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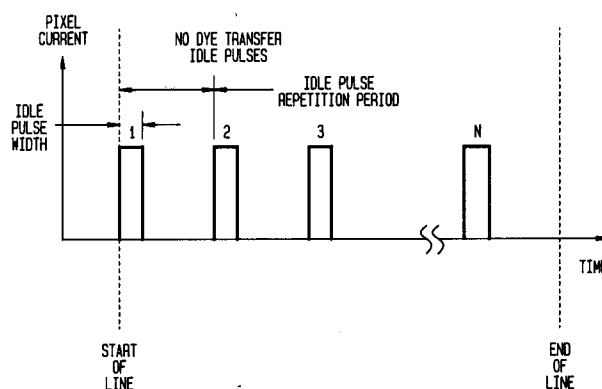
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Printer head modulation technique for thermal printers.

The present invention relates to a technique including method and apparatus for modulating the power to thermal pixels of a thermal print head. The technique energizes each thermal pixel with a plurality of N-M idle power modulating pulses and a plurality of M print power modulating pulses during each line printing period. The idle power modulating pulses are used for substantially maintaining the thermal pixel at a first temperature which is (1) below a dye transfer temperature of a dye color on a dye carrier member, and (2) above a base temperature of a material forming a heat sink of the print head. The print power modulating pulses are used to raise the first temperature of the thermal pixel to a second temperature above the dye transfer temperature of the dye carrier member so as to cause an M dye color density level of N density levels of the dye color to be transferred from the dye carrier member to a receiver member engaging the dye carrier member opposite the thermal pixel, where M is a value between 0 and N. Alternatively, for modulating large area thermal pixels, two sequential sets of N power modulating pulses can be generated, each plurality of N pulses having M/2 print power modulating pulses. During a first line printing period, after a cold start, a plurality of idle power modulating pulses can initially be generated to raise each thermal pixel from the base temperature to the first temperature.

FIG. 4



Field of the Invention

The present invention relates to thermal printers wherein the selective energization of thermal pixels causes a transfer of dye from a dye carrier member to a receiver member.

Background of the Invention

In a thermal printer, a carrier member containing dye color is disposed between a receiver member, such as paper, and a print head assembly formed of, for example, a plurality of individual thermal elements often referred to as thermal pixels. When a thermal pixel is energized it is heated and causes dye from the carrier member to transfer to the receiver member. The density (darkness) of the printed dye is a function of the temperature of the thermal pixel and the time the carrier member is heated (the energy delivered from the thermal pixel to the carrier member). Thermal dye transfer printers offer the advantage of true "continuous tone" dye density transfer. This result is obtained by varying the energy applied to each thermal pixel, yielding a variable dye density image pixel on the receiver member.

A print head is usually organized into a plurality of groups of thermal pixels where the thermal pixels in each group are simultaneously addressed in parallel. Each group is addressed sequentially one at a time, or all simultaneously. The reason that groups are used is that if all of the thermal pixels are energized at the same time, a large and more expensive power supply is needed. For example, if a thermal pixel draws 68 milliamperes and 512 thermal pixels are used, the power supply has to produce 33.3 amperes if all of the thermal pixels are simultaneously energized. Therefore, the group arrangement is preferred. In this regard see, for example, U. S. patent No. 4,621,271 (S. A. Brownstein, issued on November 4, 1986) which describes method and apparatus for controlling a thermal printer with a plurality of groups of thermal pixels. When a group of thermal pixels are addressed, the thermal pixels are each selectively energized and are driven by a constant voltage.

Referring now to FIG. 1, there is shown a prior art pulse width modulation technique used to drive a thermal pixel. The pulse width modulation technique of FIG. 1 is also described in the Brownstein patent (cited above) and is repeated hereinbelow for purposes of clarity. As shown in FIG. 1, for pulse width modulation techniques, the maximum time a current pulse can be provided to a thermal pixel is for the period of t_0 - t_i , where "i" is the letter and not the number one. This will produce the maximum density dye image pixel. If the pulse width is made smaller (e.g., t_0 - t_b), then a less dense image pixel is formed. If a still smaller pulse width (e.g., t_0 - t_a) is used, then an even lower dye density image pixel is formed. Such an arrangement presents several drawbacks. Generally, all thermal pixels in a print head are not driven simultaneously, but are addressed in separate groups. Thus when a group is undergoing a heat cycle, all other groups are either cold, or cooling. Dye carrier member heat resisting (slipping) layers applied to the side of the carrier member adjacent the print head must, therefore, continue to perform well under both hot and cold conditions. This makes the design of the dye carrier member slipping layer difficult since a designer must optimize both "hot" and "cold" carrier slipping layer performance. Layers that may function well under hot conditions may tend to aggregate or stick to the print head when run with cold print head surfaces. This difficulty complicates the design of the dye carrier member slipping layer.

A second problem involves the surface temperatures of the thermal pixels along the print head. A thermal pixel in the middle of a group that is being addressed and energized generally has neighboring pixels on both sides that are warm. As such, the temperature profile of the thermal pixel itself, as well as any interpixel gap in this group, tends to average to some level, since the temperature gradients in the print head tends to equilibrate. The temperature of a thermal pixel on the end of a group can be significantly reduced due to the heat flow to the cold terminal pixels of the adjacent group which are not being addressed and energized. When dye images are transferred with such a thermal printer, low density streaks (or group lines) often appear due to cold end thermal pixels of a group.

A logical solution to this problem is to energize all of the thermal pixels of the print head at once, eliminating the existence of cold spots due to these cold end thermal pixels. However, two factors make such a technique rather impractical. First, as discussed above, thermal pixels draw significant currents. If all of the thermal pixels are driven simultaneously, print head currents are increased by a multiplicative factor equal to the number of groups. This causes difficult design constraints on both the power supply and the power buses within the print head.

When a thermal pixel is energized for an extended period of time (e.g., 4 milliseconds or more), limited thermal conductivity within the thermal pixel itself results in rather large temperature gradients across the thermal pixel's surface. Thus, very high peak temperatures (hot spots) are experienced in the center of the thermal pixel, while the outside regions of the pixel remain relatively cool due to thermal lag. As a result,

damage to the thermal pixel, the dye carrier member, or the receiver member can result since very high peak temperatures can be reached. For example, such hot spots can cause melted regions of the dye carrier member or the receiver member, or reduced life of the thermal pixel.

U. S. patent No. 4,621,271 (cited above) describes a technique which addresses the thermal pixels of each group a plurality of times, and has means for selectively energizing the thermal pixels of each group when they are addressed. In this manner each thermal pixel supplies thermal energy to the dye carrier member which substantially corresponds to a desired dye color density in an image pixel to be reproduced on the receiver member.

It is to be understood that the power modulation technique that is used with a print head determines the maximum print speed and the dynamic range of the print (i.e., the number of unique dye density levels). In the power modulation techniques used with prior art thermal print heads (e.g., the technique disclosed in U. S. patent No. 4,621,271), it is known that the maximum line rate attainable without loss of dynamic range is determined by the material structure (the thermal time constant) of the print head. For the conventional resistive print heads, the thermal time constants have been measured to be approximately 4 milliseconds. The temperature of the resistance heaters of the thermal pixels on the print head obeys exponential growth and decay functions, such that the temperature profiles of the heaters can be expressed as:

$$T_{\text{heater}} = T_{\text{initial}} + (T_{\text{final}} - T_{\text{initial}}) \times (e^{-t/T_c}) \quad \text{Eq. (1)}$$

for cooling, and

$$T_{\text{heater}} = T_{\text{initial}} + (T_{\text{final}} - T_{\text{initial}}) \times (1 - e^{-t/T_c}) \quad \text{Eq. (2)}$$

for heating, where "Tc" designates the thermal time constant, and "t" designates the time along, for example, the X-axis of FIG. 1.

From Equations (1) and (2) above, where the thermal time constant Tc has a value of approximately 4 milliseconds, the rise time of one time constant Tc provides a 63.2% change in the resistive heater temperature. Three time constants, 3(Tc), are required to provide a 95% change in temperature of a resistive heater. All power modulation techniques currently employed in thermal printers rely on the pixel temperature to achieve a temperature which is sufficiently high for transferring dye from the dye carrier member when dye transfer is required, and a temperature which is sufficiently low for not transferring dye from the dye carrier member when dye transfer is not required. Such power modulation technique functions to enable varying print densities, where the low temperature is usually a base temperature of a heat sink of the print head. All prior art power modulation techniques, therefore, require the print head to return to the base temperature for minimum print density, and such return requires three time constant periods (3Tc). With such prior art print heads, if the line times are faster than the single 4 milliseconds time constant Tc, then the thermal printer loses print density levels. The currently used print heads are, therefore, limited to line speeds of approximately 5 milliseconds which is slower than the single time constant Tc. It is desirable to provide a print head which responds faster to printing demands.

Summary of the Invention

The present invention is directed to a technique (method and apparatus) for modulating the power to a thermal print head to enable high print speeds without loss of density level resolution. In a first embodiment, the method comprises a first step of energizing the thermal pixel with a plurality of N idle power modulating pulses during each line printing period. The idle power modulating pulses are used for heating and substantially maintaining each thermal pixel at a first temperature which is (1) below a dye transfer temperature of a dye color on a dye carrier member engaging the thermal pixel, and (2) above a base temperature of a material forming a heat sink of the print head. A second step of the method extends each of M of the N idle power modulating pulses by a predetermined time period so as to raise the first temperature of the thermal pixel to a second temperature above the dye transfer temperature of the dye carrier member for a predetermined portion of the line printing period. Such second temperature causes a predetermined dye color density level, corresponding to a value of M of N density levels of the dye color, to be transferred from the dye carrier member to a receiver member engaging the dye carrier member opposite the thermal pixel, where M is a value between 0 and N.

