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(54) Method for detecting and correcting an intrusion of air into a printhead substrate of an ink jet cartridge.

(57) An intrusion of air (22) into the ink chambers (24) of a printhead substrate (50) is a symptom of either a depleted ink supply (26) or a deprimed printhead substrate (50). When the printer (20) attempts to print with a depleted ink supply (30) or a deprimed printhead substrate (50), the printhead substrate (50) must absorb all of the energy dissipated in the ink chambers (24) to eject the drops. This causes the printhead substrate (50) to reach high temperatures. The present invention detects a depleted ink supply (26) and a deprimed printhead (50) by monitoring the temperature of the printhead substrate (50) and comparing this temperature with a threshold (84, 90, 96). When this temperature exceeds the threshold (84, 90, 96) for more than an allotted amount of time, then corrective action is taken.

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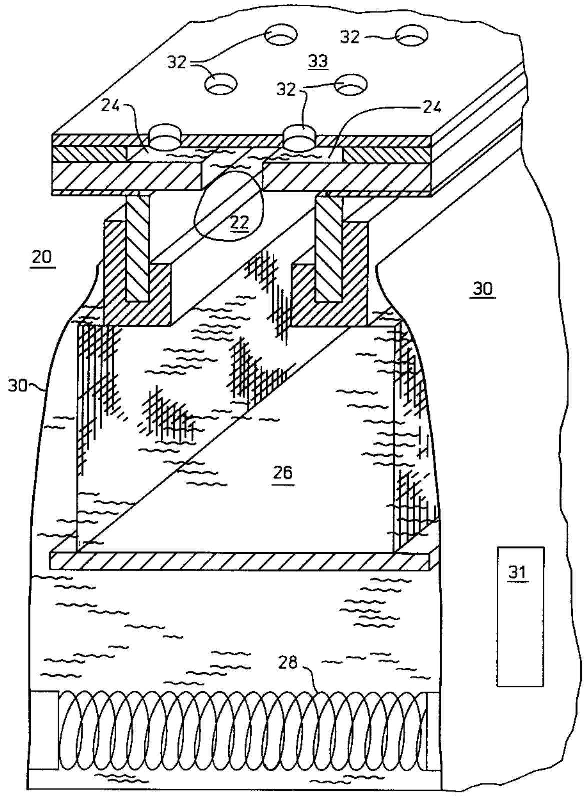


FIG. 1A

This application relates to application Serial No. 08/056,330, entitled "Densitometer" filed on 30 April 1993 and application Serial No. 08/056,243, entitled "Pen Start-Up Algorithm for Black and Color Thermal Ink Jet Pens" filed on 30 April 1993.

Field of the Invention

This invention relates generally to the field of ink jet printing and more particularly to adequate ink flow into the ink chambers of an ink jet printhead.

Background of the Invention

Ink jet printers have gained wide acceptance. These printers are described by W.J. Lloyd and H.T. Taub in "Ink Jet Devices," Chapter 13 of *Output Hardcopy Devices* (Ed. R.C. Durbeck and S. Sherr, Academic Press, San Diego, 1988) and by U.S. Patent 4,490,728. Ink jet printers produce high quality print, are compact and portable, and print quickly but quietly because only ink strikes the paper. The major categories of ink jet printer technology include continuous ink jet, intermittent ink jet, and drop on demand ink jet. The drop on demand category can be further broken down into piezoelectric ink jet printers and thermal ink jet printers. Drop on demand ink jet printers produce drops by rapidly decreasing the volume of a small ink chamber to initiate a pressure wave which forces a single drop through the nozzle. Capillary action causes the ink chamber to refill. The typical ink jet printhead has an array of precisely formed nozzles attached to an ink jet printhead substrate that incorporates an array of ink chambers that receive liquid ink (i.e., colorants dissolved or dispersed in a solvent) from an ink reservoir. In thermal ink jet printheads, each ink chamber has a thin-film resistor, known as a "firing resistor", located near or opposite the nozzle so ink can collect between it and the nozzle. When electric printing pulses heat the firing resistor, a small portion of the ink near it vaporizes and ejects a drop of ink from the printhead. In piezoelectric ink jet printheads, each ink chamber has a piezoelectric transducer located near or opposite the nozzle so ink can collect between it and the nozzle. When electric printing pulses deflect the diaphragm of the piezoelectric transducer, a drop of ink ejects from the nozzle. Properly arranged nozzles form a dot matrix pattern. Properly sequencing the operation of each nozzle causes characters or images to form on the paper as the printhead moves past the paper.

Previously existing ink jet printers can not detect depletion of their ink supply and consequently, they sometimes attempt to print with a depleted ink supply. Another problem ink jet printheads have is the intrusion of an air bubble into an ink chamber. The intruding air bubble will deprime (i.e., air intrudes into the ink chamber and replaces ink) that ink chamber, and grow in size until it deprimes many if not all ink chambers in the printhead. Since the ink chambers are refilled through capillary action, once an ink chamber is deprimed, it is starved of ink until the printhead is reprimed. Meanwhile, the printer will attempt to print and the firing resistors will dissipate the energy required to eject drops. However, the deprimed printhead substrate can not eject drops and must absorb the energy that ejected drops would normally transport out of the printhead. Absorbing this energy causes the printhead substrate temperature to increase significantly.

Summary of the Invention

It would be advantageous to have a device that automatically detects and corrects for an intrusion of air into a printhead substrate regardless of whether the the air intrusion represents a deprimed printhead or a depleted ink supply. This device would prevent the printhead substrate from printing when empty and prevent the temperature of the printhead substrate from reaching dangerously high levels. High temperatures can damage the firing resistors in thermal ink jet printers and boiling ink can build-up a charred remnant on the firing resistor that will reduce drop volume once the printhead is reprimed. Additionally, these high temperatures may scorch the print medium, burn a user removing the printhead cartridge from the printer, and possibly present a fire hazard.

The ability to detect and correct for a depleted ink supply and a deprimed printhead is an important feature of printheads installed in facsimile machines because the data is lost if not printed out correctly. (If the receiver does not have a printed record of who made the transmission, this data is irretrievably lost.) The ability to detect and correct for a depleted ink supply and deprimed printhead is an important feature of printers that create large color plots that require a large investment of ink and print time that would be lost if the printhead becomes deprimed during creation of the plot. Large volume printers, where the user is always absent, must be able to detect and correct for an intrusion of air into the printhead substrate to prevent them from printing with an empty printhead substrate for an extended time.

The present invention detects an intrusion of air into a printhead substrate by monitoring the temperature of the printhead substrate with a "printhead substrate temperature sensor' (i.e., a temperature sensitive resistive trace on the printhead surface) and by comparing this temperature with a threshold temperature that signifies an intrusion of air into the printhead substrate. The threshold may be a constant, a constant plus the equilibrium idle temperature, or vary according the density of the print and/or the "print mode" (i.e., a label for the speed at which the ink jet cartridge moves across the page and the maximum denisty at which it can print at that speed). When the temperature of the printhead substrate has exceeded the threshold temperature, corrective action is taken. In some embodiments, the temperature of the printhead substrate must exceed the threshold for a given time interval. The corrective action may be to interrupt the print job and move the "printer carriage" (i.e., a mechanism that moves one or more ink jet cartridges across the medium) to a service station where the ink jet cartridge (i.e., ink jet printhead, ink supply, and outer packaging) is reprimed. Other embodiments of the invention, with multiple ink jet cartridges, will not interrupt the print job but will cut-off power to the deprimed ink jet cartridge and will reprime the ink jet cartridge upon completion of the print job. In still other embodiments of the invention that have only one ink cartridge, such as those found in facsimile machines, the printer will stop printing and alert the user to the malfunctioning ink cartridge.

Brief Description of the Drawings

Figure 1A shows an ink jet cartridge with an air bubble.

Figure 1B shows an ink jet cartridge with a large air bubble that has deprimed several ink chambers.

Figure 1C shows an output of an ink jet cartridge as it becomes deprimed.

Figure 2 shows the printhead substrate temperature sensor on the printhead substrate.

Figures 3A and 3B are schematic drawings of the printhead substrate temperature sensor electrical circuit.

Figures 4A - 4C show plots of temperature versus time for a printhead when printing normally and when deprimed for various print densities and print modes.

Figure 5 is a flow chart of a method for preventing the printhead from printing with a deprimed printhead or a depleted ink supply that has a threshold that varies according to print density and the print mode.

Figures 6 and 7 are flow charts of two alternative methods, using a constant threshold delta, for preventing the printhead from printing with a deprimed printhead or a depleted ink supply.

Figure 8 is a functional block diagram of the apparatus that prevents the printhead from printing with a deprimed printhead or a depleted ink supply.

Figure 9A shows a desk top printer with a service station and Figure 9B shows the service station in more detail.

Detailed Description of the Invention

A person skilled in the art will readily appreciate the advantages and features of the disclosed invention after reading the following detailed description in conjunction with the drawings.

Figure 1A shows an air bubble 22 inside an ink jet cartridge 20 that is relatively small and that has not deprimed any ink chamber 24. Air bubble 22 moves with the flow of ink 26 toward ink chambers 24. Eventually, it will reach one ink chamber 24 and deprime it. Spring 28 pushing against film 30 creates a back pressure (i.e., a negative pressure) throughout the ink supply shown in Figure 1A. This back pressure keeps the ink from spilling out of nozzles 32, but it also causes a deprimed ink chamber 24 to take in more air that causes air bubble 22 to grow. Figure 1B shows air bubble 22 after it has grown very large and has deprimed several ink chambers 24.

Figure 1C shows the effect of an air bubble and the growth of that air bubble on a printer output 40. Printer output 40 is "blackout printing" (i.e., every ink chamber is dissipating the power needed to eject drops). A print sample 42 is example of blackout printing when all nozzles 32 are ejecting ink drops. At location 44 of print sample 42, an air bubble deprimes one nozzle 32. The back pressure of printhead 20 causes air bubble 22 to grow as more air is drawn into it. As air bubble 22 grows, it deprimes more ink chambers 24 and creates large blank spaces 46 in the print where there should be solid black ink. Eventually, air bubble 22 has grown so large that it has deprimed the entire printhead and print sample 48 is entirely blank.

When an ink supply 26 becomes depleted, air replaces the ink and ink chambers 24 of the printhead substrate will resemble those shown in Figure 1B and the output of the printer will resemble print sample 48 of Figure 1C. A partial remedy to this problem is a label 31 shown in Figure 1B, attached to an outer film 20 of ink supply 26, that changes color from black to green gradually as ink supply 26 runs out of ink. These labels are ineffective unless examined frequently by the user. Another disadvantage of these labels is that they have poor sensitivity to the ink level so that the user must replace the ink cartridge when there is still some ink in the cartridge to prevent the printhead from printing with an empty ink cartridge.

The present invention detects a depleted ink supply and deprimed printhead by monitoring the temperature of the printhead substrate with a "printhead substrate temperature sensor" 52, shown in Figure 2, and by comparing this temperature with a threshold value. (Figures 5 and 6 provide more detail.) The threshold may be set at a constant value, set at a constant value over the ambient temperature or it may vary according the density of the print and/or the print mode. This list is intended to be exemplary and not exhaustive. The scope of this invention includes all thresholds. When the temperature of the printhead substrate has exceeded the threshold for more than a prescribed interval of time (which may be 0 seconds in some embodiments and 10 seconds in others), corrective action is taken. The corrective action may be to interrupt the print job and move the printer carriage 108, shown in Figure 9A, to a service station 107 where the ink cartridge is reprimed either automatically or manually. Other embodiments of the invention with multiple ink jet cartridges, as shown in Figures 8, 9A, and 9B, will not interrupt the print job but will stop printing with that ink jet cartridge. After completing the print job, carriage 108 will move the print cartridges 116 to service station 107 for repriming. In some embodiments, such as that found in a facsimile machine, there is only one ink cartridge and the corrective action is to stop printing and notify the user.

