray level for each pixel.

Figure 3 illustrates an exemplary 3-bit gray halftone dot layout according to a full dot type embodiment of the present invention.

Figure 4 shows a cell with dots that have been formed.

Figure 5 illustrates an exemplary halftone dot mask.

Figure 6 shows a 3-bit gray halftone dot layout according to a partial dot type embodiment of the present invention.

Figure 7 shows a 3-bit gray halftone dot layout according to a mixed dot type embodiment of the present invention.

Figure 8 shows a 4-bit gray halftone dot layout according to a mixed dot type embodiment of the present invention.

Figure 9 illustrates a thresholding mask for a 4-bit gray halftone dot layout according to a mixed dot type embodiment of the present invention.

Figure 10 illustrates a thresholding mask for a 4-bit gray halftone dot layout according to a fixed threshold dot type embodiment of the present invention.

Figure 11 shows a method for unified image rendering in accordance with an embodiment of the present invention.

Figure 12 shows a tone reproduction control chart.

Figure 13 shows a method for unified image rendering in accordance with another embodiment of the present invention.

Figure 14 is a graphic illustration of the building up of a cell in accordance with another embodiment of the present invention.

Figure 15 shows an example of templates used for gray scale rendering in accordance with the embodiment of Figure 14.

Figure 16 illustrates a 189 line gray scale dot sequence in accordance with the embodiment of Figures 14 and 15.

Figure 17 shows the exposure levels of the pixels of a cell having a gray level of 100 that has been formed according to the layout of Figure 16.

Figure 18 is a lightness vs. exposure time curve for gray level halftone of one type.

Figure 19 is a lightness vs. exposure time curve for gray level halftone of a different type.

Figure 20 is a block diagram of a method for modifying gray levels using a classifier according to an embodiment of the present invention.

Figure 21 illustrates an example of a 4x4 classifier.

Figure 22 is a block diagram showing an alternative embodiment of the method for modifying gray levels using a classifier.

Figure 23 shows a Bayer dispersion dot template.

Figure 24 illustrates a 4-bit partial dot pattern set using the dot template of Figure 23.

Figure 25 shows a threshold pattern for gray scale rendering using the dot template of Figure 23 and the dot pattern set of Figure 24.

Figure 26 shows a cluster dot template.

Figure 27 illustrates a 4-bit partial dot pattern set using the dot template of Figure 26.

Figure 28 shows a threshold pattern for gray scale rendering using the dot template of Figure 26 and the dot pattern set of Figure 27.

Figure 29 is a basic block diagram of a gray scale rendering process in accordance with one aspect of the present invention.

Figure 30 is a flowchart of a method for imbedding dot structure in accordance with an embodiment of the present invention.

Figure 31 illustrates a cell before and after dot stabilitization according to the present invention.

Figure 32 shows a power spectrum of an output print of a black density patch with full dot type.

Figure 33 shows a power spectrum of an output print of a black density patch with partial dot type.

Figure 34 shows a power spectrum of an output print of a black density patch with mixed dot type.

Figure 35 shows contour suppression of every pixel.

Figure 36 illustrates a 282/inch (45 degree screen).

Figure 37 illustrates a 200/inch (90 degree screen).

Figure 38 shows a basic flow diagram of a descreening method in accordance with an aspect of the present invention.

Figure 39 shows the design of the descreening filter of the present invention.

Figure 40 is a flowchart of an embodiment of the descreening method of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates an apparatus which reproduces a document in accordance with the various aspects of the invention described herein. The document 10 can contain different types of images on the same document. For example, document 10 may contain both text and continuous tone areas, and may also contain halftone areas.

The document 10 is scanned in and digitized by a conventional scanner 12, which operates to provide digital signals representative of the densities of the areas of the document 10 corresponding to various pixels. These signals are sent to a memory (or buffer) 14. Under the direction of a controller 16, these signals may be modified and provided as gray level signals through a frame store 17 to a printer 18 and/or a display 20 for each pixel. The printer 18 and/or display 20 will then reproduce the document 10 by energizing each of the individual pixels according to the gray levels as modified (or

not modified) by the controller 16. The printer may be a gray level LED printhead or a laser printer or other grey level exposure device. Alternatively, the printer may be an electrographic recording device that imagewise charges an electrostatic image supporting member. For exposure devices, the member may be photographic film or a photoconductive image supporting member.

The controller 16 of the present invention may include a computer that is programmed or hardwired in accordance with the teachings herein to carry out the various aspects of the invention. The controller operates to modify the gray level that is to be printed for a pixel in dependence on the local contrast. In providing a gray level signal for a specific pixel to be printed, the controller 16 will select between a "mixed dot" type rendering technique and a "fixed threshold" type rendering technique. Before describing the selection process, these two rendering techniques will now be discussed.

In gray level printing, each pixel has the capability to be rendered in several different dot sizes, and thus different gray levels. However, instead of simply providing each pixel with an independent gray level, several pixels may be organized together to form a superpixel, or cell. Each of the pixels in a cell is then provided with a gray level. The human visual response integrates the various gray levels of the individual pixels in the cell to a single perceived gray level for the cell. This is similar to the basic concept of binary halftoning. The number of tone scales for a cell is increased greatly, however, due to the number of different gray levels available for each pixel. For example, instead of only the two levels provided in binary halftoning for each pixel, eight levels can be provided with gray level printing for each pixel in a cell (3 bits/pixel). When the cell is made up of 4x4 pixels, for example, the gray level printing allows 121 different gray shades to be rendered for that cell. An example of a 4x4 cell 28 with numbers that represent gray levels for each pixel is shown in Figure 2.

The formation of the dots in the pixels of a cell can be performed in a number of different manners to achieve different

desired results. The dots can be formed as "full" dot, "partial" dot, or "mixed" dot to provide gray level halftoning.

Figure 3 illustrates an example of a 3-bit gray halftone dot layout for a full dot type cell formation. Also illustrated are seven different pixel-dot sizes, corresponding to the sizes that each individual pixel-dot can obtain. There are 57 possible gray levels for the exemplary eight element cell 30 shown here. An example of the formation of a cell that is at gray level 12 will now be given.

The pixel circled in level 1, reference numeral 1, is formed to dot-size 1 in level 1. (Only one cell will be described, although the pixels of other cells are changed according to the same layout, as shown in Figure 3). The dot at this circled pixel grows larger and larger as the levels increase from level 1 to level 2 all the way to level 7. One can see that this pixel increases in value from 1 to 7 as the levels increase. If the desired gray level for the cell 30 was 7, then the formation of this cell would be completed once the circled pixel 1 has reached the dot-size of 7 in level 7. In this example, however, the gray level for the cell 30 is desired to be 12. At gray level 7, the circled pixel 1 has reached its maximum dot-size, so that a dot at another pixel within cell 30 must now start forming. This dot starts forming at the pixel indicated with a square around it in level 1, with the numeral 8.

The dot formation process continues, with the dot at this second pixel growing larger and larger as the levels again increase from level 1 to level 5. The formation process stops at level 5, since the pixel has now reached the value of 12. The halftone cell 30 now contains, as seen in Figure 4, a dot of dot-size 7, and a dot of dot size 5. The extension of this formation process to 57 gray levels is easy to see from this example. Thus, to form a cell of gray level 55 it will be noted that gray level 55 is at Level 6 in Figure 3. All pixel locations in cell 30 that are less than 55 in Level 6 are grown to dot-size 7, whereas the pixel at location 55 is grown to dot size 6.

The full dot type process thus involves forming dots in a cell at the highest priority pixels to their maximum allowable

dot-size before beginning the formation of the dots at the next highest priority pixels. An exemplary halftone dot mask 32 with pixel priorities indicated is shown in Figure 5. Different matrix sizes, cell shapes and priorities can be used for the cells than that illustrated in Figure 3, without departing from the spirit and scope of the present invention.

In the electrophotographic process, the full dot type formation process is favored because it forms stable dots and exhibits less granularity (halftone printing noise). Another method which carries more information detail than full dot, but at the cost of less stable dots, is the partial dot type, described below.

A 3-bit gray halftone dot layout for the partial dot type formation process is shown in Figure 6. In this process, the cell 34 is built by providing a dot of the same size to each pixel in the cell to the extent possible, before building up the dot at any particular pixel to the next larger size. Thus, for a gray level of 6 for the cell 34, the circled pixel in level 1 would have a dot formed at that pixel with a dot-size of 1, as would similarly pixel locations "2", "3", "4", "5" and "6". For larger gray levels, for example gray level 13, each of the pixels in the cell 34 would be built up to at least dot-size of 1. The pixels indicated with a square around them in level 2 would be built up to have a dot size of 2.

The partial dot formation process can thus be seen to spread out the information over the cell, and therefore carries more information detail than the full dot. It does suffer from less stable dots and more granularity, however.

The mixed dot type, discussed below, combines the merits of both the full dot and the partial dot types in gray level halftoning. A number of different processes can be provided to combine the full dot type and the partial dot type, with the specific mixed dot type being chosen based on which renders an image with more smoothness, less graininess, and more image details. Suggested strategies are: 1) build small stable dots in the highlight (toe) region; 2) keep tone response linear in the mid-tone region; 3) reduce dot structure in the shadow

(shoulder) region and render more details. Based on these considerations and the teachings herein, a specific mixed dot type can be chosen by one of ordinary skill in the art to optimize stable dots, more image detail and less graininess.

An example of a specific mixed dot type 3-bit gray halftone dot layout is illustrated in Figure 7. As can be seen, until gray level 41 is reached, the pixels are constrained from growing beyond dot-size of 5. The pixels grow in a full dot type process, with the pixel circled growing to a dot-size of 5, with the pixel that is squared then starting to grow in size. Once all of the pixels in the cell have attained a dot-size of 5, corresponding to gray level 40, the cell then increases in gray level by using a partial dot type process. In other words, each of the pixels in the cell must grow to a dot-size of 6 before any of the pixels begins growing to a dot-size of 7.

An example of a 4-bit gray halftone dot layout for mixed dot type is illustrated in Figure 8. The formation of the dots is the same in concept to that illustrated in Figure 7. Because there are 15 dot sizes available for each pixel, 121 gray levels for an eight element cell are obtainable.

In this 4-bits/pixel example of Figure 7, the highest priority pixel grows to dot-size 11 for corresponding cell gray levels 0 to 11. At cell gray level 12, the pixel of the next highest priority is then added and is of dot size 1. Similarly, for succeeding increases of cell gray level, the corresponding increases are made to the pixel of next highest priority until both said pixels are at gray level 11. Then further growth in cell density occurs by increasing the dot-size or density of the pixel at the third highest priority location and so on. When all pixels are at dot-size 11 (cell gray level 88) further increases in cell gray level are made by distributing the increases to the pixels in accordance with the growth pattern described for the partial dot approach.

Another type of rendering technique is a fixed threshold method. In this method each individual pixel is rendered with only limited tone scales. For example, 4 bits/pixel renders 16 different tone shades. The fixed threshold type renders the

highest resolution among the various types, and an edge can be rendered more accurately down to each pixel. The fixed threshold type renders an image with even higher sharpness than the partial dot type since it is not limited by the cell size as is the partial dot type. The problem with the fixed threshold type is that it has less tone scale, so that a false contour could easily be seen in the rendered image. However, the fixed threshold type will provide excellent rendering results on text and halftone originals.

Although any one of the three dot types (full, partial or mixed) couyld be used to produce a satisfactory continuous tone image, the mixed dot type is the best choice for continuous tone rendering. For scanned text and halftone, the full dot type creates a screen structure in the background of text and a Moire pattern in the halftone. The mixed dot type also creates a screen structure in the background of text and creates a Moire pattern in the halftone, though weaker than that created by the full dot type. As stated above, the fixed threshold type renders well on both text and halftone. The unified rendering technique of the present invention uses both fixed threshold type and mixed dot types according to local image content so that text, halftone and continuous tone images are all reproduced well.

A 4-bit mixed dot type thresholding mask is illustrated in Figure 9, while the fixed threshold type thresholding mask is shown in Figure 10. These thresholding masks are derived from a dot layout, such as shown in Figure 8 for the mixed dot type. (The dot layout for the fixed threshold type is not shown, only the derived thresholding mask).

The thresholding masks are derived from the dot layouts using a tone reproduction control chart, such as shown in Figure 12. The tone reproduction chart has four quadrants. The first quadrant (I) contains the input and output density of a specific tone reproduction curve, which specifies the gamma or the contrast of the image to be reproduced. The second quadrant (II) captures the characteristics of the gray level printing process. The fourth quadrant (IV) preserves the characteristics of the scanner, which converts the density to a gray value. The

third quadrant (III) maps gray values into gray steps linking the quadrants IV, I and II together.

To determine a thresholding mask value using this chart, the step number of the dot sequence in the dot layout of a cell is replaced by a gray value. For example, for step number 110 (found in threshold level 14 of Figure 8 for the mixed dot type) the mapping along arrows a, b, c, and d provides the gray value of 12. Similarly, for step number 5, the gray value maps to 224. (The values of the step number and the gray values are inversely related). In this manner, the thresholding masks of Figures 9 and 10 are derived.

An exemplary embodiment of a method for unified image rendering is illustrated in Figure 11. A document 10 is scanned in step 40, using the scanner 12 as shown in Figure 1. The controller 16 collects statistical information from each dot region (e.g. 4x4 pixels) in step 42. This statistical information can include contrast, variance, variation or roughness, for exAlthough any one of the three dot types (full, partial or mixed) coample. The contrast is defined as the difference between local maximum intensity and local minimum intensity. The variation is defined as the average of the intensity difference between the nearest neighboring pixels. Techniques for finding the contrast or the variation are well known to those of ordinary skill in the art.

The present invention determines in step 43 (Figure 11) whether the contrast or variance of a dot region is greater than a specified value in step 43. If the contrast or variance is greater than the value, a fixed threshold type dot is selected for that dot region (step 44), otherwise, a mixed dot is selected (step 46). Finally, the image is reproduced by the printer 18 in step 48, with the specific dot region rendered in either the selected fixed threshold type or mixed type dot.

Thus, in the present invention, a fixed threshold type dot is rendered for text and halftone, since text and halftone are usually higher contrast in nature. This will not cause the Moire pattern in the halftone and will produce a smooth text boundary.

The mixed dot, the best of the different dot types for continuous tone images, is rendered for the continuous tone region.

Collecting the statistical information and locally selecting the appropriate dot type from between a fixed threshold type and a mixed dot type provides superior reproduction of an image that contains different types of image regions, such as text, halftone and continuous tone regions.

Another exemplary embodiment of a method for unified image rendering is illustrated in Figure 13. This method is the same as that shown in Figure 11, except that if the contrast or variance is greater than the value, a partial dot is selected for that dot region (step 44), otherwise, a mixed dot is selected (step 46).

Thus, in this embodiment of the present invention, a partial dot is rendered for text and halftone, since text and halftone are usually higher contrast in nature. As with the fixed threshold type, the partial dot type will not cause the Moire pattern in the halftone and will produce a smooth text boundary. The mixed dot, the best of the different dot types for continuous tone images, is still rendered for the continuous tone region in this embodiment of the present invention.

Collecting the statistical information and locally selecting the appropriate dot type from between a partial dot type and a mixed dot type provides superior reproduction of an image that contains different types of image regions, such as text, halftone and continuous tone regions.

The unified rendition method described above achieves many quality goals to render a mixed type document. However, there are some noise problems associated in the halftone printing due to its rendered weak dots in the halftone picture. To stabilize the rendered dots in the halftone picture, a different screen structure is necessary to impose on the original halftone screen. However, this enhances the Moire pattern in the halftone picture. A compromise between the noise issues and the Moire pattern is necessary to minimize the problem in printing halftone pictures and other mixed types of images.

In accordance with another aspect of the invention, a method and apparatus for reproducing an original image scans an original image to

produce a digitized image, performs a local structure analysis of the digitized image and selectively applies a descreening filter to a region of the digitized image based on the results of the local structure analysis to remove a specific frequency of the digitized image caused by halftone screens. The descreening filter bypasses regions of the digitized image such that the bypassed regions remain unfiltered. The filtered regions and the bypassed regions are printed as a single, unified reproduction of the original image. This removes halftone screens from the image while maintaining the contrast of the text.

The approach of the present invention, a basic flow diagram of which is illustrated in Figure 38, further enhances the quality of the unified rendition method in dealing with a mixed type document. With reference now to Figure 38, a document is scanned in step 40, and this scanned document is processed through a descreening filter in step 42 which removes only a certain frequency caused by the halftone screen. The descreening filter can be resident in the scanner 12 or the controller 16 of Figure 1. The text blurring effects of this filter have been minimized for the specific designed filter characteristics.

A local structure analysis of the image is performed by the controller in step 44. The filter operation is applied selectively to the image region based on the results of this local structure analysis. The controller will not alter those pixels along the text border (see bypass 43) while it filters those pixels in a low contrast region and in a halftone dot region. In this way, the text contrast is maintained and the noise and the halftone screen are smoothed out. The processed image is then stored (step 46) and rendered later through the unified method (step 48) and printed (step 50).

The design of the filter will now be described with reference to Figure 39. First, a frequency spectrum is selected in which the frequency response needs to be achieved. For example, in the present invention, it is desired to boost a certain frequency region while smoothing out another frequency region in the 256x256 size spectrum because of the scanner modulation transfer function which needs to be corrected in this manner. This frequency spectrum has a real number representation instead of a conventional complex number (a real part and an imaginary part) representation.

Second, the filter modifies the frequency strength around some frequency spots of the desired frequency spectrum to a minimum (i.e., approaching zero response) in a continuous but sharp slope change. These frequency spots are the locations of the halftone screen frequency. Other frequencies will not be altered.

Third, this modified frequency spectrum is then applied to an inverse FFT (Fast Fourier Transform) back to the spatial domain where image processing is operated. It has now a complex number representation in the spatial domain. An mxn window near the center (i.e., low frequency response region) of the real part of the spatial spectrum is cropped out. This window size is the designed filter size, for example a 5x5 filter kernel size. Due to this window cropping operation, certain regions in the spatial domain were excluded, in other words, coefficients are set to zero outside of the window. This cropping will modify some of the response shape in the desired frequency spectrum. Hence several feedback loops between the second step and the third step of previous described method are performed to enforce the strength of the screen frequency to be removed to the minimum. A final m x n window in the spatial domain is then chosen as the kernel of the descreening filter. This filter, when operated on the image, will then remove the specific frequency generated by the halftone screens. However, this filtering operation will also smooth out some contrast of text (the blurring effects) to a certain extent.

In the image descreening operation (step 42 of Figure 38), the filter is convolved with image pixels to produce a result. During the convolution operation, a structure analysis in the current window (for example, 5x5 sizes) is taken to make a decision whether it will convolve the image pixels or not. The original pixel is output instead of the convolved result if there is a text structure in the operated window. Hence, some regions with text structures are maintained in the original pixel values while other regions with halftone structures are convolved with a descreening filter.

The present descreening invention makes a determination that a region is halftone or text, or is low or high contrast. Both text and halftone structure are high contrast, but their local structures are different. For example, text as normally presented has a high contrast

transition across its border. One side has a high pixel value while the other side (in vertical direction or in horizontal direction) has a low pixel value. If the pixel value difference from one side to the other side is greater than a certain threshold, it is determined to be a high contrast window. Otherwise, it is determined to be a low contrast window. If there is a consistent transition in the high contrast window such that one side has high values while the other side has low values, it is assumed that a text structure is in this window. If there is no consistent transition in the window and it causes a saddle point in the window, a halftone structure is assumed. This classification strategy based on the image structure makes about 95% - 98% of correct decisions on text. Only a few percentage errors are made which is due to a small font of text whose body has a similar size to the window. In this situation, the structure may not be clearly defined. However, this small percentage error does not cause a problem of blurring in the normal size of text. Hence, an original image can be reproduced so as to maintain its text contrast in the text region while its screen structure is smoothed out in the halftone region and some noise is filtered out in the low contrast region.

With reference now to Figure 40, there is shown a more detailed flow chart of the process of the descreening embodiment of the present invention. In step 60, a moving window (such as a 5x5 window) is established for the image, with the pixel being processed at the center of this image. In step 62, it is determined whether there is a large intensity difference in the window. If there is not a large intensity difference, then the windowed region is a low contrast region, so that a smoothing filter operation to remove noise is applied in step 64, and these filtered pixels are provided to step 74 to be stored (compressed), rendered, and printed. A simple smooth filter that can be used is a weighted average operated with 3x3 or 5x5 window size.

When a large intensity difference is detected in step 62, the window is determined to be a high contrast window. The consistency of the transition within the window around the central pixel is then evaluated in step 66. If there is a consistent transition, then the window is considered to contain text structure and the original pixel is provided as an output in step 68.