In a second embodiment of the invention, a plurality of Y idle power modulating pulses are used to energize the thermal pixel prior to performing the first and second steps during a first line printing period after a cold start of the thermal pixel so as to raise the temperature of the thermal pixel from the base

temperature to the first temperature.

A third embodiment of the invention is used where the thermal pixel has a large surface area to be heated. In the third embodiment, the thermal pixel is energized with a first and a second sequential plurality of N idle power modulating pulses during each line printing period for heating and substantially maintaining the thermal pixel at the first temperature. During each of the first and second plurality of N idle power modulating pulses, M/2 of the N idle power modulating pulses are extended by a predetermined time so as to raise the first temperature of the thermal pixel to the second temperature above the dye transfer temperature of the dye carrier member. The M time extended power modulating pulses cause (1) a substantially uniform temperature to occur across the surface area of the thermal pixel, and (2) a predetermined print density level corresponding to M of N density levels of the dye color to be transferred from the dye carrier member to the receiver member, where M is a value between 0 and N.

The apparatus modulates power to each of a plurality of K thermal pixels of a thermal print head during a line printing period comprising means for storing and latching K-bits of data relating to an M color dye density level out of a maximum of N color dye density levels (where M is a value between 0 and N) associated with each of the K thermal pixels during the line printing period, and energizing means. The energizing means is responsive to a binary value of the bits of data latched in the storing and latching means for energizing each thermal pixel with a plurality of N power modulating pulses during a line printing period. The N power modulating pulses for each thermal pixel comprise N minus M idle power modulating pulses and M print power modulating pulses. The N minus M idle power modulating pulses have a first width which substantially maintain each thermal pixel at a first temperature which is both below a dye transfer temperature of a dye color on a dye carrier member engaging the thermal pixel and above a base temperature of a material forming a heat sink of the print head. The M print power modulating pulses have a second width which is wider than the first width of the idle power modulating pulses. The M print power modulating pulses are used to raise the first temperature of the thermal pixel to a second temperature above the dye transfer temperature of the dye carrier member for a predetermined portion of the line printing period. This second temperature causes a predetermined dye color density level corresponding to a value of M of N density levels of the dye color to be transferred from the dye carrier member to a receiver member engaging the dye carrier member opposite the thermal pixel.

The invention will be better understood from the following more detailed description taken with the accompanying drawings and claims.

Brief Description of the Drawings

FIG. 1 illustrates a pulse width modulation technique used in prior art thermal printers;

FIG. 2 is a schematic side view of a thermal printer apparatus which is usable with a thermal pixel power modulation technique in accordance with the present invention;

FIG. 3 is a curve illustrating an exemplary temperature profile for a thermal pixel at half maximum density for two print lines using a conventional power modulation technique;

FIG. 4 shows an exemplary idle pulse train of N sequential idle power modulating pulses that are equal to N printing (density) levels for application to each thermal pixel of a print head for printing one image pixel of minimum density during a line printing period in accordance with a first embodiment of the present invention;

FIG. 5 shows an exemplary pulse train of N printing (density) levels similar to FIG. 4 where each pulse includes an idle power modulation pulse portion and a print power modulating pulse portion for printing one image pixel of maximum density (N density level) during a line printing period in accordance with the first embodiment of the present invention;

FIG. 6 shows an exemplary pulse train of N printing (density) levels similar to FIG. 5 for printing one image pixel of 3 density levels out of N density levels during a line printing period in accordance with the first embodiment of the present invention;

FIG. 7 is a curve illustrating an exemplary temperature profile for a thermal pixel at half maximum density for two print lines using a pulse count modulation technique in accordance with the present invention;

FIG. 8 shows an exemplary pulse train of N printing levels for printing one image pixel of 2 density levels out of N density levels which is preceded by a number of Y idle pulses for preheating a thermal pixel during a first line printing period after a cold start in accordance with a second embodiment of the present invention;

FIG. 9 shows an exemplary pulse train of N printing (density) levels for use in printing one image pixel of a predetermined density level of 2 out of N density levels when the print head includes very large

thermal pixels during a first line printing period after a cold start in accordance with a third embodiment of the present invention; and

FIG. 10 shows an exemplary arrangement of a control system for operating thermal pixels of a print head and practicing the power modulation technique of FIGS. 4-9 in accordance with the present invention.

5 The drawings are not necessarily to scale.

Detailed Description

Referring now to FIG. 2, there is shown a thermal print apparatus 10 in accordance with the present invention. Apparatus 10 comprises a receiver member 12, a dye carrier member 14, a rotatable drum 16, a thermal print head 18, a dye carrier member supply roller 20, a dye carrier member take-up roller 22, a drum drive mechanism 24, a roller drive mechanism 26, and print head control circuitry 28 which is in accordance with the present invention. The thermal print apparatus 10 is arranged to print color images on the receiver member 12 from dyes transferred from the dye carrier member 14. The receiver member 12, in the form of a sheet of material such as paper, is secured to and positioned around a portion of the rotatable drum 16 which is coupled to the drum drive mechanism 24. It is to be understood that the drum drive mechanism 24 includes a motor (not shown) adapted to advance the drum 16 and the receiver member 12 under the thermal print head 18. The thermal print head 18 has a plurality of thermal pixels (not shown but are formed with heating elements) which press the dye carrier member 14 against the receiver member 12. The dye carrier member 14 is in the form of a web which is driven from the supply roller 20 onto a take-up roller 22 by a roller drive mechanism 26 coupled to the take-up roller 22. The drive mechanisms 24 and 26 each include a motor (not shown) which advance the dye carrier member 14 and the receiver member 12 relative to the thermal pixels of the thermal print head 18. During printing, while the thermal pixels are being energized under the control of the print head control circuitry 28, the members 12 and 14 are moved such that a resultant dye image pixel is somewhat larger than if the members 12 and 14 are stationary during dye transfer. This is advantageous since it minimizes discernable interpixel image boundaries. Additionally, it reduces sticking of the dye carrier member 14 to the thermal pixels in the thermal print head 18.

In operation, drive signals are continuously provided to the drum drive mechanism 24 from, for example, a microcomputer (not shown) to rotate the drum 16 and bring successive contiguous areas of the receiver member 12 into the print region opposite the thermal pixels in the thermal print head 18. A portion of a dye frame (not shown) containing a particular dye color on the dye carrier member 14 is disposed between the print head 18 and the receiver member 12. As noted above, the receiver member 12 and the dye carrier member 14 are moved relative to the print head 18 during the printing operation. Energizing signals are provided to the thermal pixels of the thermal print head 18 by the print head control circuitry 28 to selectively heat the thermal pixels and cause dye from the particular dye frame to be transferred from the dye carrier member 14 to the receiver member 12.

As the receiver member 12 moves through each print line of the print region opposite the thermal print head 18, the selective energization of the thermal pixels results in the printing of a color image on the receiver member 12. The color of this image is determined by the color of the thermally transferable dye contained in the particular dye frame (not shown here but illustrated in FIG. 3 of U. S. patent No. 4,621,271) of the dye carrier member 14 that is driven past the print region. After one complete color frame of the image has been printed, the receiver member 12 is returned to an initial, or "home" position. Dye carrier member 14 is advanced to move a frame of another dye color into position for printing. The thermal pixels in the print head 18 are selectively energized so as to print the next color frame of the image superimposed on the first printed color frame. This process is repeated until all of the different color frames needed to produce the desired image are superimposed on the receiver member 12. For purposes of discussion hereinafter, it is assumed that the plurality of thermal pixels in a line of thermal pixels of the print head 18 are all simultaneously energized instead of dividing such line of thermal pixels into two or more groups of thermal pixels and energizing the groups sequentially.

Referring now to FIG. 3, there is shown a curve illustrating an exemplary temperature profile for a thermal pixel at half maximum density for two print lines using a conventional power modulation technique. For printing the first line, during the time period of approximately 0.000-0.032 seconds, the thermal pixel being heated starts at a base temperature (e.g., approximately 40 degrees Centigrade) of the thermal print head 18 and rises to a print temperature which is above a dye transfer temperature (150 degrees Centigrade). For a period of time (the time period of approximately 0.008-0.017 seconds) the thermal pixel is heated to a temperature above the dye transfer temperature which causes dye from the dye carrier member 14 to be transferred to the receiver member 12. After the thermal pixel is no longer energized, the

thermal pixel cools down to the base temperature again during the time period of approximately 0.017-0.032 seconds.

This sequence of steps is repeated for each subsequent line of an image to be printed as shown, for example, during the time period of approximately 0.032-0.064 seconds for printing a second line of the image. It is to be understood that five time constants $5(T_c)$ used in Equations (1) and (2) is the time required for the thermal pixel temperature to change from the base temperature to the steady state temperature of the thermal pixel. The dye transfer temperature is defined as the temperature at which dye will transfer from the dye carrier member 14 to the receiver member 12, and is somewhat below the steady state pixel temperature. As shown in FIG. 3, the thermal time response for the transfer process is approximately 0.008 seconds which is the amount of time required to increase the image pixel temperature on the thermal head 18 from the base temperature to the dye transfer temperature. The rise time of the curve of FIG. 3 is of a constant shape since it is a material function of the print head 18. More particularly, the rise time is a function of the material that the print head 18 is made of and is represented by the term e^{-t/T_c} in the Equations (1) and (2). The rise time is analogous to the charging of a capacitor, where a particularly sized capacitor takes a predetermined time to charge from a zero charge state to a maximum charge state at a constant potential.

