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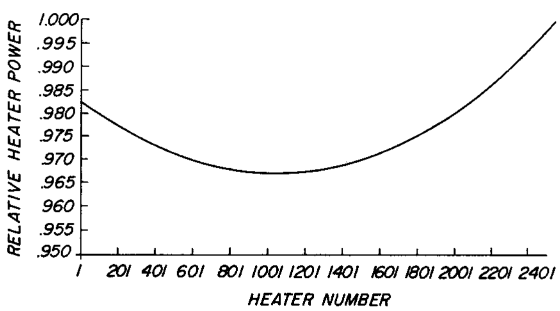
(54) **Compensation for voltage drops due to resistive heating element location in thermal printer heads.**

(57) Compensation is provided for location-dependent voltage drops within a thermal printhead by adjusting the duration of application of current to selected resistive heating elements as a function of the location of (*i*) the resistive heating elements on the printhead and (*ii*) of the number of heating elements which are simultaneously activated. A histogram of the frequency that different duration of current application occur during each print line is produced and used for producing a location-dependent correction factor. The resistive heating elements may be segmented into a plurality of groups based on physical location on the printhead, and the duration of application of current to the selected resistive heating elements is adjusted as a group.

FIG. 1



EP 0 673 774 A2

BACKGROUND OF THE INVENTION

1. Technical Field

The invention relates to thermal printers and more particularly to circuitry for supplying energy to thermal printhead resistive heating elements.

2. Background Art

As is well known in the art, a thermal printhead utilizes a row of closely spaced resistive heat generating elements which are selectively energized to record data in hard copy form. The data may comprise stored digital information related to text, bar codes, pictorial, or graphical images. In operation, the thermal printhead resistive heating elements receive energy from a power supply through driver circuits in response to the stored digital information. The heat from each energized element may be applied directly to thermal sensitive material or may be applied to a dye coated web to cause transfer of the dye by diffusion to paper or other receiver medium.

The heat developed in each resistive heating element is a function of a number of factors including the voltage applied to the element, the thermal state of the element and the thermal states of the surrounding elements. Often, the structure of the system is such that unwanted voltage drops occur between the power supply and the resistive heating elements, due in large part to characteristics of the electrical power supply, the electrical resistance of wires and connectors linking the thermal printhead to the power supply, and the resistance of the electrical buses internal to the thermal printhead.

This voltage drop, due to so called "parasitic resistance", varies as a function of the number of simultaneously energized resistive elements. If a large number of elements are energized, the effective voltage across the resistive heating elements decreases; and, correspondingly, the optical density of the printed image decreases. Thus, the optical density of a single pixel becomes dependent on the number of heating elements energized and the corresponding system parasitic resistance.

These density variations due to the system parasitic resistance produce significant image artifacts. Excessive loading of the power supply due to a large number of heating elements being simultaneously energized causes the effective voltage drop across the heating elements to fluctuate during the energizing period; creating an additional image artifact. Further, the power supply can not fully recover to the design voltage before the next energy pulse is asserted if the time period between the energy pulses is considerably short; as in the case of a fast line time printer.

Many different techniques have been devised to control the factors which determine the print quality. U.S. Patent No. 4,724,336 (issued to Takashu Ichikawa et al. on February 9, 1988) discloses a power circuit for a thermal printhead in which the printhead resistance values are stored and the reference voltage of printhead power supply is selected from memory for each printhead element resistance. In this way, compensation is provided for the variations in the individual printhead element resistance.

U.S. Patent No. 4,531,134 (issued to Frank J. Horlander on July 23, 1985) discloses a regulated voltage circuit for a thermal printhead in which the voltage at one electrode of each resistive heating element is monitored and the lowest voltage is fed back to determine the current in a resistive ribbon printer via a differential amplifier control circuit. In this way, the energy to the resistive heating elements is maintained above a predetermined minimum. U.S. Patent No. 4,434,356 (issued to Timothy P. Craig et al. on February 28, 1984) discloses a current drive circuit for a thermal ribbon printer in which the voltage at each ribbon resistance is monitored and used as a control input to a voltage regulator circuit that produces a printhead resistance drive voltage.

U.S. Patent No. 4,774,528 (issued to Nobuhisa Kato on September 27, 1988) discloses thermal recording apparatus in which the black density of pixels to be recorded by thermal recording elements are compared to reference density levels. A counter accumulates a value representing the number of pixels having density levels in certain ranges as a result of the comparison. The counter value is used to adjust the pulse width of energizing pulses to compensate for voltage fluctuations at the printhead resistive heating elements due to the number of recording elements energized at one time.

Commonly assigned U.S. Patent No. 5,053,790 (issued to Stanley W. Stephenson et al. on October 1, 1991) discloses a thermal printing apparatus in which a thermal printhead receives electrical current from a voltage source and directs the current to selected ones of a plurality of resistive heating elements under control of a sequence of data bits. The number of selected resistive heating elements is sensed by generating a signal representative of the current coupled from the voltage source to the printhead, or by counting the sequence of data bits applied to the printhead; and the voltage coupled to the printhead is controlled responsive to the sensed number of selected resistive heating elements to maintain a prescribed voltage across the selected resistive heating elements substantially constant independent of the number of selected resistive heating elements. The voltage coupled to the printhead is modified in response to the number of selected resistive heating elements to maintain the prescribed voltage across the selected resistive heating elements substantially constant and independent of the number of selected resistive heating elements.

U.S. Patent No. 4,442,342 (issued to Shigeo Yoneda on April 10, 1984) discloses a voltage-to-frequency converter with an output frequency determined by the value of the voltage applied to the printhead. The printhead enabling voltage is applied to the printhead until a count characteristic of the frequency output of the voltage-to-frequency converter reaches a predetermined value.

While these patents provide various solutions to the problem associated with the dependency of the electrical power dissipated at a given heating element upon the number of heating elements which are simultaneously excited, they do not address the problem of drops in voltage along the printhead. Voltage drops within the thermal printhead are dependent upon heating element location. As illustrated in Figure 1, larger voltage drops typically occur for a heating element in the center of the printhead than for a heating element at one of the ends of the printhead. Thus, the prior methods for correcting only for voltage drops due to the number of heating elements activated are only approximate in nature, and fail to eliminate the problems associated with the location of the heating elements along the printhead.