When there is not a consistent transition in the window around the central pixel, the structure in the window is considered to be halftone structure, and the 5x5 descreening filter is applied to remove the screen in step 70. Briefly stated again, in the filtering operation, the image is Fourier transformed into the frequency domain and then some specific frequency content (such as 133, 150, or 200 lines per inch or respectively 5.24, 5.91 or 7.87 lines per mm screens) are removed. This modified Fourier image spectrum is then transformed back to the spatial image domain to complete the removal of the halftone screen. After being descreened, the image pixels are provided to step 74 for final processing.

The design of the descreening filter can be performed "on-line" as indicated by step 72, or it can be already provided. However, this is computationally slow, and it is preferred to operate the filter design off-line and only perform convolution in the halftone window structures on-line.

A simplified block diagram illustrating the gray scale rendering process is provided in Figure 29 and reference will now be made to elements described in Figure 29. Eight-bit image data is input to the digital halftone process block 60, which also receives signals relating to a calibrated thresholding mask that is created. The tone reproduction block 62 performs the 40-quadrant mapping illustrated in Figure 12 to create a threshold pattern such as shown in Figure 9 and described below. The tone reproduction block receives as inputs the desired tone response curve, the gray steps density measurements, and the scanner converstion and generates a mapping from step number to gray code value output as the calibrated thresholding mask.

The digital halftoning process block 60 converts the input pixel value into output exposure levels through the thresholding value setting at each pixel location in the cell. This can be implemented by a SRAM 64 lookup table that receives the thresholding mask. An image with a reduced bit-depth of four bits in the output of the digital halftoning process block 60. The 4-bit image is provided to a framestore and can then be printed by a 6-bit gray scale printer. (Other information such as 2-bit

pixel classification information can be added to the 4-bit image data from the framestore.)

The generation of the threshold mask will now be described. A 4-bit mixed dot type thresholding mask is illustrated in Figure 9. This thresholding mask is derived from a dot layout, such as shown in Figure 8 for the mixed dot type, using the tone reproduction control chart, as shown in Figure 12. The tone reproduction chart has four quadrant. The first quadrant (I) contains the input and output density of a specific tone reproduction curve, which specifies the gamma or the contrast of the image to be reproduced. The second quadrant (II) captures the characteristic of the gray level printing process. The fourth quadrant (IV) preserves the characteristics of the scanner, which converts the density to a gray value. The third quadrant (III) maps gray values into gray steps linking the quadrants IV, I and II together.

To determine a thresholding mask value using this chart, the step number of the dot sequence in the dot layout of a cell is replaced by a gray value. For example, for step number 110 (found in dot level 14 of Figure 8 for the mixed dot type) the mapping along arrows a, b, c, and d provides the gray value of 12. Similarly, for step number 5, the gray value maps to 224. (The values of the step number and the gray values are inversely related). In this manner, the thresholding masks of Figure 9 is derived.

The thresholding mask is used to determine what the gray level of an output pixel should be given corresponding to its input pixel gray value. Assume, for example, that the input image pixel at location (1,1) of the 4x4 matrix cell of Figure 9 has a gray value of 56. The 15 thresholding values at the (1,1) location of the 4x4 cell are:

71, 69, 66, 64, 61, 59, 57, 54, 53, 51, 50, 49, 19, 12 and 9.

Since the input image pixel has a gray value of 56, which is between the two threshold values 57 and 54, the output gray level 7 is given to that pixel.

The layouts described above used a 4x4 cell template, and renders a picture with a 45 degree orientation, 141 screen frequency with 121 gray levels. The present invention provides a screen layout using a 6x6 cell template which will render a picture with 45 degree, 189 lines per inch (7.44 lines per mm) type screens at 400 dpi (15.74 dots per mm) resolution, and can produce a maximum of 181 gray levels for the 4-bit image, although it will normally render 156 gray levels. The increase in the number of gray levels and the higher screen frequency provide the present invention with successful picture rendering results.

In the electrophotographic process, a stable latent image structure needs to be formed. Accordingly, in another aspect of the present invention, several gray levels at first contribute so as to stabilize the line structure, as can be seen in the following.

Figure 14 graphically depicts the basic process for constructing the dots. The dots, according to a set of templates, such as those shown in Figure 15, are built in a line-type structure. The selection of how many gray levels are used with the first template is based on the printing process characteristics in which the dots start to form a stable line structure instead of a dust appearance. An exemplary embodiment of the present invention uses the gray level of 5 for the initial line build-up, and indicated by template A of Figure 15. Thus, for gray level one, plural dots of size 1 are laid down along lines according to the arrangement of template A. Similarly, for the next increment in gray level up to gray level 2, the dots are laid down along lines also according to the arrangement of template A, but are all of size 2. The template A arrangement for growth is similarly used for growth to successive gray levels up to gray level 5. The process continues by building multiple pixel dots at each gray level on top of the line structure so as to produce a more stable line structure that has a smoother shade gradation. This step uses templates B and C to build the dots.

Once the one-pixel-width line structure has been completed, construction of the other lines for higher gray levels begins according to the templates D and E. This can continue until the pixel dots fill up the cell (level 155).

Figure 16 provides an example of a 189 lines per inch, gray scale dot sequence with indicated level numbers. In this example, there are 16 levels for each dot (15 levels and zero) because there are 4 bits/pixel. The pixels are arranged in 6x6 blocks. The formation of the dots follows the same process as already described with respect to Figures 3, 6, 7 and 8 for different layout designs. An example of the exposure levels for the cell at gray level 100 is shown in Figure 17. This exposure level is found in level 8 of Figure 16. There are a number of pixels that have been built up to exposure level 12, and those pixels that have number 100 at level 8 are indicated in Figure 17 with exposure level 8. Those pixels in Figure 17 that have exposure levels of 7 correspond to those pixels in Figure 16, level 8 that are greater than 100, and so have not reached level 8 exposure yet.

From Figure 17, showing an example of the exposure levels at gray level 100, the line structure constructed with the dot layout design of the present invention is revealed.

Description will now be made of still another embodiment of the present invention. With reference to Figures 18-22, it has been found experimentally that if it is assumed that:

$R = R_p + A_D\{ f(t) - R_P\}$, where R_P is the reflectance of the paper base, A_D is the toned dot area/unit area and f(t) is the reflectance of the toned area as a function of exposure time (t) for a continuous tone patch and R is the reflectance of the halftone patch, then for more than 5 pixels in a cell that are turned on, A_D approaches 1 (the continuous tone case). This assumption is true only for a mixed dot of a specified type of 141/inch screen (at 45 degree angle) with a 400 dpi system. If the number of pixels within a cell (assume one cell has 8 pixels in this case) that are turned on

is less than 5, then $A_D < 1$ and A_D increases from 0 to 1 with respect to a function that is related to the perimeter of the dot/unit area.

This indicates that with a lower number of pixels turned on in a cell, A_D (the dot area) increases and f(t), which is related to the density within a pixel, decreases as a function of exposure t. If the number of pixels within a cell that is supposed to be turned on in a gray level mixed dot is more than 5, then the halftone behaves like a continuous tone system. In other words, $A_D = 1$ and R almost follows the predicted curve of f(t) for a continuous tone system (see Figure 18). However, when using a mixed dot type, the lightness vs. exposure time curve exhibits non-even lightness jump in some steps (Figure 19). If the unevenness of the lightness jump is too much, this is noticed in contouring. Accordingly, this aspect of the present invention uses a different set of exposure times (in each gray level) for pixels that are isolated in a cell (a "low density region") than those pixels that are grouped together with other pixels in a cell (a "high density region").

The printhead of the printer 18 (Figure 1) may be a 6 bits/pixel gray level printhead. This may provide 40 uniformly corrected gray levels per pixel. In the present invention, only 3 bits or 4 bits per pixel are used to identify the gray level image data of the pixel so as to provide a device independent approach in printing. By using the halftone structural information, it is possible to produce a more even lightness jump between steps.

Figure 20 illustrates a flow chart for converting the device independent 4-bits/pixel image data to 6 bits/pixel gray level exposure time (or intensity) data (see in this regard, WO 91/10311). In addition to the 4 bit/pixel image data received from the frame store 17 in step 50, the printer 18 receives 2-bit classification information that identifies which pixel location and line location inside a halftone cell is being addressed. This information is generated by a classifier in step 52 which essentially indicates whether the pixel is in

the center of a cell or on the periphery of the cell by the generation of a 2-bit sub-address.

The 2-bit sub-address containing structural information is combined with the 4-bits of image information to act as an address for a 40 levels/pixel look up table (LUT). The printhead pixel location in the line is provided to address which one of the 4992 pixels in a full wide printhead for which the pixel is supposed to extract the 40 levels of information. The output from the LUT is 6 bits/pixel printer information that is sent to the printhead in step 56. Although the above description assumes that the classification and the LUT are resident on the printer 18, it should be apparent to one of ordinary skill in the art that this process can also be performed by the controller 16 (Figure 1).

Figure 22 illustrates another embodiment of the method of the present invention. Instead of using the single LUT 54 of Figure 11, two LUT's are used. The first LUT 55 is a non-uniformity brightness LUT (8K bytes). The second LUT 53 is a 14-bit address LUT that provides the correct exposure for each pixel when provided with gray value input and position classifier input. The non-uniformity LUT 55 can be an 8K byte SRAM, for example.

The brightness of the LED elements is sorted into 256 "bins" so that a better usage of the non-uniformity range of an LED is used. The pixel counter points to each individual element which then outputs its brightness bin (1 of 256). This eight-bit brightness bin acts as an index pointer to the 14-bit LUT 53, which can be a 14-bit x 8 SRAM ~ 16K bytes LUT. The 14-bit LUT 53 has the rest of the LUT address (6 bits) from the 4-bit gray levels input and the 2-bit position classifier. Although there are theoretically 64 levels for each pixel, due to the nonuniformity of the printhead, there are only approximately 40 real levels that exist after non-uniformity correction for some elements.

An example of a classifier is shown in Figure 21, which illustrates a 4x4 classifier 60. In this example, there are 3 designated classes of pixels within a cell. The first

class is a pixel within the center of a cell (1). The second class are those pixels which surround the center pixel (2). The third class are those pixels which may overlap pixels in the surrounding halftone dots (3). The 2-bit sub-address provides information sufficient for three classifications.

Class 3 pixels are essentially very much like continuous tone, so that one can use the exposure times for the continuous tone curve for exposure (the 8 pixels curve) that was illustrated in Figure 18. For the single pixel of class 1, it is better to use a higher exposure time, such as the 1 pixel curve of Figure 18, to achieve the same lightness change. For the pixels of class 2, the effect is made more intermediate, near the 4 pixels curve of Figure 18. These exposure values are stored in the LUT, so that once the pixel location in a halftone cell is classified by the classifier, a different exposure level is provided by the LUT to achieve a more even halftone lightness jump.

As an example, for a pixel of class 1, the exposure level may be (a). If the pixel next to the first one is class 2, and would have an exposure level of (a) if standing alone, this second pixel of class 2 will be assigned an exposure level of (b), which will be lower than (a), to achieve an equivalent change in lightness in the halftone. When all the pixels in a cell have been classified and provided with an exposure level based on that classification within a cell, there will be 16 equivalent gray level outputs per pixel irrespective of the pixel location in the gray level halftone cell. These 16 equivalent gray levels have been provided from the 40 available levels after the correction for the location of the pixel in the cell.

In accordance with still another aspect of the invention, the approach of still another embodiment of the present invention has reduced the bit-depth from 8-bits to 4-bits, so that a compression or data packing is achieved. This rendition goal, however, is not the same as that of data compression. In data compression, it is mainly for storage/transmission purposes which later expand the

compressed image to the original image form without visual loss of information. The result of data packing in the multi-bit rendering of the present invention benefits the throughput of the system and the bandwidth of the data transfer.

The present invention extends the dispersion dot type which is often used in binary halftone rendering to a multi-bit dot pattern. For gray scale printing, the gray scale dot designs "full", "partial", and "mixed" dot types have been defined above. Each dot type has its own tonal characteristics and texture patterns. With the proper choice of dot template (i.e., the optimal Bayer dot pattern or the cluster dot pattern), pixel bit-depth (i.e., 4-bit or 5-bit per pixel), and the "partial" dot type structure, a set of gray dot patterns is generated that will create a continuous tone look image.

For example, a Bayer dispersion dot template is illustrated in Figure 23, and the 4-bit partial dot pattern set gray dot pattern in Figure 24. The thresholding pattern for gray scale rendering obtained from the patterns of Figure 24 by the 4-quadrant tone reproduction process are illustrated in Figure 25. Another example, a cluster dot pattern dot template is illustrated in Figure 26, and the 4-bit partial dot pattern set gray dot pattern in Figure 27. The thresholding pattern for gray scale rendering obtained from the patterns of Figure 27 by the 4-quadrant tone reproduction process are illustrated in Figure 28.

The generation of the threshold mask patterns of Figures 25 and 28 will be described. These thresholding masks are derived from the dot layouts, such as shown in Figures 24 and 27, respectively, using a tone reproduction control chart, such as shown in Figure 12. The tone reproduction chart has four quadrants. The first quadrant (I) contains the input and output density of a specific tone reproduction curve, which specifies the gamma or the contrast of the image to be reproduced. The second quadrant (II) captures the characteristic of the gray level

printing process. The fourth quadrant (IV) preserves the characteristics of the scanner, which converts the density to a gray value. The third quadrant (III) maps gray values into gray steps linking the quadrants IV, I and II together.

To determine a thresholding mask values of Figure 25 using this chart, the step number of the dot sequence in the dot layout of a cell is replaced by a gray value. For example, for step number 110 (found in dot level 7 of Figure 24 for the partial dot pattern) the mapping along arrows a, b, c, and d provides, in this example, the gray value of 145 (not shown in Figure 12 but see Figure 25, level 7). Similarly, for step number 5 (found in dot level 1 in Figure 24), the gray value maps to 250 (not shown in Figure 12 but see Figure 25, level 1). (The values of the step number and the gray values are inversely related). In this manner, the thresholding masks of Figures 25 and 28 are derived.

The thresholding mask is used to determine what the gray level of an output pixel should be given corresponding to its input pixel gray value. Assume, for example, that the input image pixel at location (1,1) of the 4x4 matrix cell of Figure 25 has a gray value of 125. The 15 thresholding values at the (1,1) location of the 4x4 cell are:

250, 234, 218, 202, 186, 170, 154, 138, 122, 106, 90, 74, 58, 42 and 26.

Since the input image pixel has a gray value of 125, which is between the two threshold values 138 and 122, the output gray level 8 is given to that pixel.

A digital halftoning process (or "gray scale rendering process") converts the image into a multi-bit image representation with the thresholding values of either Figure 25 or Figure 28, depending on which dot template is used. This multi-bit image has a continuous-tone look structure with a weak dot screen imbedded in it. A continuous-tone look image is then reconstructed from the multi-bit rendered image through a gray scale printer. The constructed images have no visual screen structure. Hence, a continuous tone

picture printing is achieved through the multi-bit image rendition method.

A simplified block diagram illustrating the gray scale rendering process of the present invention is provided in Figure 29. Eight-bit image data is input to the digital halftone process block 60, which also receives signals relating to the calibrated thresholding mask that has been created as in Figures 25 and 28. The tone reproduction block 62 performs the 4-quadrant mapping illustrated in Figure 12 to produce threshold masks from the dot layouts. The tone reproduction block receives as inputs the desired tone response curve, the gray steps density measurements, and the scanner conversion, and generates a mapping from step number of a dot layout to a gray code value output of the calibrated thresholding mask.

The digital halftoning process block 60 converts the pixel value into output exposure levels through the thresholding value setting at each pixel location in the cell. This can be implemented by a SRAM 64 lookup table that receives the thresholding mask. An image with a reduced bit-depth of four bits is the output of the digital halftoning process block 60. This 4-bit image is provided to a framestore and can then be printed by a 6-bit gray scale printer. (Other information such as 2-bit pixel classification information, can be added to the 4-bit image data from the framestore).

With the above described process, an image that looks like a continuous tone picture is provided using a reduced (4-bits) image representation and gray scale printing.

The electrophotographic printing process involves: electrostatically charging, exposure, developing (or toning), transfer to a receiver sheet such as paper or plastic, and image fixing stages. Due to its unique toning process which is based on the differential electrostatic force generated by the charge potential on the latent image, a well (i.e, satisfactorily) formed cluster type of charge-potential-well is

advantageous for developing a stable dot. Such a well (i.e., satisfactorily) formed potential-well is already built in to the mixed-dot and the full dot types of dot designs described above. Hence, the rendered images are visually less grainy. However, it is not true as an image rendered through the partial dot structure. The image looks grainy. This is because there is no such well formed charge-potential-well for the partial dot structure on the latent image to stabilize the dot. There is a similar effect in error diffused gray scaled images. Therefore, an imbedded controlled dot structure in error diffused gray scale image or partial dot rendered image will stabilize the dot. Furthermore, the imbedded structure can be in either dot form or line form. The rendered images are more pleasing with the controlled structures added in.

In accordance with a further aspect of the present invention, there is an error diffusion algorithm, for example, to illustrate one method of imbedding dot structure in gray scale images during the rendering process. A number of known different error diffusion algorithms could be used in the present invention, such as shown in "An Adaptive Algorithm for Spatial Gray Scale", by Flord and Steinberg, Proc. SID, Vol. 17/2, pp. 75-77 and "Digital Halftoning" by Ulichney. Accordingly, the specifics of an error diffusion algorithm will not be further described here.

In the first step (50 in Figure 30) of the method of said further aspect of the present invention, the screen frequency and the angle are determined in order to decide what are the imbedded dot structures; i.e. which dots are the dots which will be stabilized. This can be as simple as a periodic screen structure in dot or line form. The structure could be, for example, 45 degree lines with 141 lines-per-inch screens at 400 dpi resoluition. Hence, when the current pixel is along these lines, this dot is determined to be a dot that is to be stabilized. Such a determination of pixels that will be stabilized is easy to perform in pixel processing. The imposed screen structure can be selected by a designer, but

should not be distracting when viewing. Therefore, the periodicity or a template can be determined that is similar to the dot design procedure of a normal halftoning method.

In the next step (52), during the error diffusion process, it is determined for a corresponding location on the template of a current pixel whether a controlled dot should be laid down or not. If a controlled dot should be layed down, the current pixel value will be lowered proportionally according to its intensity value. Otherwise, it will proceed normally as error diffusion does by jumping to step 58 and use the normal error diffusion process on the current pixel. With the partial dot method (as shown in dashed lines), if a controlled dot should not be laid down, step 60 is performed so that gray scale rendering process such as that shown in Figure 29 is used on the current pixel.

The purpose of the adjustment on those specific locations is that on this current pixel, more light will be exposed (i.e., the pixel-dot will be slightly darker in the Neg/Pos electrophotographic process) than its original. This current pixel then will act as a stabilized center for the neighboring rendered pixels. The amount of adjustment on each pixel could be determined experimentally from the process latitude (i.e., it may be adjusted in two or few more exposure steps on those specific locations according to the process). The amount of the adjustment is dependent on the process conditions such as the toner size, developing potential, photoconductor characteristics, etc. Since the main factor in the toning and transfer process is the electrostatic force mechanism, a larger potential difference created between the pixels is advantageous to stabilize the developing dot and provide an easier transfer.

Experimentation has indicated that a 3 to 6 exposure level difference stabilizes the developed dots. Also, the difference of the exposure level may vary with respect to exposures so that a larger difference of exposure is set at lower exposures. For example, if the mean exposure is at level 3 or 4, the controlled pixels should be adjusted to

exposure level 9 or 10. However, when the mean exposure is at level 9 or 10 the controlled pixels should be adjusted only to exposure level 11 or 12.

As the error diffusion process continues, in step 54, the further introduced error on that specific (the current) pixel will then be distributed to its neighborhood pixels to balance the specific pixel. Since this adjustment will not change the total tone value but redistributes it as the error diffusion does, the imbedded dot structure is carried naturally in the gray scale error diffusion image. This added dot structure provides a stabilized center on the latent image and improves the toning development process in the electrophotographic printing.

Similarly, this imbedded controlled dot structure can be utilized to the partial dot structure described earlier or other dot structures without a stable dot center in the image.

An example of a 6x6 cell subjected to gray scale error diffusion according to the present invention is illustrated in Figure 31. The shaded pixels, with higher exposure levels, are the controlled pixels that are to be stabilized. In the 6x6 cell shown on the left without stabilization, there are no large exposure differences among the pixels. The exposure at each pixel is scattered among levels 8, 9 and 10, so that there is no well formed structure in the cell.

By contrast, the cell on the right of Figure 31 after dot stabilization provides a stable dot structure for developing the flat field, and appears as a screen imposed on top of the 6x6 cell.