Referring now to FIG. 4, there is shown a pulse count modulation technique for powering a thermal pixel of the print head 18 during a line printing period in accordance with a first embodiment of the present invention. More particularly, FIG. 4 illustrates an exemplary idle pulse train of N sequential idle power modulating pulses that are equal to N printing (density) levels for application to a thermal pixel of the print head 18 for printing one line of minimum density on the receiver member 12. The pulse train includes a plurality of N idle power modulating pulses which have a width equaling a predetermined percentage of an idle power modulating pulse repetition rate. It is to be understood that the predetermined percentage of the width of each idle power modulating pulse is a function of the efficiency of the thermal head 18, or the dye transfer temperature of the dye carrier member 14. The idle power modulating pulse repetition rate is equal to the line printing time minus the latch load time (time to latch onto the information signals denoting the print level for a thermal pixel) divided by the number of print density levels (N). In accordance with the first embodiment of the present invention, to produce a minimum density pixel image on the receiver member 12 by a thermal pixel of the print head 18, the thermal pixel is repetitively pulsed N times during the time period required to print one line of the image as shown in FIG. 4. This repetitive use of N idle power modulating pulses during a line printing period functions to maintain the thermal pixel at a temperature which is slightly below the dye transfer temperature of the dye carrier member 14. For purposes of discussion hereinafter, it is assumed that N equals 256. It is to be understood that each of the other thermal pixels of the print head 18 are preferably simultaneously energized in a similar manner to achieve a separate printing level at each thermal pixel.

Referring now to FIG. 5, there is shown the pulse count modulation technique of FIG. 4 to permit a thermal pixel to print one line of maximum density (N density levels) during a line printing period in accordance with the first embodiment of the present invention. The pulse train of FIG. 5 includes a plurality of N repetitive print power modulating pulses which (1) have a predetermined width which is wider than the N idle power modulating pulses of FIG. 4, (2) are coincident with the N idle power modulating pulses of FIG. 4, and (3) have a pulse repetition rate that equals the pulse repetition rate of the idle power modulating pulses of FIG. 4. More particularly, each print power modulating pulse of FIG. 5 includes the idle power modulating pulse of FIG. 4 (denoted by the portion to the left-hand side of the dashed line in each pulse), and an added print power modulating portion to the right-hand side of the dashed line in each pulse. Therefore, the N print power modulating pulses are wider and have a shorter relaxation time than the N idle power modulating pulses of FIG. 4. As a result, more energy is pulsed to the thermal pixel to raise its temperature from the idle temperature to a predetermined level above the dye transfer temperature of the dye carrier member 14.

Referring now to FIG. 6, there is shown the pulse count modulation technique of FIG. 4 for permitting a thermal pixel to print 3 density levels out of N density levels during a line printing period in accordance with the first embodiment of the present invention. The pulse train of FIG. 6 includes a plurality of N repetitive pulses which are coincident with the N idle power modulating pulses of FIG. 4, and have a pulse repetition rate that equals the pulse repetition rate of the idle power modulating pulses of FIG. 4. However, in the pulse train of FIG. 6, the first three idle power modulating pulses have been modified to increase their width in the manner of the pulses of FIG. 5 while the remaining N-3 pulses are idle power modulating pulses. More particularly, in the pulse train of FIG. 6, the first three pulses are print power modulating pulses which transfer dye from the dye carrier member 14 to the receiver member 12, and the last N-3 pulses are idle power modulating pulses which maintain the thermal pixel at the idle temperature prior to the printing of the

next line of the image to be reproduced on receiver member 12. It is to be understood that where the printing (density) level is less than the maximum 256 level shown in FIG. 5, the print power modulating pulses (e.g., the 3 print power modulating pulses of FIG. 6) can be positioned in any of the 256 power modulating pulses of the pulse train instead of just the first sequential power modulating pulses.

Referring now to FIG. 7, there is shown a curve similar to FIG. 3 illustrating an exemplary temperature profile for a thermal pixel at half maximum density for two print lines using the pulse count power modulation technique shown in FIGs. 4, 5, and 6. In FIG. 7, at time 0.00 seconds, the thermal pixel starts at a base temperature (about 40 degrees Centigrade) of the print head 18, since during a cold start no printing has occurred before this point in time. From the base temperature, the temperature curve rises in a corresponding manner to the curve shown in FIG. 3 (for the conventional power modulation technique) in achieving the print temperature with the N power modulating pulses. However, after the print power modulating pulses of, for example, FIGs. 5 or 6 are complete, the remaining idle power modulating pulses maintain the thermal pixel temperature at the predetermined idle temperature before the next line of the image is printed. The predetermined idle temperature is slightly less than the dye transfer temperature of the dye carrier member 14 and greater than the base temperature of the print head 18. From FIG. 7, it is shown that the thermal response time for dye transfer of the present pulse count power modulation technique is much less than the thermal response time for dye transfer associated with the conventional power modulation technique of FIG. 3. For example, the thermal time response for dye transfer for the conventional technique of FIG. 3 is approximately 0.008 seconds whereas the technique of FIG. 7 in accordance with the present invention reduced the thermal response time for dye transfer down to 0.0024 seconds. FIGs. 3 and 7 indicate curves for a same predetermined maximum dye transfer temperature and energy input during a line printing period. The shorter response time achieved using the pulse count modulation technique of FIGs. 5 and 6 allows for a faster line rate for the print head 18.

Referring now to FIG. 8, there is shown an exemplary pulse train for N printing levels to permit a thermal pixel to print 2 density levels out of N density levels during a first line period from a cold start in accordance with a second embodiment of the present invention. In the pulse train of FIG. 8, an initial plurality of Y idle power modulating pulses are provided primarily for preheating the associated thermal pixel to the idle temperature which is slightly below the dye transfer temperature during the initial rise time. Following the initial Y idle power modulating pulses, a plurality of N repetitive power modulating pulses including a first and a second print power modulating pulse designated pulses Y+1 and Y+2 are provided, followed by N-2 idle power modulating pulses designated Y+3 to Y+N. The Y+1 to Y+N print power modulating pulses bring the thermal pixel temperature to the second density level of N density levels before the thermal pixels returns to the idle temperature in the manner shown in FIG. 7. It is to be understood that the 1 to Y initial idle power modulating pulses are only used during a first line printing period from a cold start, and that the printing of subsequent lines of an image use the pulse train sequence of FIGs. 4-6 since the thermal pixel is already at the idle temperature after the first line printing period. Alternatively, in instances where more than N idle and print pulses are needed for printing each line of an image, the technique of FIG. 8 can be used for each line.

Referring now to FIG. 9, there is shown an exemplary pulse train for N printing (density) levels to permit a thermal pixel to print one line of a predetermined density level of two out of N density levels from a cold start when each of the thermal pixels of the print head 18 includes a very large surface area in contact with the dye carrier member 14 in accordance with a third embodiment of the present invention. More particularly, the pulse train of FIG. 9 comprises a plurality of U (U-1) idle power modulating pulses at the beginning of a line printing operation during a cold start for primarily preheating the associated thermal pixel to the temperature slightly below the dye transfer temperature. Following the plurality of U preheating idle power modulating pulses, two sets of N density level power modulating pulses are provided, where the first set of N density levels are shown as power modulating pulses U+1 to 2U+1, and the second set of N density level pulses are shown as power modulating pulses 2U+2 to KU+N. To provide a two out of N density level, a first print power modulating pulse (designated U+1) of the two needed power pulse is provided in the first set of N density level power modulating pulses followed by 255 idle power modulating pulses (pulses U+2 to 2U+1). The second print power modulating pulse (designated 2U+2) of the two needed print power modulating pulse is provided in the second set of N density level power modulating pulses followed by 255 idle power modulating pulses (pulses U+2 to 2U+1). With this technique, the required two density level print power modulating pulses (U+1 and 2U+2) are provided and spread over the line printing period. Alternatively, in instances where more than two sets of N density levels idle and print pulses are needed for printing each line of an image, the technique of FIG. 9 can be used for each line.

The technique of FIG. 9 is best used with very large thermal pixels where the heat must travel over a very large surface area. More particularly, when a very large thermal pixel is heated at one end, by the time the heat travels to the other end, the thermal pixel would be cold at the first end. Therefore, the spreading out of the print power modulating pulses over the line printing period assures a more uniform heat across the surface of the thermal pixel. The more uniform heating of the very large thermal pixels avoids white lines in the image printed on the receiver member 12 which are caused by a non-uniform heated surface of a thermal pixel. It is to be understood that if a ten density level of out N density levels is to be printed, five consecutive print power modulating pulses would be placed at pulses $U+1$ to $U+5$ and at pulses $2U+2$ to $2U+6$ in FIG. 9, each group of five print power modulating pulses being followed by 251 idle power modulating pulses.

The discussion of FIGs. 3-9 is directed to simultaneously energizing all of the thermal pixels in a line during a line printing. It is to be understood that the embodiments described hereinbefore for FIGs. 4, 5, 6, 8 and 9 are also applicable for use in an arrangement where a line of thermal pixels is divided into separate groups of thermal pixels. With such arrangement, the thermal pixels in a group are simultaneously energized, and the groups of thermal pixels are sequentially energized in a separate portions of the line printing period. It is to be understood that the pulse trains described hereinbefore would be applied to each thermal pixel of the group when that group is addressed or enabled. Additionally, the N idle power modulating pulses for the thermal pixels of each of the groups would be staggered with the N idle power modulating pulses of each of the other groups. In other words, the first power modulating pulse of the set of N power modulating pulses is generated and delivered to each thermal pixels of the first group of thermal pixels. This is followed by the first idle power modulating pulse of the set of N power modulating pulses being delivered to each thermal pixel of the second group of thermal pixels. This process is continued until the first idle power modulating pulse for the thermal pixels of each group of thermal pixels is generated and delivered before starting the sequence again for the second idle power modulating pulse of the set of N power modulating pulses for each group of thermal pixels.