DISCLOSURE OF INVENTION

Accordingly, it is an object of the present invention to provide compensation for location-dependent voltage drops within a thermal printhead.

It is another object of the present invention to provide a thermal printing apparatus in which a thermal printhead receives electrical current from a voltage source and directs the current to selected ones of a plurality of resistive heating elements with location-dependent voltage drop compensation.

In a preferred embodiment of the present invention, the duration of application of current to selected resistive heating elements is adjusted as a function of the location of the resistive heating elements on the printhead.

In another preferred embodiment of the present invention, the duration of application of current to selected resistive heating elements is adjusted as a function (*i*) of the location of the resistive heating elements on the printhead and (*ii*) of the number of heating elements which are simultaneously activated.

In yet another preferred embodiment of the present invention, the duration of application of current to selected resistive heating elements is adjusted as a function (*i*) of the location of the resistive heating elements on the printhead, (*ii*) of the number of heating elements which are simultaneously activated, and (*iii*) of the locations of the activated elements.

Preferably, a histogram of the frequency that different duration of current application occur during each print line is produced and used for producing a location-dependent correction factor. The resistive heating elements may be segmented into a plurality of groups based on physical location on the printhead, and the duration of application of current to the selected resistive heating elements is adjusted as a function of the location of the group, and the degree of activation and the location of other groups.

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

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a graph illustrating the relative power available at each heating element on a printhead as a function of heating element location, wherein all the heating elements are simultaneously powered, as determined by electrical modeling of a commercial thermal printhead;

Figure 2 is a schematic illustration of a thermal printer in which the invention may be employed;

Figure 3 is a block diagram of the thermal printer of Figure 2;

Figure 4 shows wave forms illustrating data bit timing in the circuits of Figure 3;

Figure 5 is a functional block diagram of the operation of a thermal printer according to the present invention;

Figure 6 is a histogram of pulse-count values for one printhead segment of image data;

Figure 7 is a cumulative histogram of pulse-count values calculated from the histogram of Figure 5; and

Figure 8 is a graph of global modulation-interval correction factors verses the number of heating elements activated according to the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

The present description will be directed in particular to elements forming part of, or cooperating more directly with the present invention. It is to be understood that elements not specifically shown or described may take various forms well known to those skilled in the art.

Referring now to Figure 2, there is shown a dye transfer thermal printer apparatus 10 in which the present invention may be employed. Thermal printer apparatus 10 comprises a rotatable drum 12, a receiver medium 14 in the form of a sheet, drive mechanisms 22 and 24, a carrier member which may be a sheet, but preferably is in the form of a web 16, a supply roller 20, a take-up roller 18, a thermal printhead 26 and a printhead control circuit 28. The printhead control circuit comprises a power supply, an image data source and a control pulse generator. Drive mechanism 22 comprises a motor (not shown) mechanically coupled to take-up roller 18. Carrier member 16 is disposed between supply roller 20 and take-up roller 18 and passes between printhead 26 and receiver medium 14. Drive mechanism 24 comprises a motor (not shown) that is mechanically coupled to rotatable drum 12. Receiver medium 14 is secured to drum 12. Thermal printhead 26 comprises a plurality of resistive heat elements. Printhead control circuit 28 is electrically coupled via conductors 30 to thermal printhead 26.

Printhead 26 is pivotally mounted and its resistive heating elements normally press against carrier member web 16. Drive mechanisms 22 and 24 cause take-up roller 18 and drum 12 to rotate and thereby advance carrier member web 16 and receiver medium 14. In operation, the resistive heating elements of printhead 26 are selectively energized in accordance with data from printhead control circuit 28 as drum 12 and take-up roller 18 are continuously advanced. As a result, the image defined by the data from printhead control circuit 28 is placed on receiver medium 14. The arrangement of Figure 2 is similar to that described and illustrated in U.S. Patent No. 4,786,917 (issued to Edward A. Hauschild et al. on November 22, 1988).

Referring now to Figure 3, there is shown a block diagram of printhead 26 and a power supply 32 portion of printhead control circuit 28 of Figure 2 according to the prior art. Figure 3 shows printhead 26, power supply 32, a power supply bus 34, a power return bus 36, and power supply connection terminals 38 and 40. Printhead 26 comprises a power supply line 42, resistive heating elements 44-1, 44-2,..., 44-N, switches 46-1, 46-2,..., 46-N, a power return line 48, latches 50-1, 50-2,..., 50-N, an N-stage shift register 52, an enable line 54 from an enable pulse generator 55, a latch line 56, a data line 58 and a clock line 60.

The control terminals of switches 46-1 through 46-N are coupled to the output terminals of latches 50-1 through 50-N, respectively. The input terminals of latches 50-1 through 50-N are coupled to successive stages of shift register 52. The latch terminals of latches 50-1 through 50-N are coupled to latch line 56 and the enable terminals of latches 50-1 through 50-N are coupled to enable line 54. A first input of shift register 52 is coupled to data line 58 and a second input of shift register 52 is coupled to clock line 60.

In operation, m-bit data codes (e.g., m = 8 bits) corresponding to the image to be printed are stored in printhead control circuit 28 of Figure 2. The data codes are used to form a sequence of data bits which are transferred from printhead control circuit 28 to printhead 26 to energize printhead heating elements 44-1 through 44-N. Each printhead resistive heating element is energized by the number of data bits needed to produce the print density required at the corresponding pixel. The number of data bits may vary from zero to 255 for an 8-bit data code.

The data bits DATA are serially shifted into shift register 52 of Figure 3 via data line 58. A clock source (not shown) in printhead control circuit 28 of a design well known in the art supplies signals CLK to shift register 52 on line 60 to control the shifting of the data bits into the shift register at a predetermined rate. When the N-data bits are received by shift register 52, they are transferred to latches 50-1 through 50-N by latch pulse LA from line 56 in a manner well known in the art. Switches 46-1 through 46-N are closed responsive to the data bits in the corresponding latches and an enable pulse EN on the enable terminals of latches 50-1 through 50-N so that resistive heating elements 44-1 through 44-N selectively receive current from power line 42 for the duration of enable pulse EN. Shift register 52 successively receives 256 sets of data bits which control printhead resistive heating elements 44-1 through 44-N so that the print density at each pixel of a print line corresponds to the data code stored in printhead control circuit 28 for that pixel and the duration of enable pulse EN.