In accordance with still another embodiment of the invention, a method and an apparatus is provided for reproducing an original image that has one or more different image type regions. A controller operates a gray level printer in a default mode when the original image contains a text region or a halftone region. This default mode includes either contour suppression applied to every pixel of the original image or uses an output screen that is a higher

frequency than the frequency of a screen of the original image.

With photographic input and digital scanning at 400 dpi, successful gray level halftones at 141/inch screen (45 degree) of the mixed dot type may be produced to represent output images with a gray level printing system at 400 dpi output resolution. The gray level halftone is tuned to balance between the visibility of the fundamental screen and the granularity of the system for a particular process. In this an exemplary embodiment, 12 microns toner with electrostatic transfer is used. A power spectrum of an output print of a 0.8 black density patch with full dot type is shown in Figure 32. As one can see, the fundamental frequency at 141/inch screen is very prominent but the granularity is low. At the other extreme, the power spectrum of an output density patch (at a similar density to the full dot) of a partial dot type is shown in Figure 33. In this figure, the fundamental frequency is no longer very prominent, yet granularity is higher (due to a change in the plotting scale, it is difficult to see the granularity change, but this change is indicated by the data). A compromise is made with the mixed dot halftone as shown in the power spectrum of Figure 34 which has a significant reduction of the fundamental frequency and yet is very similar in granularity to that of the full dot type.

What can be concluded from Figures 32-34 is that for large toner particle size, a fundamental screen frequency is desirable to stabilize the system and reduce granularity. But when reducing the visual sensation for the screen (to make the system more continuous tone like), one wants to have a weaker screen. Also if the input is a halftone screen itself, it is desirable to have a weak output screen (or no screen at all), so as to reduce moire effects.

For continuous tone input, the output images using the mixed dot type with a 141/inch screen (45 degree) exhibit a fine balance between sharpness, granularity and screen texture. However, if the input to the scanner is a halftone (in

this case a 150/inch screen picture), then using this output screen (which is good for continuous tone pictorial input) will create a strong moire pattern. Furthermore, if the input is high quality text and graphics, the 141/inch may break up the fine structures and may not be desirable.

Therefore, for digital copying, the situation can be summarized as follows. For photographic continuous tone input, it may be desirable to have a photographic mode which reduces granularity and stabilizes the system with a 141/inch screen. This screen has the advantages of lower grain, higher sharpness, a weak screen and a stable process. The disadvantages include moire patterns with halftone inputs, and broken lines for fine line graphics and text. One may therefore program the controller to provide a default mode for the digital copier which will be able to handle halftone input, text/graphics input and continuous tone input reasonably well. There are many approaches to providing a default mode. One method is segmentation and descreening, which requires extensive pre-processing and text/picture/halftone segmentation in real time. A second method uses gray level error diffusion and provides high resolution scanning and no more for halftone input.

This aspect of the present invention provides two different methods for providing a default mode that produces satisfactory images for each of the different image types. The first of these is termed "contour suppression/pixel" and the second is termed "higher screen frequency".

The contour suppression/pixel method of providing a default mode is shown in Figure 35. In this method, contour suppression is applied to every input pixel. For example, assume that there are 16 gray levels (4 bits) within one pixel and the input data value is just at gray level 3. Then gray level 3 will have a 50% probability to be on, but gray levels 4 to 16 will have a 100% probability to be on and gray levels 1 and 2 will have a 0% probability to be on. When a halftone input (150/inch screen) is used in this case with a 400 dpi gray level writer, the moire is reduced significantly.

Here the original halftone is in fact stabilizing tone reproduction with this per pixel contour suppression method.

The contour suppression/pixel method will be further explained with an example below. The generation of a threshold mask has been described with regard to the 4-bit mixed dot type thresholding mask illustrated in Figure 9. This thresholding mask is derived from a dot layout, such as shown in Figure 8 for the mixed dot type, using a tone reproduction control chart, such as shown in Figure 12. Assume, for example, that the input image pixel at location (1,1) of the 4x4 matrix cell of Figure 9 has a gray value of 56. The 15 thresholding values at the (1,1) location of the 4x4 cell are:

71, 69, 66, 64, 61, 59, 57, 54, 51, 50, 49, 19, 12, and 9.

Since the input image pixel has a gray value of 56, which is between the two threshold values 57 and 54, the output gray level 7 would be given to that pixel in the method previously described. Hence, that input image pixel with value 56 at location (1,1) will have a probability of gray level 7 being on of 100%. Similarly, the same output gray level 7 would also be given to an image input pixel with a gray value of 55 using the method previously described. In the present aspect of the invention, however, contour suppression does not involve assigning 100% probability to all pixel values in between the thresholds. Instead, the probability is made proportional to the difference of the pixel value relative to the thresholds. For example, the value 56 will not have gray output level 7 all of the time. If the probability is set to 80%, then this pixel will be output with gray level 7 80% of the time, and with gray level 8 20% of the time.

This method of contour suppression, which does not fix the probability of a specific gray level being on at 100% for values between thresholds, but rather makes it a function of the difference of the pixel value relative to the thresholds, delivers more accurate tone and eliminates false contouring due to large differences between threshold values.

The contour suppression/pixel method used on scanned in text also shows high resolution. Therefore the system should be able to preserve images whether it is a halftone input or high resolution text/graphics input and has been going through the copying process more than once (recopying). However, if the method is used on continuous tone input, the output can be grainy. In this case, the contour suppression scheme does reduce density contouring compared with a straight threshold value matrix in gray level printing. Further improvement includes passing the original image through an 8 bits to 4 bits conversion type of Bayer matrix to give the system more gray levels, thereby eliminating contour suppression.

The second method of the present invention uses a higher output screen such as a 282/inch or 11.10/mm (45 degree screen) shown in Figure 36 or a 200/inch or 7.87/mm (90 degree screen) shown in Figure 37 with gray level printing. As the output screen stays at a frequency far away from some of the more popular magazine type screen frequencies (133/inch, 150/inch), a moire pattern generated due to the frequency beating of the input and output screens will go to a higher frequency. The moire pattern thus generated will therefore be less observable than the moire created by two frequencies that are close to each other, like 141/inch and 150/inch screens. Also, the moire pattern from a halftone input image can be further reduced if the strength of the output screen is lessened (e.g., by a partial dot as in Figure 33 or a mixed dot as in Figure 34). Of course, a balance is made between reducing the moire and the granularity that is generated from a continuous tone image with a certain toner size. In any event, the granularity for these higher screen systems with continuous tone input would still be better than that of just contour suppression on each pixel since a weak screen is provided to stabilize the system. Contour suppression on the halftone may still be necessary for a high screen in order to generate enough gray

levels to reduce contouring. Text screening at 282/inch screen has also been shown to be quite satisfactory.

The above two methods provide a default mode for universal color document digital copying in addition to a photographic mode which can produce very good output with photographic input. Namely, the default mode will preserve text/graphics, halftone with the least moire and reasonable photographic pictorial inputs. Although the default mode can reproduce photographic input reasonably well, it is preferred that this default mode be supplemented by a photographic mode which deals with continuous tone input very well.

Although the invention has been described and illustrated in detail, it is to be clearly understood that the same is by way of illustration and example, and is not to be taken by way of limitation. The scope of the present invention are to be limited only by the terms of the appended claims.

WHAT IS CLAIMED:

1. A method of producing a gray level image, comprising:

controlling a gray level printhead such that the printhead forms dots of variable dot sizes on a recording medium at plural pixel locations, the pixel locations being grouped into cells having cell gray levels, wherein a characteristic of the dots of a cell are determined such that for each increase in cell gray level, a dot at at least one of said pixels in the cell forms a larger dot-size.

2. The method of claim 1 and wherein the sizes and locations of dots at the pixels in the cell grow in accordance with an order such that each dot is formed to a first dot-size, larger than a minimum dot size but less than a maximum dot-size before beginning the formation of a dot at another pixel within the cell.

3. The method of claim 2 and wherein when all of the dots have been formed to the first dot-size corresponding to a specific cell gray level, providing further sequential increases in cell gray levels by correspondingly sequentially increasing the dot-size of each of the dots to a second dot-size, to provide corresponding increases in cell gray levels by distributing said increases successively to different pixels in the cell.

4. The method of claim 1 and sequentially forming the dots at the pixels in the cell in a predefined order such that, with successive increases in gray level, each dot is formed to a maximum dot-size before beginning the for mation of a dot at another pixel within the cell.

5. The method of claim 1 and including

collecting statistical information of dot regions from a digitized image signal;

for each dot region of the digitized image signal, selecting a dot type to render that cell dot region in accordance with the statistical information, the cell dot type being either a mixed dot type or a fixed threshold type.

6. The method of Claim 5, wherein the statistical information collected for a dot region includes information relating to at least one of contrast, variance, variation or roughness for that dot region.

7. The method of Claim 6, wherein the fixed threshold type is selected for dot regions in which the contrast or variance is above a specified value, and the mixed dot type is selected for dot regions in which the contrast or variance is below a specified value.

8. The method of claim 1 and including

collecting statistical information of dot regions from a digitized image signal;

for each dot region of the digitized image signal, selecting a dot type to render that cell dot region in accordance with the statistical information, the cell dot type being either a mixed dot type or a partial dot type.

9. The method of Claim 8, wherein the statistical information collected for a dot region includes information relating to at least one of contrast, variance, variation or roughness for that dot region.

10. A method of printing using a dot matrix printer comprising:

analyzing information about a dot region from an image signal representing gray level pixels forming the dot region;

for each dot region of the digitized image signal, selecting a dot type growth pattern to render that dot region in accordance with the analysis, the dot type growth pattern being either a mixed dot type or a different dot type than said mixed dot type.

11. The method of Claim 10 wherein the information for a dot region includes at least one of contrast, variance or roughness for that dot region.

12. The method of Claims 9 or 11 wherein a fixed threshold type is selected for dot regions in which the contrast or variance is above a specified value and the mixed

dot type is selected for dot regions in which the contrast or variance is below a specified value.

13. The method of Claims 11 and wherein either of a partial dot or fixed threshold type is selected for dot regions in which the contrast or variance is above a specified value and the mixed dot type is selected for dot regions in which the contrast or variance is below a specified value.

14. The method of any of Claims 1 through 13 and including the step of scanning an original image and generating a digital signal representing the scanned image.

15. The method of any of Claims 1 through 14 and including printing of the image using a non-impact printer that creates pixels of different dot sizes.

16. The method of claim 1 and including

scanning and digitizing an original image into pixels;

arranging the pixels of the digitized image into cells;

controlling a gray level printer to form dots of at least three gray level dot sizes along lines in accordance with at least a first template corresponding to increasing cell gray levels until a first line structure is stable and controlling the gray level printer to form dots of at least three gray level dot sizes along lines in accordance with at least a second template corresponding to further increasing cell gray levels.

17. The method of Claim 16 wherein the pixels are grouped into a cell having 6x6 pixel locations, and the dots are capable of forming to one of fifteen different dot sizes.

18. The method of claim 1 and including

scanning and digitizing the original image into pixels;

processing the pixels by cells, each of plural pixels, wherein in accordance with at least one template, a halftone cell of one gray level is defined as having a first line structure that is stable before beginning formation of an additional line within a cell corresponding to an increased cell gray level;

producing a first signal corresponding to a gray level halftoned representation of the original image; and

in response to said first signal controlling a printer to produce at least three gray level dot sizes to form a gray level halftoned reproduction of the original image.

19. The method of Claim 18 and including controlling the processing of the pixels with at least two templates, with pixels being assigned along lines defined by a first of said two templates corresponding to increasing cell gray levels until said first line structure is stable, and then assigning pixels along lines defined by the other of said two templates corresponding to increasing cell gray levels.

20. The method of Claims 18 or 19 and including processing the pixels into a 6x6 cell of pixels, wherein fifteen different levels of dots are available for assignment at each pixel in the cell.

21. The method of Claim 19 and wherein in accordance with the first template, dot sizes are increased simultaneously at plural pixel locations along a first line in a cell when the cell gray level is increased from one gray level to a second and next succeeding gray level.

22. The method of Claim 21 and wherein in accordance with the first template, the plural pixel locations are contiguous.

23. The method of Claim 21 and wherein in accordance with the first template, all pixel locations along the first line grow simultaneously from the one cell gray level to the next succeeding gray level.

24. The method of Claim 23 and wherein in accordace with the first template, pixel locations along plural parallel first lines in the cell grow simultaneously from the one cell gray level to the next succeeding cell gray level.

25. The method of Claim 24 and wherein in accordance with a second template, every second pixel location along the first line grows in dot size simultaneously upon an increase from a third all gray level to a fourth next succeeding all gray level.

26. The method of claim 25 and wherein in accordance with a third template, every third pixel location

along the first line grows in dot size simultaneously upon an increase from a fifth cell gray level to a sixth cell gray level.

27. The method of Claim 26 and wherein in accordance with a fourth template, dots are formed along a second line of pixel locations contiguous to pixel locations on the first line.

28. The method of claim 1 and wherein

a cell of one gray level is defined in accordance with a template such that plural contiguous pixels along one line in the cell are of one dot size and a cell of a next succeeding gray level has said plural contiguous pixels of a next succeeding dot size; and printing the image using plural dot sizes to form a gray level halftoned reproduction of the image.

29. The method of claim1 and including

scanning an original image to produce a digitized image, said digitized image containing a plurality of pixels;

grouping the pixels into cells;

classifying the pixels in each cell into one of at least two classes;

modifying an exposure level for printing said pixels according to said classification;

printing said pixels according to said modified exposure levels to reproduce the original image.

30. The method of Claim 29 and wherein the step of classifying includes classifying the pixels of a cell into a first class which includes a central pixel of the cell, and a second class which includes pixels which surround the central pixel.

31. The method of Claim 30, wherein the step of classifying includes classifying the pixels of the cell into a third class which includes pixels which may overlap pixels in surrounding cells.

32. The method of Claim 31, wherein the pixels of the first class are modified to have a higher exposure time, the pixels of the second class are modified to have an

intermediate exposure time, and the pixels of the third class are modified to have a lesser exposure time.

33. The method of Claim 29, wherein the step of classifying includes producing a classifying signal indicating a position of a pixel within a cell.

34. The method of Claim 33, wherein the step of modifying an exposure level includes receiving at inputs of a lookup table (LUT) device image data relating to exposure of a pixel of a cell and said classifying signal for that pixel, said LUT providing a modified exposure level for that pixel.

35. The method of Claim 29 and wherein the cells have a mixed dot density growth pattern.

36. The method of claim 1 and including

scanning an original image into pixels having determined pixel values;

comparing said pixel values to a set of thresholding values that are defined by a 4-quadrant tone reproduction analysis using a dot template, selected bit depth and dot type structure;

producing a first signal corresponding to a gray level halftoned representation of the digitized image using the thresholding values; and

printing from the first signal a gray level halftoned reproduction of the original image.

37. The method of Claim 36, wherein the dot template is one of a Bayer dot pattern or a cluster dot pattern.

38. The method of Claim 36, wherein the pixel bit-depth is one of 4 bits or 5 bits.

39. The method of Claim 36, wherein the dot type structure is a partial dot type structure.

40. An apparatus for reproducing an original image, comprising:

a scanner which scans the original image and generates first signals representing said original image as pixels of different gray level values;

a controller coupled to the scanner and responsive to the first signals, and which generates second signals

corresponding to a gray level halftoned representation of the original image; and

a printer coupled to the controller to receive said second signals and which produces a gray level halftoned reproduction of the original image; and

wherein the controller includes means for defining a criteria for stable pixel locations in accordance with a screen frequency and screen angle of the image to be reproduced and for determining in accordance with said criteria whether or not there is to be a stable dot at a current pixel and if the current pixel is determined to be at a location meeting said criteria for a stable pixel location, alters a gray level value of the current pixel to increase the density of the current pixel for stabilizing said pixel at said location and diffuses error introduced by increasing the density of the current pixel to pixels that neighbor the current pixel.

41. A method of reproducing an original image, comprising:

scanning an original image to produce first signals representing said original image divided into pixels of varying intensity values;

in accordance with a criterion based on screen frequency identifying a current pixel as a preferred pixel location for formation of a stable dot;

modifying the intensity values of some of said pixels by introducing errors to intensity values of pixels at such preferred locations such that pixels along screen lines have a greater likelihood to be printed with stable dots than pixels not at such preferred locations;

diffusing errors, created by modifying the intensity values of pixels at such preferred locations, to pixels neighboring the pixels at said preferred locations; and

printing the modified image with a gray level printer after the error as been diffused.

42. The method of Claim 41, and including the step of comparing each current pixel's modified intensity value with a threshold value forming a part of a matrix of partial

dot threshold values to determine a grey level value for printing said current pixel.

43. The method of Claim 42, wherein the step of modifying includes adjusting an intensity value of a pixel at a preferred location in accordance with a factor related to the pixel's intensity value to increase a density of the specified pixel when printed.

44. A method of reproducing an original image comprising the steps of:

generating first signals representing an original image divided into pixels of varying intensity values;

in accordance with a criterion based on screen frequency, identifying a current pixel as being a preferred pixel for forming of a stable dot if the current pixel meets said criterion;

in response to a current pixel being identified as a preferred pixel introducing an error to adjust the intensity value of the current pixel to form a modified intensity value;

comparing the modified intensity value with a threshold value; and

as a result of said comparing step defining a grey level value for printing the current pixel; and

distributing the error to adjust intensity values of pixels neighboring a preferred pixel that are not preferred pixels.

45. The method of Claim 44 and in the step of comparing there is compared each current pixel's modified intensity value with a threshold value forming a part of a matrix of partial dot threshold values to determine a grey level value for printing said current pixel.

46. The method of Claims 44 or 45, wherein the step of introducing an error includes adjusting an intensity value of a preferred pixel in accordance with a factor related to the pixel's intensity value to increase a density of the specified pixel when printed.

47. A method of reproducing an original image that contains at least one of a text region or a halftone region, comprising:

scanning said original image to produce a signal representing a digitized original image;

determining that a region of said original image contains either a text region or a halftone region; and

performing contour suppression on every pixel of said digitized original image;

controlling a gray level printer to print the digitized original image after contour suppression has been performed.

48. The method of Claim 47, wherein each pixel has an input pixel gray value, and the step of performing contour suppression includes assigning for input pixel gray values that are between first and second output gray levels a probability of having the first output gray level and a probability of having the second output gray level.

49. The method of Claim 48, wherein the probability is assigned as a function of a difference of the input pixel gray value to the first and second output gray levels.

50. A method of reproducing an original image that contains at least one of a text region or a halftone region, comprising:

scanning said original image to produce a signal representing a digitized original image, said original image having a screen frequency;

determining that a region of said original image contains either a text region or a halftone region; and controlling a gray level printer to print the digitized original image with an output screen frequency higher in screen frequency than the screen frequency of the original image.

51. A method of reproducing an original image, comprising:

scanning an original image to produce a digitized image;

performing a local structure analysis of the digitized image;

selectively applying a descreening filter to a region of the digitized image based on the results of the local structure

analysis to remove a specific frequency of the digitized image caused by halftone screens;

bypassing the descreening filter with regions of the digitized image such that said bypassed regions remain unfiltered by said descreening filter;

printing said filtered regions and said bypassed regions as a single, unified reproduction of the original image; and

wherein the step of performing the local structure analysis includes the steps of:

establishing a moving window for the digitized image around a central pixel;

determining if the moving window is a low contrast window or a high contrast window;

determining if there is a consistent transition in the moving window around the central pixel; and

causing the application of the descreening filter to the moving window when the moving window is a high contrast window and there is not consistent transition in the moving window around the central pixel.

52. The method of Claim 51, wherein the step of determining if the moving window is a low contrast window or a high contrast window includes detecting the intensity difference in the moving window, with a large intensity difference indicating a high contrast window and a small intensity difference indicating a low contrast window.

53. The method of Claim 51, further comprising smooth filtering a moving window determined to be a low contrast window.

54. The method of Claim 53, wherein the bypassed regions have been determined to be a moving window that is a high contrast window with a consistent transition in the moving window around the central pixel.

55. An apparatus for reproducing an original image, comprising:

scanner means which scans and digitizes the original image;

controller means coupled to the scanner means to receive the digitized original image, perform a local structure analysis of the digitized original image, selectively apply a descreening filter to a region of the digitized original image based on the results of the local structure analysis to remove a specific frequency of the digitized image caused by halftone screens, allow a bypass of the descreening filter of other regions of the digitized image such that bypassed regions remain unfiltered by said descreening filter, and which produces a first signal representing filtered regions and unfiltered regions, said first signal corresponding to the digitized original image;

a printer coupled to the controller to receive said first signal and which produces a gray level halftoned reproduction of the original image; and

wherein the descreening filter includes means for transforming the digitized image into a frequency domain, means for reducing the strength at a specific frequency content from the digitized image, and means for transforming the digitized image back into the spatial image domain and feedback means between the spatial domain and the frequency domain to iteratively reduce to a minimum the specific frequency in the digitized image.