Further tests determine whether the printhead is merely deprimed or whether the ink supply is depleted. (See Figures 5 and 6).

Figure 2 shows a portion of printhead substrate 50 with a printhead substrate temperature sensor 52 located on it. Printhead substrate temperature sensor 52 is constructed from thin-film aluminum has a width of 8 μm and is located approximately 1 mm away from ink chambers 54. Printhead substrate temperature sensor 52 is a resistive trace whose resistance changes with temperature. Printhead substrate temperature sensor 52 is a bulk printhead substrate temperature sensor because it circles ink chambers 54 and ink slot 56, as shown in Figure 3A and 3B and because silicon is very thermally conductive and the heat in one ink chamber will conducted throughout printhead substrate 50.

Printhead substrate temperature sensor 52 is inexpensive to manufacture because it does not require any processing steps or materials that are not already a part of the manufacturing procedure for thermal ink jet printheads. Also, printhead substrate temperature sensor 52 has several functions. In addition to sensing the temperature of the printhead substrate 50 for detecting the deprime condition or a depleted ink supply, this temperatures sensor is part of a temperature control system for the printhead during its normal operation.

The resistance of printhead substrate temperature sensor 52 is defined by:

$$R_{TS} = R_{TS}\big|_{T_o} + \alpha (T - T_o) \qquad (1)$$

where T_o is the temperature of printhead substrate 50 when it is "idling" (i.e., the printer is powered-on but has not started printing),

$$R_{TS}\big|_{T_0}$$

is the resistance of substrate 50 when its temperature is T_o, α is the change in resistance of temperature sensor 52 with a change in temperature of printhead substrate 50, T is the present temperature of printhead substrate 50, R_{TS} is the present resistance of printhead substrate temperature sensor 52 when its temperature equals T. When this equation is solved for T it gives the temperature of printhead substrate 50:

$$T = \frac{R_{TS}}{\alpha} - \frac{R_{TS}\big|_{T_0}}{\alpha} + T_0 . \qquad (2)$$

The value of α is accurately controlled by the manufacturing process but the value of

$$R_{TS}|_{T_0}$$

is not and each printhead substrate temperature sensor 52 must be cross calibrated with a thermistor on the carriage. The printhead can be calibrated once at power-on or continuously. This is just one of the many ways that printhead substrate temperature sensor 52 can be calibrated. The scope of the invention includes all ways to calibrate this temperature sensor.

Figures 3A and 3B are schematic diagrams of printhead substrate temperature sensor 52 and circuitry that calibrates it, measures its resistance, determines when the ink supply is depleted, and determines when the printhead is deprimed. In the embodiment shown in Figure 3A, the threshold is calculated by adding a constant threshold delta to an "equilibrium idle temperature" (i.e., the most recent steady state temperature of a powered-on but at rest printhead substrate). If printhead substrate temperature sensor 52 frequently calibrated, such as once every print job, then T_0 equals the equilibrium substrate temperature. In the embodiment shown in Figure 3B, the threshold is calculated by adding the equilibrium idle temperature to a threshold delta that varies with the print density and the print mode.

In Figures 3A and 3B, this circuitry consists of a voltage divider network that includes two matching resistors 58 and 60; an accurate, calibrated thermistor 62; a voltage supply; and printhead substrate temperature sensor 52. An A/D converter 64 is connected to this network in such a way that it reads the voltage dropped across thermistor 62 and printhead substrate temperature sensor 52. Using well known network analysis techniques, R_{TS} can be calculated. Except for the printhead substrate temperature sensor 52, this circuitry is located on the carriage board that is attached to carriage 108, shown in Figure 9A and 9B, that moves printhead cartridges 116, each of which contains a printhead substrate, along slider rod 110 and into service station 107. Additionally, the circuitry has a microprocessor 66 connected to A/D converter 64 by a bus 65, and memory 67 for storing software, temperature, and resistance values of both thermistor 62 and substrate temperature sensor 52.

Calibration is possible because the temperature difference between the carriage board and the printhead substrate 50 (shown in Figure 2), in the preferred embodiment of the invention, is predictable. When the printer is powered-on the temperature difference is zero and it rises at an exponential rate to approximately 5° C after approximately 15 minutes where it levels-off. The temperature of the printhead substrate 52, T_0, is obtained by subtracting this temperature difference from the temperature of thermistor 62.

$$R_{TS}|_{T_0}$$

is the resistance of printhead substrate 50 when it temperatures equals T_0. The values of T_0 and

$$R_{TS}|_{T_0}$$

are stored in memory 67 of microprocessor 66 and are used when microprocessor 66 calculates the temperature of printhead substrate 50.

The threshold for deprime detection and depleted ink supply detection must be carefully chosen so that it detects all deprimes and depleted ink supplies without making false detections. The temperature of a printhead substrate depends on many factors in addition to whether or not there is ink in the ink chambers 24 shown in Figure 1A and 1B. These factors include the environmental temperature, the printer box temperature rise, and the rate and duration of energy supplied to the printhead substrate.

The rate of energy supplied to the printhead is a function of the print density and the print mode. The print density is a measure of the number of dots per square inch combined with the image to be printed to give the % of the page that will be covered with dots when that particular image is printed. In the preferred embodiment, the print density is measured by a densitometer that is described in patent application Serial No. 08/056,330, entitled "Densitometer" filed on 30 April 1993.

In "fast print mode", the printer has a maximum drop ejection rate of 8 KHz and can print a matrix having 300 x 300 dots per inch. In the "high quality print mode", the printer still has a maximum drop ejection rate of 8 KHz but it prints a matrix of 300 x 600 dots per inch by reducing the speed of the horizontal movement. When in fast mode, some printers will heat the printhead substrate with nonprinting pulses to increase the size of the printed dots. This heating represents another influence on the temperature of the printhead substrate.

Figures 4A-4C show the temperature rise of a normally function printhead and a deprimed printhead for two different types of print density and two different types of print mode. Figure 4A has plots of temperature versus time for a normally functioning printhead and a deprimed printhead when the printer is printing at maximum density, known as blackout printing (i.e., every nozzle ejects a drop at every opportunity and the print is a solid black band). Temperature versus time plot 80 belongs to a normally functioning printhead. Temperature versus time plot 82 belongs to the printhead that printed Figure 1C while it was printing Figure 1C. Point 85 is the equilibrium idle temperature of the printhead substrate when the printer is powered-on but at rest (i.e., not printing). It is affected by the environmental ambient temperature and the printer box temperature rise in the air surrounding the resting printhead. The temperature rise of the deprimed printhead over the equilibrium idle temperature is on the order of 90°C. The temperature rise of the normally functioning printhead over the equilibrium idle temperature is less than 35° C. In Figure 4A, a threshold 84 of the deprime detector is set at 85° C. At this setting, the deprime detector would have signaled the deprime condition 11 seconds into the deprime.

Figure 4B shows temperature versus time plots for a normal printhead and a deprimed printhead when printing standard density text at the fast print mode. Plot 86 shows the temperature rise versus time of a normally functioning printhead substrate. The maximum temperature rise is approximately 30° C over the equilibrium idle temperature 91. Plot 88 shows the temperature rise versus time of a deprimed printhead substrate. The maximum temperature rise of the deprimed printhead substrate is approximately 40° C over the equilibrium idle temperature 91. A threshold 90 placed 40° C above equilibrium idle temperature 91 will prevent false alarms and will result in a triggering of the deprime detector within seconds of the deprime.

Figure 4C shows temperature versus time plots for normal printhead and a deprimed printhead when printing standard density text at high quality print mode. The lower curve, plot 92, shows the temperature rise versus time of a normally functioning printhead substrate. The maximum temperature rise is approximately 15° C over equilibrium idle temperature 93. The higher temperature curve, plot 94, shows the temperature rise versus time of a deprimed printhead substrate. The maximum temperature rise is approximately 40° C over the equilibrium idle temperature 93. A threshold 96 placed at approximately 30° C over equilibrium idle temperature will prevent false alarms and will result in triggering of the deprime detector within seconds of the deprime.

If the deprime detector used the threshold 84 (85° C) of Figure 4A for plots 88 and 86 in Figure 4B, it would not have detected the deprimed printhead represented by plot 88 and would have printed through a deprime. Similarly, if the deprime detector of Figure 4C used the threshold (65° C) 96, it would have falsely labeled a normally functioning printhead as deprimed. Thus, a threshold that is desirable for one type of print density and print mode may result in attempting to print with a deprimed printhead or false alarms that disrupts printing.

Figures 5 and 6 are flow charts of two different embodiments of the invention. The difference between these two embodiments is the method for computing the threshold. The remaining aspects are the same.

Figures 5 and 6 show in their upper right-hand corners that after the printer is powered-on, printhead substrate temperature sensor 52, shown in Figures 2, 3A, and 3B, is calibrated. This calibration procedure has been described earlier in conjunction with an explanation of Figures 3A and 3B. After calibration, the print job begins. For a printer having a scan approximately equal to the width of an average sheet of paper, the temperature of the printhead substrate 50 is measured once every scan. For wider printer media, such as plots having a width of several feet, the temperature of printhead substrate 50 may be measured several times per printhead substrate 50 scan across the medium. The temperature is compared to a threshold.

In Figure 5, input from a densitometer or any other device giving the density of dots printed on the page and input concerning the print mode are used to access the proper threshold delta from a look-up table. This threshold delta is added to the equilibrium idle temperature (e.g., items 85, 91, 93 in Figures 4A, 4B, and 4C) and the result is the threshold. The threshold delta that varies with print density and print mode has the advantage that the threshold can be set to the lowest setting for each print density and print mode combination without making false detections. This embodiment has the advantage of enabling the detection of the deprime condition while the printhead is printing low density print.

In Figure 6, the threshold delta is a constant, approximately 80° C, and the threshold is generated by adding it to the equilibrium idle temperature. This threshold delta must be large to prevent it from making false detections. A constant threshold delta has the advantage of simplicity.

In Figures 5 and 6, if the temperature of printhead substrate 50 is less than the threshold, then continue printing. If the temperature is greater than the threshold, then the detector may have another test of whether the temperature has exceeded the threshold for more than an allotted interval of time. The allotted interval of time may be measured in milliseconds or in the number of times the temperature has exceeded the threshold or in some other parameter that characterizes the persistence of the threshold exceeding temperatures. If the temperature has not exceeded the threshold for more than the allotted interval, the printer continues printing. If it has exceeded the threshold, then the printhead is sent a service station such as service station 107 shown in Figure 9A and 9B.

Service station 107, in Figure 9A and 9B, is an example of a service station located in a desk top printer 100. The scope of the invention includes the use of any type of service station in any type of ink jet printing device, including a service station with a fully automated cartridge selector and primer. Below a protective front lid 102, there is a slider rod 110 for carriage 108. When the deprime condition is detected, carriage 108 moves into service station 107 where an individual ink cartridge 116 is manually selected for repriming through the use of cartridge selector 114. Once a cartridge 116 is selected for repriming, then a manual primer actuator 112 is used to prime cartridge 116. After repriming cartridge 116, the service station will wipe a nozzle plate 33.