The data bits in latches 50-1 through 50-N and enable pulses EN control the energy developed in resistive heating elements 44-1 through 44-N, respectively, and thereby determine the densities of the pixels of the print line. For example, latch 50-1 controls switch 46-1 so that a number of predetermined width pulses corresponding to the data code in printhead control circuit 28 are coupled to the control terminal of switch 46-1. Switch 46-1 is closed in response to enable pulse EN and the state of latch 50-1. When the data bit in the latch is a one, a predetermined width enable pulse EN closes switch 46-1. In this way, resistive heating element 44-1 is energized by power supply 32 in accordance with the density defined by the image pixel data code in printhead control circuit 28 and the width of enable pulse EN. In like manner, latches 50-2 through 50-N control the operations of switches 46-2 through 46-N to determine the heat generated by resistive heating elements 44-2 through 44-N, respectively.

Referring now to Figure 4, there are shown pulse wave forms (volts) as a function of time (microseconds) illustrating the data bits supplied to shift register 52, the clock signals used to insert the data bits into shift register 52, the latch pulse used to insert the data bits into latches 50-1 through 50-N, and the enable pulse used to transfer the data bits in the latches to control switches 46-1 through 46-N, respectively. For purposes of illustration, the magnitudes of the wave forms are shown as uniform. A wave form 62 shows clock pulses CLK which control the insertion of data bits into shift register 52. A wave form 63 shows a portion of the data bit stream DATA on line 58 corresponding to the data bits for one of the 256 sets of data bits transferred to shift register 52 for a print line. A wave form 64 shows latch pulse used to insert the set of data bits shown in wave form 63 into latches 50-1 through 50-N. A wave form 65 shows an enable pulse EN that transfers the data bits in latches 50-1 through 50-N to the control inputs of switches 46-1 through 46-N.

A latch pulse occurs at the end of the transfer of each set of data bits into shift register 52. The data stream DATA on line 58 shown in wave form 63 is shifted into shift register 52 by clock signals CLK shown in wave form 801 so that each data bit is positioned to control a specified resistive heating element. A data bit may be a ZERO (i.e., LOW level) bit or a ONE (i.e., HIGH level) bit. Heating elements 44-1 through 44-N are energized by data bits that are ONEs. For example, the data bit labeled 1 of wave form 63 (a ONE data bit) is positioned so that it is transferred to latch 50-1 when the N-data bit set for a print line are aligned in shift register 52. The data bit labeled N (a ONE data bit) is positioned so that it is transferred to latch 50-N. In response to a latch pulse LA on line 56, a one data bit is transferred from shift register 52 into latch 50-1 and the ONE data bit N is transferred into latch 50-N. Enable pulse EN then provides a predetermined width pulse to the control input of each switch of switches 46-1 through 46-N for each latch that stores a one data bit. The data bits in latches 50-1 and 50-N cause predetermined width pulses to be applied to switches 46-1 and 46-N so that the heat energy in the corresponding resistive heating elements 44-1 and 44-N are precisely controlled.

As is readily seen, the number of resistive heating elements selected for each print line varies in accordance with the data supplied to printhead 26. Referring again to Figure 3, all, some, or none of resistive heating elements 44-1 through 44-N may be selected concurrently. Each selected resistive heating element is coupled to power supply 32 through power supply bus 34, connection terminal 38, power supply line 42, power return line 48, connection terminal 40, and power return bus 36.

Thus, it is see that for pulse-count modulation, higher densities are achieved by pulsing heating elements more times within the time interval to print one line of image data. For the case where up to 255 pulses are available, it is apparent that the number of heating elements simultaneously activated can change as many as 255 times during one print line, depending upon the image data.

Figure 5 is of a block diagram of the apparatus which calculates correction factors and applies these corrections to alter the pulse-count modulation which is applied to the thermal head. Two types of correction are made. The first is a "global" correction which is determined by the total number of heaters in the thermal printhead which are simultaneously activated. This takes into account those factors which affect all the heaters equally, such as those due to power supply voltage regulation, electrical cables and connectors linking the power supply to the thermal printhead. The second, or "local" correction, is applied to compensate for voltage drops within the thermal printhead, which are dependent upon both image data and heating element location.

The apparatus functions as follows: One image line of pulse-count data for 2,560 heating elements is transferred to an image line buffer 70. The line buffer is divided into a plurality of sections. In the illustrative embodiment, eight sections have been assumed, although more or less can be used. Each of the eight sections correspond to a 320 heating element physical region of the thermal printhead.

Histograms of the frequency of pulse count level are constructed for each print line for each of the eight sections of line buffer 70. An example of such a histogram for one section is illustrated in Figure 6. From these histograms, cumulative histograms, such as illustrated in Figure 7, are computed according to the operation:

$$N_{i,s} = \sum_{j=i}^{255} F_{j,s}$$

where i is the current modulation pulse-count level, $N_{i,s}$ is the number of heating elements simultaneously activated in printhead segment s during modulation interval i, and $F_{j,s}$ are the frequencies of occurrence at other modulation levels j. The computations of $N_{i,s}$ histograms are stored in eight printhead segment registers 72_a through 72_h.

All the eight-segment cumulative histograms are then combined to give a single histogram which is representative of the entire print line, and which is stored in a full-line pulse-count histogram register 74. A pulse-level sequencer 76 cycles through stages which represent individual modulation intervals within the time of one print line. For each modulation interval, the total number of heating elements activated is fed to a pulse-correction look-up table 78, and a "global" modulation-interval correction factor, which is common to all the heating elements on the printhead, is output. These modulation-interval correction factors are summed, and the sum is then divided by the number ***n*** of the total pulse counts by an accumulator and divider 80, according to the operation:

$$G_n = \frac{1}{n}\sum_{i=0}^{n} K[N_i]$$

where G_n are the "global" correction factors, and $K[N_i]$ are the correction factors for each modulation interval as determined by the total number of heaters that are simultaneously activated

Register 82 holds an unique gain correction-factor for each pulse-count level, to be applied regardless of heating element location. The global correction factors are inputted to a composite gain factors unit 84.