56. A method of reproducing an original image, comprising:

scanning an original image to produce a digitized image;

performing a local structure analysis of the digitized image;

selectively applying a descreening filter to a region of the digitized image based on the results of the local structure analysis to remove a specific frequency of the digitized image caused by halftone screens;

bypassing the descreening filter with regions of the digitized image such that bypassed regions remain unfiltered by said descreening filter;

printing filtered regions and bypassed regions as a single, unified reproduction of the original image; and

wherein in the descreening filter the image is transformed to a frequency spectrum and the strength at a certain frequency is reduced and the modified image transformed into the spatial domain, and there is feedback between the spatial domain and the frequency domain to iteratively reduce to a minimum the certain screen frequency.

57. The method of Claims 51 or 56 and including rendering regions processed by the descreening filter with a partial dot growth structure.

58. The method of Claims 51, 56 or 57 and including rendering bypassed regions with a mixed dot growth structure.

59. The method of Claims 1-39, 41-54 and 56-58 and including the step of printing dots with an electrophotographic printing process.

60. An apparatus for reproducing an original image, comprising:

a scanner which scans and digitizes the original image into pixels;

a controller means coupled to the scanner to receive the digitized original image, and which produces a first signal corresponding to a gray level halftoned representation of the digitized original image; and

a printer coupled to the controller to receive said first signal and which produces a gray level halftoned reproduction of the original image;

wherein the controller means groups the pixels into cells that each have a determined cell gray level, and controls the formation of dots within the pixels of an individual cell by the printer such that for each increase in cell gray level, a dot at at least one of said pixels in the cell forms to a larger dot-size.

61. The apparatus of claim 60 and wherein the controller means controls cell gray levels so that sequential forming of dots occurs at the pixels in the cell in an order

such that each dot is formed to a first dot-size, larger than a minimum dot size but less than a maximum dot-size, before beginning the formation of a dot at another pixel within the cell, and when all of the pixels in the cell have been formed to the first dot-size corresponding to a specific cell gray level, there is provided further sequential increases in cell gray levels by correspondingly sequentially increasing the dot-size of each of the dots in said cell to a second dot-size, to provide progressive corresponding increases in cell gray levels by distributing said increases successively to different pixels in the cell.

62. The apparatus of claim 60 and wherein said controller includes:

means for collecting statistical information of dot regions;

means for selecting for each dot region a dot type to render that dot region in accordance with the statistical information; the dot type being either a mixed dot type or a type different than said mixed dot type and

mean for controlling the printer to print the reproduction of the original image by rendering the dot regions of the first signal in accordance with the selected dot type for each dot region.

63. The apparatus of claim 62 and wherein said different dot type is a fixed threshold type.

64. The apparatus of claim 62 and wherein said different dot type is a partial dot type.

65. The apparatus of claim 60 and wherein the controller includes means for classifying the pixels in each cell into one of at least two classes, and means for modifying an exposure level for printing said pixels according to said classification.

66. The apparatus of Claim 65, wherein the means for classifying includes means for classifying the pixels of a cell into a first class which includes a central pixel of the cell, and a second class which includes pixels which surround the central pixel.

67. The apparatus of Claim 66, wherein the pixels of the first class are modified to have a higher exposure time, the pixels of the second class are modified to have an intermediate exposure time and the pixels of the third class are modified to have a lesser exposure time.

68. The apparatus of Claim 65, wherein the means for classifying includes means for producing a classifying signal indicating a position of a pixel within a cell.

69. The apparatus of Claim 68, wherein the means for modifying an exposure level includes a look up table (LUT) device which receives at its input image data relating to exposure of a pixel of a cell and said classifying signal for that pixel, said LUT providing a modified exposure level for that pixel.

70. The apparatus of Claims 65 - 68, wherein the means for modifying an exposure level includes first and second look up tables (LUTs) the first LUT being a nonuniformity LUT that receives printhead pixel position counter information and produces a brightness uniformity pointer, the second LUT receiving as inputs the brightness uniformity pointer, independent image data relating to exposure of a pixel of a cell, and the classifying signal for that pixel, the second LUT producing a modified exposure level for that pixel.

71. An apparatus for reproducing an original image, comprising:

means for scanning and digitizing the original image into pixels;

controller means for producing a first signal corresponding to a gray level halftoned representation of the original image; and

a gray level printer means coupled to the controller means and responsive to said first signal for producing at least three gray level dot sizes to form a gray level halftoned reproduction of the original image;

wherein the controller means includes first means for processing the pixels by cells, each of plural pixels, and for controlling the printer means to form dots of variable size in a cell along lines in accordance with at least one template, such that a first line structure is formed that is stable before beginning formation of additional lines within the cell corresponding to increasing cell gray levels.

72. The apparatus of Claim 71 wherein the controller means controls the printer means to form dots in accordance with at least two templates, with dots being formed along lines defined by a first of said two templates corresponding to increasing cell gray levels until said first line structure is stable, and then forming dots along lines defined by the other of said two templates corresponding to increasing cell gray levels.

73. The apparatus of Claim 71 wherein the controller means processes the pixels into a 6x6 cell of pixels, and fifteen different levels of dots are available for printing at each pixel in the cell.

74. The apparatus of Claim 72 and wherein in accordance with the first template, dot sizes are increased simultaneously at plural pixel locations along a first line in a cell when the cell gray level is increased from one gray level to a second and next succeeding gray level.

75. The apparatus of Claims 72 or 74 and wherein in accordance with the first template, the plural pixel locations are contiguous.

76. The apparatus of Claim 72 and wherein in accordance with the first template, all pixel locations along the first line grow simultaneously from the one cell gray level to the next succeeding gray level.

77. The apparatus of Claim 76 and wherein in accordance with the first template, pixel locations along plural parallel first lines in the cell grow simultaneously from the one cell gray level to the next succeeding cell gray level.

78. The apparatus of Claim 76 and wherein in accordance with a second template, every second pixel

location along the first line grows in dot size simultaneously upon an increase from a third cell gray level to a fourth next succeeding cell gray level.

79. The apparatus of Claim 78 and wherein in accordance with a third template, every third pixel location along the first line grows in dot size simultaneously upon an increase from a fifth cell gray level to a sixth cell gray level.

80. The apparatus of Claim 79 and wherein in accordance with a fourth template, dots are formed along a second line of pixel locations contiguous to pixel locations on the first line.

81. The apparatus of claim 60 and wherein the controller means includes means for obtaining a set of thresholding values at each pixel from a specified set of gray dot patterns by 4-quadrant tone reproduction analysis.

82. The apparatus of Claim 81, wherein the controller includes means for generating said gray dot patterns that are dependent on a dot template, pixel bit-depth, and partial dot type structure.

83. The apparatus of Claim 82, wherein the dot template is an optimal Bayer dot pattern.

84. The apparatus of Claim 82, wherein the dot template is a cluster dot pattern.

85. The apparatus of Claim 82, wherein the pixel bit-depth is 4 bits.

86. The apparatus of Claim 82, wherein the pixel bit-depth is 5 bits.

87. The apparatus of claim 60 and

wherein the controller means includes means for operating the printer in a first mode when the original image contains a text region or a halftone region, said first mode including contour suppression applied to every pixel of said original image.

88. The apparatus of Claim 87, wherein each pixel has an input pixel gray value and is assigned an output gray level by the means for operating the printer in the first mode, and wherein the contour suppression includes assigning for input pixel gray values that are between first and second output gray levels a probability of having the

first output gray level and a probability of having the second output gray level.

89. The apparatus of Claim 88, wherein the probabilities are assigned as a function of the differences of the input pixel gray value to the first and second output gray levels.

90. The apparatus of claim 60 and wherein the controller includes means for operating the printer in a first mode when the original image contains a halftone region, said first mode including reproducing the original image with an output screen that is higher in frequency than a frequency of a screen of the original image.

91. The apparatus of claims 87 through 90 and wherein said first mode is a default mode.

92. The apparatus of any of claims 40, 55 and 60 through 91 and including means for printing the dots with an electrophotographic printing process.

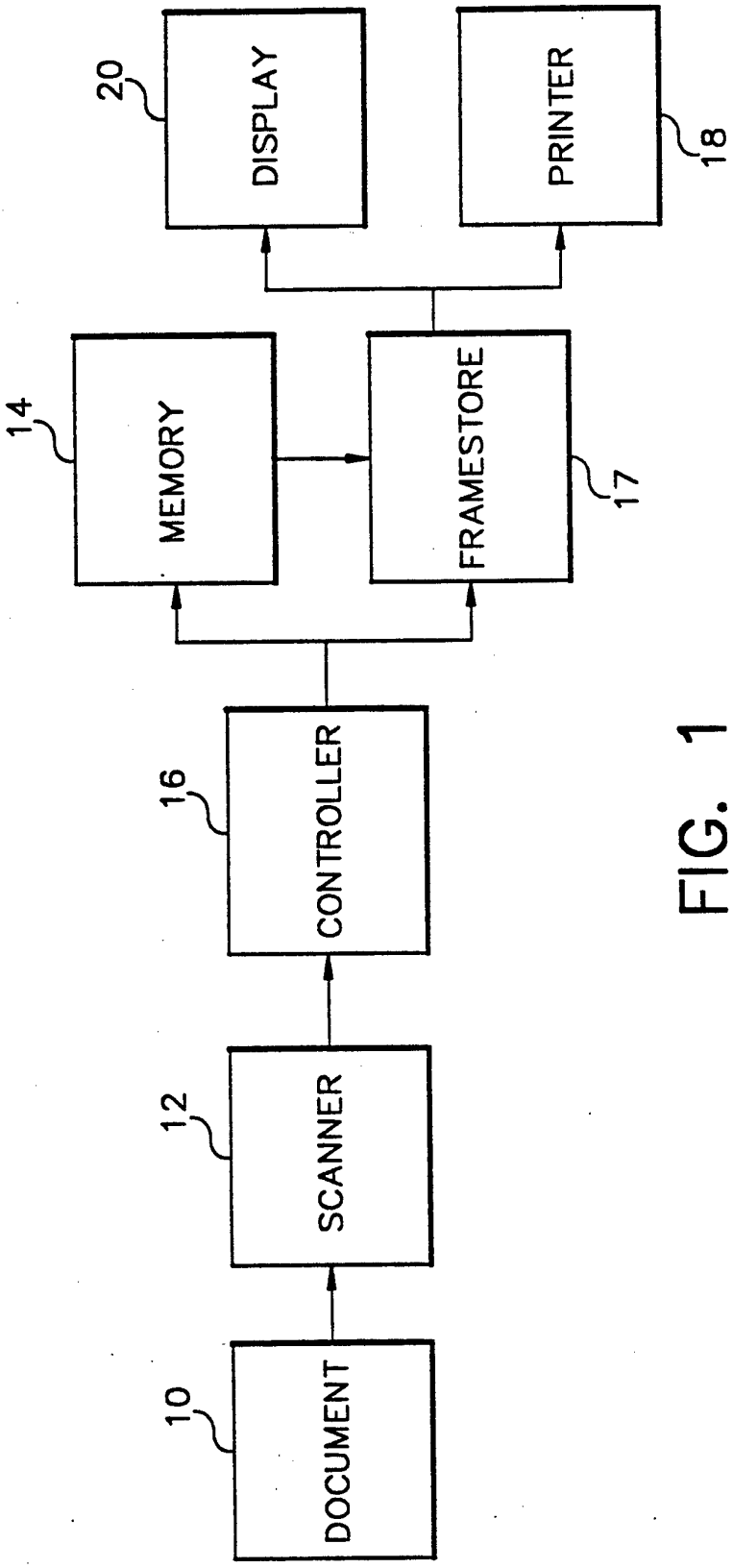

DOCUMENT
10
SCANNER
12
CONTROLLER
16
MEMORY
14
FRAMESTORE
17
DISPLAY
20
PRINTER
18

FIG. 1

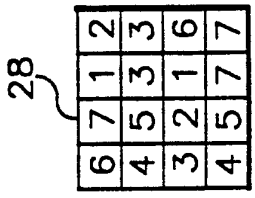
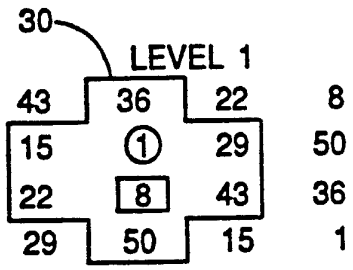

28
6 7 4 5 3 2 4 5
7 1 5 3 2 1 5 7
2 3 6 7

FIG. 2



LEVEL 2

44	37	23	9
16	2	30	51
23	9	44	37
30	51	16	2

LEVEL 3

45	38	24	10
17	3	31	52
24	10	45	38
31	52	17	3

LEVEL 4

46	39	25	11
18	4	32	53
25	11	46	39
32	53	18	4

LEVEL 5

47	40	26	12
19	5	33	54
26	12	47	40
33	54	19	5

LEVEL 6

48	41	27	13
20	6	34	55
27	13	48	41
34	55	20	6

LEVEL 7

49	42	28	14
21	7	35	56
28	14	49	42
35	56	21	7

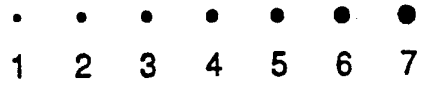


FIG. 3

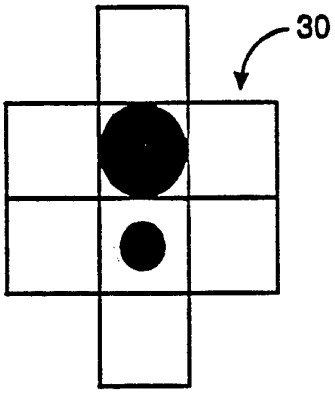


FIG. 4

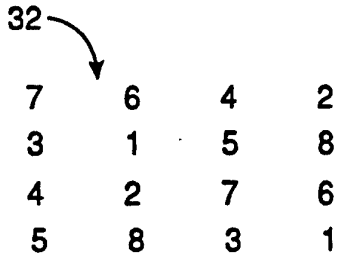
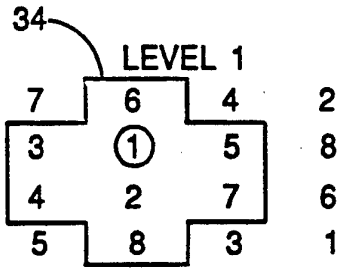