Another alternate embodiment will pulse ink chambers 24 in Figures 1A and 1B and check whether they eject drops. If they fail to eject drops, the user is alerted that ink supply 26 is depleted and to replace ink jet cartridge 20. If ink jet cartridge 20 passes this test, it is subjected to this test several more times and if it passes, then printhead 20 can continue printing. Otherwise, the user is alerted that ink supply 26 is depleted and to replace printhead cartridge 20. The portion of the service station 107 in Figures 9A and 9B that wipes the nozzle plates and tests whether the printhead ejects drops is described in the above referenced copending application.

Figure 7 is flow chart of an embodiment of the present invention that avoids the high temperatures that can be reached when attempting high density printing with a deprimed printhead or a depleted ink supply. This embodiment does not attempt to reprime during the print job. Instead, it blocks current flow to the firing resistor of the deprimed printhead, keeping it cool.

The individual operations of the embodiment shown in Figure 7 are very similar to those of the embodiment shown in Figure 6, the major difference between these embodiments is in the arrangement of the operations. Both flow charts begin by taking a constant threshold delta (approximately 80° C) and adding it to the equilibrium idle temperature to the create the threshold. Additionally, both flow charts calibrate the printhead substrate temperature sensor 52, shown in Figures 2, 3A, and 3B, before beginning a print job.

As the job is printed, both systems (represented by Figure 6 and Figure 7) monitor the temperature of all printhead substrates 50. In the system represented by Figure 7, if the temperature of printhead substrate 50 of one cartridge (typically there are four printhead substrates, each in a separate cartridge 20 as shown in Figure 8) exceeds the threshold, the printer stops printing with that cartridge. This can be implemented in many ways. For example, stop sending firing pulses to ink chambers 24 of that cartridge or eliminate the energy of the "firing pulses" by reducing their voltage or their duration. Thus, current will not flow through the firing resistors of a thermal ink jet printhead and this should keep the temperature of the printhead at safe levels. Current flow should remain blocked until after the print job has ended.

Before the beginning of the next print job, each cartridge will be tested by the drop detection system. This testing procedure is described in copending application "Pen Start-Up Algorithm for Black and Color Thermal Ink Jet Pens" described and incorporated by reference earlier. This will detect cartridges that became deprimed during the previous print job, along with any other problems that may have developed. While the embodiment described by Figure 7 only depicts replacement of non-functioning cartridges, several cartridge recovery techniques could also be performed. (For example: repriming, nozzle spitting, nozzle wiping.) By deferring pen service and recovery to the time interval between plots, alternate and simpler algorithms for handling the print jobs can be used.

One advantage of the embodiment described by Figure 7 is that print cartridge failures in low-density and high-density print jobs are treated identically. In the embodiment described by Figure 6, a failure during a low-density print job may not cause the threshold to be exceeded, so the print job will continue even though cartridge is not printing.

If the embodiment of the invention shown in Figure 7 is implemented in a printer having one ink jet cartridge, such as a printer in a facsimile machine, and the printhead substrate tempeature exceeds the threshold, then the printer will stop printing and notify the user.

Figure 8 is a block diagram of the circuitry used to implement the present invention. There are four ink cartridges, each with an ink supply held at a negative back pressure by spring bag, a substrate, a temperature sensor on the substrate, a tab circuit for transmitting the output of the temperature sensor to a flex circuit. The output of the temperature sensor is fed into an A/D converter through a direct line. The multiplexer connects each of the temperature sensors on the different print cartridges to a voltage divider network that includes an accurate, calibrated thermistor. The output of the thermistor is also fed into the A/D converter. The output of the A/D converter is fed into a microprocessor.

Input from the memory, threshold table, densitometer, and print mode are used to calculate the threshold. (In the alternate embodiment with a constant threshold delta, input from only the memory would be needed.) The microprocessor calculates the threshold and processes the data from the temperature sensor to determine whether a deprime condition exists.

All publications and patent applications cited in the specification are herein incorporated by reference as if each publication or patent application were specifically and individually indicated to be incorporated by reference.

The foregoing description of the preferred embodiment of the present invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive nor to limit the invention to the precise form disclosed. Obviously many modifications and variations are possible in light of the above teachings. The embodiments were chosen in order to best explain the best mode of the invention. Thus, it is intended that the scope of the invention to be defined by the claims appended hereto.

Claims

1. A method for detecting and correcting an intrusion of air (22) into a printhead substrate (50), comprising the steps of:

a. measuring a temperature (80, 83, 86, 88, 92, 94) of the printhead substrate (50) during a print job;

b. producing a threshold temperature (84, 90, 96) that signifies the intrusion of air (22) into the printhead substrate (50);

c. comparing the temperature (80, 83, 86, 88, 92, 94) of the printhead substrate (50) with the threshold temperature (84, 90, 96);

d. continuing the print job without changes if the temperature (80, 83, 86, 92, 94) of the printhead substrate (50) is less than the threshold temperature (84, 90, 96); and

e. correcting for the air intrusion (22) into the printhead substrate (50) if temperature (80, 83, 86, 88, 92, 94) of the printhead substrate (50) is greater than the threshold temperature (84, 90, 96).

2. A method for detecting and correcting an intrusion of air (22) into a printhead substrate (50), comprising the steps of:

a. calibrating a resistive temperature sensor (52) located on the printhead substrate (50);

b. measuring an equilibrium idle temperature (85, 91, 93) of the printhead substrate (50);

c. beginning a print job;

d. measuring the temperature (80, 83, 86, 88, 92, 94) of the printhead substrate (50) using the resistive temperature sensor (52) located on the printhead substrate (50);

e. producing a threshold temperature (84, 90, 96) that signifies the intrusion of air (22) into the printhead substrate (50);

f. comparing the temperature of the printhead substrate (50) with the threshold temperature (84, 90, 96);

g. continuing the print job without changes if the temperature (80, 83, 86, 92, 94) of the printhead substrate (50) is less than the threshold temperature (84, 90, 96); and

h. correcting for an air intrusion (22) into the printhead substrate (50) if the temperature (80, 83, 86, 88, 92, 94) of the printhead substrate (50) is greater than the threshold temperature (84, 90, 96).

3. A method, as in claim 1 or 2, wherein the producing step further comprising the step of:

changing the threshold temperature (84, 90, 96) with changes in an equilibrium idle temperature (85, 91, 93).

4. A method, as in claim 1 or 2, further comprising the step of:

changing the threshold temperature (84, 90, 96) with a change in a print density.

5. A method, as in claim 1 or 2, further comprising the step of:

changing the threshold temperature (84, 90, 96) with a change in a print mode (72).

6. A method, as in claim 1 or 2, further comprising the step of:

changing the threshold temperature (84, 90, 96) with a change in a print density and with a change in a print mode (72).

7. A method, as in claim 1 or 2, further comprising the steps of:
reading an output of a densitometer (70); and
changing the threshold temperature (84, 90, 96) with changes in the output of the densitometer (70).

8. A method, as in claim 1, 2, 3, 4, 5, 6, or 7, further comprising the step of:
turning-off a power to the printhead substrate (50) when the temperature (80, 83, 88, 89, 92, 94) of the printhead substrate (50) is above the threshold temperature (84, 90, 96);
b. continuing the print job with another printhead substrate (50); and
c. servicing the printhead substrate (50) when the print job is completed.

9. A method, as in claim 1, 2, 3, 4, 5, 6, or 7, further comprising the step of:
a. repriming the printhead (20); and
b. continuing the print job.

10. A method, as in claim 1 or 2, wherein the correcting step, further comprises:
a. terminating the print job; and
b. notifying a user.