Referring now to FIG. 10, there is shown a control system 28 (shown in a dashed line rectangle) coupled to thermal pixels 50 in the print head 18 (shown in a dashed line rectangle, and also shown in FIG. 2). Control system 28 comprises a plurality of NAND gates 60, a plurality of OR gates 55, a plurality of latch stages 59, and a plurality of shift register stages 61. Control system 28 selectively energizes the thermal pixels 50 to print superimposed color frames of an image on the receiver member 12 of FIG. 2. As a numerical example, the assembly of print head 18 is formed of a line of 512 individual thermal pixels (resistors) 50, where each thermal pixel 50 is shown as a resistor. With the line of thermal pixels 50, one line at a time of a particular color dye of the image is printed, after which the receiver member 12 and the dye carrier member 14 are moved a predetermined distance for printing the next line of the image. If, for example, each printed line corresponds to a column in a video image, then one thermal pixel is used for each horizontal line of the image to be printed. For purposes of illustration, the 512 individual thermal pixels 50 are divided into four Groups. The first 128 thermal pixels 50 (numbered 0-127) are assigned to Group 1. The next 128 thermal pixels 50 (numbered 127-255) are assigned to Group 2. The next 128 thermal pixels 50 (numbered 256-383) area assigned to Group 3 while the last 128 thermal pixels 50 (numbered 384 to 511) are assigned to Group 4. Each of the 512 thermal pixels (resistors) 50 is electrically coupled by a first terminal to a heater voltage supply via a lead 51, and by a second terminal of each thermal pixel 50 to an output of a separate corresponding one of a series of 512 NAND gates 60.

One input to each of the NAND gates 60 associated with a particular Group is via a separate lead from an enable signal source (ENABLE) for that Group. More particularly, lead 52_1 provides the Group enable signal (ENABLE) for the NAND gates 60 of Group 1, lead 52_2 provides the Group enable signal (ENABLE) for the NAND gates 60 of Group 2, lead 52_3 provides the Group enable signal (ENABLE) for the NAND gates 60 of Group 3, and lead 52_4 provides the Group enable signal (ENABLE) for the NAND gates 60 of Group 4. A second input to each of the 512 NAND gates 60 is provided from an output of a separate corresponding OR gate 55 of a series of 512 OR gates 55. When both inputs to a NAND gate 60 are "high" (a "1"), the output of the NAND gate is "low" (e.g., ground, a "0") and a current pulse is generated through the thermal pixel 50 connected thereto. For all other combinations of the two inputs to a NAND gate 60, the output of the NAND gate is "high" and no current pulse is generated through the thermal pixel 50 connected thereto.

One input to each of the OR gates 55 associated with a particular Group is via a separate lead from an idle enable signal source (IDLE) for that Group. More particularly, lead 56_1 provides the idle enable signal (IDLE) for the OR gates 55 of Group 1, lead 56_2 provides the idle enable signal (IDLE) for the OR gates 55 of Group 2, lead 56_3 provides the idle enable signal (IDLE) for the OR gates 55 of Group 3, and lead 56_4 provides the idle enable signal (IDLE) for the OR gates 55 of Group 4. A second input to each of the 512

OR gates 55 is provided from the output of a separate corresponding latch 59 of a series of 512 latches 59, one latch 59 being provided for each OR gate 55. When both inputs to an OR gate 55 are "low", the output of the OR gate is "low" (e.g., ground). For all other combinations of the two inputs to an OR gate 55 (either one or both of the inputs are "high"), the output of the OR gate is "high". The latches 59 are connected in parallel to 512 stages 61 of a shift register. The stages 61 of the shift register serially receive image data for each of the 512 pixels of a line of the image from a remote source via the image data line. This image data is shifted into the stages 61 of the shift register under the control of a clock signal. The image data stored in a stage 61 indicates the density level to which the associated thermal pixel 50 is to be energized during the printing of an image line.

In operation, a first set of binary image data signals are shifted into the 512 stages 61 of the shift register under the control of the clock pulses until all of the 512 stages 61 either contain a high "1" or a low "0" signal level or state. A latch signal causes the data in each shift register stage 61 to be latched by the corresponding latch 59. At this point a next 512 bits of image data can be shifted into the stages 61 of the shift register. A high or low level signal held at the output of a latch stage 59 is connected to the input of its corresponding OR gate 55. The idle enable signal for each Group of OR gates 55 simultaneously addresses that Group of OR gates. The Groups 1-4 are addressed in sequence, where, for example, the idle enable signal for Group 1 is initially turned high, a "1", and the others are low, "0's". After the Group 1 idle enable signal is turned low, only the idle enable signal for Group 2 is turned high, a "1", and the others are low, "0's". Since there are four Groups, this process takes place four times.

Referring again to FIG. 6, the idle enable signal for a particular Group of OR gates 55 has a duration corresponding to the idle power modulating pulse width shown in FIG. 6. During this time duration, the idle enable input to each OR gate 55 of the Group is high. Concurrent therewith, the input to the OR gate 55 from the latch 59 has either a high or a low level signal depending on the signal level latched by the corresponding latch stage 59. Such input from latch 59 remains at the latch input to the OR gate 55 until an next bit is latched into the latch stage 59. Therefore, the idle enable pulse provides just an idle power modulating pulse at the output of the OR gate 55 when the output from the latch stage 59 is low. When the output of the latch stage 59 is high, however, the latch input to the OR gate 55 maintains a high output both during and after the idle enable pulse until a next bit is latched into the latch stage 59.

The output from each OR gate 55 is provided to the second input of the corresponding NAND gate 60. A Group enable signal pulse, having a width equal to a print power modulating pulse width in FIG. 6, is provided to a first input of the NAND gate. Each NAND gate 60 of a Group of NAND gates is simultaneously addressed by the Group enable signals for that Group of NAND gates. The Groups 1-4 of NAND gates 60 are addressed in sequence, where, for example, the Group enable signal for Group 1 is initially turned high (and the other are low). After the Group 1 enable signal is turned low, only the Group enable signal for Group 2 is turned high (and the other are low). Since there are four Groups, this process takes place four times. Therefore, when the input signal to a NAND gate 60 from the associated OR gate 55 is high only during the idle enable pulse time of the OR gate 55, the NAND gate is low for only the period of an idle power modulating pulse width of FIG. 6. This causes the associated thermal pixel to only be energized for the period of an idle power modulating pulse width. When the input signal to a NAND gate 60 from the associated OR gate 55 is high during the entire latch period by a binary "1" being stored in the latch stage 59, the NAND gate is low for the entire period of a print power modulating pulse width of FIG. 6. This causes the associated thermal pixel to be energized for the entire print power modulating pulse width. In this manner, a binary "0" stored in a latch stage 59 causes the associated thermal pixel 50 to only be energized during an idle power modulating pulse width period, while a binary "1" stored in a latch stage 59 causes the associated thermal pixel 50 to be energized during an entire print power modulating pulse width period.

Assuming that there are N possible dye density levels, as shown in FIG. 6. The stages 61 of the shift register have to be loaded with data N times since each bit of data stored in a stage 61 of the shift register represents only one level of each of the N density levels. Therefore, each group of thermal pixels 50 is addressed N times and energized N times with an idle power modulating pulse or a print power modulating pulse depending on the density level to be produced. More particularly, for the pulse train shown in FIG. 6, the binary image data shifted sequentially into a particular register stage 61 contains the sequential bits of 1,1,1, followed by N-3 "0's" for producing the power modulating pulses for the density level of 3 at the associated thermal pixel 50 during Group enable signal N-1 to the associated NAND gate 60.

The following Table I indicates the operation for the logic circuit comprising the latch register stage 59, the OR gate 55, and the NAND gate 60.

TABLE I

ENABLE	IDLE ENABLE	DATA	PIXEL
Low	N/A	N/A	Off
High	Low	Low	Off
High	Low	High	On
High	High	Low	On
High	High	High	On

It is to be appreciated and understood that the specific embodiments of the invention described hereinbefore are merely illustrative of the general principles of the invention. Various modifications may be made by those skilled in the art which are consistent with the principles set forth. For example, the latch stages 59 and the gating means 55 and 60 can be modified in any suitable manner, or with other types of gating means, to produce the necessary idle and print power modulating pulses for a predetermined density printing level by the associated thermal pixel 50.