FIG. 5



LEVEL 2

15	14	12	10
11	9	13	16
12	10	15	14
13	16	11	9

LEVEL 3

23	22	20	18
19	17	21	24
20	18	23	22
21	24	19	17

LEVEL 4

31	30	28	26
27	25	29	32
28	26	31	30
29	32	27	25

LEVEL 5

39	38	36	34
35	33	37	40
36	34	39	38
37	40	35	33

LEVEL 6

47	46	44	42
43	41	45	48
44	42	47	46
45	48	43	41

LEVEL 7

55	54	52	50
51	49	53	56
52	50	55	54
53	56	51	49

FIG. 6

LEVEL 1

31	26	16	6
11	(1)	21	36
16	[6]	31	26
21	36	11	1

LEVEL 2

32	27	17	7
12	2	22	37
17	7	32	27
22	37	12	2

LEVEL 3

33	28	18	8
13	3	23	38
18	8	33	28
23	38	13	3

LEVEL 4

34	29	19	9
14	4	24	39
19	9	34	29
24	39	14	4

LEVEL 5

35	30	20	10
15	5	25	40
20	10	35	30
25	40	15	5

LEVEL 6

47	46	44	42
43	41	45	48
44	42	47	46
45	48	43	41

LEVEL 7

55	54	52	50
51	49	53	56
52	50	55	54
53	56	51	49

FIG. 7

THRESHOLD LEVEL 1

56	67	34	12
23	1	45	78
34	12	56	67
45	78	23	1

THRESHOLD LEVEL 2

57	68	35	13
24	2	46	79
35	13	57	68
46	79	24	2

THRESHOLD LEVEL 3

58	69	36	14
25	3	47	80
36	14	58	69
47	80	25	3

THRESHOLD LEVEL 4

59	70	37	15
26	4	48	81
37	15	59	70
48	81	26	4

THRESHOLD LEVEL 5

60	71	38	16
27	5	49	82
38	16	60	71
49	82	27	5

THRESHOLD LEVEL 6

61	72	39	17
28	6	50	83
39	17	61	72
50	83	28	6

THRESHOLD LEVEL 7

62	73	40	18
29	7	51	84
40	18	62	73
51	84	29	7

THRESHOLD LEVEL 8

63	74	41	19
30	8	52	85
41	19	63	74
52	85	30	8

THRESHOLD LEVEL 9

64	75	42	20
31	9	53	86
42	20	64	75
53	86	31	9

THRESHOLD LEVEL 10

65	76	43	21
32	10	54	87
43	21	65	76
54	87	32	10

THRESHOLD LEVEL 11

66	77	44	22
33	11	55	88
44	22	66	77
55	88	33	11

THRESHOLD LEVEL 12

94	95	92	90
91	89	93	96
92	90	94	95
93	96	91	89

THRESHOLD LEVEL 13

102	103	100	98
99	97	101	104
100	98	102	103
101	104	99	97

THRESHOLD LEVEL 14

110	111	108	106
107	105	109	112
108	106	110	111
109	112	107	105

THRESHOLD LEVEL 15

118	119	116	114
115	113	117	120
116	114	118	119
117	120	115	113

FIG. 8

THRESHOLD LEVEL 1

71	48	107	190
128	249	89	38
107	190	71	48
89	38	128	249

THRESHOLD LEVEL 2

69	47	106	185
126	243	88	37
106	185	69	47
88	37	126	243

THRESHOLD LEVEL 3

66	47	104	179
124	238	86	35
104	179	66	47
86	35	124	238

THRESHOLD LEVEL 4

64	46	103	173
122	231	84	34
103	173	64	46
84	34	122	231

THRESHOLD LEVEL 5

61	45	101	167
120	224	83	34
101	167	61	45
83	34	120	224

THRESHOLD LEVEL 6

59	44	100	161
118	217	82	33
100	161	59	44
82	33	118	217

THRESHOLD LEVEL 7

57	44	98	156
116	212	80	32
98	156	57	44
80	32	116	212

THRESHOLD LEVEL 8

54	43	97	153
114	209	79	32
97	153	54	43
79	32	114	209

THRESHOLD LEVEL 9

53	42	95	151
113	205	78	31
95	151	53	42
78	31	113	205

THRESHOLD LEVEL 10

51	41	94	146
111	202	77	30
94	146	51	41
77	30	111	202

THRESHOLD LEVEL 11

50	40	92	142
110	198	75	29
92	142	50	40
75	29	110	198

THRESHOLD LEVEL 12

49	40	91	135
108	195	74	28
91	135	49	40
74	28	108	195

THRESHOLD LEVEL 13

19	18	22	25
24	27	20	17
22	25	19	18
20	17	24	27

THRESHOLD LEVEL 14

12	12	14	15
15	16	13	12
14	15	12	12
13	12	15	16

THRESHOLD LEVEL 15

9	8	10	11
11	11	10	8
10	11	9	8
10	8	11	11

THRESHOLD LEVEL 16

FIG. 9

THRESHOLD LEVEL 1

179	179	179	179
179	179	179	179
179	179	179	179
179	179	179	179

THRESHOLD LEVEL 2

142	142	142	142
142	142	142	142
142	142	142	142
142	142	142	142

THRESHOLD LEVEL 3

122	122	122	122
122	122	122	122
122	122	122	122
122	122	122	122

THRESHOLD LEVEL 4

110	110	110	110
110	110	110	110
110	110	110	110
110	110	110	110

THRESHOLD LEVEL 5

101	101	101	101
101	101	101	101
101	101	101	101
101	101	101	101

THRESHOLD LEVEL 6

89	89	89	89
89	89	89	89
89	89	89	89
89	89	89	89

THRESHOLD LEVEL 7

78	78	78	78
78	78	78	78
78	78	78	78
78	78	78	78

THRESHOLD LEVEL 8

68	68	68	68
68	68	68	68
68	68	68	68
68	68	68	68

THRESHOLD LEVEL 9

58	58	58	58
58	58	58	58
58	58	58	58
58	58	58	58

THRESHOLD LEVEL 10

48	48	48	48
48	48	48	48
48	48	48	48
48	48	48	48

THRESHOLD LEVEL 11

40	40	40	40
40	40	40	40
40	40	40	40
40	40	40	40

THRESHOLD LEVEL 12

27	27	27	27
27	27	27	27
27	27	27	27
27	27	27	27

THRESHOLD LEVEL 13

18	18	18	18
18	18	18	18
18	18	18	18
18	18	18	18

THRESHOLD LEVEL 14

13	13	13	13
13	13	13	13
13	13	13	13
13	13	13	13

THRESHOLD LEVEL 15

8	8	8	8
8	8	8	8
8	8	8	8
8	8	8	8

THRESHOLD LEVEL 16

FIG. 10

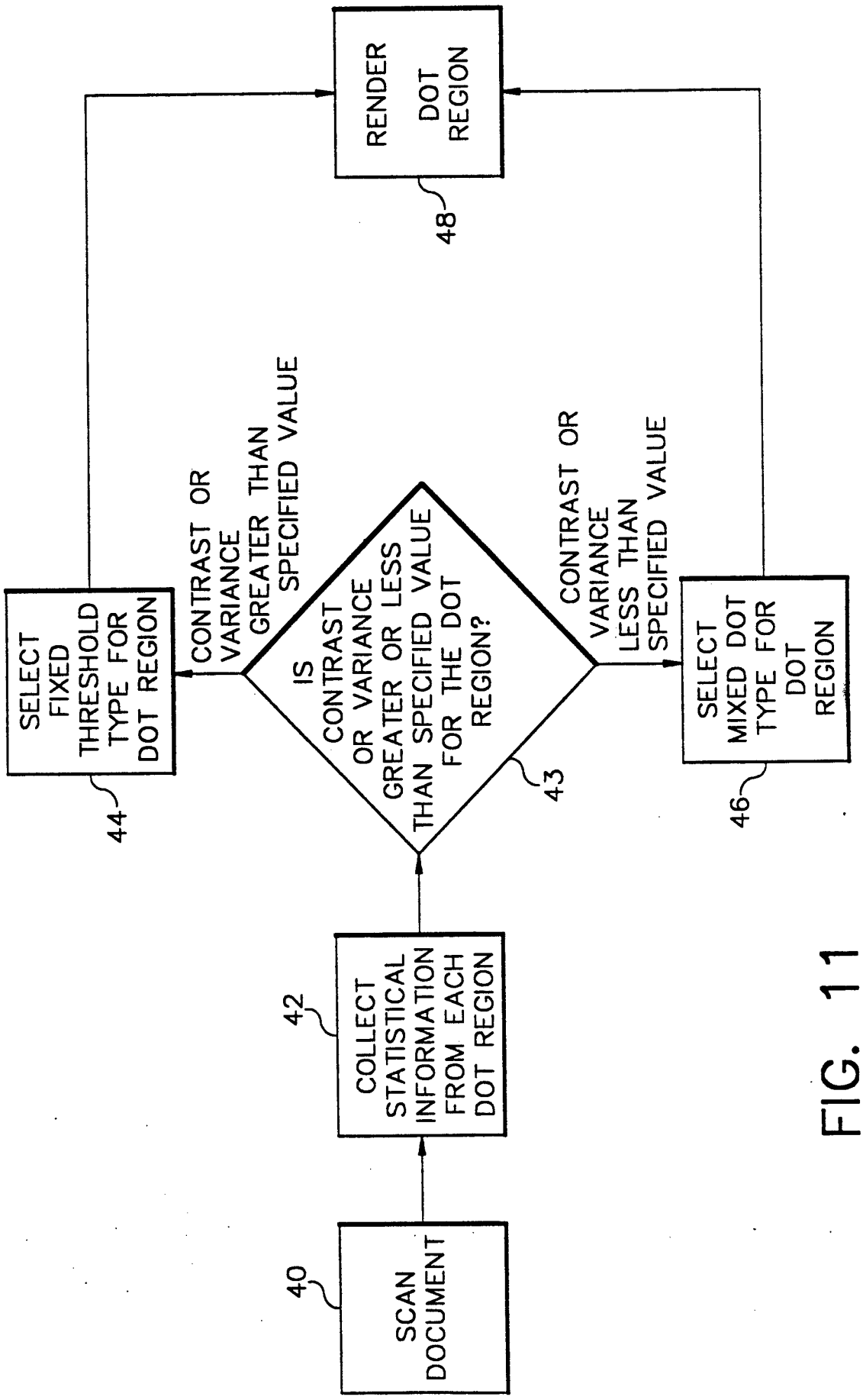

SCAN DOCUMENT
40
COLLECT STATISTICAL INFORMATION FROM EACH DOT REGION
42
IS CONTRAST OR VARIANCE GREATER OR LESS THAN SPECIFIED VALUE FOR THE DOT REGION?
43
CONTRAST OR VARIANCE GREATER THAN SPECIFIED VALUE
CONTRAST OR VARIANCE LESS THAN SPECIFIED VALUE
SELECT FIXED THRESHOLD TYPE FOR DOT REGION
44
SELECT MIXED DOT TYPE FOR DOT REGION
46
RENDER DOT REGION
48

FIG. 11

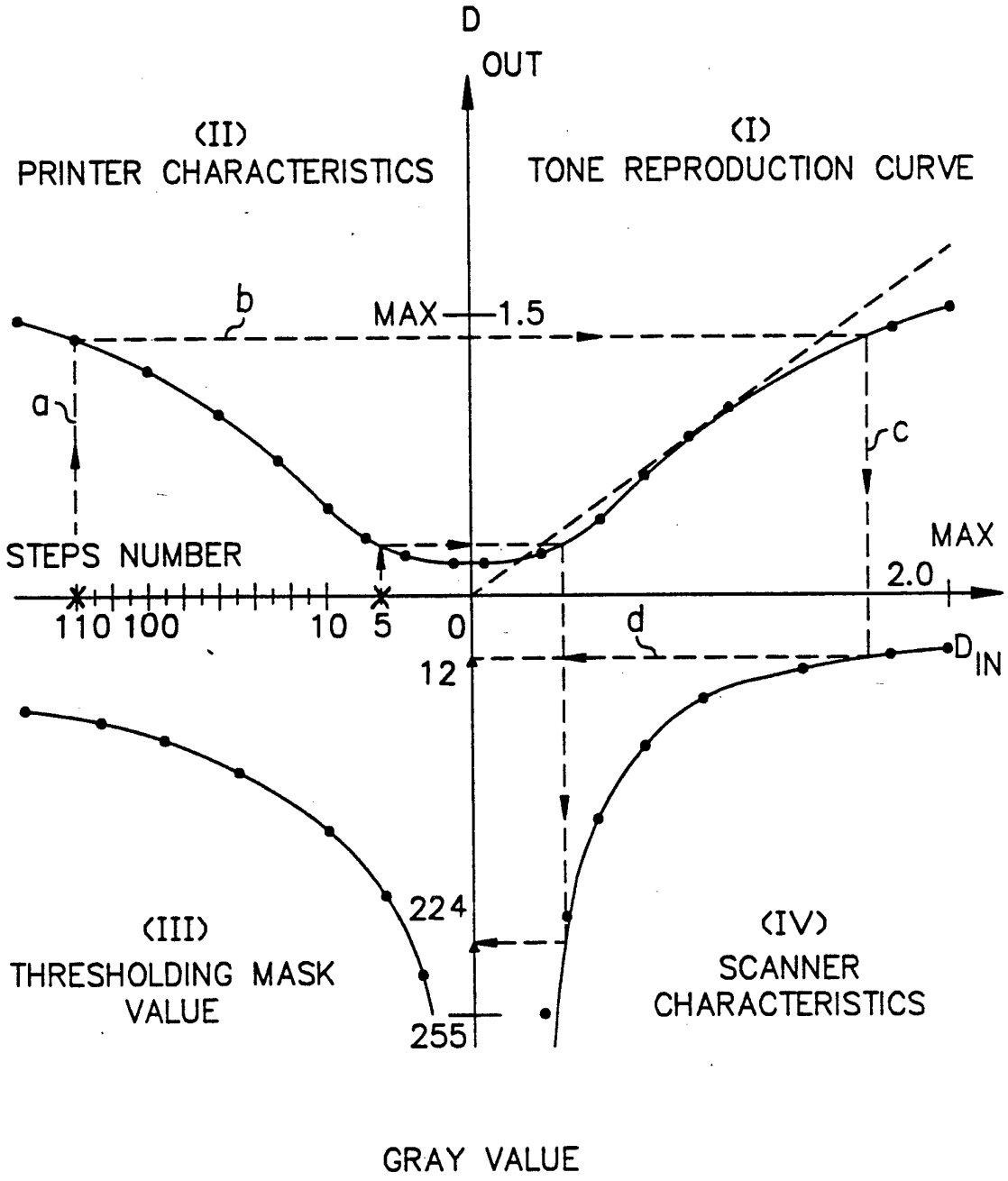

D
OUT
(II)
PRINTER CHARACTERISTICS
(I)
TONE REPRODUCTION CURVE
b
MAX
1.5
a
c
STEPS NUMBER
MAX
2.0
110 100
10 5
0
d
12
D_{IN}
224
(III)
THRESHOLDING MASK
VALUE
(IV)
SCANNER
CHARACTERISTICS
255
GRAY VALUE

FIG. 12

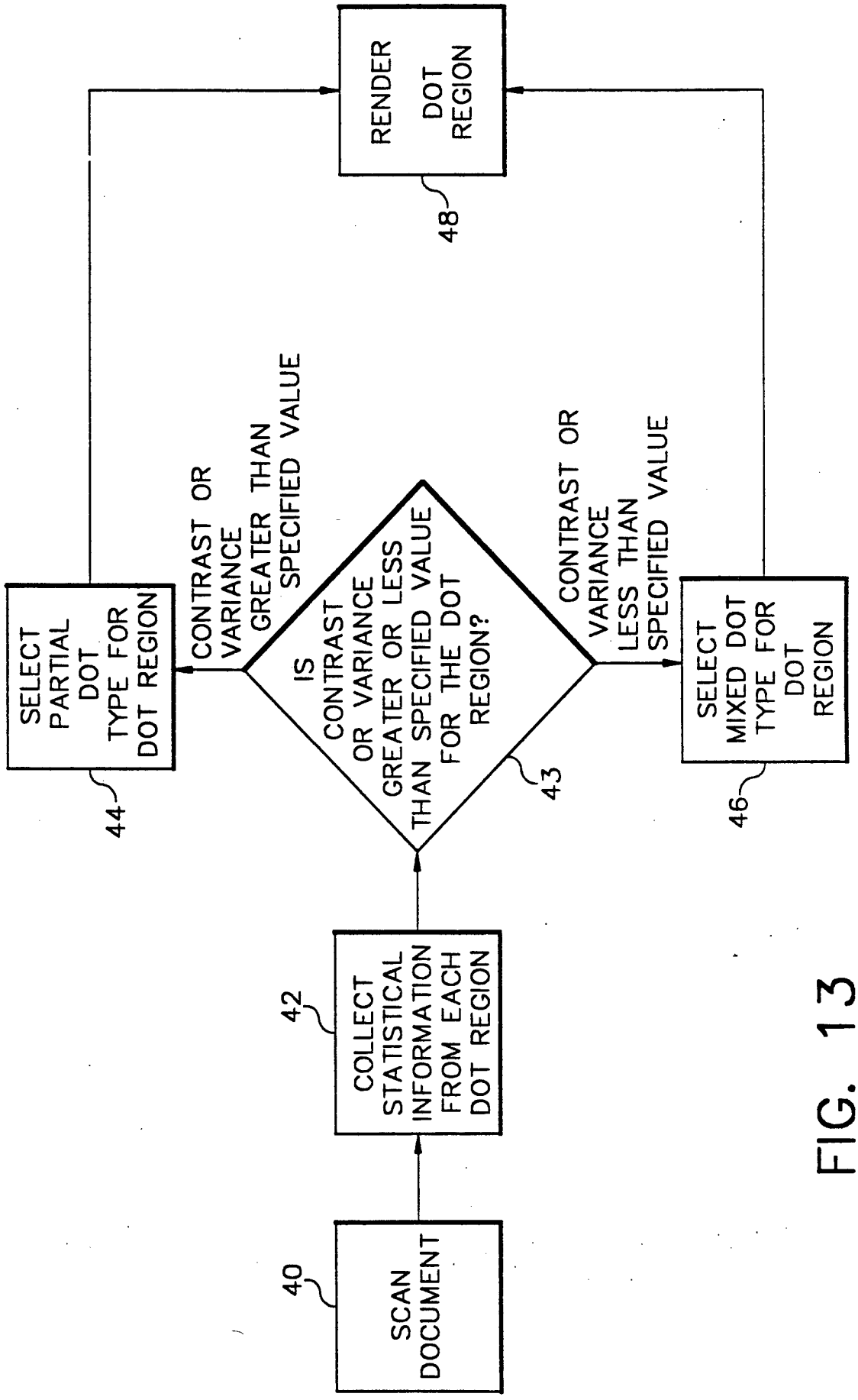

SCAN DOCUMENT
40
COLLECT STATISTICAL INFORMATION FROM EACH DOT REGION
42
IS CONTRAST OR VARIANCE GREATER OR LESS THAN SPECIFIED VALUE FOR THE DOT REGION?
43
CONTRAST OR VARIANCE GREATER THAN SPECIFIED VALUE
CONTRAST OR VARIANCE LESS THAN SPECIFIED VALUE
SELECT PARTIAL DOT TYPE FOR DOT REGION
44
SELECT MIXED DOT TYPE FOR DOT REGION
46
RENDER DOT REGION
48

FIG. 13

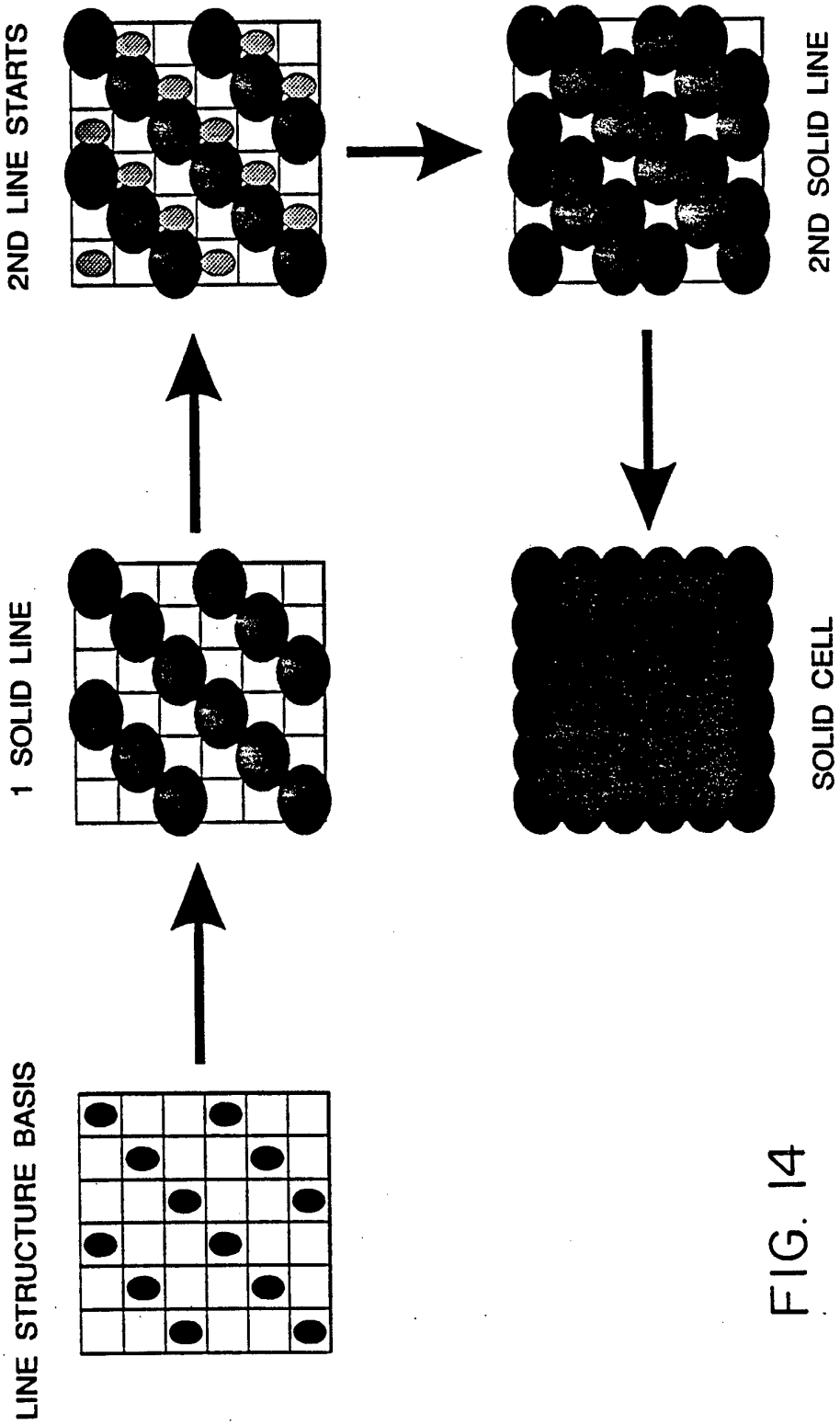

LINE STRUCTURE BASIS
1 SOLID LINE
2ND LINE STARTS
2ND SOLID LINE
SOLID CELL

FIG. 14

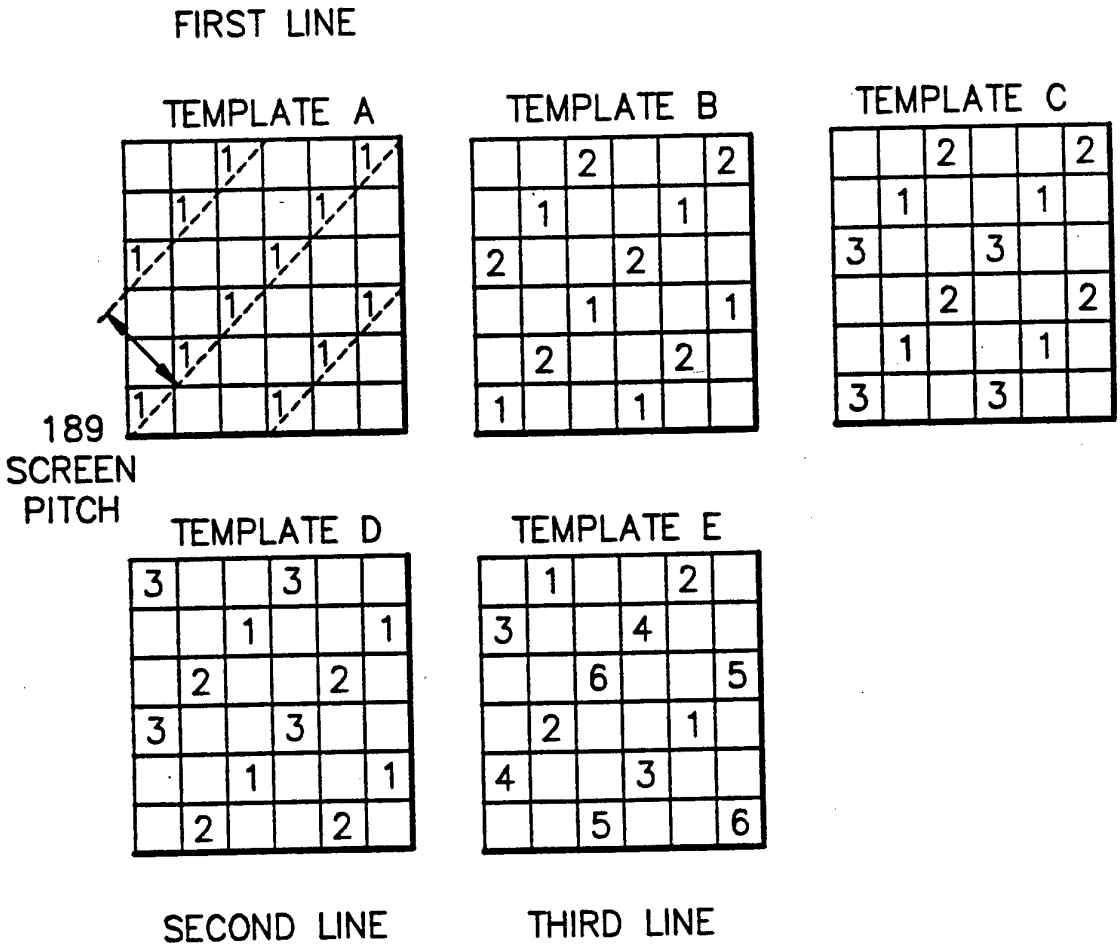

FIRST LINE
TEMPLATE A
TEMPLATE B
TEMPLATE C
189 SCREEN PITCH
TEMPLATE D
TEMPLATE E
SECOND LINE
THIRD LINE

FIG. 15

LEVEL 1

23	57	1	23	58	1
59	1	21	60	1	21
1	22	62	1	22	61
23	58	1	23	57	1
60	1	21	59	1	21
1	22	61	1	22	62

