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Pippin

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(54) **TEMPERATURE-BASED COOLING DEVICE CONTROLLER APPARATUS AND METHOD**

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Related U.S. Application Data

(62) Division of application No. 09/093,988, filed on Jun. 8, 1998, now abandoned, which is a continuation of application No. 08/660,016, filed on Jun. 6, 1996, now Pat. No. 5,838, 578, which is a continuation of application No. 08/124,980, filed on Sep. 21, 1993, now abandoned.

(51) **Int. Cl.**[7] **H01K 3/08**
(52) **U.S. Cl.** **307/117**; 364/488; 327/512; 374/173
(58) **Field of Search** 307/117; 364/488, 364/489; 327/512; 374/173, 101

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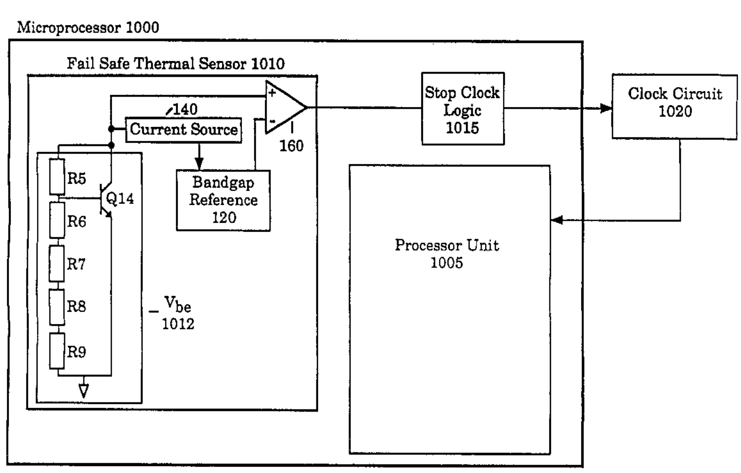
(57) **ABSTRACT**

A temperature-based cooling device controller includes a register to store a threshold temperature value, a thermal sensor, and cooling activation logic to activate an active cooling device in response to an interrupt signal. The thermal sensor includes a current source, a voltage reference coupled to the current source to provide a bandgap reference voltage, wherein the bandgap reference voltage is substantially constant over a range of temperatures, programmable circuitry providing an output voltage that varies with the integrated circuit temperature and in accordance with the register value, and a comparator, wherein the comparator generates an interrupt signal if a difference between the output voltage and the bandgap reference voltage indicates that the threshold temperature has been exceeded.