The invention may be summarized as follows:

1. A method of modulating power to a thermal pixel of a print head during a line printing period comprising the steps of:
 - (a) energizing the thermal pixel with a plurality of N sequential idle power modulating pulses during each line printing period for heating and substantially maintaining the thermal pixel at a first temperature which is (1) below a dye transfer temperature of a dye color on a dye carrier member engaging the thermal pixel, and (2) above a base temperature of a material forming a heat sink of the print head; and
 - (b) extending each of M of the N idle power modulating pulses by a predetermined time period so as to raise the first temperature of the thermal pixel to a second temperature above the dye transfer temperature of the dye carrier member for a predetermined portion of the line printing period so as to cause a predetermined dye color density level corresponding to a value of M of N density levels of the dye color to be transferred from the dye carrier member to a receiver member engaging the dye carrier member opposite the thermal pixel, where M is a value between 0 and N.
2. The method of 1 comprising the further step of:
 - (c) energizing the thermal pixel with a plurality of Y sequential idle power modulating pulses prior to performing step (a) during a first line printing period after a cold start of the thermal pixel so as to raise the temperature of the thermal pixel from the base temperature to the first temperature.
3. The method of 1 wherein the thermal pixel has a large surface area to be heated comprising the further steps of:
 - (c) energizing the thermal pixel with (i) the first plurality of N sequential idle power modulating pulses of step (a), and (ii) a next second plurality of N sequential idle power modulating pulses during each line printing period for heating and substantially maintaining the thermal pixel at the first temperature; and
 - (d) extending each of M/2 of the N idle power modulating pulses in each of the first and second plurality of N power modulating pulses in each line printing period by a predetermined time so as to raise the first temperature of the thermal pixel to the second temperature above the dye transfer temperature of the dye carrier member to cause (1) a substantially uniform temperature to occur across the surface area of the thermal pixel, and (2) a predetermined print density level corresponding to M of N density levels of the dye color to be transferred from the dye carrier member to the receiver member, where M is a value between 0 and N.
4. The method of 3 comprising the further step of:
 - (e) energizing the thermal pixel with a plurality of U idle power modulating pulses prior to performing steps (c) and (d) during a first line printing period after a cold start of the thermal pixel so as to raise the temperature of the thermal pixel from the base temperature to the first temperature.
5. A method of modulating power to a thermal pixel of a print head during a line printing period comprising the steps of:
 - (a) addressing the thermal pixel during a plurality of N predetermined spaced intervals during the line printing period;

(b) energizing the thermal pixel during each of the N predetermined spaced intervals with an idle power modulating pulse having a first predetermined time period which is sufficient to maintain the thermal pixel at a first temperature which is (1) below a dye transfer temperature of a dye color on a dye carrier member engaging the thermal pixel, and (2) above a base temperature of a material forming a heat sink of the print head; and

(c) energizing the thermal pixel during a predetermined number M of the N predetermined spaced intervals with a print power modulating pulse which extends the first predetermined time period of the idle power modulating pulse produced in step (b) in the M spaced intervals by a second predetermined time period which raises the first temperature of the thermal pixel above the dye transfer temperature of the dye carrier member to a second temperature during a predetermined portion of the line printing period so as to cause a predetermined print density level corresponding to a value of M of N density levels of the dye color to be transferred from the dye carrier member to a receiver member engaging the dye carrier member opposite the thermal pixel, where M is a value between 0 and N.

6. The method of 5 comprising the further steps of:

(d) addressing the thermal pixel during a plurality of Y predetermined spaced intervals during a first line printing period after a cold start of the thermal pixel; and

(e) energizing the thermal pixel during each of the Y predetermined spaced intervals with an idle power modulating pulse so as to raise the temperature of the thermal pixel from the base temperature to the first temperature prior to performing steps (a) to (c) in the first line printing period.

7. The method of 5 wherein the thermal pixel has a large surface area to be heated comprising the further steps of:

(d) addressing the thermal pixel during (i) the first plurality of N predetermined spaced intervals of step (a), and (ii) a second plurality of N predetermined spaced intervals during a first line printing period;

(e) energizing the thermal pixel during each of the first and second N predetermined spaced intervals with an idle power modulating pulse having a third predetermined time period which is sufficient to maintain the thermal pixel substantially at the first temperature; and

(f) energizing the thermal pixel during a predetermined number M/2 of each of the first and second N predetermined spaced intervals with a print modulating pulse which extends the third predetermined time period of the idle power modulating pulse produced in step (e) by a fourth predetermined time period which raises the first temperature of the thermal pixel above the dye transfer temperature of the dye carrier member to the second temperature so as to cause (i) a substantially uniform temperature to occur across the surface area of the thermal pixel, and (ii) a predetermined print density level corresponding to M of N density levels of the dye color to be transferred from the dye carrier member to the receiver member, where M is a value between 0 and N.

8. The method of 7 comprising the further steps of:

(g) addressing the thermal pixel during a plurality of U predetermined spaced intervals prior to performing step (d) during a first line printing period after a cold start of the thermal pixel; and

(h) energizing the thermal pixel during each of the U predetermined spaced intervals with an idle power modulating pulse so as to raise the temperature of the thermal pixel from the base temperature to the first temperature prior to performing steps (d) to (f) in the first line printing period.

9. Apparatus for modulating power to each of a plurality of K thermal pixels of a thermal print head during a line printing period comprising:

means for storing and latching K-bits of data relating to an M color dye density level out of a maximum of N color dye density levels associated with each of the K thermal pixels during the line printing period, where M is a value between 0 and N; and

energizing means responsive to a value of the bits of data latched in the storing and latching means for energizing each thermal pixel with a plurality of N power modulating pulses during a line printing period, the N power modulating pulses for each thermal pixel comprising (i) N minus M idle power modulating pulses having a first width which substantially maintains each thermal pixel at a first temperature which is both below a dye transfer temperature of a dye color on a dye carrier member engaging the thermal pixel and above a base temperature of a material forming a heat sink of the print head, and (ii) M print power modulating pulses having a second width which is wider than the first width of the idle power modulating pulses.

10. The apparatus of 9 wherein the storing and latching means comprises:

a K-bit storage device for sequentially receiving and storing for a predetermined time period a first bit of N bits of the data which define the M color dye density level out of a maximum of N color dye

density levels for each thermal pixel, the first bit being sequentially followed by each of a remaining N-1 bits of data defining the M color dye density level during the line printing period; and

a K-bit latching device for latching a binary value of each bit of data stored in the K-bit storage device in a separate latching means during the predetermined time period the bit is stored in the K-bit storage device.

11. The apparatus of 10 wherein the energizing means comprises:

enabling means coupled between the K-bit latching means and each of the K thermal pixels which is responsive to each bit of data instantaneously stored in the K-bit latching means for modulating the thermal pixel with an idle power modulating pulse when the bit in the latching means has a first value which in combination with all other idle power modulating pulses in a line printing period is sufficient to maintain the thermal pixel at the first temperature, and a print power modulating pulse when the bit has a second value which in combination with all of the other M print power modulating pulses in a line printing period is sufficient to raise the first temperature of the thermal pixel above the dye transfer temperature of the dye carrier member to a second temperature so as to cause a predetermined dye color density level corresponding to the value of M of N density levels of the dye color to be transferred from the dye carrier member to a receiver member engaging the dye carrier member opposite the thermal pixel.

12. The apparatus of 9 wherein the energizing means comprises:

enabling means coupled between the storing and latching means and each of the K thermal pixels which is responsive to each bit of data instantaneously stored in the K-bit storing and latching means for modulating the thermal pixel with an idle power modulating pulse when a bit in the storing and latching means has a first binary value which in combination with all other idle power modulating pulses in the line printing period is sufficient to maintain the thermal pixel at the first temperature, and a print power modulating pulse when the bit has a second binary value which in combination with all of the other M print power modulating pulses in the line printing period is sufficient to raise the first temperature of the thermal pixel above the dye transfer temperature of the dye carrier member to a second temperature so as to cause the value of M of N density levels of the dye color to be transferred from the dye carrier member to a receiver member engaging the dye carrier member opposite the thermal pixel.

13. The apparatus of 9 wherein the energizing means further energizes each thermal pixel with a plurality of Y idle power modulating pulses prior to energizing each thermal pixel with the plurality of N power modulating pulses during a first line printing period after a cold start of the thermal pixel so as to raise the temperature of the thermal pixel from the base temperature to the first temperature.

14. The apparatus of 9 wherein:

each thermal pixel has a large surface area to be heated; and

the energizing means further energizes each of the thermal pixel with (i) the first plurality of N power modulating pulses, and (ii) a next sequential second plurality of N power modulating pulses during each line printing period, each of the first and second plurality of N power modulating pulses including a plurality of N-M/2 idle power modulating pulses for heating and substantially maintaining the thermal pixel at the first temperature, and M/2 print power modulating pulses so as to raise the first temperature of the thermal pixel to the second temperature above the dye transfer temperature of the dye carrier member so as to cause (1) a substantially uniform temperature to occur across the surface area of the thermal pixel, and (2) a predetermined print density level corresponding to M of N density levels of the dye color to be transferred from the dye carrier member to the receiver member.

15. The apparatus of 14 wherein the energizing means energizes each thermal pixel with a plurality of U idle power modulating pulses prior to energizing the pixel with the first and second plurality of N power modulating pulses during a first line printing period after a cold start of the thermal pixel so as to raise the temperature of the thermal pixel from the base temperature to the first temperature.

16. The apparatus of 9 wherein the plurality of K thermal pixels are divided into a plurality of J groups of thermal pixels and each of the J groups of pixels are cyclically energized N times during the line printing period.

17. Apparatus for modulating power to each of a plurality of K thermal pixels of a thermal print head during a line printing period comprising:

means for sequentially storing and latching N bits of data relating to a predetermined separate M color dye density level of a maximum of N color dye density levels for each of the K thermal pixels during the line printing period;

enabling means coupled between the storing and latching means and each of the K thermal pixels which is responsive to each bit of the N sequentially stored and latched bits of data associated with each thermal pixel for generating a separate power modulating pulse to the thermal pixel having (i) a first width when the bit has a first binary value which in combination with all other first width power

modulating pulses in a line printing period is sufficient to maintain the thermal pixel at a first temperature which is both below a dye transfer temperature of a dye color on a dye carrier member engaging the thermal pixel and above a base temperature of a material forming a heat sink of the print head, and (ii) a second width which is wider than the first width when the bit has a second binary value which in combination with all of a plurality of M second width power modulating pulses in a line printing period is sufficient to raise the first temperature of the thermal pixel above the dye transfer temperature of the dye carrier member to a second temperature so as to cause a predetermined dye color density level corresponding to a value of M of N density levels of the dye color to be transferred from the dye carrier member to a receiver member engaging the dye carrier member opposite the thermal pixel, where M is a value between 0 and N.