LEVEL 2

26	63	2	26	64	2
65	2	24	66	2	24
2	25	68	2	25	67
26	64	2	26	63	2
66	2	24	65	2	24
2	25	67	2	25	68

LEVEL 3

29	69	3	29	70	3
71	3	27	72	3	27
3	28	74	3	28	73
29	70	3	29	69	3
72	3	27	71	3	27
3	28	73	3	28	74

LEVEL 4

32	75	4	32	76	4
77	4	30	78	4	30
4	31	80	4	31	79
32	76	4	32	75	4
78	4	30	77	4	30
4	31	79	4	31	80

LEVEL 5

35	81	5	35	82	5
83	5	33	84	5	33
5	34	86	5	34	85
35	82	5	35	81	5
84	5	33	83	5	33
5	34	85	5	34	86

LEVEL 6

38	87	7	38	88	7
89	6	36	90	6	36
7	37	92	7	37	91
38	88	6	38	87	6
90	7	36	89	7	36
6	37	91	6	37	92

LEVEL 7

41	93	9	41	94	9
95	8	39	96	8	39
9	40	98	9	40	97
41	94	8	41	93	8
96	9	39	95	9	39
8	40	97	8	40	98

LEVEL 8

44	99	11	44	100	11
101	10	42	102	10	42
11	43	104	11	43	103
44	100	10	44	99	10
102	11	42	101	11	42
10	43	103	10	43	104

LEVEL 9

47	105	13	47	106	13
107	12	45	108	12	45
13	46	110	13	46	109
47	106	12	47	105	12
108	13	45	107	13	45
12	46	109	12	46	110

LEVEL 10

50	111	15	50	112	15
113	14	48	114	14	48
15	49	116	15	49	115
50	112	14	50	111	14
114	15	48	113	15	48
14	49	115	14	49	116

LEVEL 11

53	117	17	53	118	17
119	16	51	120	16	51
17	52	122	17	52	121
53	118	16	53	117	16
120	17	51	119	17	51
16	52	121	16	52	122

LEVEL 12

56	123	19	56	124	19
125	18	54	126	18	54
20	55	128	20	55	127
56	124	19	56	123	19
126	18	54	125	18	54
20	55	127	20	55	128

LEVEL 13

140	147	130	140	147	130
148	129	138	148	129	138
131	139	149	131	139	149
140	147	130	140	147	130
148	129	138	148	129	138
131	139	149	131	139	149

LEVEL 14

143	150	133	143	150	133
151	132	141	151	132	141
134	142	152	134	142	152
143	150	133	143	150	133
151	132	141	151	132	141
134	142	152	134	142	152

LEVEL 15

146	153	136	146	153	136
154	135	144	154	135	144
137	145	155	137	145	155
146	153	136	146	153	136
154	135	144	154	135	144
137	145	155	137	145	155

FIG. 16

GRAY STEP 100

12	8	12	12	8	12			
7	12	12	7	12	12			
12	12	7	12	12	8	12	12	7
12	8	12	12	7	12	12	12	7
7	12	12	7	12	12			
12	12	7	12	12				

FIG. 17

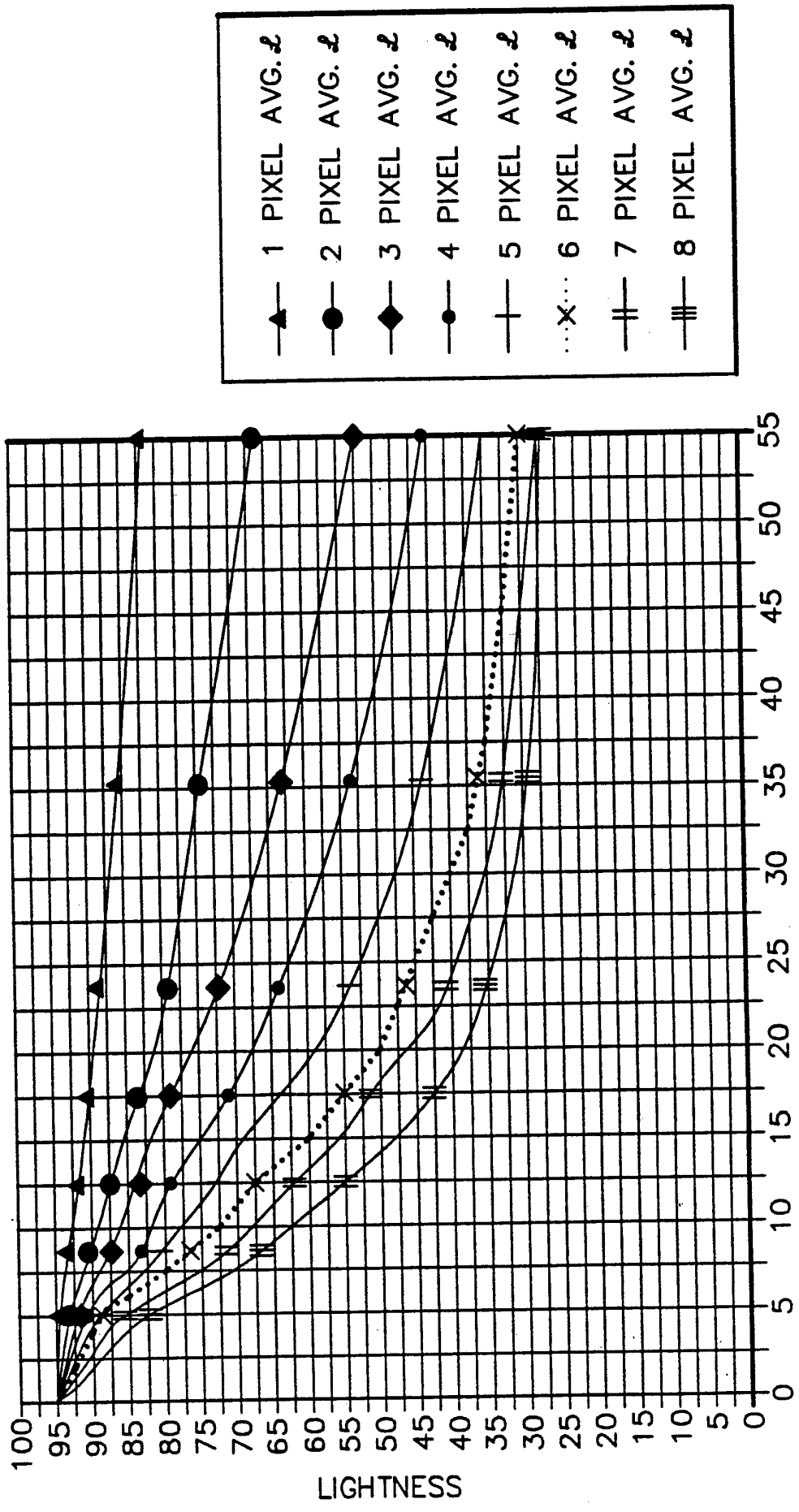

1 PIXEL AVG. 2
2 PIXEL AVG. 2
3 PIXEL AVG. 2
4 PIXEL AVG. 2
5 PIXEL AVG. 2
6 PIXEL AVG. 2
7 PIXEL AVG. 2
8 PIXEL AVG. 2
LIGHTNESS
EXPOSURE TIME (MICROSECONDS)

FIG. 18

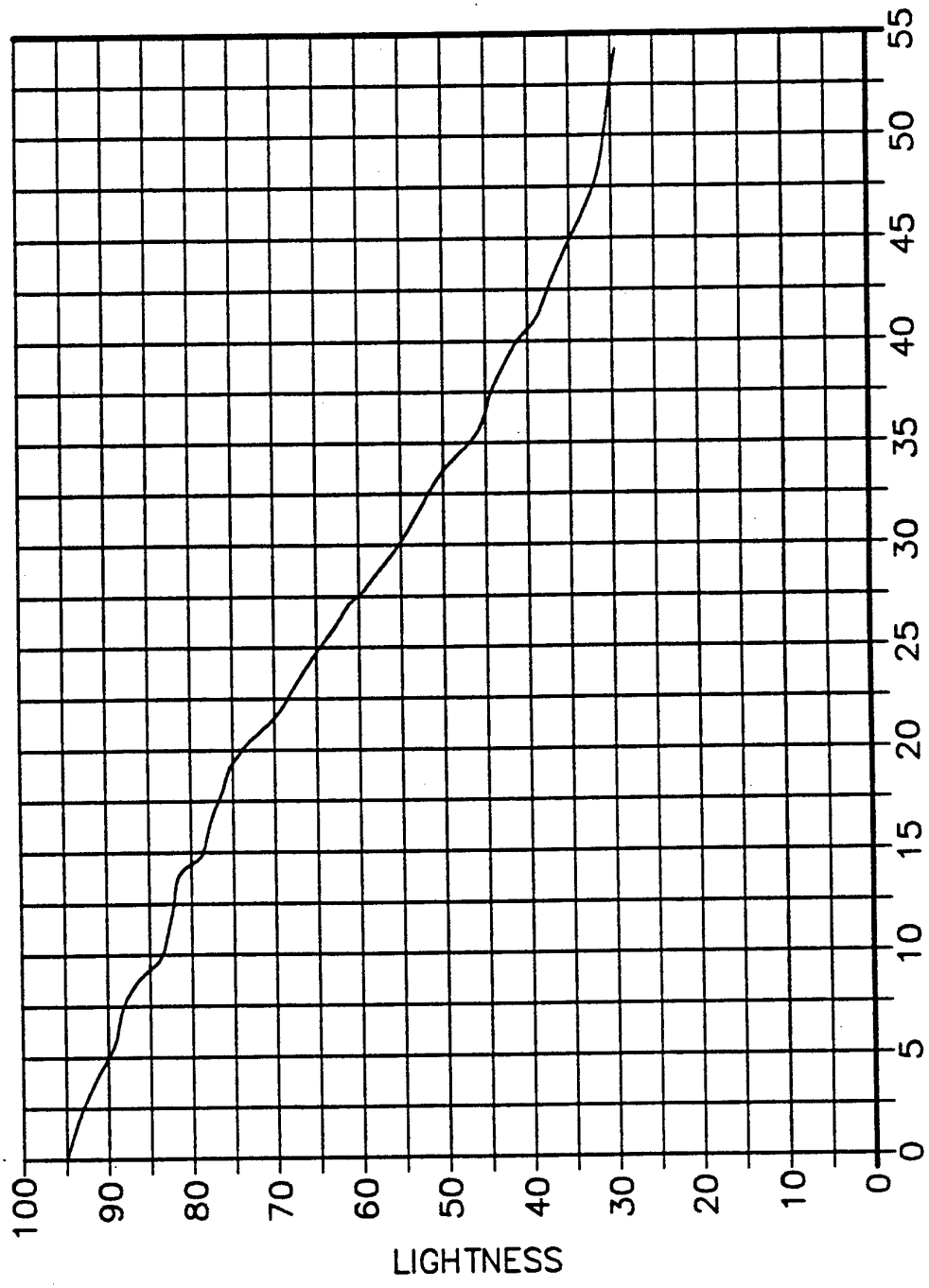

100
90
80
70
60
50
40
30
20
10
0
LIGHTNESS
0
5
10
15
20
25
30
35
40
45
50
55
STEP NUMBER

FIG. 19

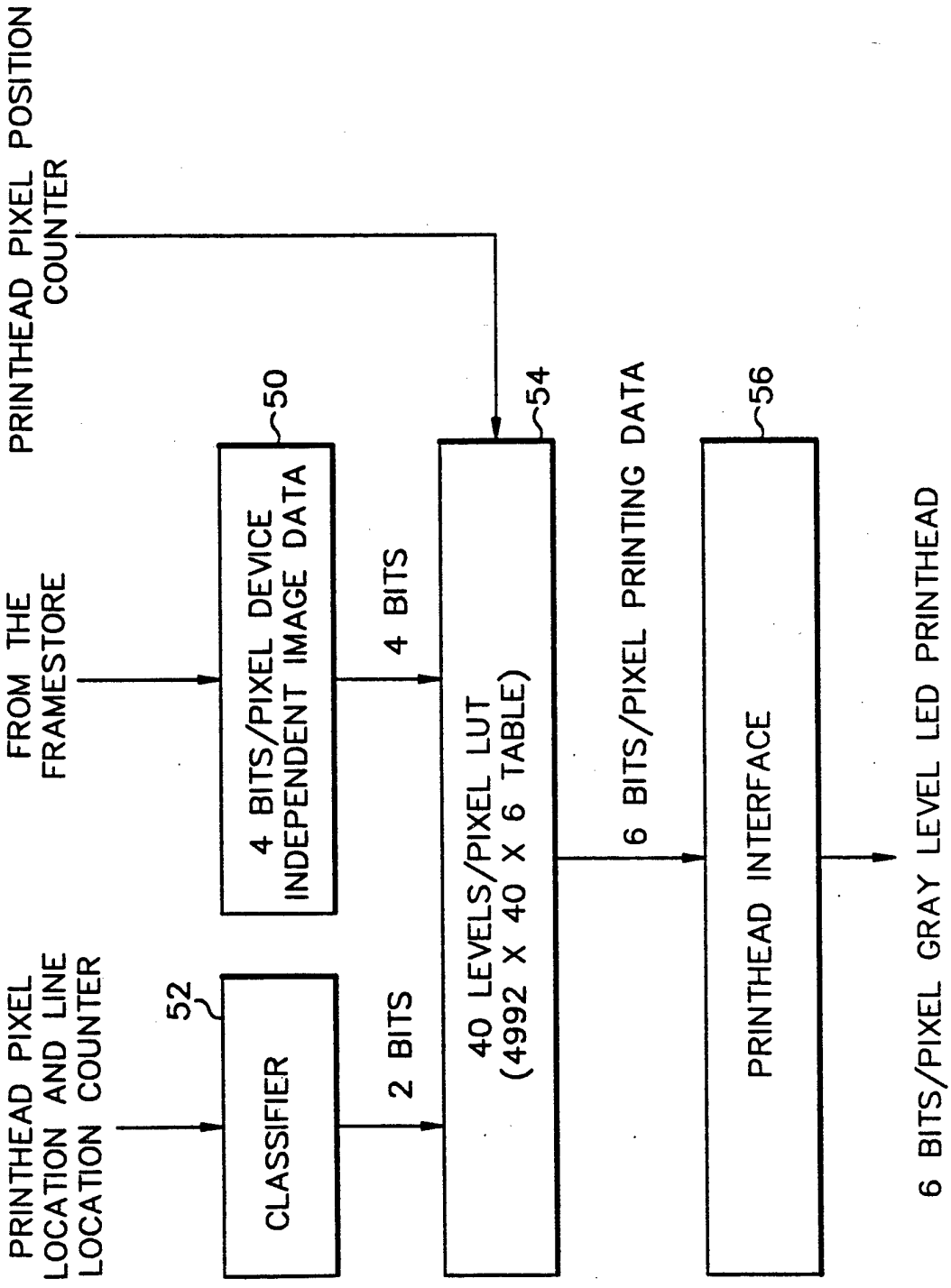

PRINTHEAD PIXEL POSITION COUNTER
FROM THE FRAMESTORE
PRINTHEAD PIXEL LOCATION AND LINE LOCATION COUNTER
52
CLASSIFIER
50
4 BITS/PIXEL DEVICE INDEPENDENT IMAGE DATA
2 BITS
4 BITS
54
40 LEVELS/PIXEL LUT (4992 X 40 X 6 TABLE)
6 BITS/PIXEL PRINTING DATA
56
PRINTHEAD INTERFACE
6 BITS/PIXEL GRAY LEVEL LED PRINTHEAD

FIG. 20

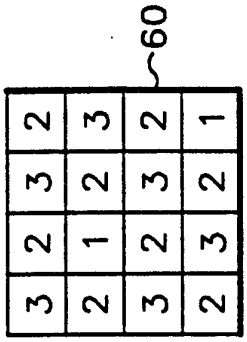

60
3 2 3 2
2 1 2 3
3 2 3 2
2 3 2 1

FIG. 21

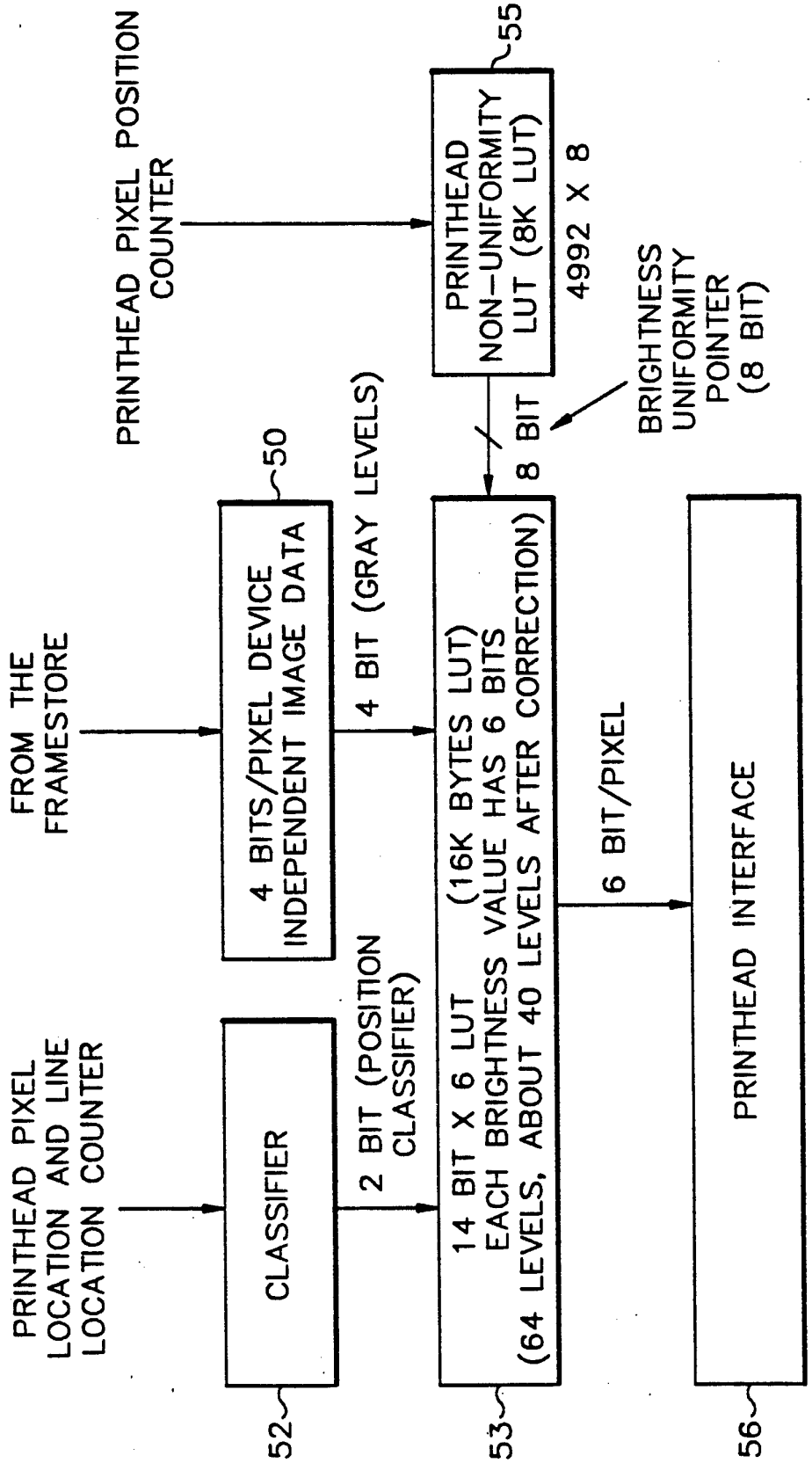

PRINTHEAD PIXEL POSITION COUNTER
PRINTHEAD NON-UNIFORMITY LUT (8K LUT)
55
4992 X 8
BRIGHTNESS UNIFORMITY POINTER (8 BIT)
8 BIT
FROM THE FRAMESTORE
4 BITS/PIXEL DEVICE INDEPENDENT IMAGE DATA
50
4 BIT (GRAY LEVELS)
PRINTHEAD PIXEL LOCATION AND LINE LOCATION COUNTER
CLASSIFIER
2 BIT (POSITION CLASSIFIER)
14 BIT X 6 LUT (16K BYTES LUT)
EACH BRIGHTNESS VALUE HAS 6 BITS
(64 LEVELS, ABOUT 40 LEVELS AFTER CORRECTION)
6 BIT/PIXEL
PRINTHEAD INTERFACE
52
53
56