Calculation of the location-dependent correction factors begins with the histograms stored in printhead segment registers 72_a through 72_h. For each modulation interval as directed by the pulse-level sequencer 76, the count of heating elements simultaneously **ON** is thresholded by an address calculator 88. In the illustrated embodiment of the present invention, the threshold operation compares the count of **ON** heating elements against a number representing half (in this case 160) of the available heating elements in a printhead segment. It will be understood that this threshold number can be changed as desired in a particular construction, or may be dithered to provide better average corrections.

If more than the threshold (half) of the heating elements are **ON**, an address bit of **ONE** is determined. If fewer than half are **ON**, an address bit is **ZERO** is set. A total address is assembled for all of the printhead segments in address calculator 88, with each printhead segment contributing one bit of the eight-bit address. This address is inputted to a look-up table 90, and represents one of 256 general electrical load states of the thermal printhead. The look-up table contains pre-determined correction factors which were derived from electrical network models of the thermal printhead. The models predict voltages available within the printhead at each of the segments, depending upon the varying load conditions for each of the 256 states of the printhead where segments can be either ON or OFF. From these voltages the electrical powers for printing are determined by,

$$P_{i,s} = \frac{V_{i,s}^2}{R_{i,s}}$$

where $P_{i,s}$ is the electrical power dissipated by segement s of the printhead, $V_{i,s}$ is the voltage and R_s is the net resistance of the heaters in the segement. Multiplicative correction factors $L_{i,s}$ for each modulation-interval *i* and printhead segment ***s*** can be determined from the relative power loss at each segment compared to a reference power, according to,

$$L_{i,s} = \frac{P_{ref}}{P_{i,s}}$$

where P_{ref} is the reference electrical power. Thus, for each address of look-up table 90, a $L_{i,s}$ factor is output for each of the eight printhead segments. These correction factors are averaged over the total number of pulse counts *n* by an accumulator and divider 92, according to:

$$C_{n,s} = \frac{1}{n}\sum_{i=0}^{n} L_{i,s}$$

where $C_{n,s}$ are printhead segment location-dependent correction factors for each total pulse-count level *n*, and printhead segment number ***s***. The $C_{n,s}$ factors are stored in register 94. A more gradual correction is made by interpolating the eight printhead segment location-dependent correction factors at 96 to obtain sixteen effective printhead segments before the factors are inputted to composite gain factors unit 84.

Composite gain factors unit 84 multiplies the global correction factors from register 82 and the location-dependent correction factors from register 96 to obtain single correction factor which is a function of pulse-count level and heating element location. The image pulse-count data of image line buffer 70 is then multiplied by each of these correction factors at a multiplier 98, and the product stored in an output buffer 100.

The invention has been described in detail with particular reference to preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention. for example, slight lines in the printed image corresponding to changes in correction factors can be minimized through well known multi-level dithering techniques, such as by the addition of noise to the digital values in output buffer 100. Bayer masking or error-diffusion dither methods may also be used. In addition, calculations may be carried out at higher mathematical precision than represented by the image data or the electrical drive of the print head in order to minimize contouring or artifacts in the printed image.

Claims

1. Thermal printing apparatus (10) comprising a printhead (12) having a plurality of resistive heating elements (44); a power supply (32); an electrical connection (34, 36, 38, 40, 42, 48) between the power supply and the printhead for supplying an electrical current to selected ones of the resistive heating elements, the efficiency of the electrical connection varying as a function of the location of a resistive heating element on the printhead; control means (28) coupled to the resistive heating elements for selecting to which of the resistive heating elements current from the power supply is applied; enable means (55) for determining the duration of application of current to the selected resistive heating elements; characterized by correcting means, associated with the enable means, for adjusting the duration of application of current to the selected resistive heating elements as a function of the location of the resistive heating elements on the printhead.

2. Thermal printing apparatus as defined in Claim 1 having means for determining the number of heating elements which are simultaneously activated, and further characterized by said correcting means adjusting the duration of application of current to the selected resistive heating elements as a function (*i*) of the location of the resistive heating elements on the printhead and (*ii*) of the number of heating elements which are simultaneously activated.

3. Thermal printing apparatus as defined in Claim 2 further characterized by said correcting means adjusts the duration of application of current to the selected resistive heating elements as a function of the location of elements which are simultaneously activated.

4. Thermal printing apparatus as defined in Claim 1 further characterized by said groups consisting of adjacent heating elements.

5. Thermal printing apparatus as defined in Claim 1 further characterized by said correcting means comprising means for producing a histogram of the frequency that different duration of current application occur during each print line; and means for producing a location-dependent correction factor.

6. A process for compensating for voltage drops due to resistive heating element location in thermal printing apparatus having a printhead with a plurality of resistive heating elements, a power supply, and an electrical connection between the power supply and the printhead for supplying an electrical current to selected ones of the resistive heating elements; said process comprising the steps of selectively applying current from the power supply to the resistive heating elements and determining the duration of application of current to the selected resistive heating elements; and characterized by adjusting the duration of application of current to the selected resistive heating elements as a function of the location of the resistive heating elements on the printhead.

7. The process defined in Claim 6 including the step of determining the number of heating elements which are simultaneously activated, and further characterized by said adjusting step including adjusting the duration of application of current to the selected resistive heating elements as a function (*i*) of the location of the resistive heating elements on the printhead and (*ii*) of the number of heating elements which are simultaneously activated.

8. The process defined in Claim 7 further characterized by said adjusting step including adjusting the duration of application of current to the selected resistive heating elements as a function of the locations of the heating elements which are simultaneously activated.