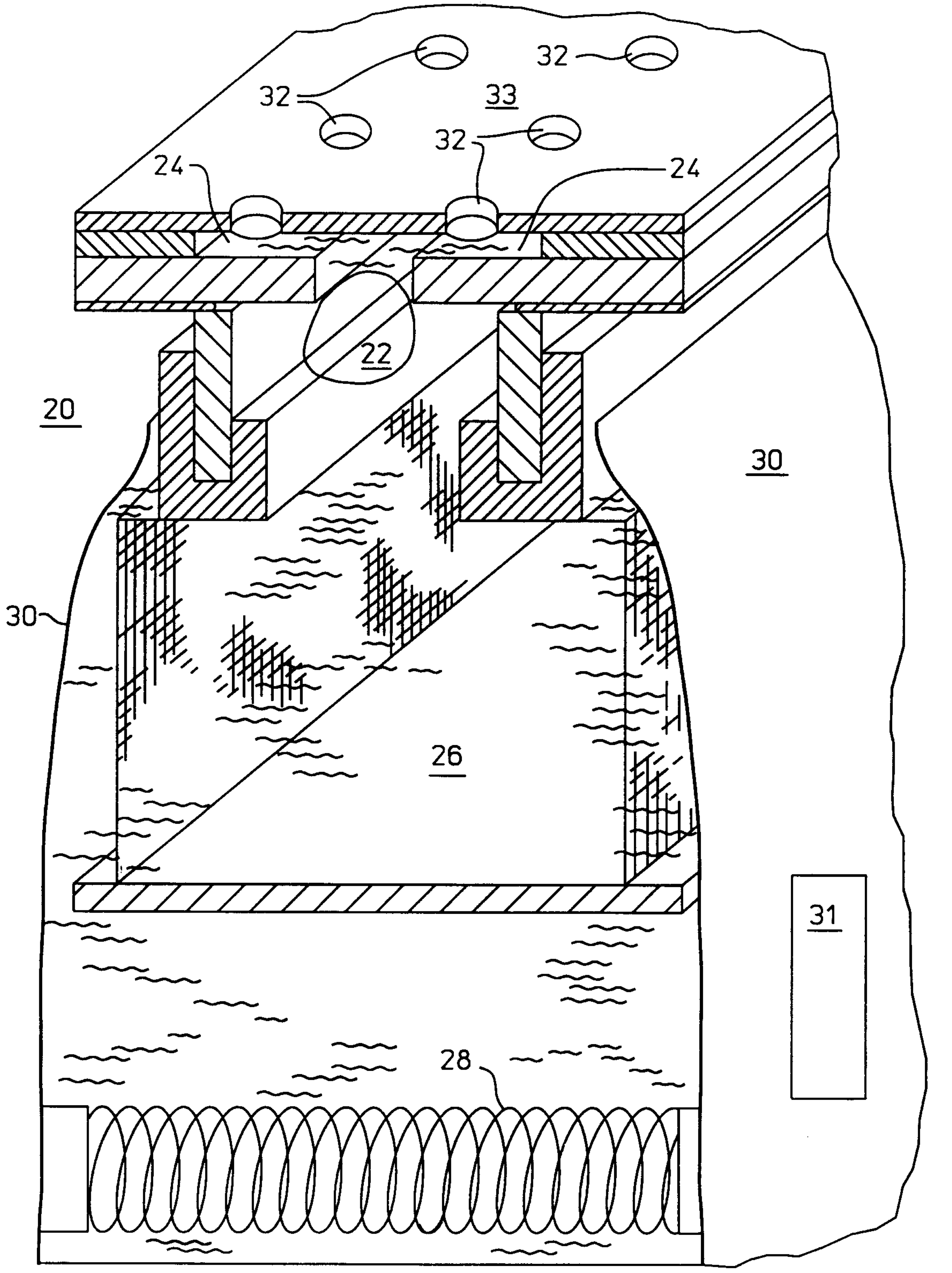


FIG. 1A

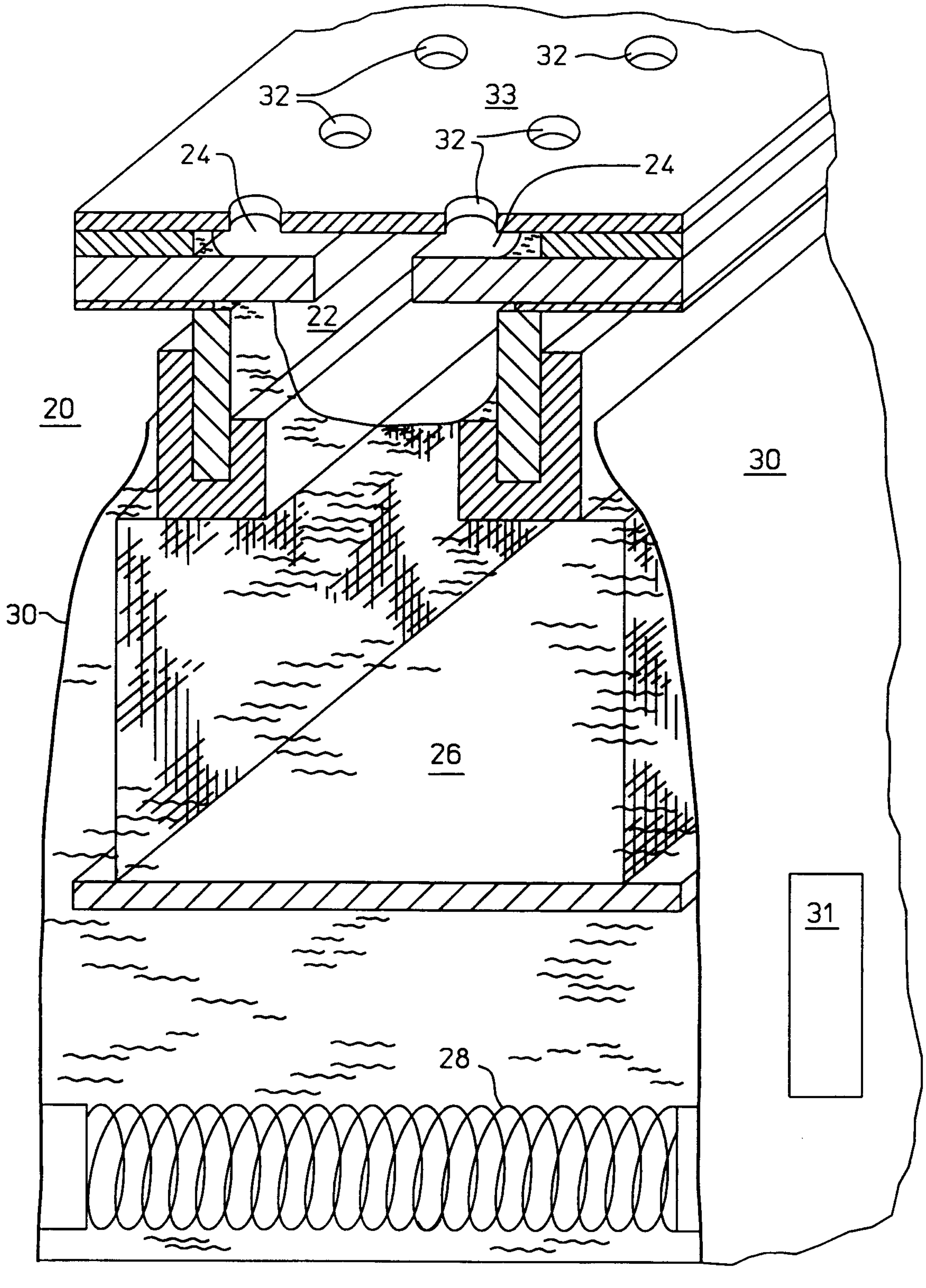


FIG. 1B

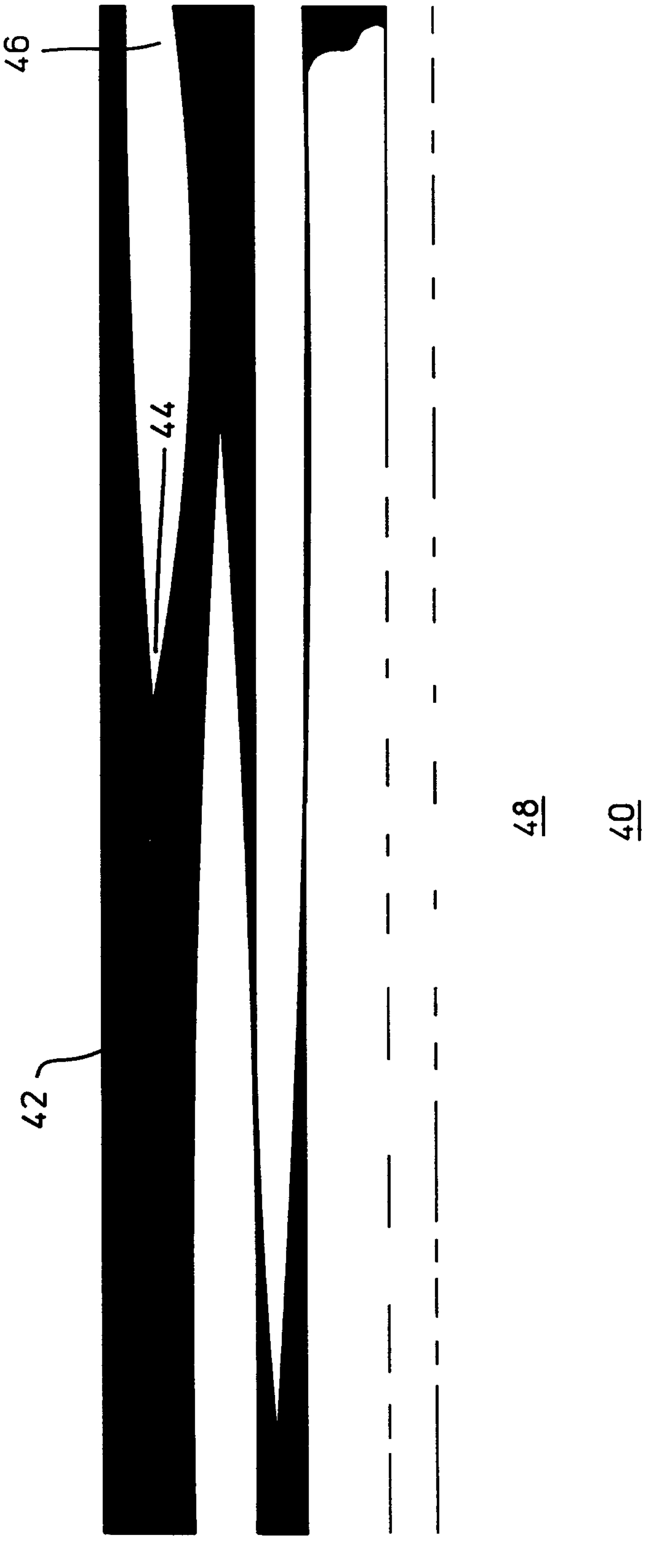


FIG. 1C

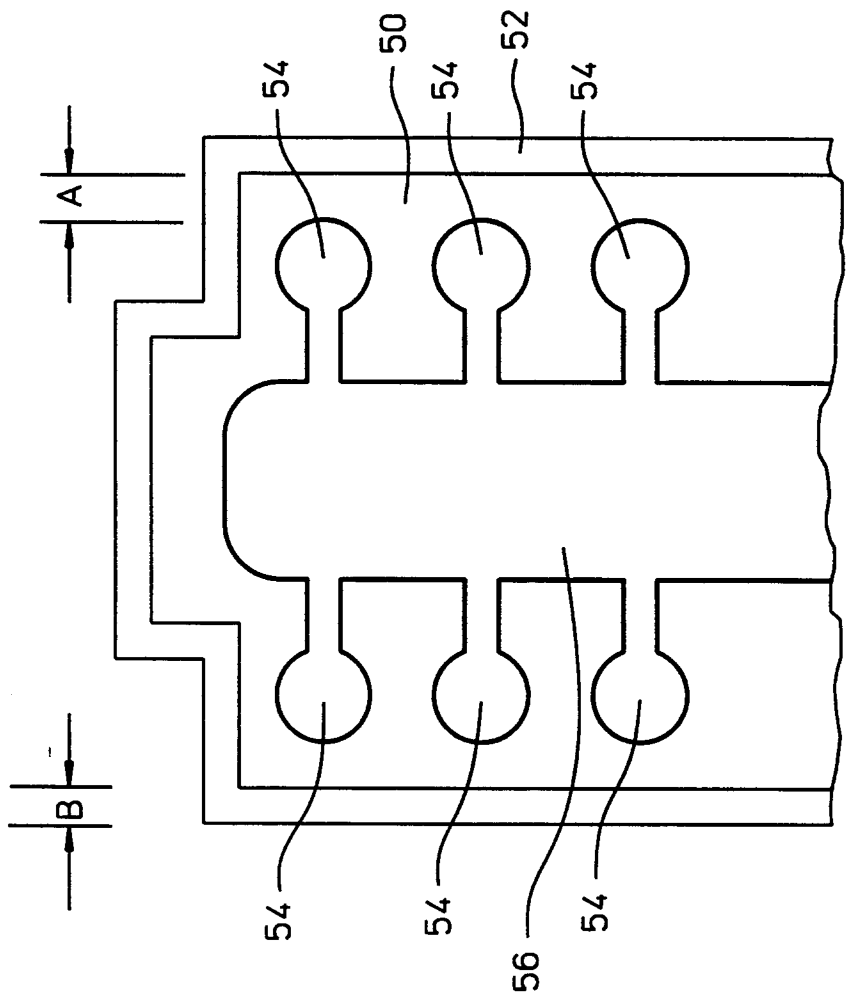


FIG. 2

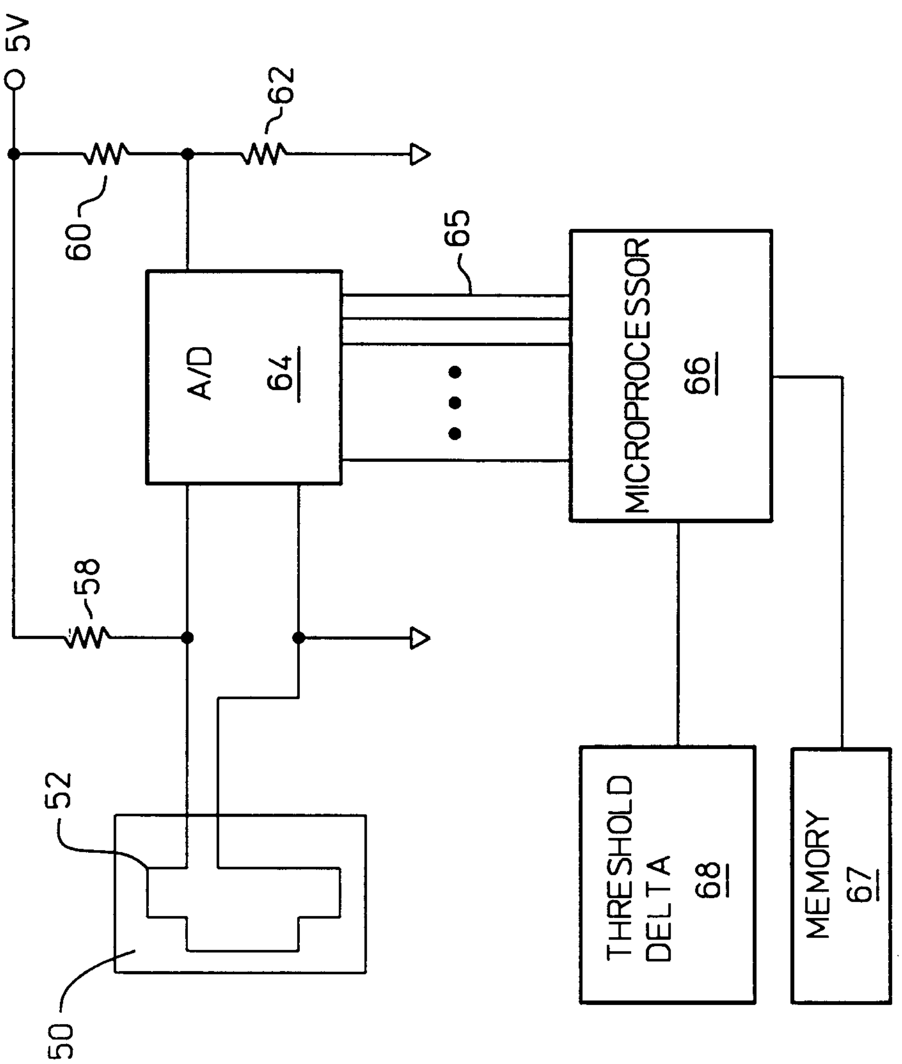
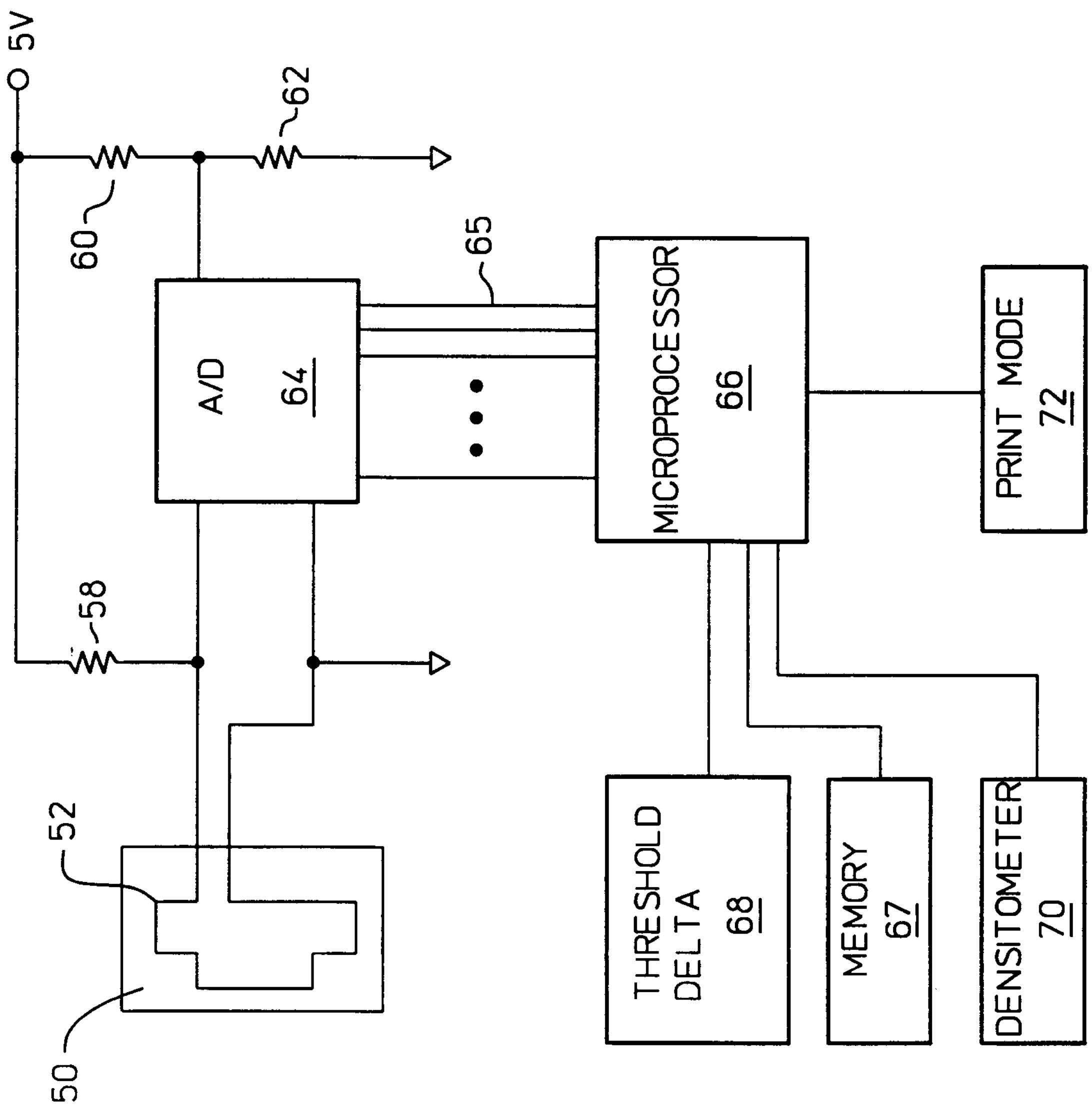