FIG. 22

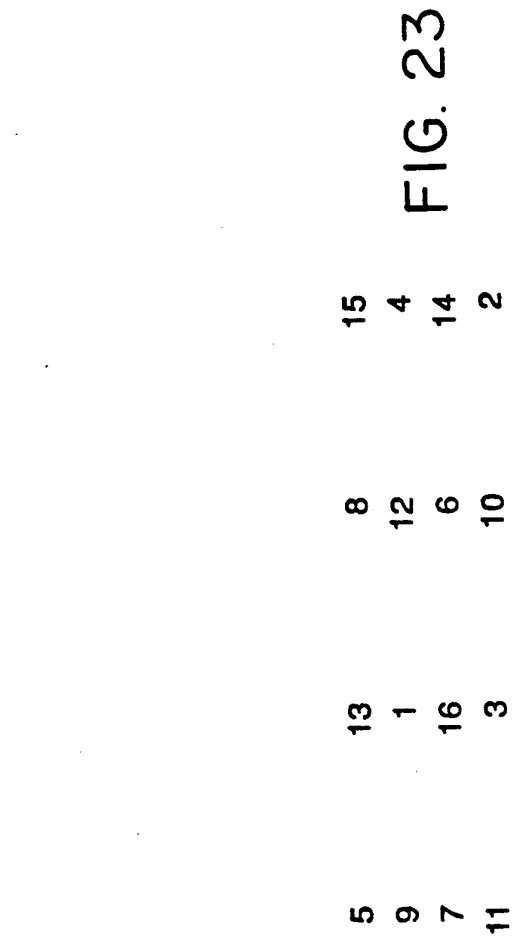


FIG. 23

DOT LEVEL 1

5	13	8	15
9	1	12	4
7	16	6	14
11	3	10	2

DOT LEVEL 2

21	29	24	31
25	17	28	20
23	32	22	30
27	19	26	18

DOT LEVEL 3

37	45	40	47
41	33	44	36
39	48	38	46
43	35	42	34

DOT LEVEL 4

53	61	56	63
57	49	60	52
55	64	54	62
59	51	58	50

DOT LEVEL 5

69	77	72	79
73	65	76	68
71	80	70	78
75	67	74	66

DOT LEVEL 6

85	93	88	95
89	81	92	84
87	96	86	94
91	83	90	82

DOT LEVEL 7

101	109	104	111
105	97	108	100
103	112	102	110
107	99	106	98

DOT LEVEL 8

117	125	120	127
121	113	124	116
119	128	118	126
123	115	122	114

DOT LEVEL 9

133	141	136	143
137	129	140	132
135	144	134	142
139	131	138	130

DOT LEVEL 10

149	157	152	159
153	145	156	148
151	160	150	158
155	147	154	146

DOT LEVEL 11

165	173	168	175
169	161	172	164
167	176	166	174
171	163	170	162

DOT LEVEL 12

181	189	184	191
185	177	188	180
183	192	182	190
187	179	186	178

DOT LEVEL 13

197	205	200	207
201	193	204	196
199	208	198	206
203	195	202	194

DOT LEVEL 14

213	221	216	223
217	209	220	212
215	224	214	222
219	211	218	210

DOT LEVEL 15

229	237	232	239
233	225	236	228
231	240	230	238
235	227	234	226

DOT LEVEL 16

FIG. 24

LEVEL 1

250	242	247	240
246	254	243	251
248	239	249	241
244	252	245	253

LEVEL 2

234	226	231	224
230	238	227	235
232	223	233	225
228	236	229	237

LEVEL 3

218	210	215	208
214	222	211	219
216	207	217	209
212	220	213	221

LEVEL 4

202	194	199	192
198	206	195	203
200	191	201	193
196	204	197	205

LEVEL 5

186	178	183	176
182	190	179	187
184	175	185	177
180	188	181	189

LEVEL 6

170	162	167	160
166	174	163	171
168	159	169	161
164	172	165	173

LEVEL 7

154	146	151	144
150	158	147	155
152	143	153	145
148	156	149	157

LEVEL 8

138	130	135	128
134	142	131	139
136	127	137	129
132	140	133	141

LEVEL 9

122	114	119	112
118	126	115	123
120	111	121	113
116	124	117	125

LEVEL 10

106	98	103	96
102	110	99	107
104	95	105	97
100	108	101	109

LEVEL 11

90	82	87	80
86	94	83	91
88	79	89	81
84	92	85	93

LEVEL 12

74	66	71	64
70	78	67	75
72	63	73	65
68	76	69	77

LEVEL 13

58	50	55	48
54	62	51	59
56	47	57	49
52	60	53	61

LEVEL 14

42	34	39	32
38	46	35	43
40	31	41	33
36	44	37	45

LEVEL 15

26	18	23	16
22	30	19	27
24	15	25	17
20	28	21	29

LEVEL 16

FIG. 25

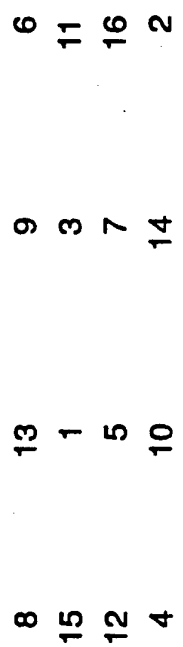


FIG. 26

DOT LEVEL 1

8	13	9	6
15	1	3	11
12	5	7	16
4	10	14	2

DOT LEVEL 2

24	29	25	22
31	17	19	27
28	21	23	32
20	26	30	18

DOT LEVEL 3

40	45	41	38
47	33	35	43
44	37	39	48
36	42	46	34

DOT LEVEL 4

56	61	57	54
63	49	51	59
60	53	55	64
52	58	62	50

DOT LEVEL 5

72	77	73	70
79	65	67	75
76	69	71	80
68	74	78	66

DOT LEVEL 6

88	93	89	86
95	81	83	91
92	85	87	96
84	90	94	82

DOT LEVEL 7

104	109	105	102
111	97	99	107
108	101	103	112
100	106	110	98

DOT LEVEL 8

120	125	121	118
127	113	115	123
124	117	119	128
116	122	126	114

DOT LEVEL 9

136	141	137	134
143	129	131	139
140	133	135	144
132	138	142	130

DOT LEVEL 10

152	157	153	150
159	145	147	155
156	149	151	160
148	154	158	146

DOT LEVEL 11

168	173	169	166
175	161	163	171
172	165	167	176
164	170	174	162

DOT LEVEL 12

184	189	185	182
191	177	179	187
188	181	183	192
180	186	190	178

DOT LEVEL 13

200	205	201	198
207	193	195	203
204	197	199	208
196	202	206	194

DOT LEVEL 14

216	221	217	214
223	209	211	219
220	213	215	224
212	218	222	210

DOT LEVEL 15

232	237	233	230
239	225	227	235
236	229	231	240
228	234	238	226

DOT LEVEL 16

FIG. 27

LEVEL 1

247	242	246	249
240	254	252	244
243	250	248	239
251	245	241	253

LEVEL 2

231	226	230	233
224	238	236	228
227	234	232	223
235	229	225	237

LEVEL 3

215	210	214	217
208	222	220	212
211	218	216	207
219	213	209	221

LEVEL 4

199	194	198	201
192	206	204	196
195	202	200	196
203	197	193	205

LEVEL 5

183	178	182	185
176	190	188	180
179	186	184	175
187	181	177	189

LEVEL 6

167	162	166	169
160	174	172	164
163	170	168	159
171	165	161	173

LEVEL 7

151	146	150	153
144	158	156	148
147	154	152	143
155	149	145	157

LEVEL 8

135	130	134	137
128	142	140	132
131	138	136	127
139	133	129	141

LEVEL 9

119	114	118	121
112	126	124	116
115	122	120	111
123	117	113	125

LEVEL 10

103	98	102	105
96	110	108	100
99	106	104	95
107	101	97	109

LEVEL 11

87	82	86	89
80	94	92	84
83	90	88	79
91	85	81	93

LEVEL 12

71	66	70	73
64	78	76	68
67	74	72	63
75	69	65	77

LEVEL 13

55	50	54	57
48	62	60	52
51	58	56	47
59	53	49	61

LEVEL 14

39	34	38	41
32	46	44	36
35	42	40	31
43	37	33	45

LEVEL 15

23	18	22	25
16	30	28	20
19	26	24	15
27	21	17	29

LEVEL 16

FIG. 28

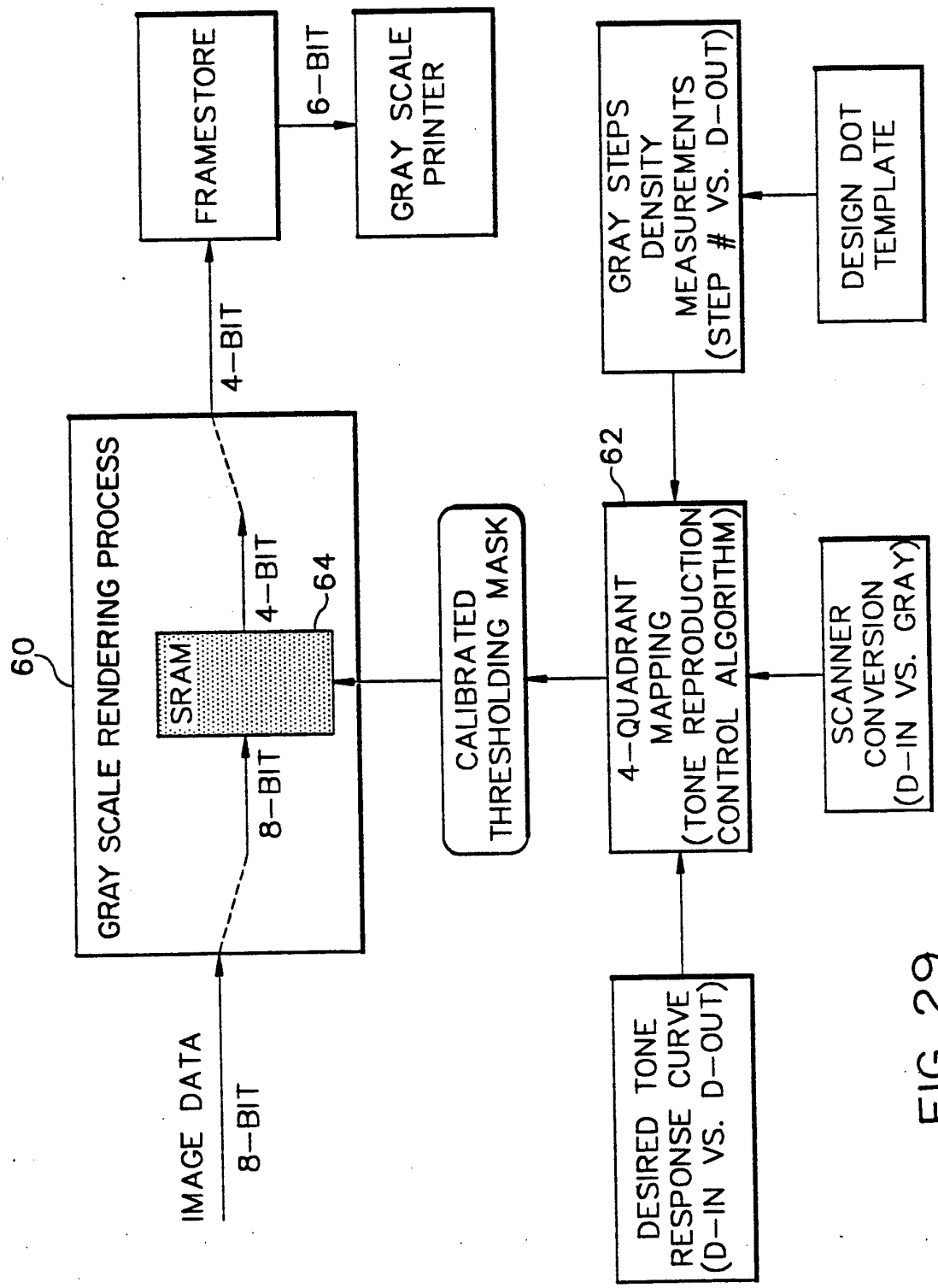


IMAGE DATA
8-BIT
GRAY SCALE RENDERING PROCESS
60
SRAM
64
8-BIT
4-BIT
4-BIT
FRAMESTORE
6-BIT
GRAY SCALE PRINTER
CALIBRATED THRESHOLDING MASK
4-QUADRANT MAPPING (TONE REPRODUCTION CONTROL ALGORITHM)
62
DESIRED TONE RESPONSE CURVE (D-IN VS. D-OUT)
GRAY STEPS DENSITY MEASUREMENTS (STEP # VS. D-OUT)
DESIGN DOT TEMPLATE
SCANNER CONVERSION (D-IN VS. GRAY)

FIG. 29

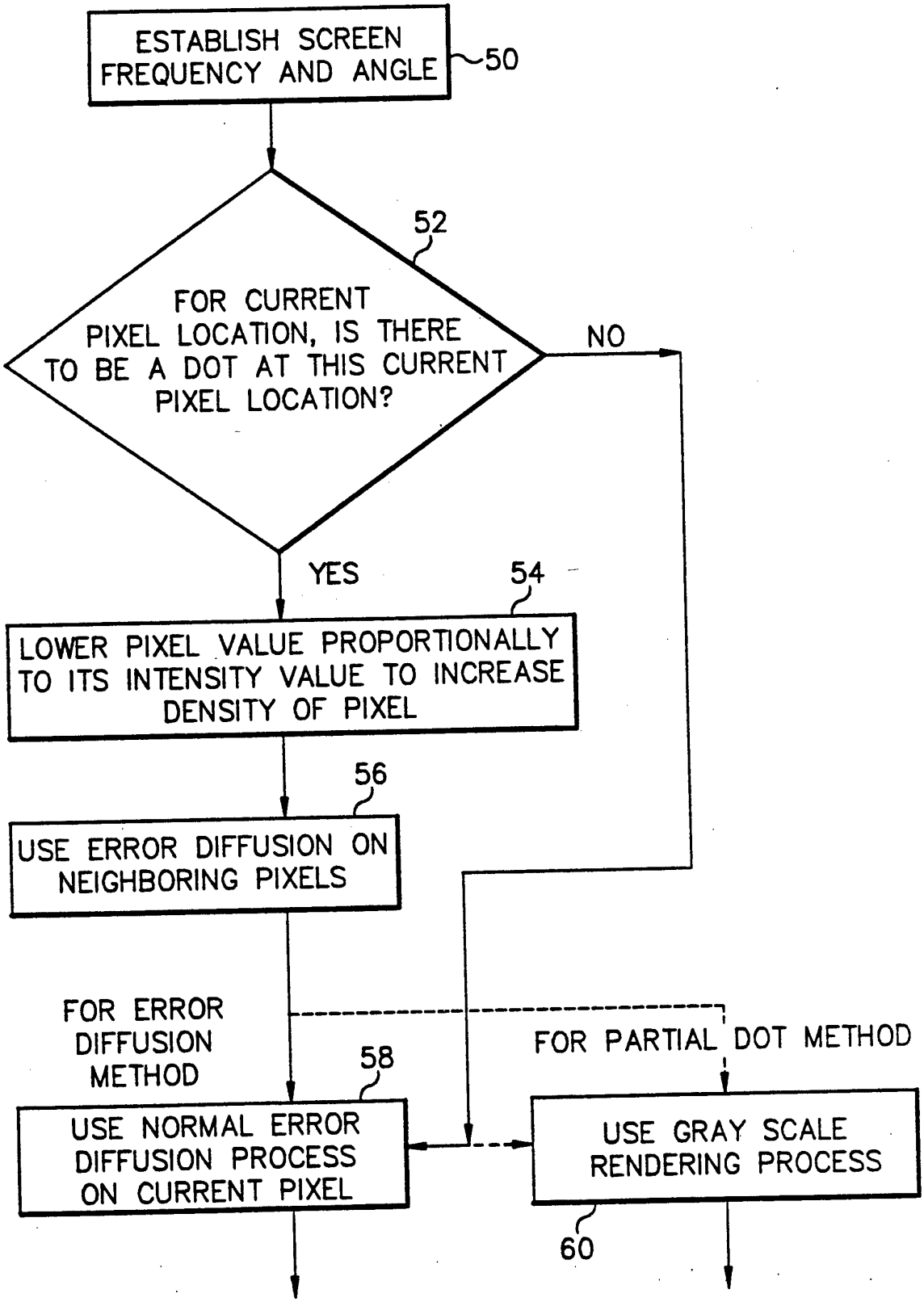

ESTABLISH SCREEN FREQUENCY AND ANGLE
50
52
FOR CURRENT PIXEL LOCATION, IS THERE TO BE A DOT AT THIS CURRENT PIXEL LOCATION?
NO
YES
54
LOWER PIXEL VALUE PROPORTIONALLY TO ITS INTENSITY VALUE TO INCREASE DENSITY OF PIXEL
56
USE ERROR DIFFUSION ON NEIGHBORING PIXELS
FOR ERROR DIFFUSION METHOD
FOR PARTIAL DOT METHOD
58
USE NORMAL ERROR DIFFUSION PROCESS ON CURRENT PIXEL
USE GRAY SCALE RENDERING PROCESS
60