18. The apparatus of 17 further comprising:

a terminal connected to a first side of the plurality of K thermal pixels for imposing power to the K thermal pixels; and

the enabling means comprises:

first gating means responsive to each of the N bits of data for each thermal pixel for generating (i) the first width power modulating pulse when a bit of the N bit sequence has the first binary value, and (ii) a third width enable pulse which corresponds to a time period that a bit is latched in the storing and latching means when a bit of the N bit sequence has the second binary value; and

second gating means responsive to a fourth width enable pulse having a width which is narrower than the time period that a bit is latched in the storing and latching means and corresponds to the width of the second width power modulating pulse so as to cause each of the plurality of K thermal pixels to be separately energized for the time period of (i) the first width power modulating pulse when the first width power modulating pulse is generated by the first gating means, and (ii) the second width power modulating pulse when the third width enable pulse is generated by the first gating means.

19. The apparatus of 18 wherein:

the first gating means comprises a plurality of K OR gates, each OR gate having a first and a second input for receiving the binary value of a separate bit from the storing and latching means and an enable pulse having a width corresponding to the width of the first width power modulating pulse, respectively, and an output for transmitting the respective a third width enable pulse or the first width power modulating pulse generated by the first gating means; and

the second gating means comprises a plurality of K NAND gates, each NAND gate having a first and a second input for receiving the binary value of a separate bit from the storing and latching means and an enable pulse having a width corresponding to the width of the first width power modulating pulse, respectively, and an output coupled to a separate one of the K thermal pixels so as to cause the thermal pixel to be energized with the first width power modulating pulse when the first width power modulating pulse is generated by the first gating means, and with the second width power modulating pulse when the third width enable pulse is generated by the first gating means.

20. The apparatus of 17 wherein the plurality of K thermal pixels are divided into a plurality of J groups of thermal pixels and each of the J groups of pixels are cyclically energized N times during the line printing period.

21. The apparatus of 17 wherein the enabling means further generates a plurality of Y first width power modulating pulses prior to generating a plurality of N power modulating pulses based on the N sequentially stored and latched bits of data for each thermal pixel during a first line printing period after a cold start of the thermal pixel so as to raise the temperature of the thermal pixel from the base temperature to the first temperature.

22. The apparatus of 17 wherein:

each thermal pixel has a large surface area to be heated; and

the enabling means further generates a first and a second plurality of N power modulating pulses based on the N sequentially stored and latched bits of data for each thermal pixel during a first line printing period, each of the first and second plurality of N power modulating pulses including a plurality of N-M/2 first width-power modulating pulses for heating and substantially maintaining the thermal pixel at the first temperature, and M/2 second width power modulating pulses so as to raise the first temperature of the thermal pixel to the second temperature above the dye transfer temperature of the dye carrier member to cause (1) a substantially uniform temperature to occur across the surface area of the thermal pixel, and (2) a predetermined print density level corresponding to M of N density levels of the dye color to be transferred from the dye carrier member to the receiver member.

23. The apparatus of 22 wherein the enabling means generates a plurality of U first width power modulating pulses prior to generating the first and second plurality of N power modulating pulses during

a first line printing period after a cold start of the thermal pixel so as to raise the temperature of the thermal pixel from the base temperature to the first temperature.

Claims

- 5 1. A method of modulating power to a thermal pixel of a print head during a line printing period comprising the steps of:
 - 10 (a) energizing the thermal pixel with a plurality of N sequential idle power modulating pulses during each line printing period for heating and substantially maintaining the thermal pixel at a first temperature which is (1) below a dye transfer temperature of a dye color on a dye carrier member engaging the thermal pixel, and (2) above a base temperature of a material forming a heat sink of the print head; and
 - 15 (b) extending each of M of the N idle power modulating pulses by a predetermined time period so as to raise the first temperature of the thermal pixel to a second temperature above the dye transfer temperature of the dye carrier member for a predetermined portion of the line printing period so as to cause a predetermined dye color density level corresponding to a value of M of N density levels of the dye color to be transferred from the dye carrier member to a receiver member engaging the dye carrier member opposite the thermal pixel, where M is a value between 0 and N.
- 20 2. The method of claim 1 comprising the further step of:
 - (c) energizing the thermal pixel with a plurality of Y sequential idle power modulating pulses prior to performing step (a) during a first line printing period after a cold start of the thermal pixel so as to raise the temperature of the thermal pixel from the base temperature to the first temperature.
- 25 3. The method of claim 1 wherein the thermal pixel has a large surface area to be heated comprising the further steps of:
 - 30 (c) energizing the thermal pixel with (i) the first plurality of N sequential idle power modulating pulses of step (a), and (ii) a next second plurality of N sequential idle power modulating pulses during each line printing period for heating and substantially maintaining the thermal pixel at the first temperature; and
 - 35 (d) extending each of M/2 of the N idle power modulating pulses in each of the first and second plurality of N power modulating pulses in each line printing period by a predetermined time so as to raise the first temperature of the thermal pixel to the second temperature above the dye transfer temperature of the dye carrier member to cause (1) a substantially uniform temperature to occur across the surface area of the thermal pixel, and (2) a predetermined print density level corresponding to M of N density levels of the dye color to be transferred from the dye carrier member to the receiver member, where M is a value between 0 and N.
- 40 4. The method of claim 3 comprising the further step of:
 - (e) energizing the thermal pixel with a plurality of U idle power modulating pulses prior to performing steps (c) and (d) during a first line printing period after a cold start of the thermal pixel so as to raise the temperature of the thermal pixel from the base temperature to the first temperature.
- 45 5. A method of modulating power to a thermal pixel of a print head during a line printing period comprising the steps of:
 - (a) addressing the thermal pixel during a plurality of N predetermined spaced intervals during the line printing period;
 - (b) energizing the thermal pixel during each of the N predetermined spaced intervals with an idle power modulating pulse having a first predetermined time period which is sufficient to maintain the thermal pixel at a first temperature which is (1) below a dye transfer temperature of a dye color on a dye carrier member engaging the thermal pixel, and (2) above a base temperature of a material forming a heat sink of the print head; and
 - 50 (c) energizing the thermal pixel during a predetermined number M of the N predetermined spaced intervals with a print power modulating pulse which extends the first predetermined time period of the idle power modulating pulse produced in step (b) in the M spaced intervals by a second predetermined time period which raises the first temperature of the thermal pixel above the dye transfer temperature of the dye carrier member to a second temperature during a predetermined portion of the line printing period so as to cause a predetermined print density level corresponding
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to a value of M of N density levels of the dye color to be transferred from the dye carrier member to a receiver member engaging the dye carrier member opposite the thermal pixel, where M is a value between 0 and N.

- 5 6. The method of claim 5 comprising the further steps of:
 - (d) addressing the thermal pixel during a plurality of Y predetermined spaced intervals during a first line printing period after a cold start of the thermal pixel; and
 - (e) energizing the thermal pixel during each of the Y predetermined spaced intervals with an idle power modulating pulse so as to raise the temperature of the thermal pixel from the base temperature to the first temperature prior to performing steps (a) to (c) in the first line printing period.
- 10 7. The method of claim 5 wherein the thermal pixel has a large surface area to be heated comprising the further steps of:
 - 15 (d) addressing the thermal pixel during (i) the first plurality of N predetermined spaced intervals of step (a), and (ii) a second plurality of N predetermined spaced intervals during a first line printing period;
 - (e) energizing the thermal pixel during each of the first and second N predetermined spaced intervals with an idle power modulating pulse having a third predetermined time period which is sufficient to maintain the thermal pixel substantially at the first temperature; and
 - 20 (f) energizing the thermal pixel during a predetermined number M/2 of each of the first and second N predetermined spaced intervals with a print modulating pulse which extends the third predetermined time period of the idle power modulating pulse produced in step (e) by a fourth predetermined time period which raises the first temperature of the thermal pixel above the dye transfer temperature of the dye carrier member to the second temperature so as to cause (i) a substantially uniform temperature to occur across the surface area of the thermal pixel, and (ii) a predetermined print density level corresponding to M of N density levels of the dye color to be transferred from the dye carrier member to the receiver member, where M is a value between 0 and N.
- 25 8. The method of claim 7 comprising the further steps of:
 - (g) addressing the thermal pixel during a plurality of U predetermined spaced intervals prior to performing step (d) during a first line printing period after a cold start of the thermal pixel; and
 - (h) energizing the thermal pixel during each of the U predetermined spaced intervals with an idle power modulating pulse so as to raise the temperature of the thermal pixel from the base temperature to the first temperature prior to performing steps (d) to (f) in the first line printing period.
- 30 9. Apparatus for modulating power to each of a plurality of K thermal pixels of a thermal print head during a line printing period comprising:
 - means for storing and latching K-bits of data relating to an M color dye density level out of a maximum of N color dye density levels associated with each of the K thermal pixels during the line printing period, where M is a value between 0 and N; and
 - energizing means responsive to a value of the bits of data latched in the storing and latching means for energizing each thermal pixel with a plurality of N power modulating pulses during a line printing period, the N power modulating pulses for each thermal pixel comprising (i) N minus M idle power modulating pulses having a first width which substantially maintains each thermal pixel at a first temperature which is both below a dye transfer temperature of a dye color on a dye carrier member engaging the thermal pixel and above a base temperature of a material forming a heat sink of the print head, and (ii) M print power modulating pulses having a second width which is wider than the first width of the idle power modulating pulses.
- 35 10. Apparatus for modulating power to each of a plurality of K thermal pixels of a thermal print head during a line printing period comprising:
 - means for sequentially storing and latching N bits of data relating to a predetermined separate M color dye density level of a maximum of N color dye density levels for each of the K thermal pixels during the line printing period;
 - enabling means coupled between the storing and latching means and each of the K thermal pixels which is responsive to each bit of the N sequentially stored and latched bits of data associated with each thermal pixel for generating a separate power modulating pulse to the thermal pixel having (i) a

first width when the bit has a first binary value which in combination with all other first width power modulating pulses in a line printing period is sufficient to maintain the thermal pixel at a first temperature which is both below a dye transfer temperature of a dye color on a dye carrier member engaging the thermal pixel and above a base temperature of a material forming a heat sink of the print head, and (ii) a second width which is wider than the first width when the bit has a second binary value which in combination with all of a plurality of M second width power modulating pulses in a line printing period is sufficient to raise the first temperature of the thermal pixel above the dye transfer temperature of the dye carrier member to a second temperature so as to cause a predetermined dye color density level corresponding to a value of M of N density levels of the dye color to be transferred from the dye carrier member to a receiver member engaging the dye carrier member opposite the thermal pixel, where M is a value between 0 and N.