36 Claims, 11 Drawing Sheets



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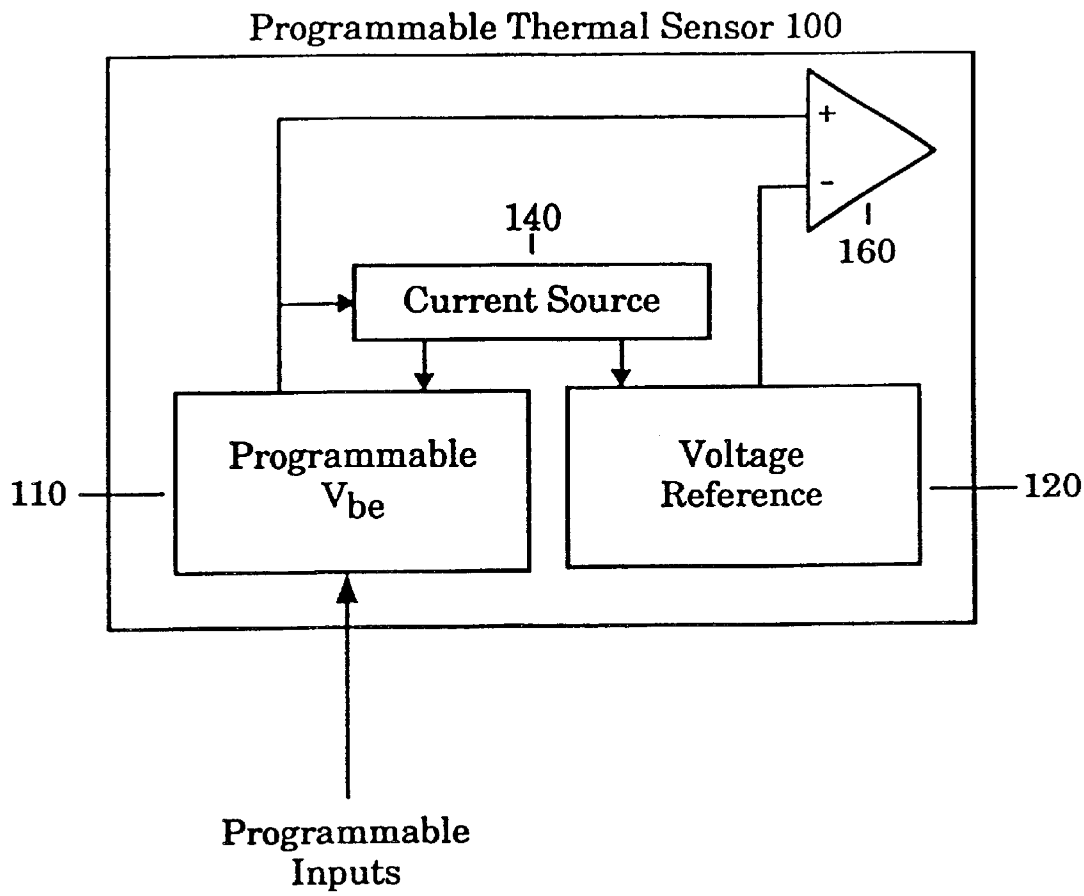
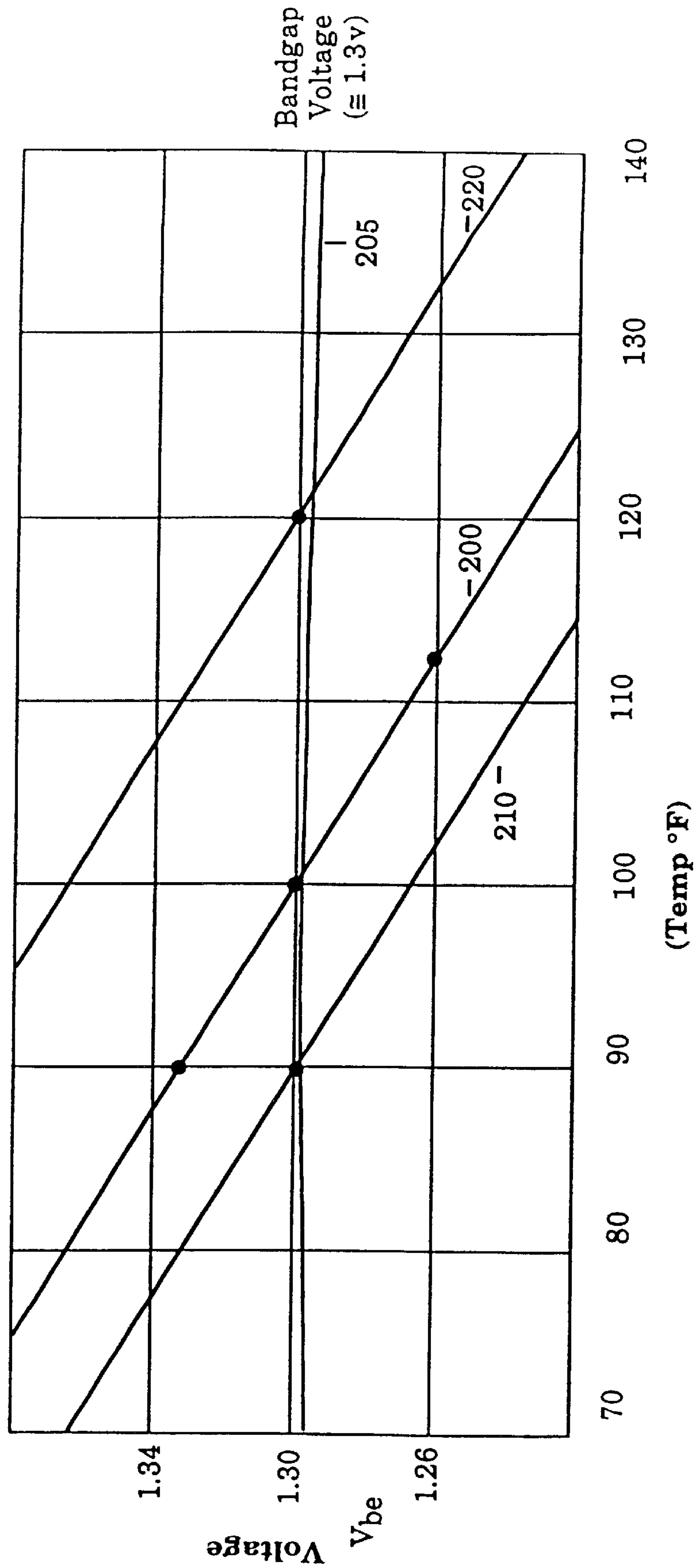