FIG. 1

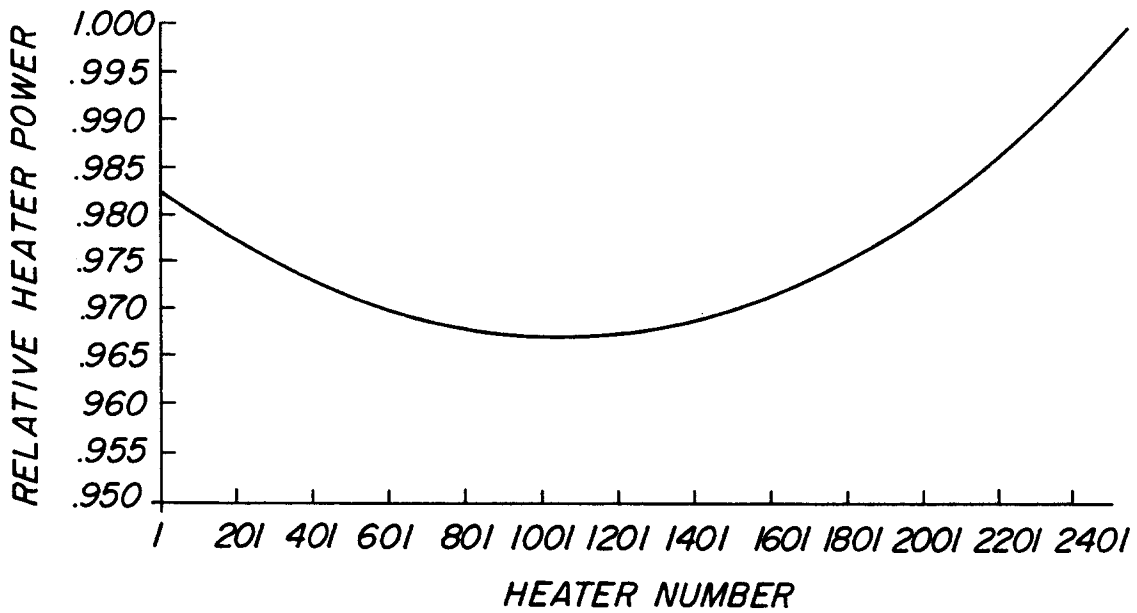
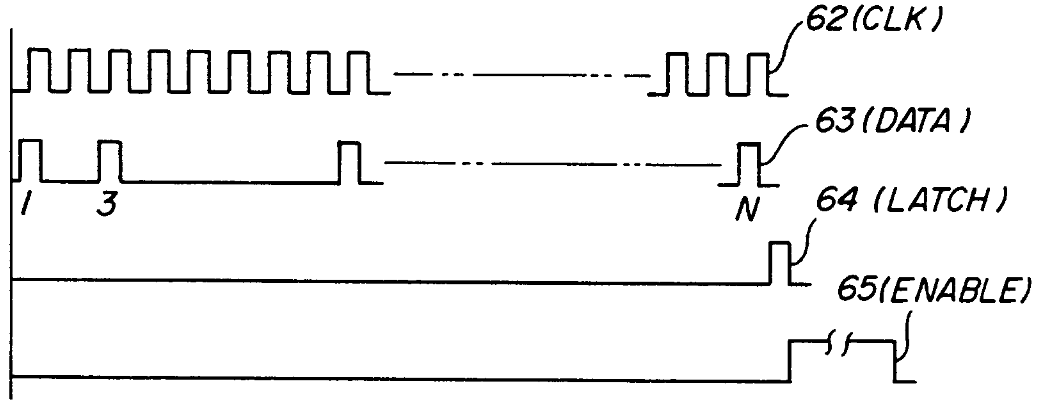

RELATIVE HEATER POWER
1.000
.995
.990
.985
.980
.975
.970
.965
960
.955
.950
1
201
401
601
801
1001
1201
1401
1601
1801
2001
2201
2401
HEATER NUMBER

FIG. 4


62(CLK)
63(DATA)
1
3
N
64 (LATCH)
65(ENABLE)