FIG. 1

(PRIOR ART)

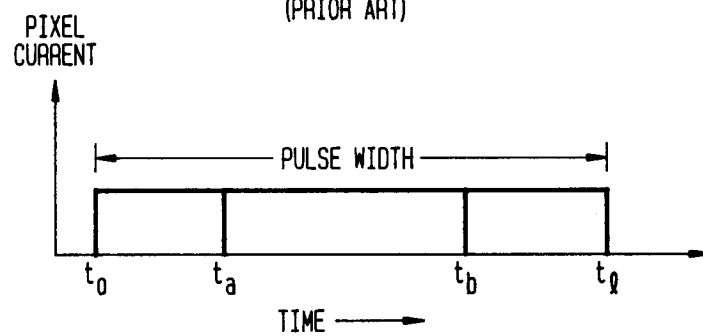
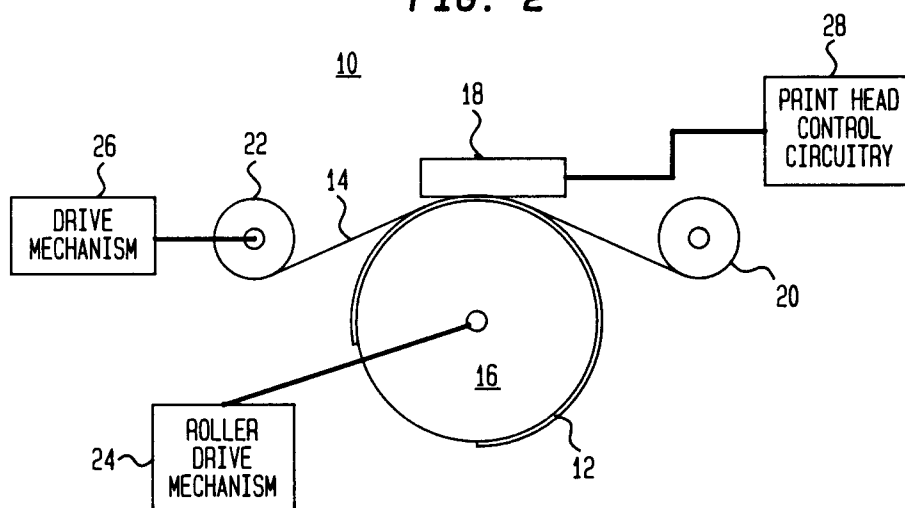


FIG. 2



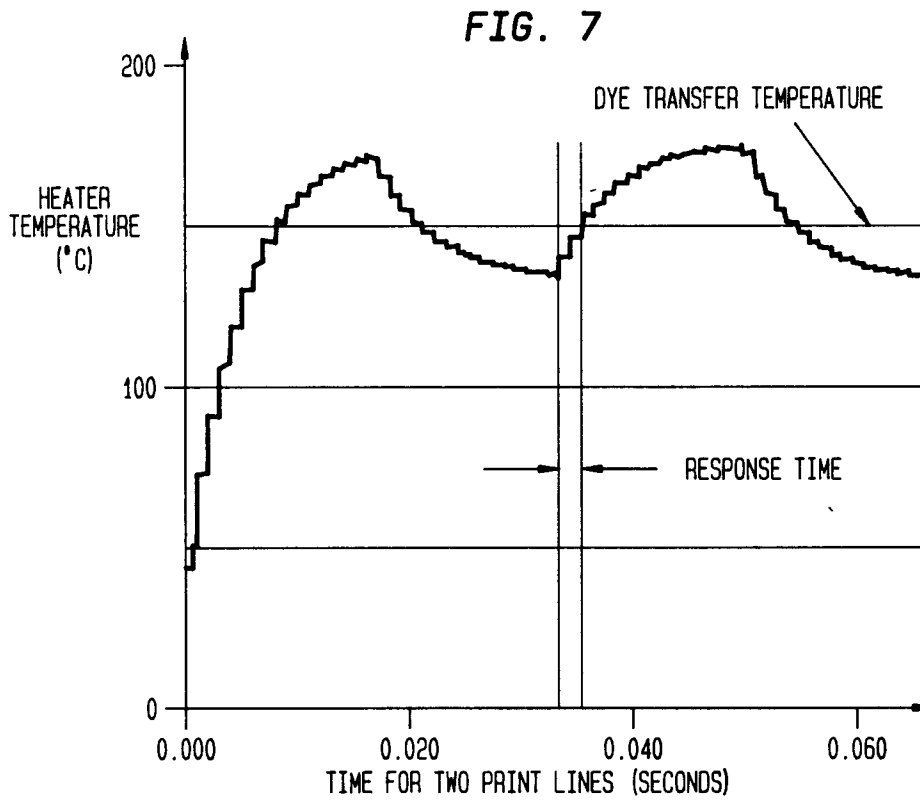
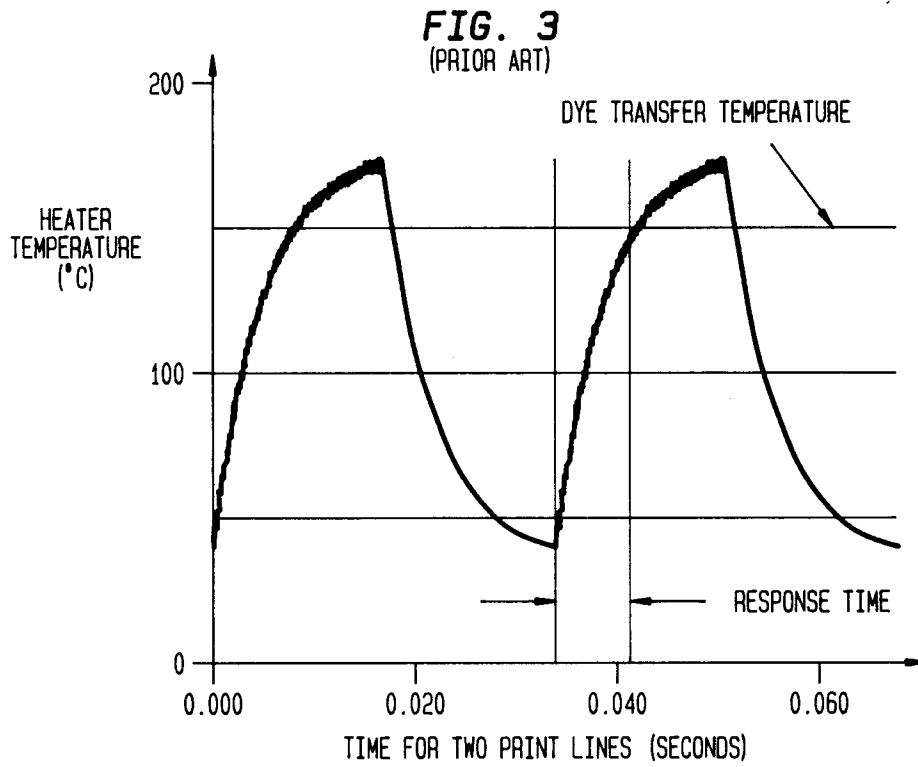