Programmable Thermal Sensor 100
+
-
140
160
Current Source
Programmable
Vbe
Voltage
Reference
110
120
Programmable
Inputs

Figure 1



Bandgap
Voltage
(≅ 1.3v)
205
220
200
210
Voltage
V_{be}
1.34
1.30
1.26
70
80
90
100
110
120
130
140
(Temp °F)

Figure 2

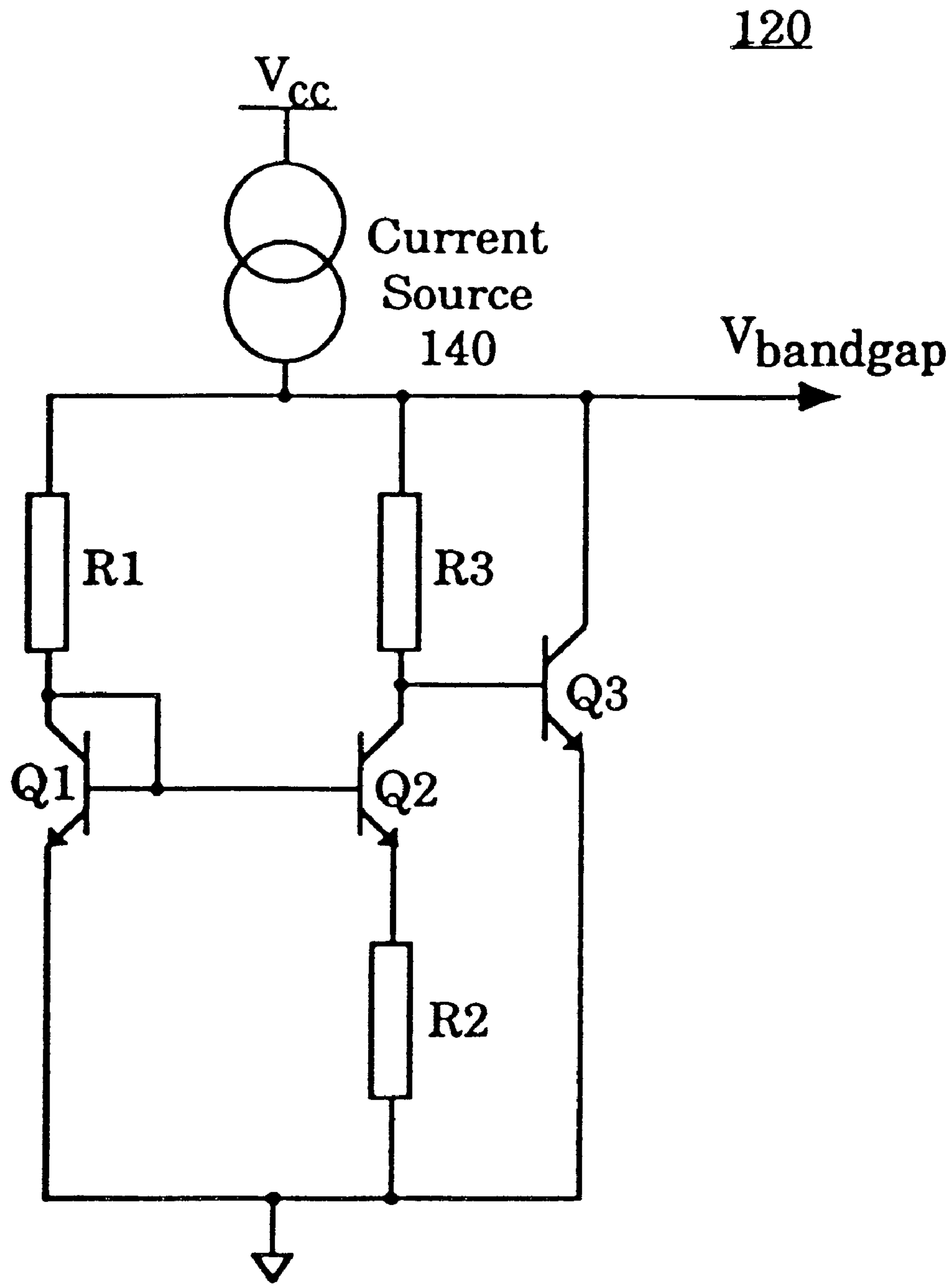
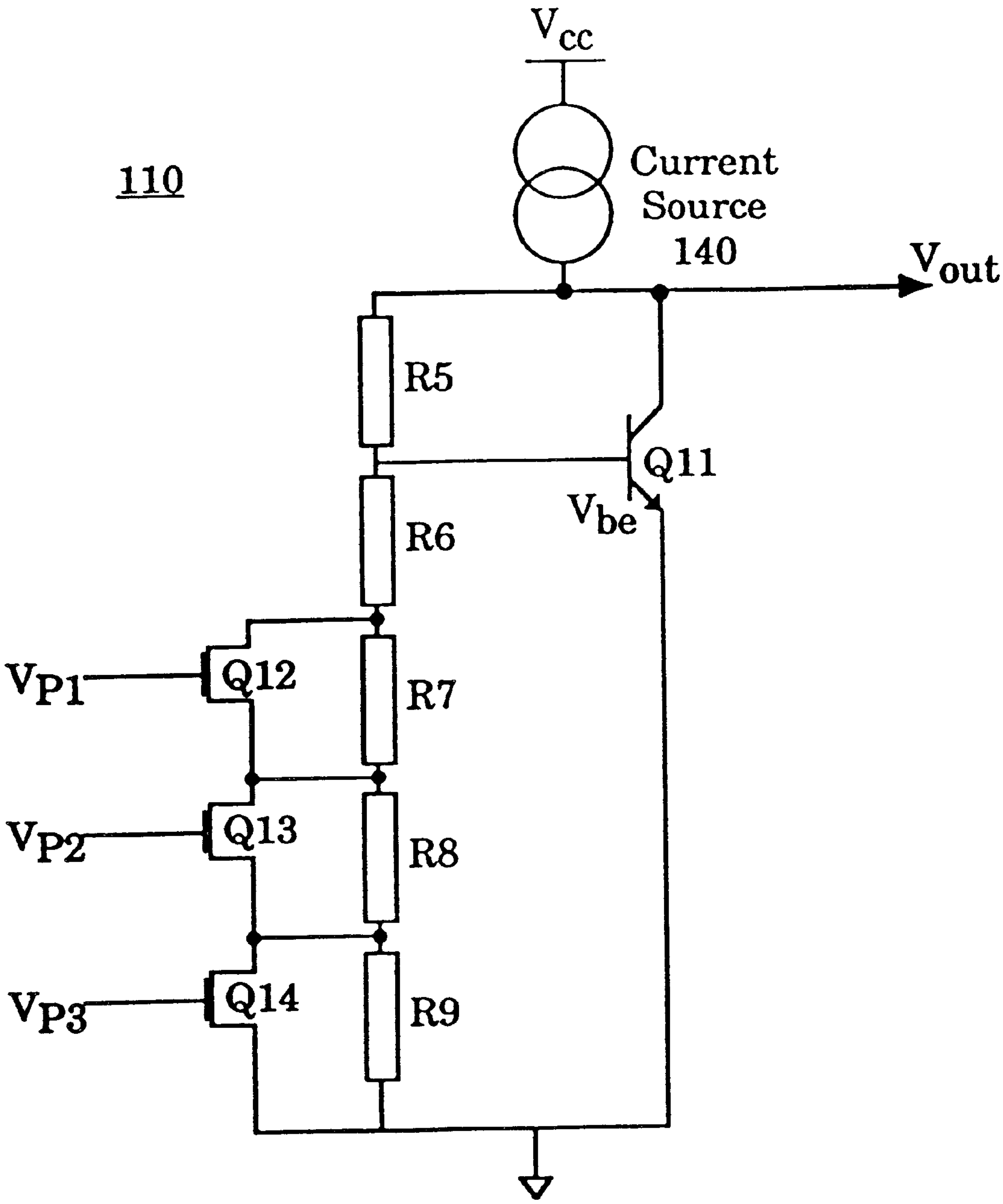
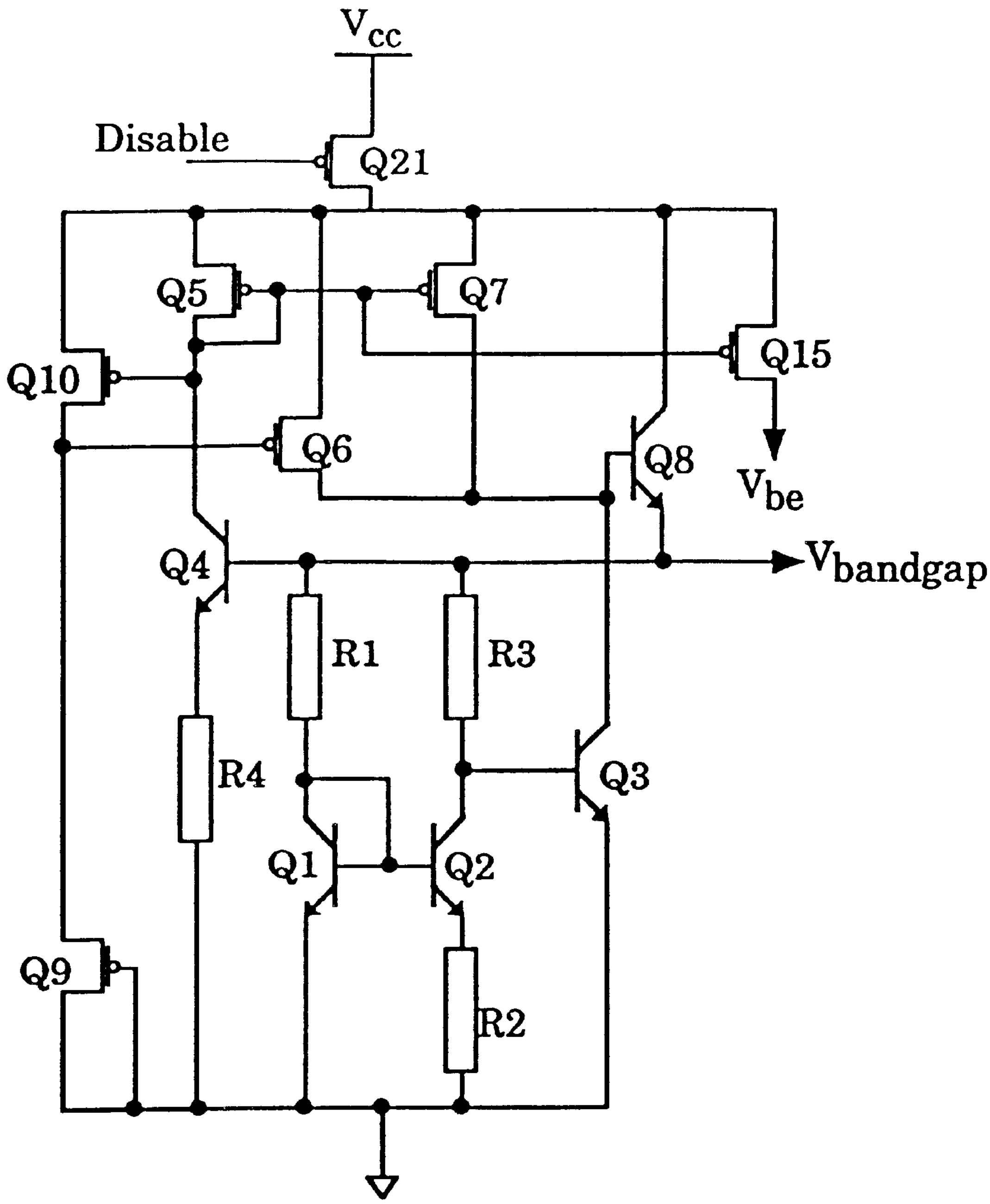