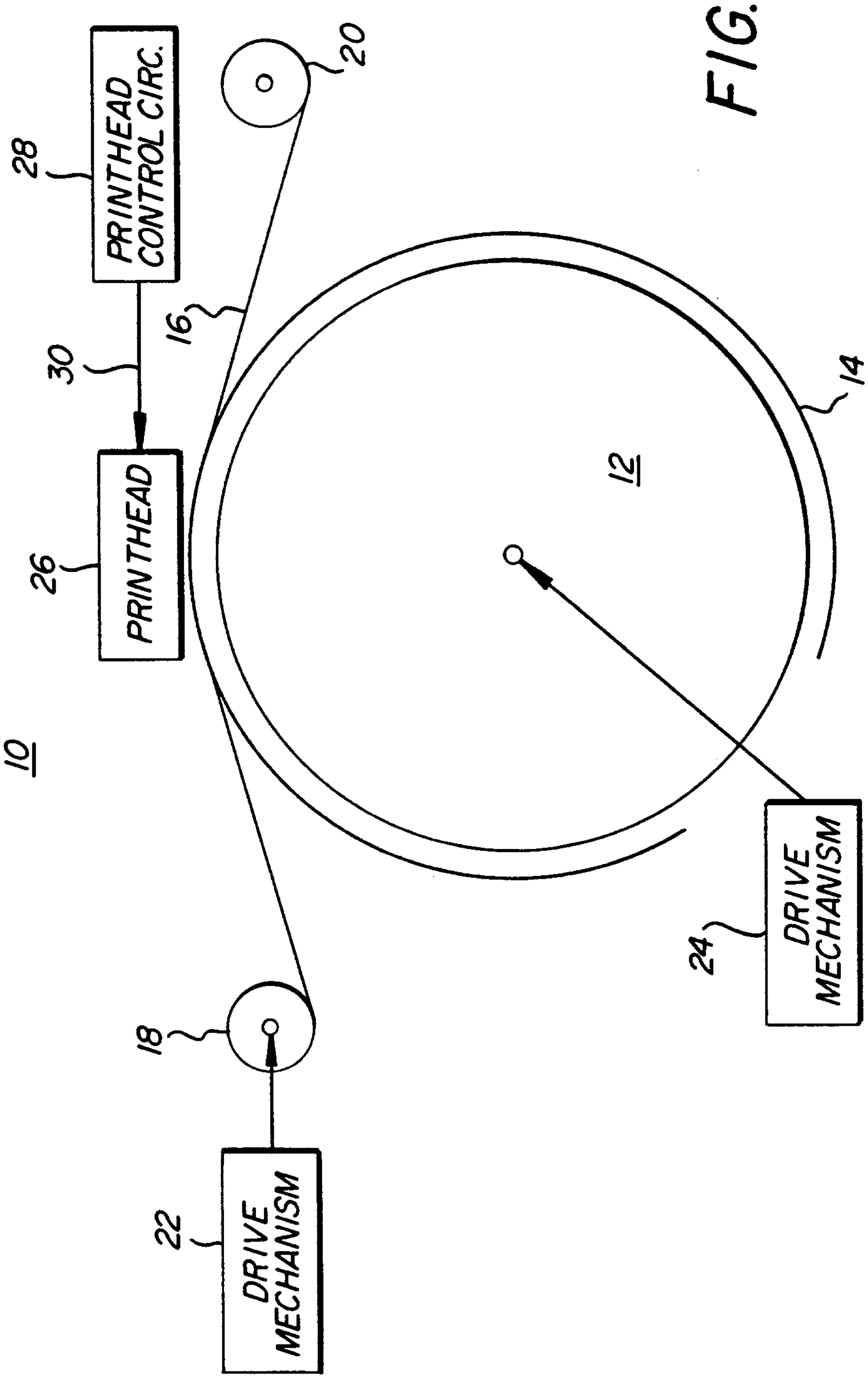
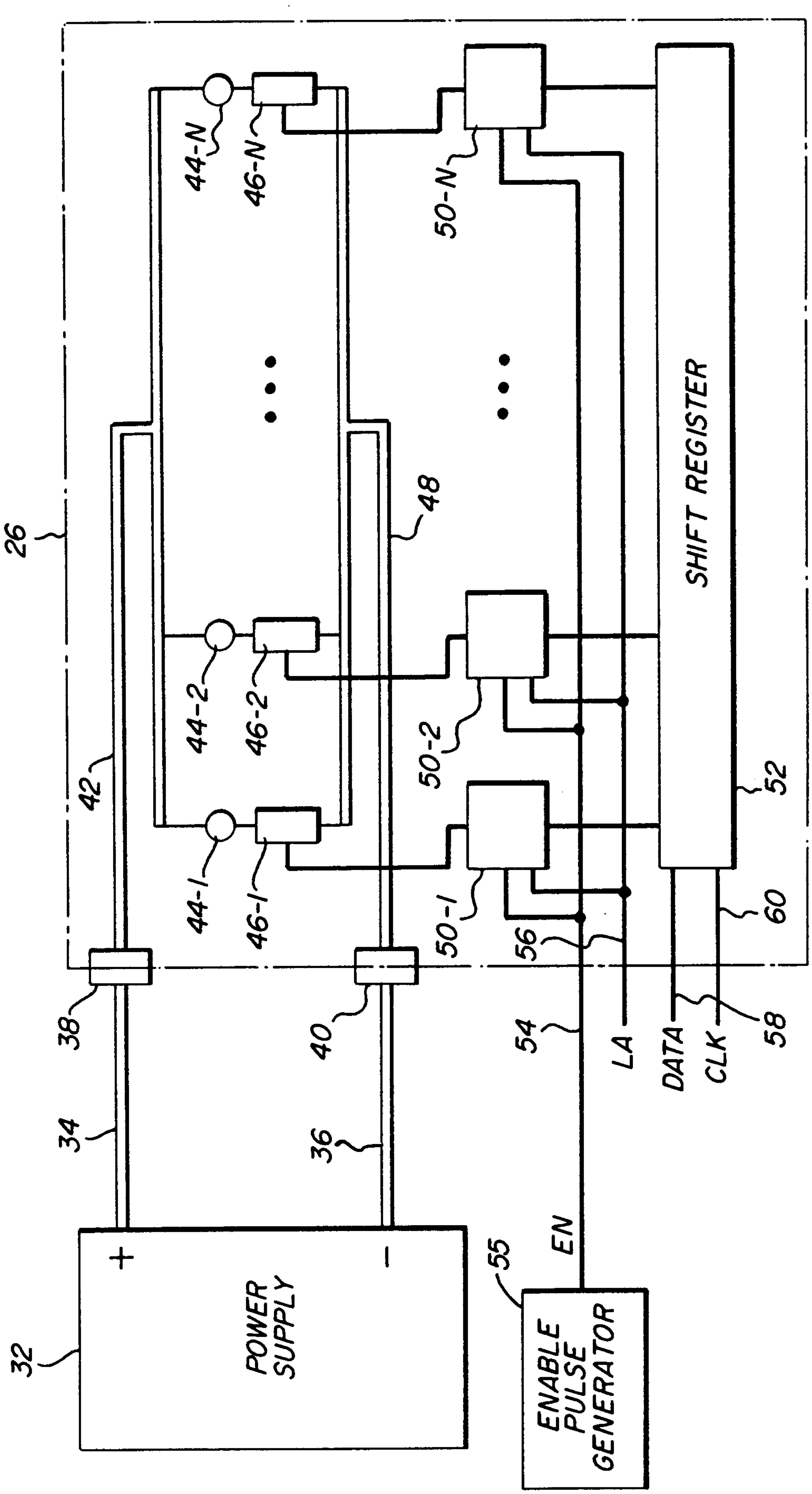

10
PRINTHEAD CONTROL CIRC.
28
30
PRINTHEAD
26
16
20
12
14
18
DRIVE MECHANISM
22
DRIVE MECHANISM
24

FIG. 2

FIG. 3
(PRIOR ART)