FIG. 4

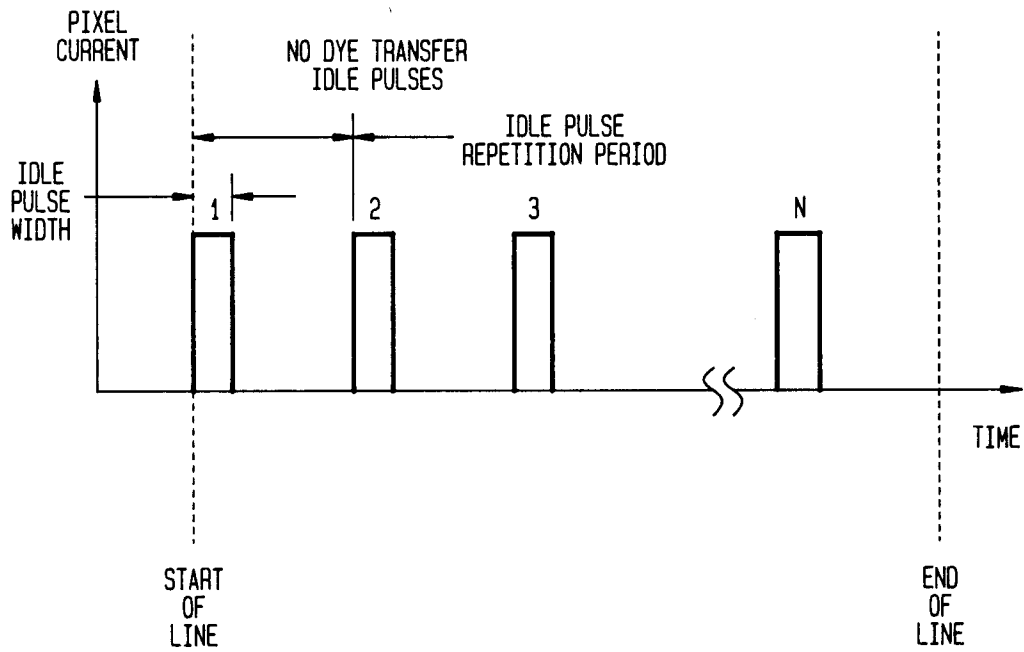


FIG. 5

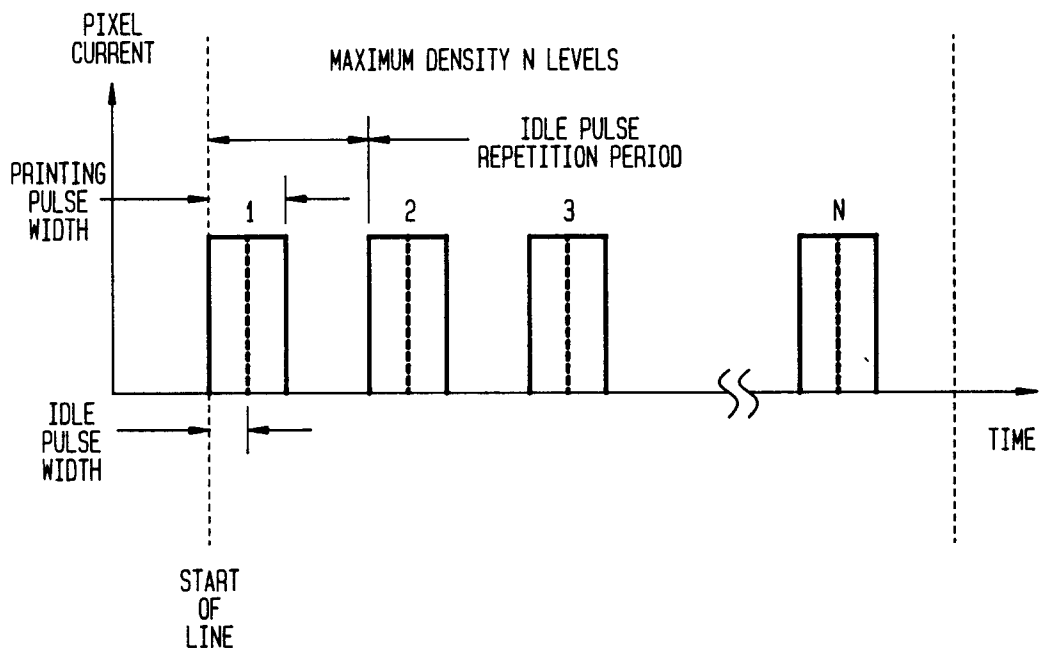


FIG. 6

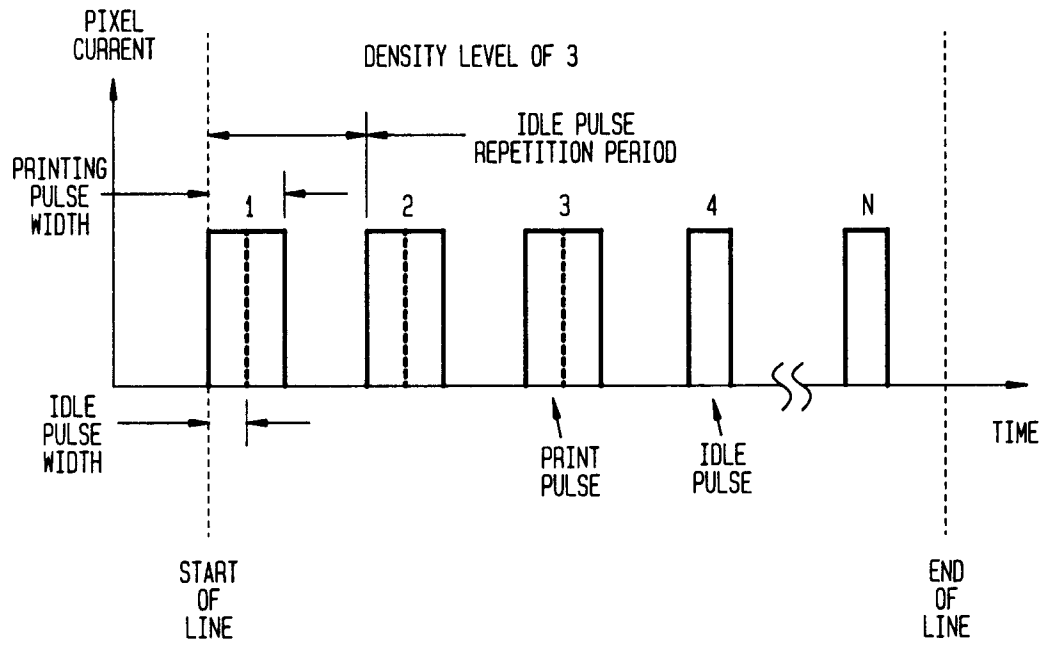


FIG. 8

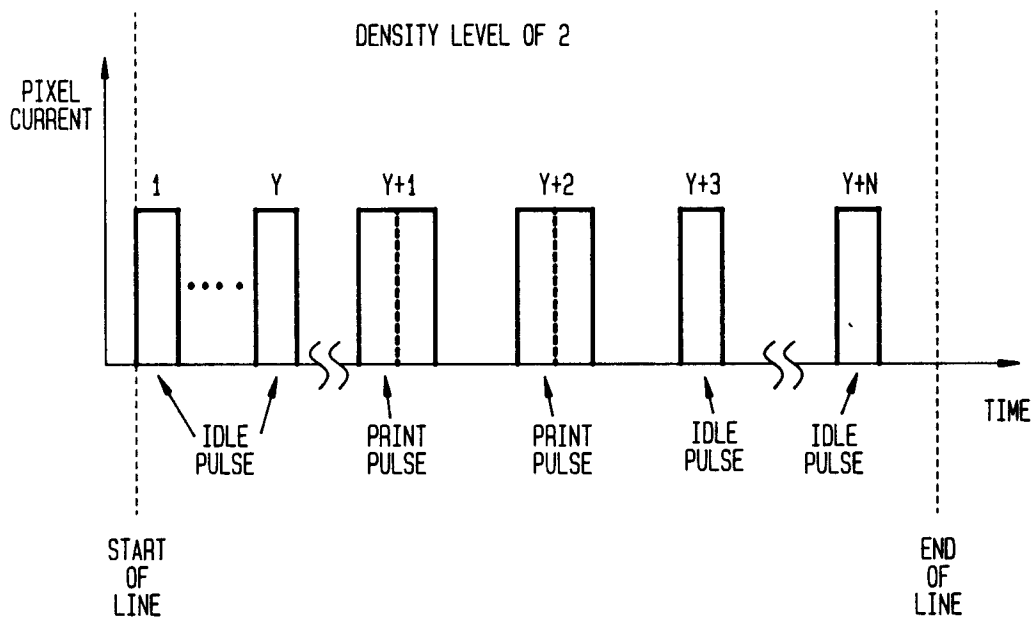


FIG. 9

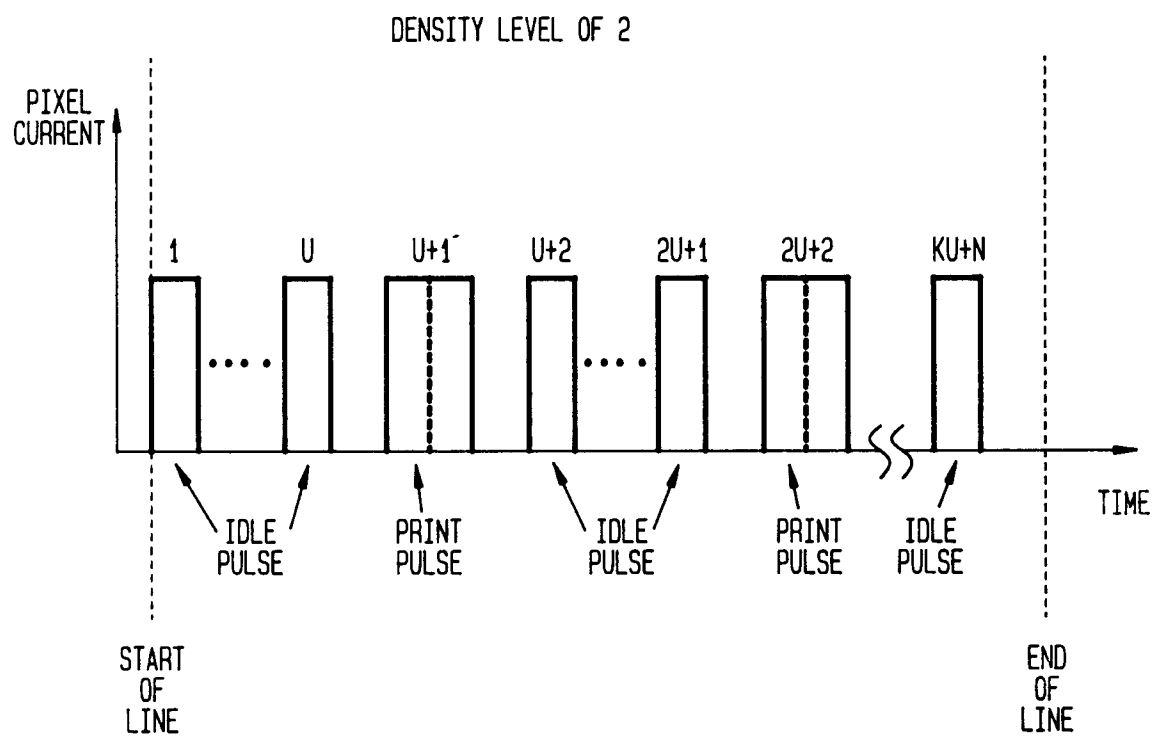


FIG. 10