FIG. 30

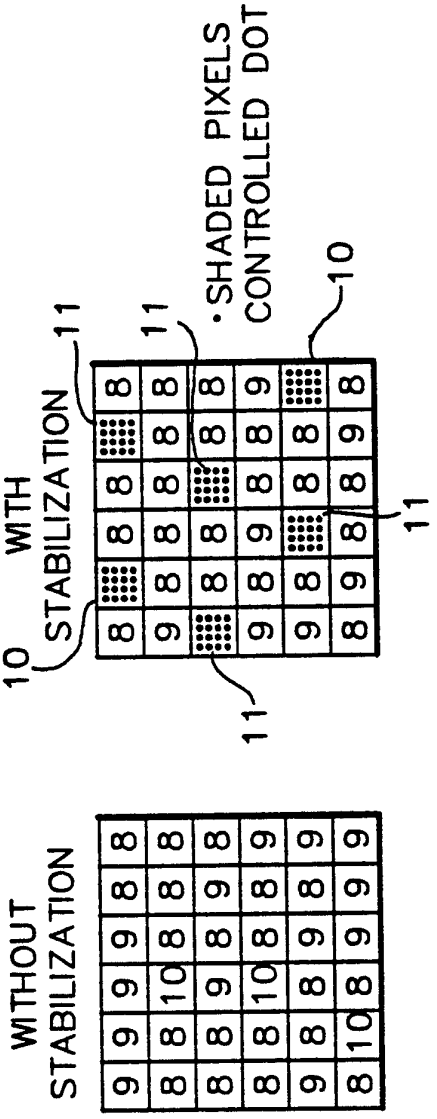

WITHOUT STABILIZATION
WITH STABILIZATION
• SHADED PIXELS CONTROLLED DOT
10
11

FIG. 31

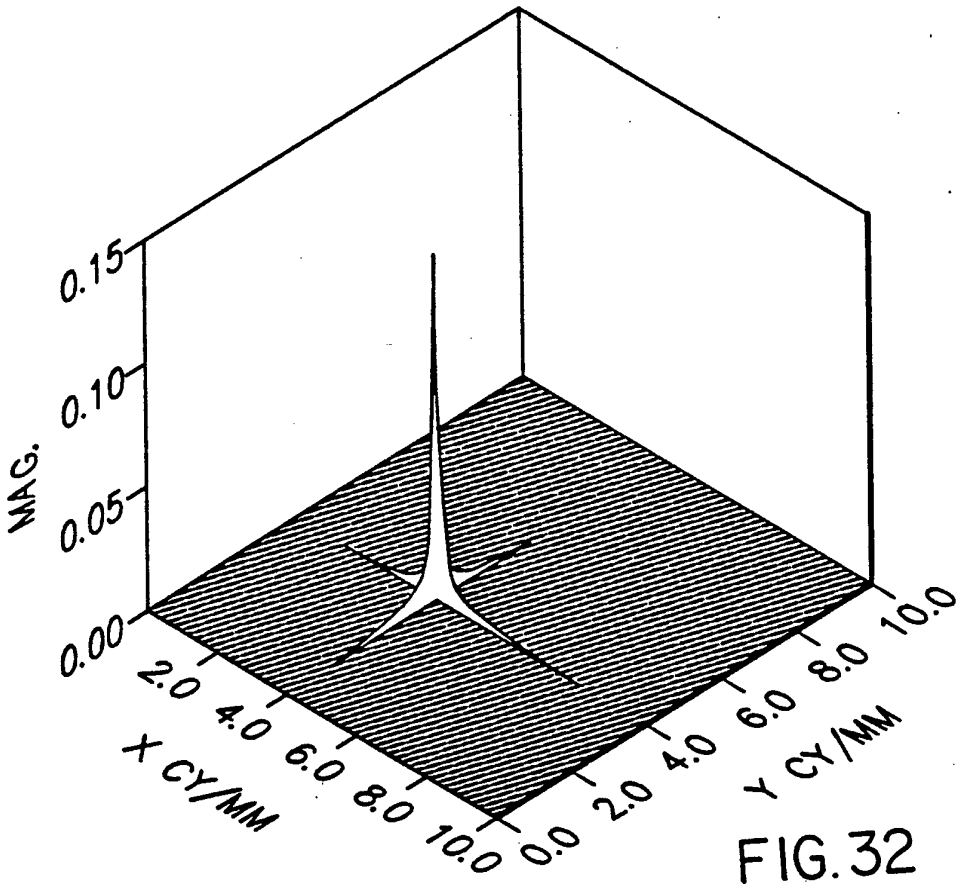

0.15
0.10
0.05
0.00
MAG.
2.0
4.0
6.0
8.0
10.0
X CY/MM
0.0
2.0
4.0
6.0
8.0
10.0
Y CY/MM

FIG. 32

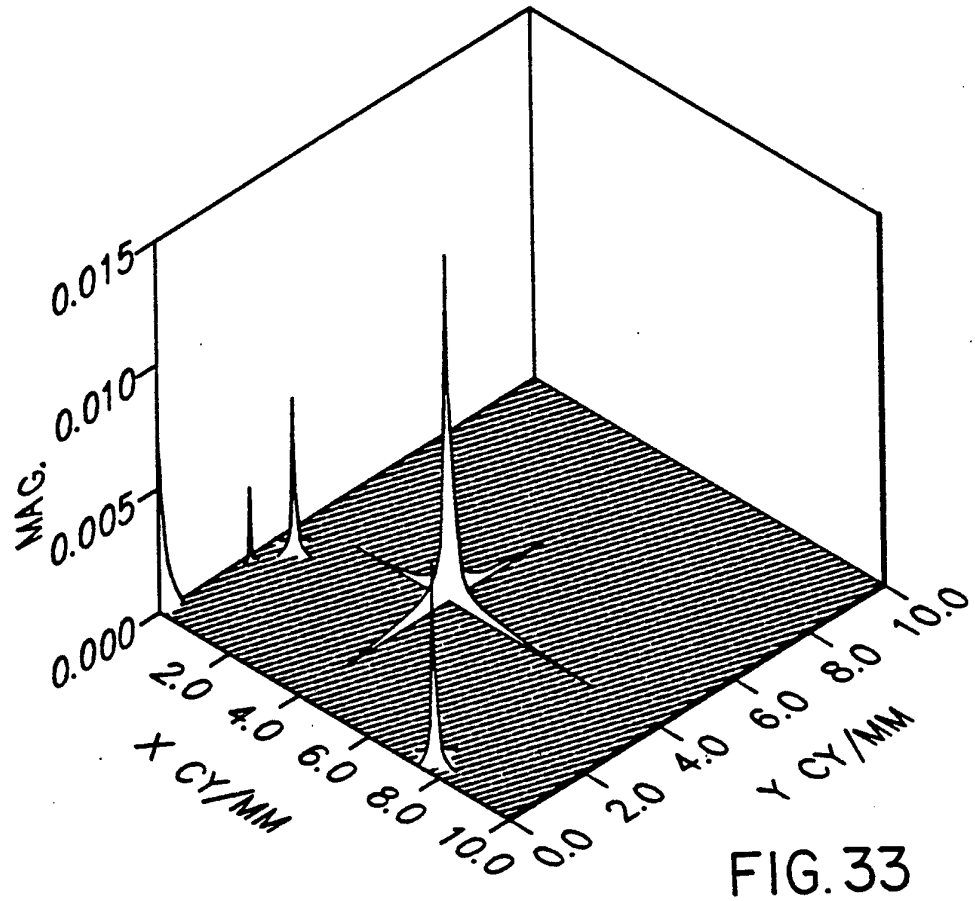

0.015
0.010
0.005
0.000
MAG.
2.0
4.0
6.0
8.0
10.0
X CY/MM
0.0
2.0
4.0
6.0
8.0
10.0
Y CY/MM

FIG. 33

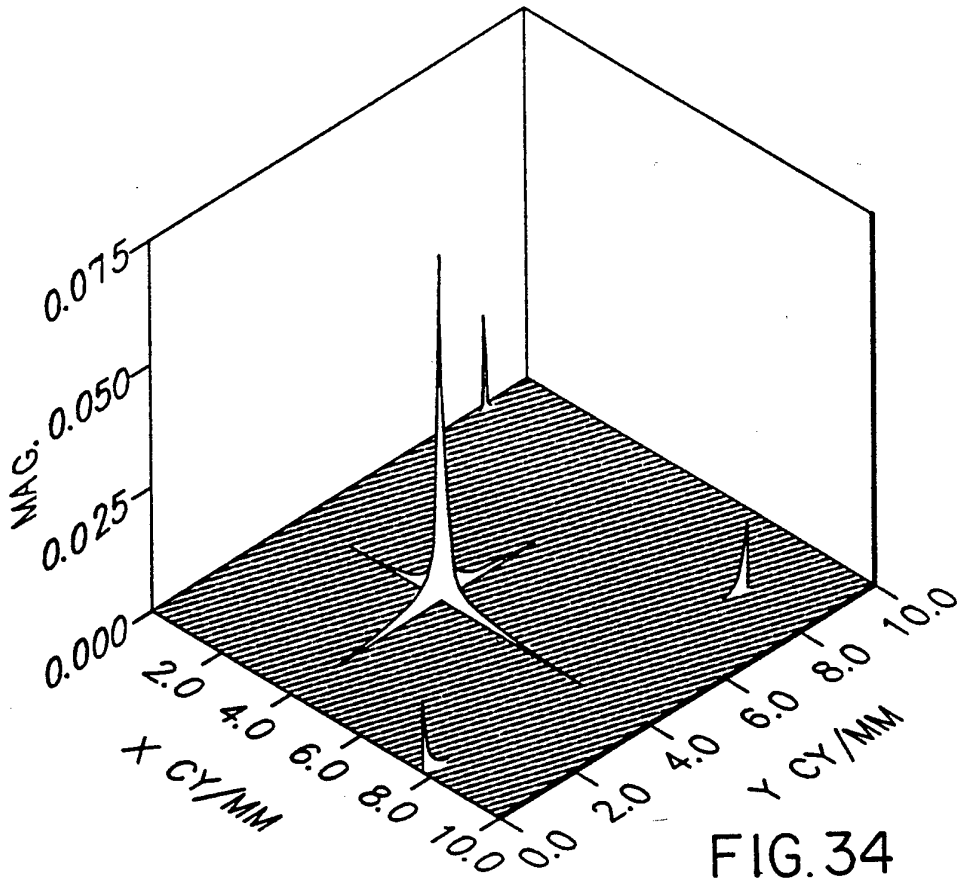

0.075
MAG. 0.050
0.025
0.000
2.0
4.0
6.0
8.0
10.0
X CY/MM
0.0
2.0
4.0
6.0
8.0
10.0
Y CY/MM

FIG. 34

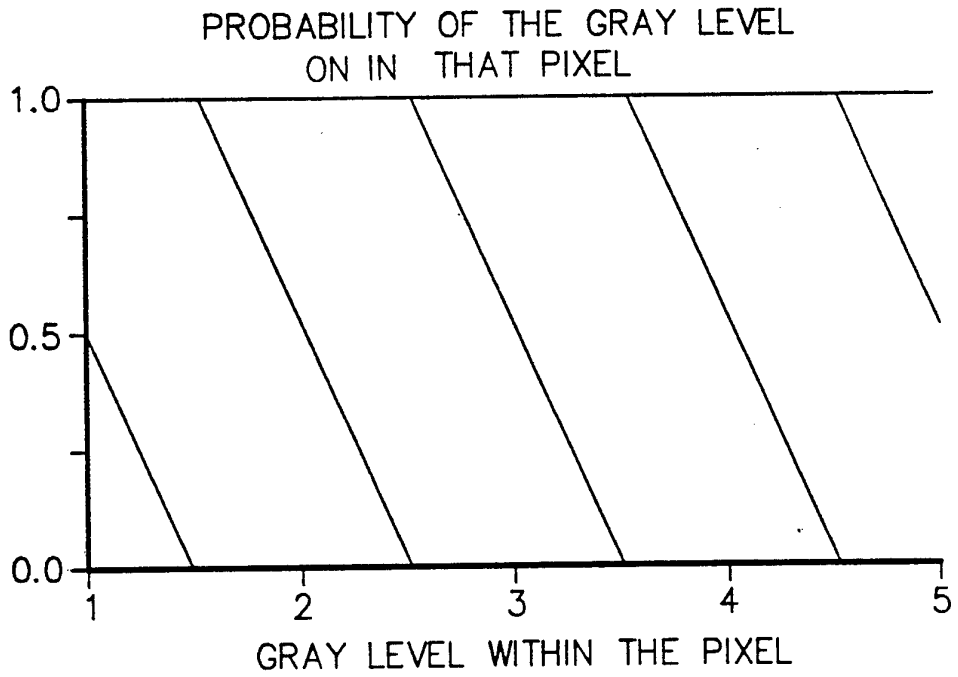

PROBABILITY OF THE GRAY LEVEL
ON IN THAT PIXEL
1.0
0.5
0.0
1
2
3
4
5
GRAY LEVEL WITHIN THE PIXEL

FIG. 35

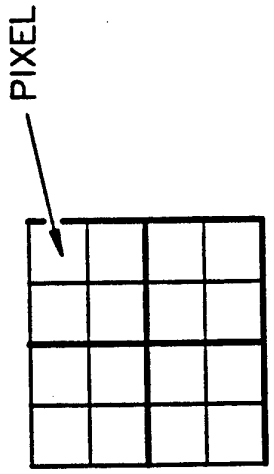


FIG. 37

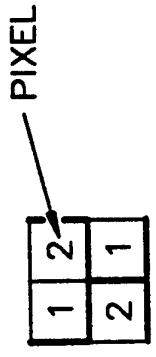


FIG. 36

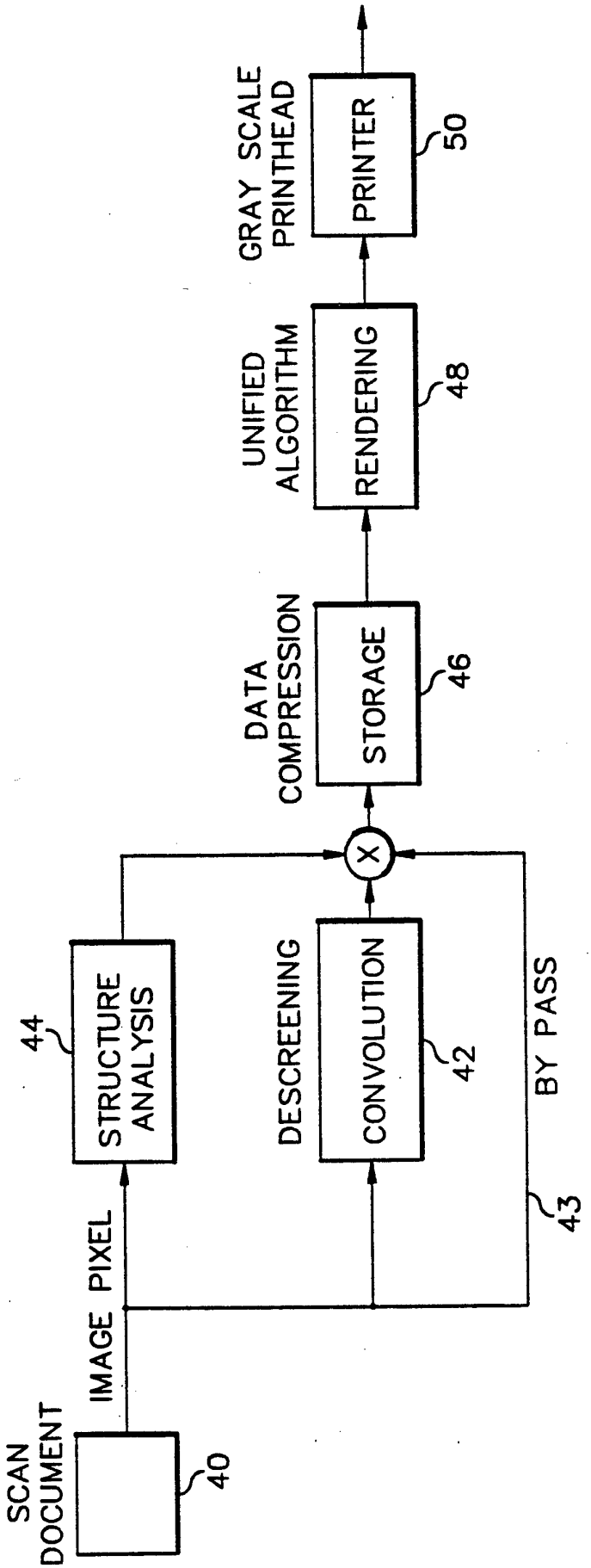

SCAN DOCUMENT
40
IMAGE PIXEL
STRUCTURE ANALYSIS
44
DESCREENING
CONVOLUTION
42
BY PASS
43
X
DATA COMPRESSION
STORAGE
46
UNIFIED ALGORITHM
RENDERING
48
GRAY SCALE PRINTHEAD
PRINTER
50

FIG. 38

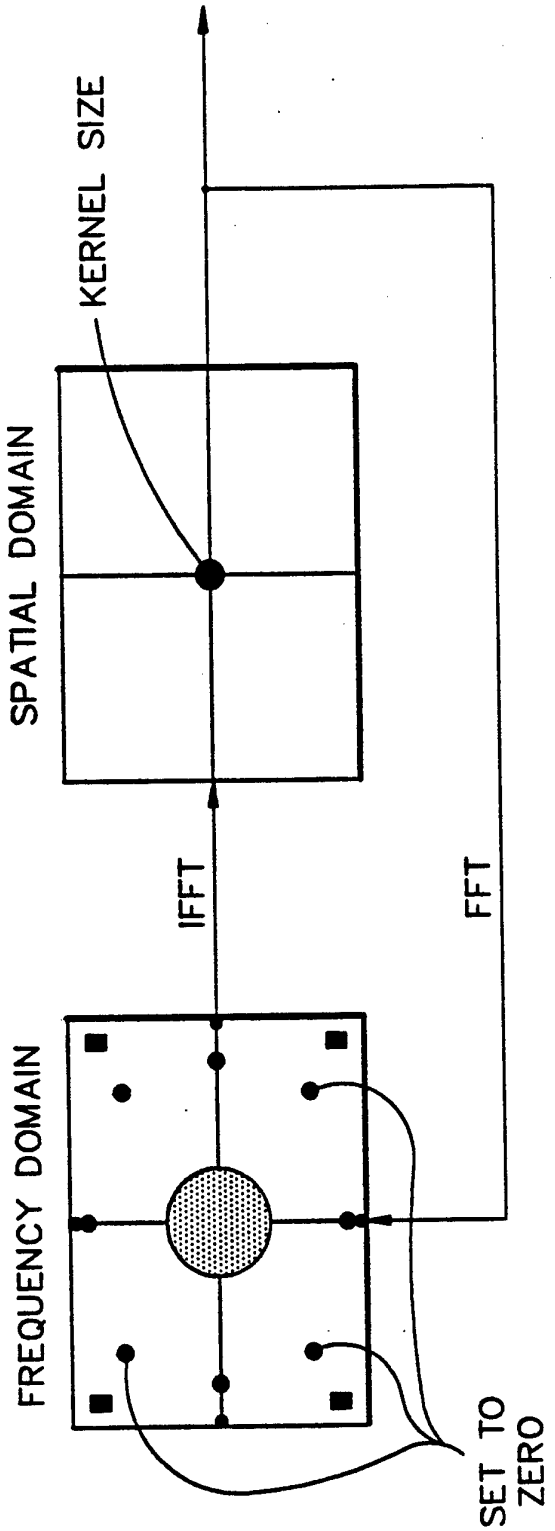

KERNEL SIZE
SPATIAL DOMAIN
IFFT
FFT
FREQUENCY DOMAIN
SET TO ZERO

FIG. 39

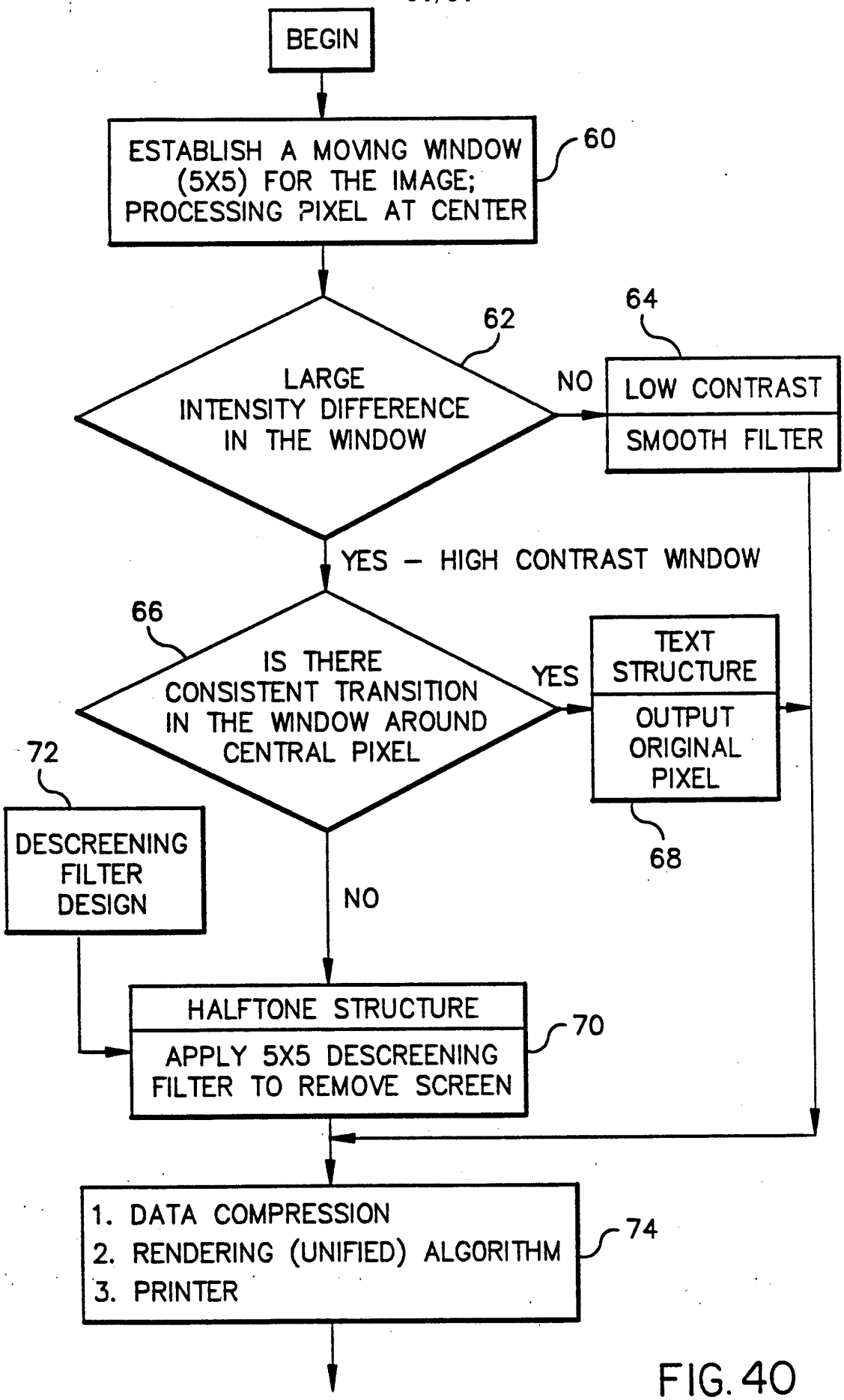

BEGIN
ESTABLISH A MOVING WINDOW (5X5) FOR THE IMAGE; PROCESSING PIXEL AT CENTER
60
LARGE INTENSITY DIFFERENCE IN THE WINDOW
62
NO
64
LOW CONTRAST
SMOOTH FILTER
YES – HIGH CONTRAST WINDOW
IS THERE CONSISTENT TRANSITION IN THE WINDOW AROUND CENTRAL PIXEL
66
YES
TEXT STRUCTURE
OUTPUT ORIGINAL PIXEL
68
72
DESCREENING FILTER DESIGN
NO
HALFTONE STRUCTURE
APPLY 5X5 DESCREENING FILTER TO REMOVE SCREEN
70
1. DATA COMPRESSION
2. RENDERING (UNIFIED) ALGORITHM
3. PRINTER
74

FIG. 40