5V
60
62
65
A/D
64
58
MICROPROCESSOR
66
52
50
THRESHOLD
DELTA
68
MEMORY
67

FIG. 3A

FIG. 3B


5V
60
62
58
65
A/D
64
MICROPROCESSOR
66
PRINT MODE
72
52
50
THRESHOLD
DELTA
68
MEMORY
67
DENSITOMETER
70

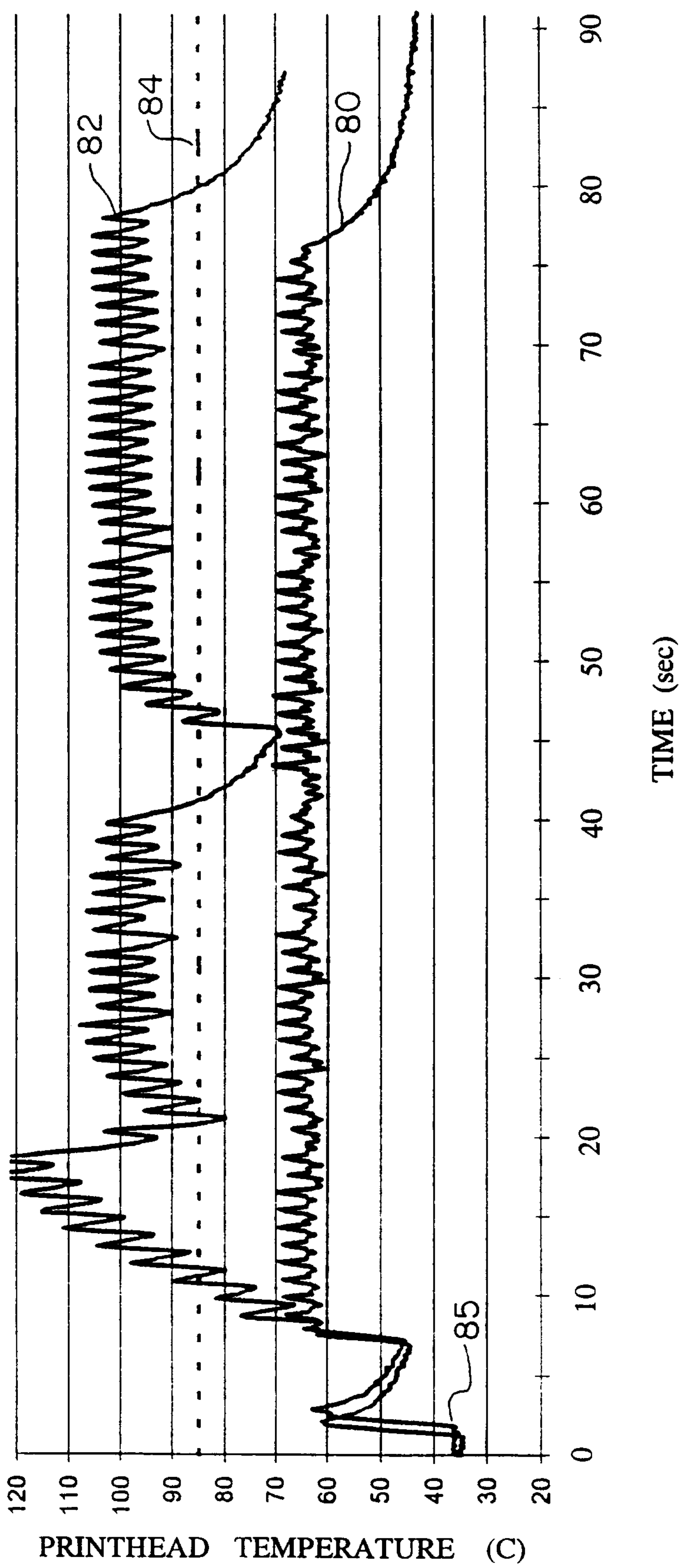
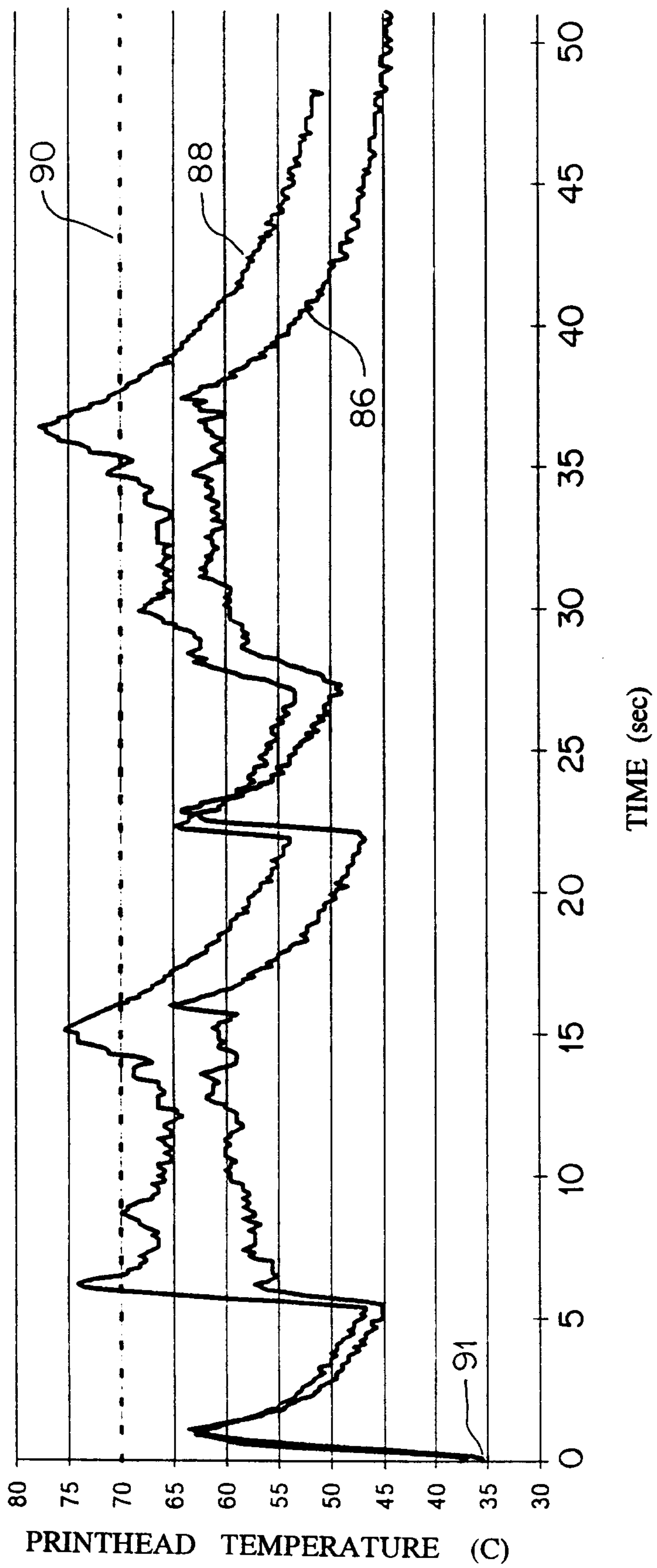