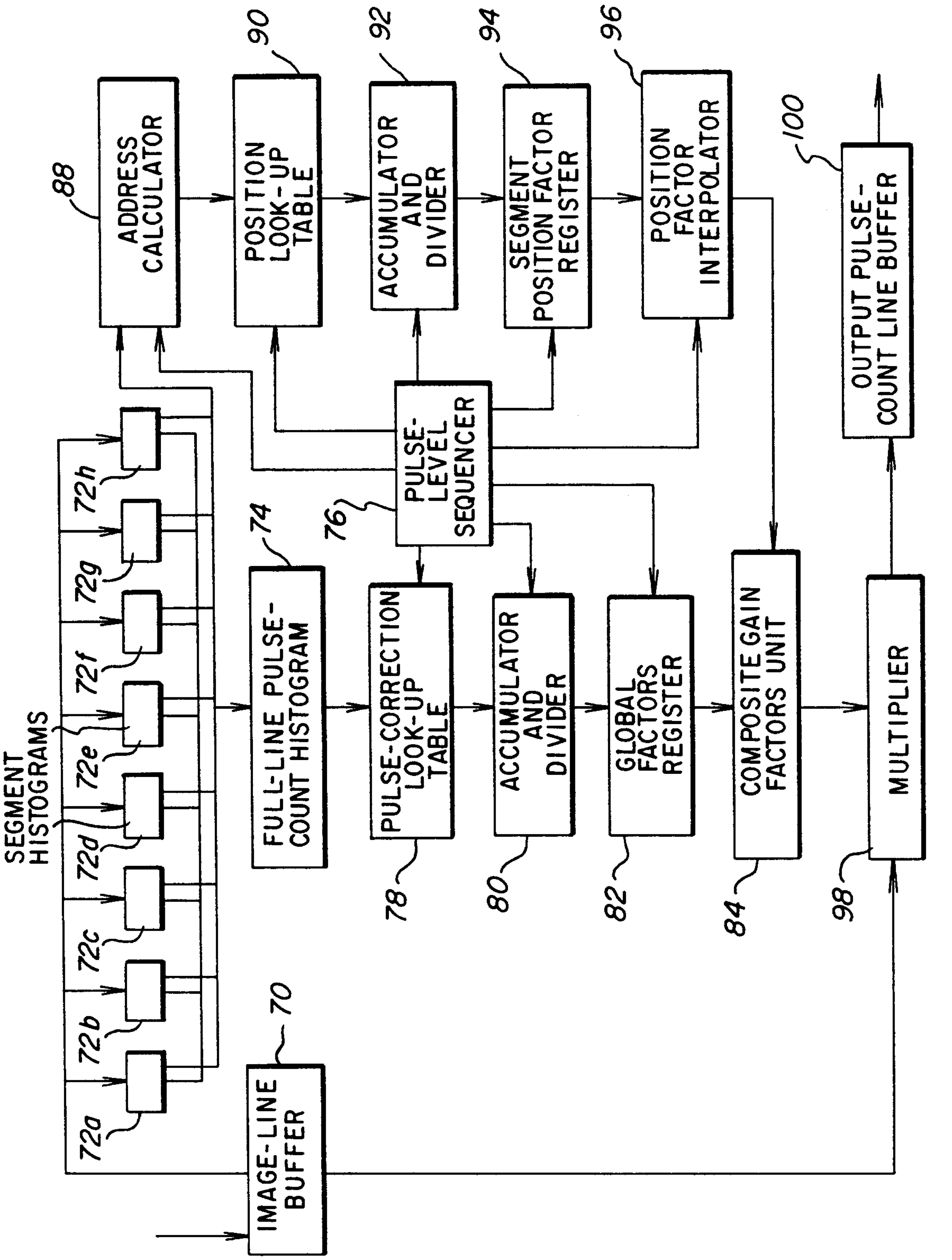

SEGMENT HISTOGRAMS
72a
72b
72c
72d
72e
72f
72g
72h
IMAGE-LINE BUFFER
70
FULL-LINE PULSE-COUNT HISTOGRAM
74
PULSE-LEVEL SEQUENCER
76
ADDRESS CALCULATOR
88
POSITION LOOK-UP TABLE
90
ACCUMULATOR AND DIVIDER
92
SEGMENT POSITION FACTOR REGISTER
94
POSITION FACTOR INTERPOLATOR
96
PULSE-CORRECTION LOOK-UP TABLE
78
ACCUMULATOR AND DIVIDER
80
GLOBAL FACTORS REGISTER
82
COMPOSITE GAIN FACTORS UNIT
84
MULTIPLIER
98
OUTPUT PULSE-COUNT LINE BUFFER
100