PRINTHEAD TEMPERATURE (C)
120
110
100
90
80
70
60
50
40
30
20
TIME (sec)
0
10
20
30
40
50
60
70
80
90
82
84
80
85

FIG. 4A



PRINTHEAD TEMPERATURE (C)
80
75
70
65
60
55
50
45
40
35
30
TIME (sec)
0
5
10
15
20
25
30
35
40
45
50
90
88
86
91

FIG. 4B

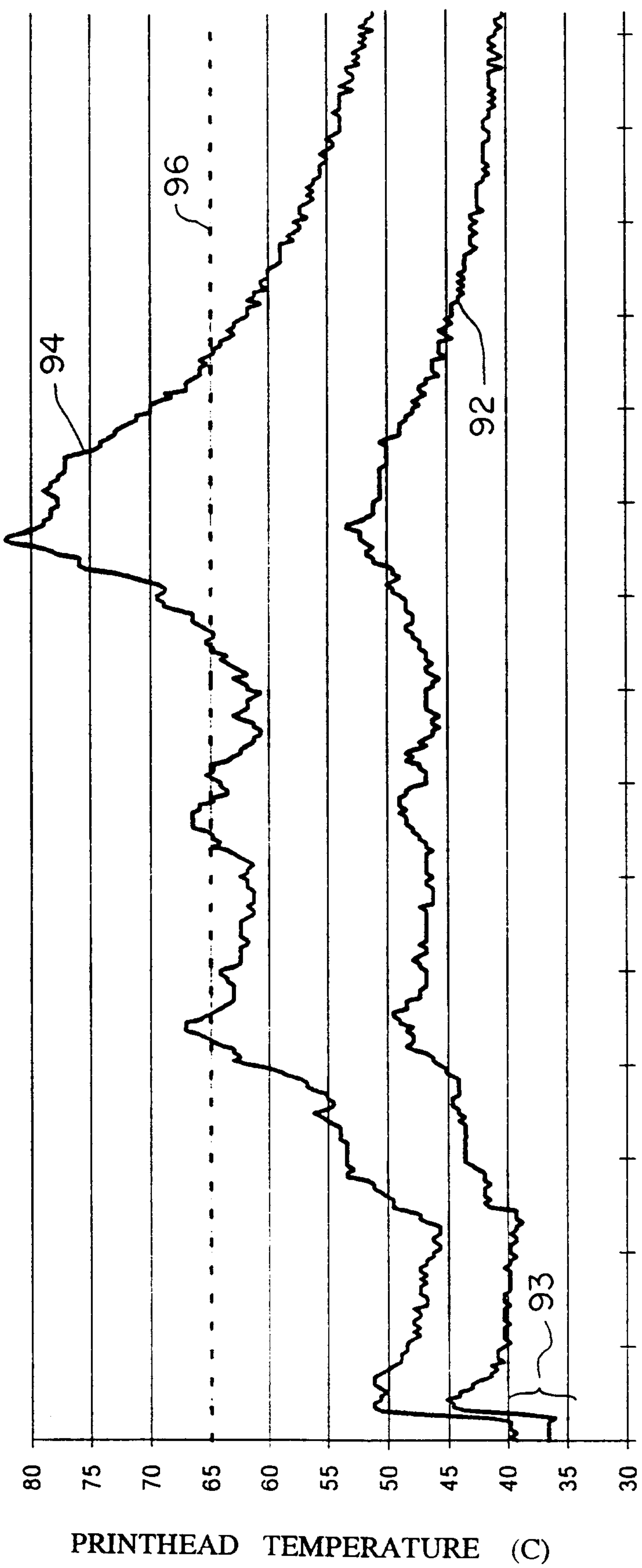

80
75
70
65
60
55
50
45
40
35
30
PRINTHEAD TEMPERATURE (C)
94
96
92
93

FIG. 4C

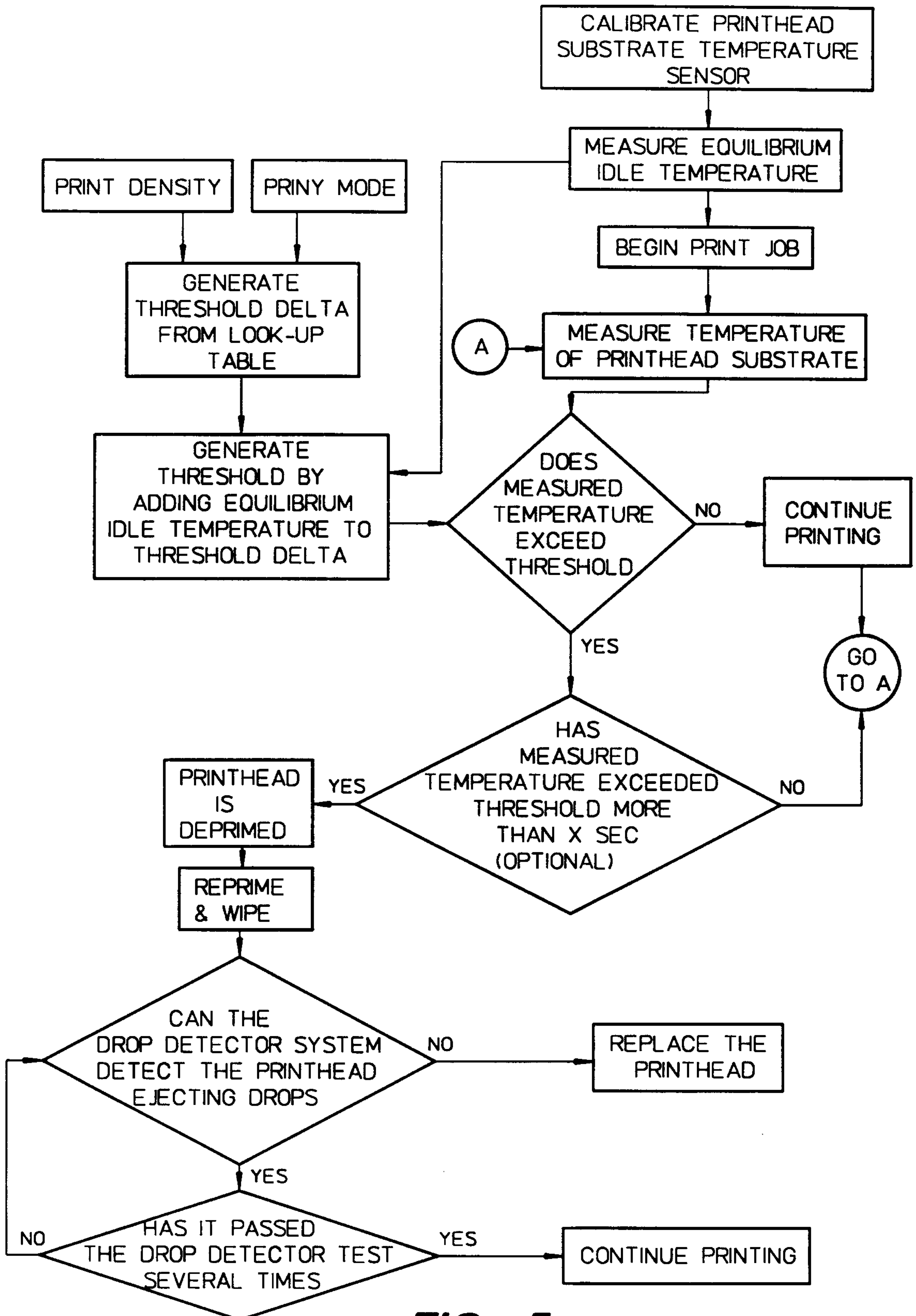

CALIBRATE PRINTHEAD SUBSTRATE TEMPERATURE SENSOR
MEASURE EQUILIBRIUM IDLE TEMPERATURE
PRINT DENSITY
PRINY MODE
BEGIN PRINT JOB
GENERATE THRESHOLD DELTA FROM LOOK-UP TABLE
A
MEASURE TEMPERATURE OF PRINTHEAD SUBSTRATE
GENERATE THRESHOLD BY ADDING EQUILIBRIUM IDLE TEMPERATURE TO THRESHOLD DELTA
DOES MEASURED TEMPERATURE EXCEED THRESHOLD
NO
CONTINUE PRINTING
YES
GO TO A
HAS MEASURED TEMPERATURE EXCEEDED THRESHOLD MORE THAN X SEC (OPTIONAL)
YES
NO
PRINTHEAD IS DEPRIMED
REPRIME & WIPE
CAN THE DROP DETECTOR SYSTEM DETECT THE PRINTHEAD EJECTING DROPS
NO
REPLACE THE PRINTHEAD
YES
HAS IT PASSED THE DROP DETECTOR TEST SEVERAL TIMES
NO
YES
CONTINUE PRINTING

FIG. 5

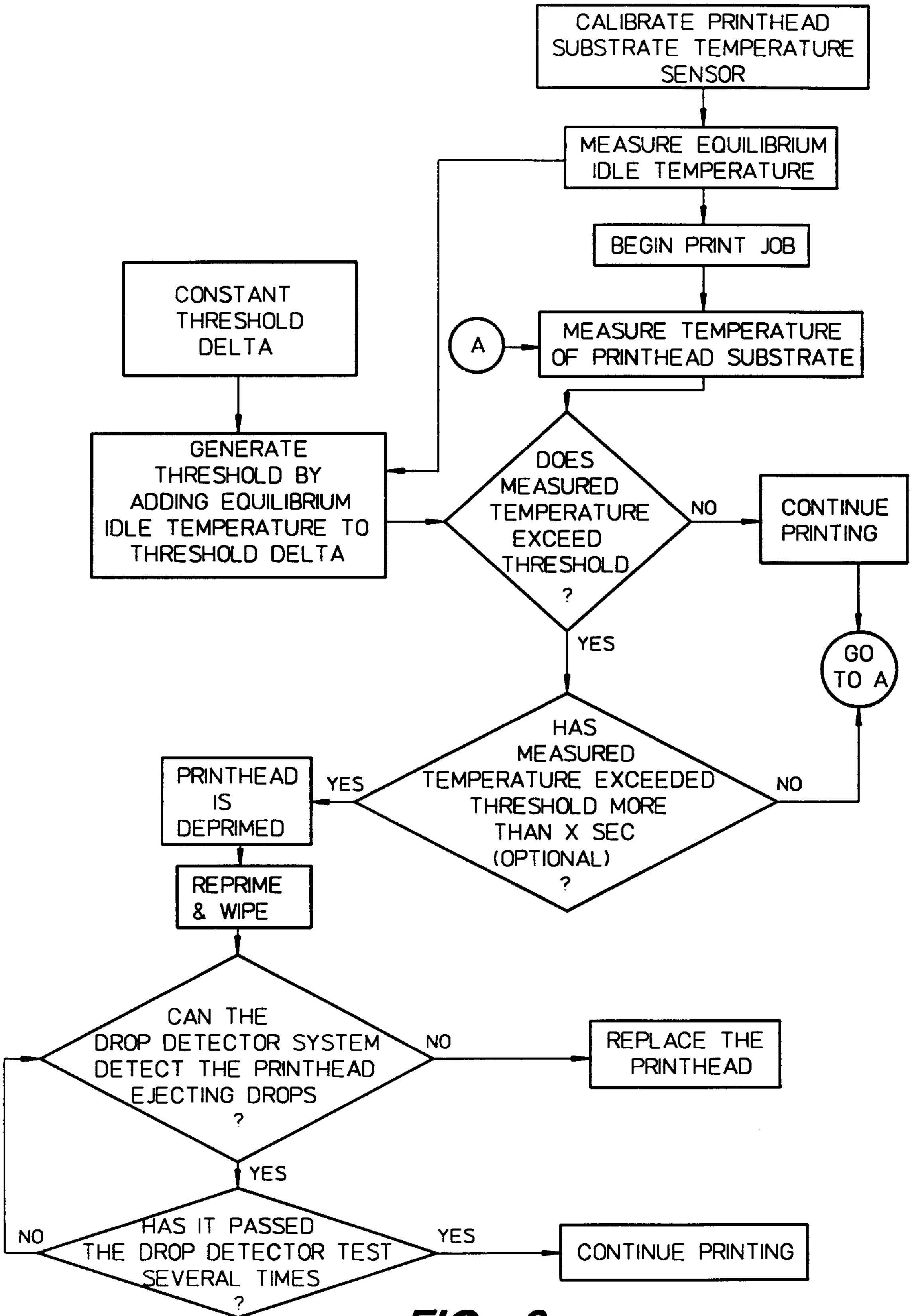

CALIBRATE PRINTHEAD SUBSTRATE TEMPERATURE SENSOR
MEASURE EQUILIBRIUM IDLE TEMPERATURE
BEGIN PRINT JOB
CONSTANT THRESHOLD DELTA
A
MEASURE TEMPERATURE OF PRINTHEAD SUBSTRATE
GENERATE THRESHOLD BY ADDING EQUILIBRIUM IDLE TEMPERATURE TO THRESHOLD DELTA
DOES MEASURED TEMPERATURE EXCEED THRESHOLD ?
NO
CONTINUE PRINTING
YES
GO TO A
HAS MEASURED TEMPERATURE EXCEEDED THRESHOLD MORE THAN X SEC (OPTIONAL) ?
YES
NO
PRINTHEAD IS DEPRIMED
REPRIME & WIPE
CAN THE DROP DETECTOR SYSTEM DETECT THE PRINTHEAD EJECTING DROPS ?
NO
REPLACE THE PRINTHEAD
YES
HAS IT PASSED THE DROP DETECTOR TEST SEVERAL TIMES ?
NO
YES
CONTINUE PRINTING

FIG. 6

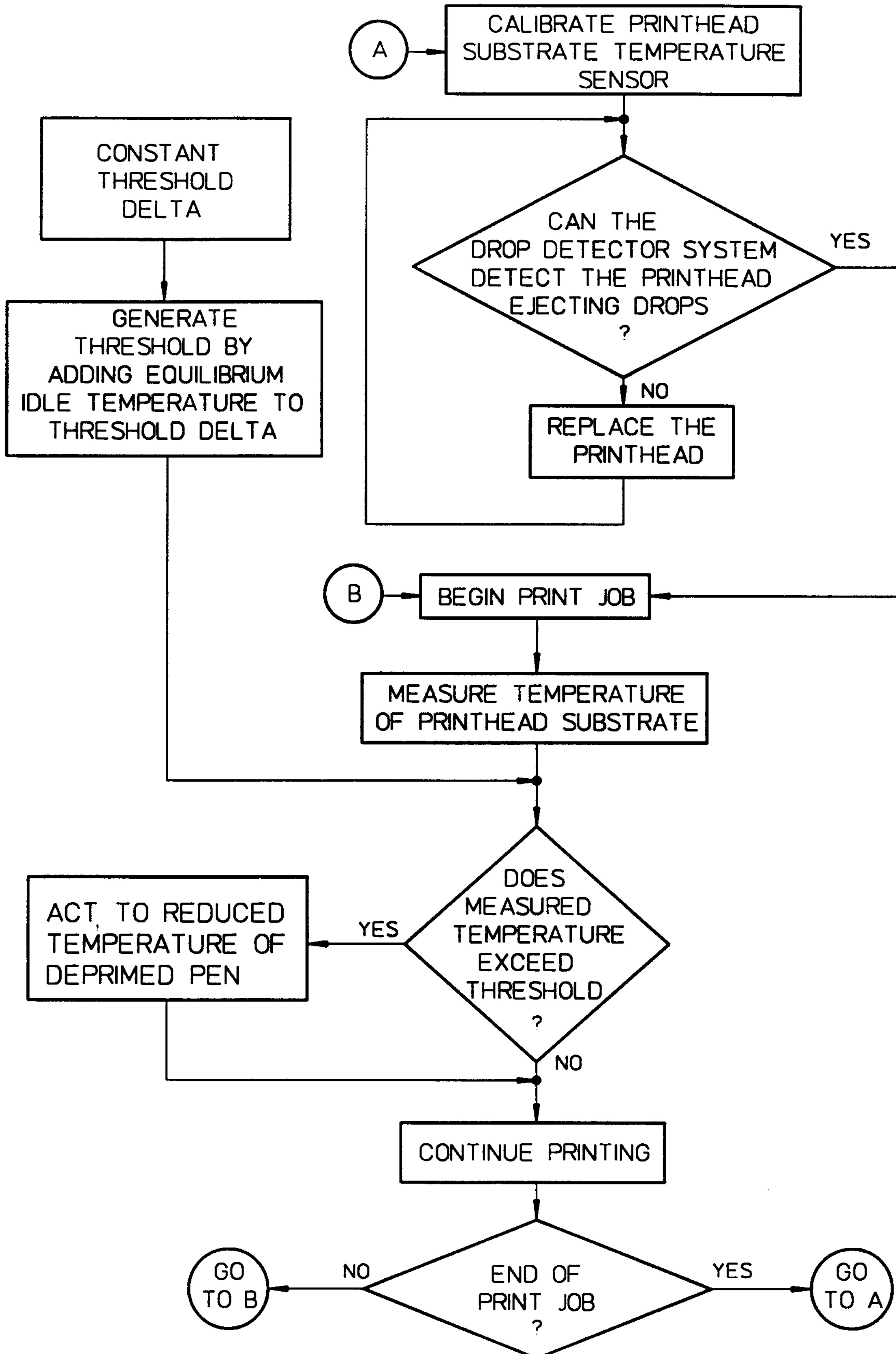

A
CALIBRATE PRINTHEAD SUBSTRATE TEMPERATURE SENSOR
CONSTANT THRESHOLD DELTA
CAN THE DROP DETECTOR SYSTEM DETECT THE PRINTHEAD EJECTING DROPS ?
YES
NO
GENERATE THRESHOLD BY ADDING EQUILIBRIUM IDLE TEMPERATURE TO THRESHOLD DELTA
REPLACE THE PRINTHEAD
B
BEGIN PRINT JOB
MEASURE TEMPERATURE OF PRINTHEAD SUBSTRATE
ACT TO REDUCED TEMPERATURE OF DEPRIMED PEN
YES
DOES MEASURED TEMPERATURE EXCEED THRESHOLD ?
NO
CONTINUE PRINTING
GO TO B
NO
END OF PRINT JOB ?
YES
GO TO A

FIG. 7

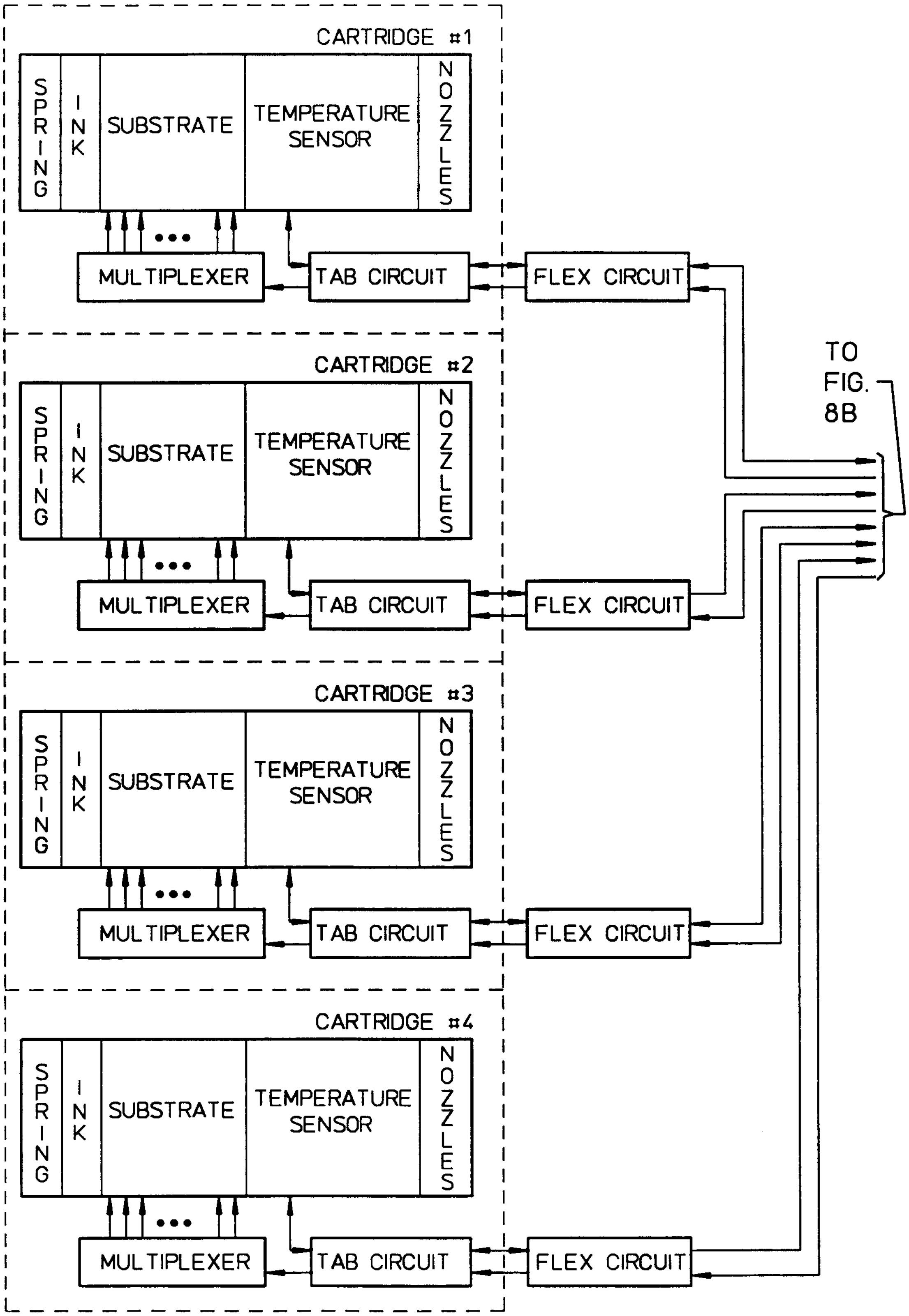

CARTRIDGE #1
SPRING
INK
SUBSTRATE
TEMPERATURE SENSOR
NOZZLES
MULTIPLEXER
TAB CIRCUIT
FLEX CIRCUIT
CARTRIDGE #2
SPRING
INK
SUBSTRATE
TEMPERATURE SENSOR
NOZZLES
MULTIPLEXER
TAB CIRCUIT
FLEX CIRCUIT
CARTRIDGE #3
SPRING
INK
SUBSTRATE
TEMPERATURE SENSOR
NOZZLES
MULTIPLEXER
TAB CIRCUIT
FLEX CIRCUIT
CARTRIDGE #4
SPRING
INK
SUBSTRATE
TEMPERATURE SENSOR
NOZZLES
MULTIPLEXER
TAB CIRCUIT
FLEX CIRCUIT
TO FIG. 8B