FIG. 5

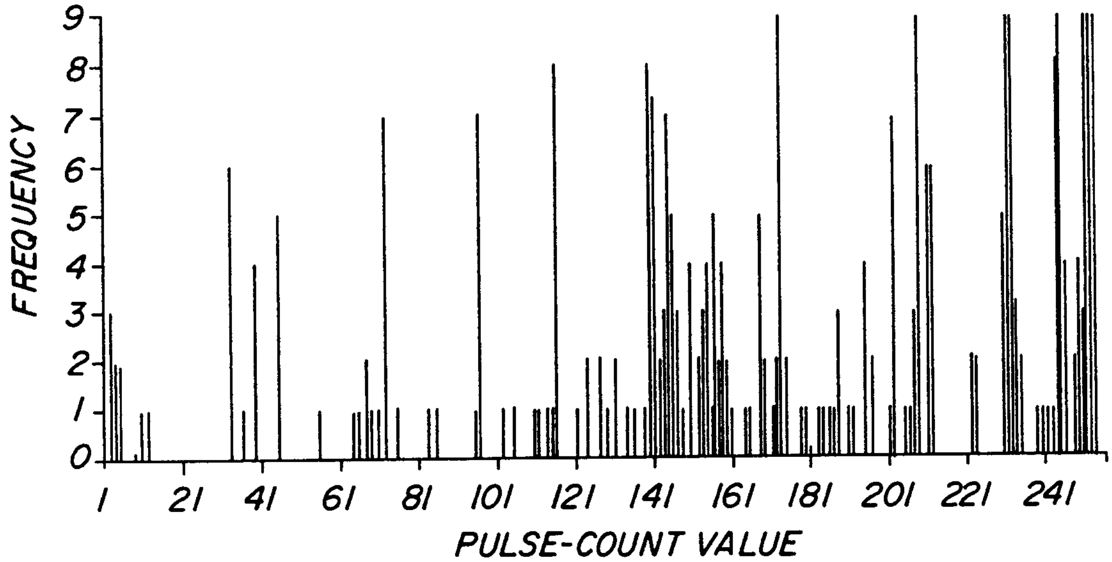

FREQUENCY
9
8
7
6
5
4
3
2
1
0
1
21
41
61
81
101
121
141
161
181
201
221
241
PULSE-COUNT VALUE

FIG. 6

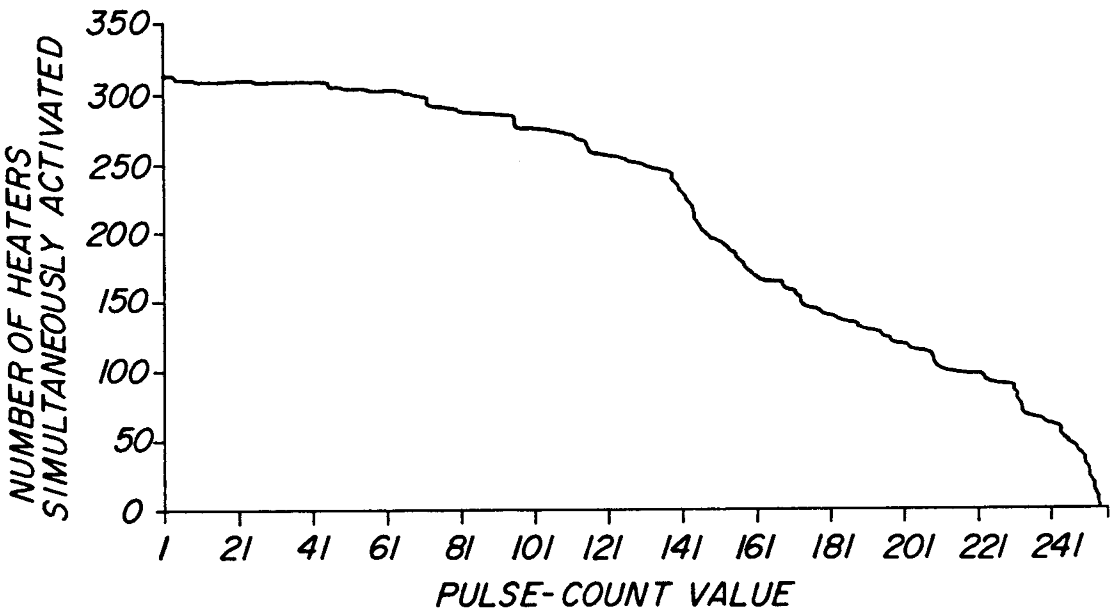

NUMBER OF HEATERS
SIMULTANEOUSLY ACTIVATED
350
300
250
200
150
100
50
0
1
21
41
61
81
101
121
141
161
181
201
221
241
PULSE-COUNT VALUE

FIG. 7

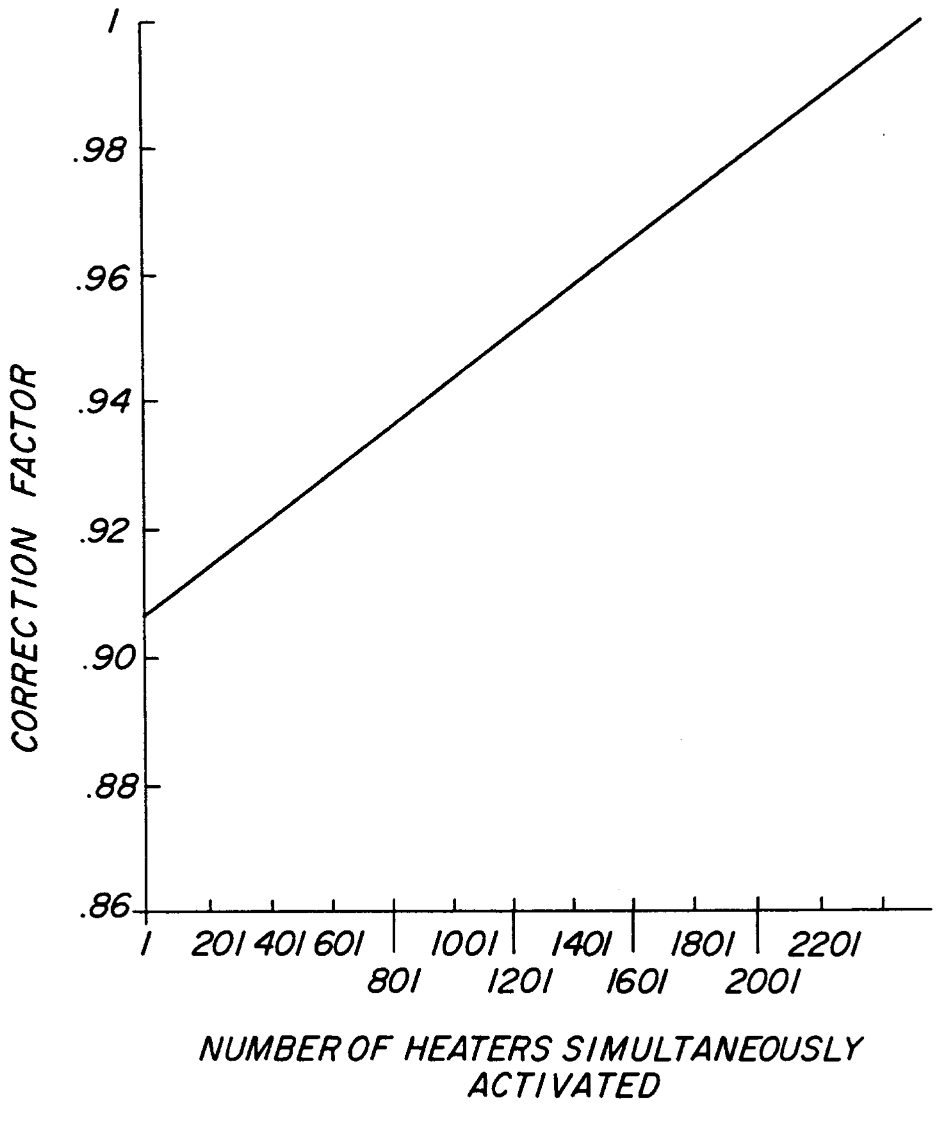

CORRECTION FACTOR
1
.98
.96
.94
.92
.90
.88
.86
1
201
401
601
801
1001
1201
1401
1601
1801
2001
2201
NUMBER OF HEATERS SIMULTANEOUSLY ACTIVATED

FIG. 8