FIG. 8A

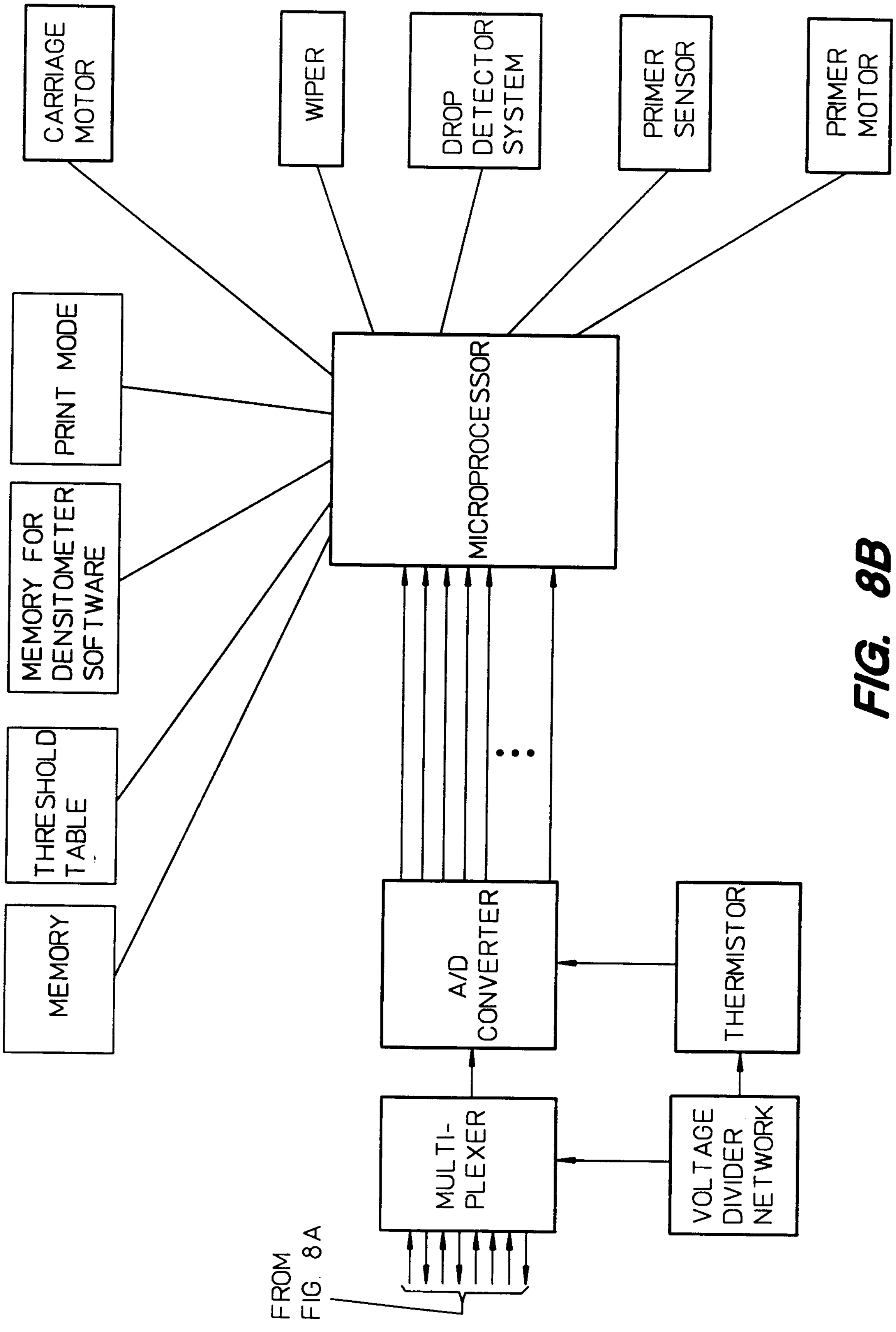

CARRIAGE MOTOR
WIPER
DROP DETECTOR SYSTEM
PRIMER SENSOR
PRIMER MOTOR
PRINT MODE
MEMORY FOR DENSITOMETER SOFTWARE
THRESHOLD TABLE
MEMORY
MICROPROCESSOR
A/D CONVERTER
THERMISTOR
MULTI-PLEXER
VOLTAGE DIVIDER NETWORK
FROM FIG. 8A

FIG. 8B

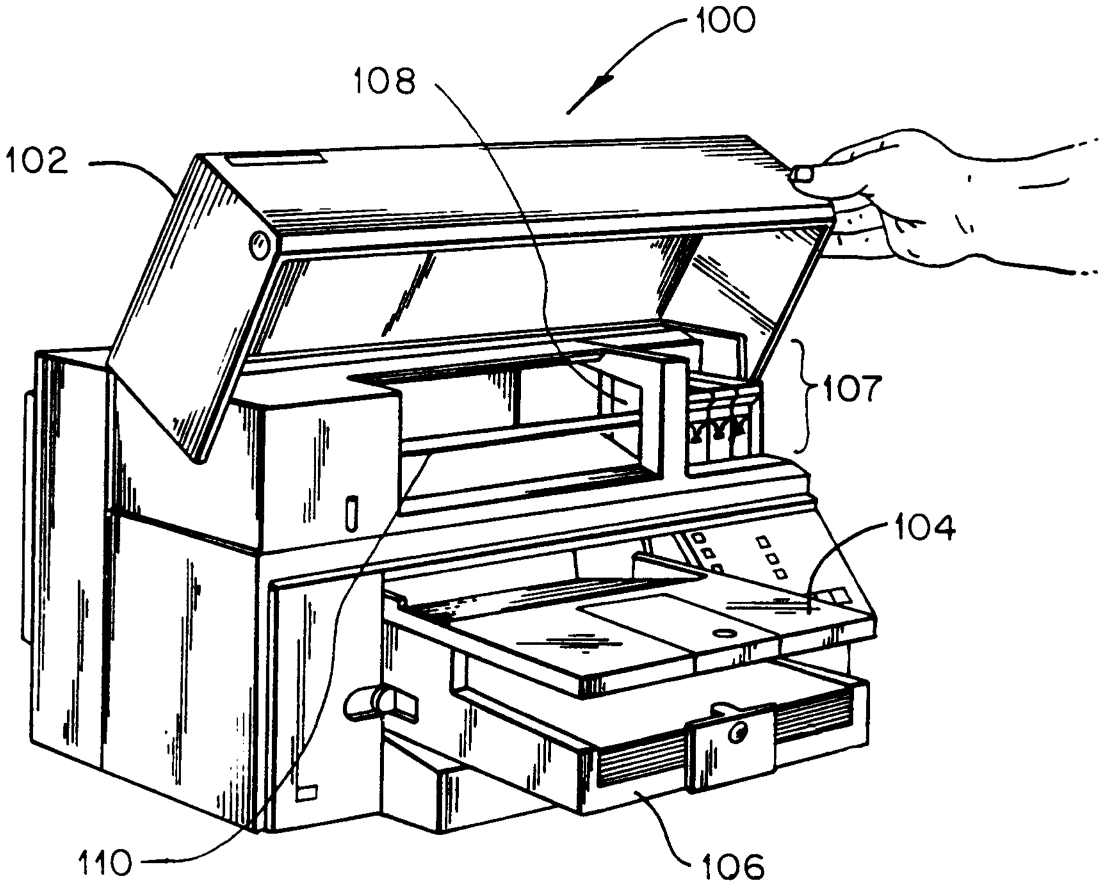


FIG. 9A

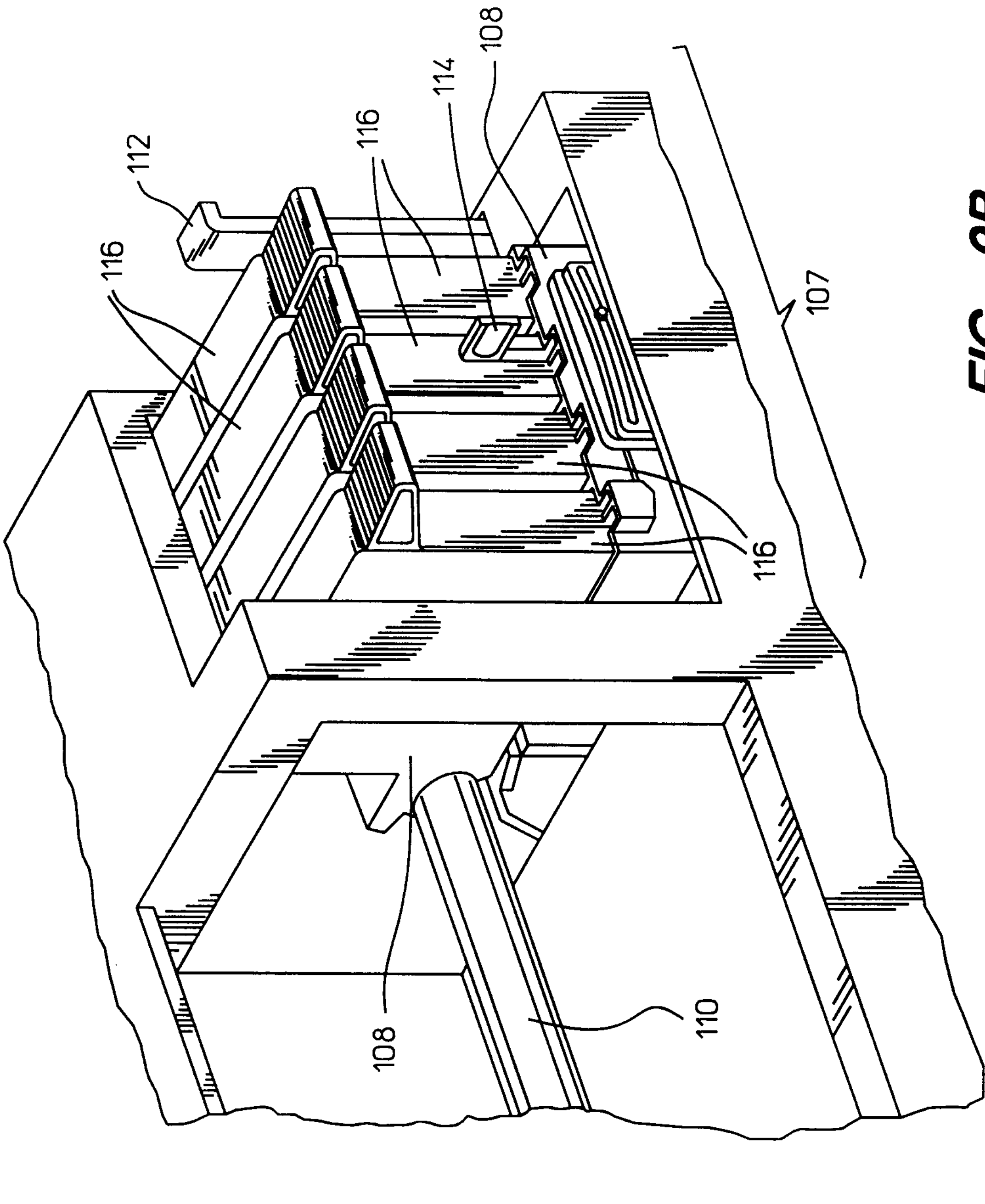


FIG. 9B