Figure 3



110
V_{cc}
Current Source 140
V_{out}
R5
Q11
V_{be}
R6
V_{P1}
Q12
R7
V_{P2}
Q13
R8
V_{P3}
Q14
R9

Figure 4



Vcc
Disable
Q21
Q5
Q7
Q15
Q10
Q6
Q8
Vbe
Q4
Vbandgap
R1
R3
R4
Q3
Q1
Q2
Q9
R2

Figure 5

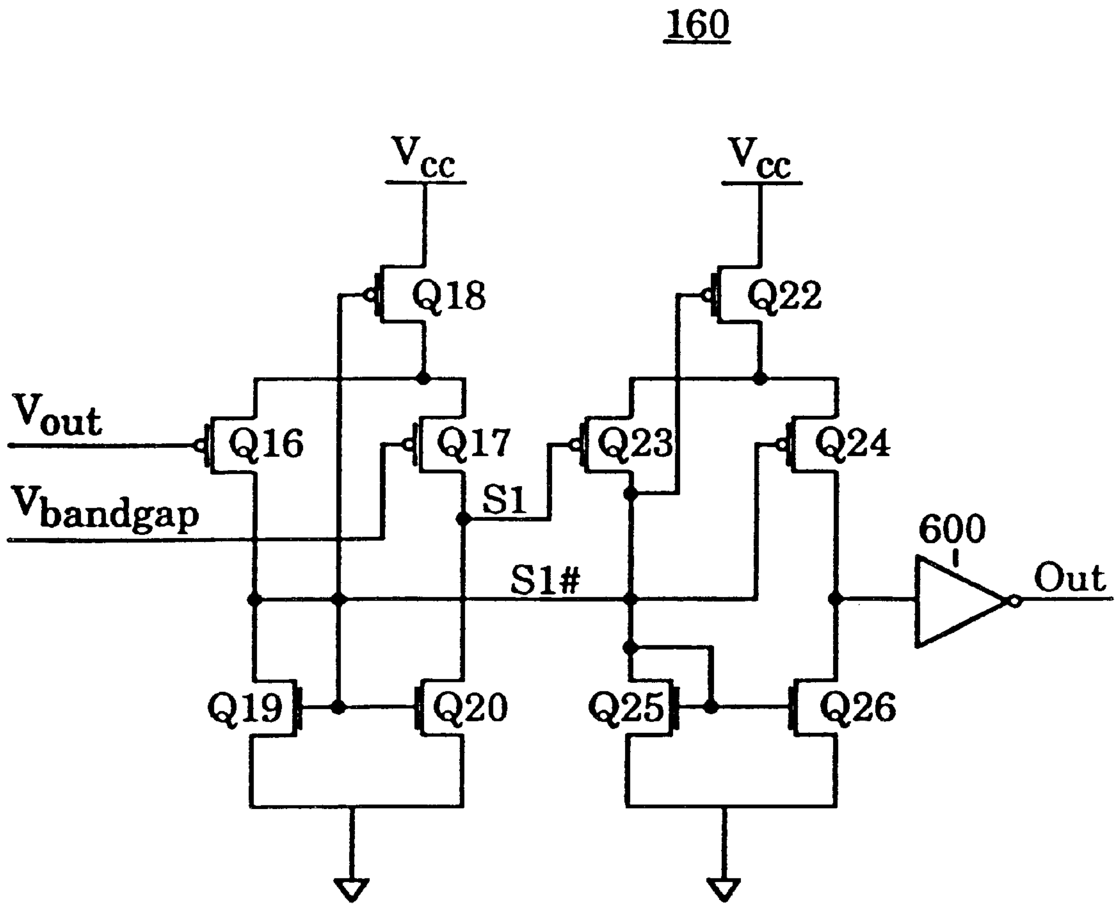

160
Vcc
Vcc
Q18
Q22
Vout
Q16
Q17
Q23
Q24
Vbandgap
S1
600
S1#
Out
Q19
Q20
Q25
Q26

Figure 6

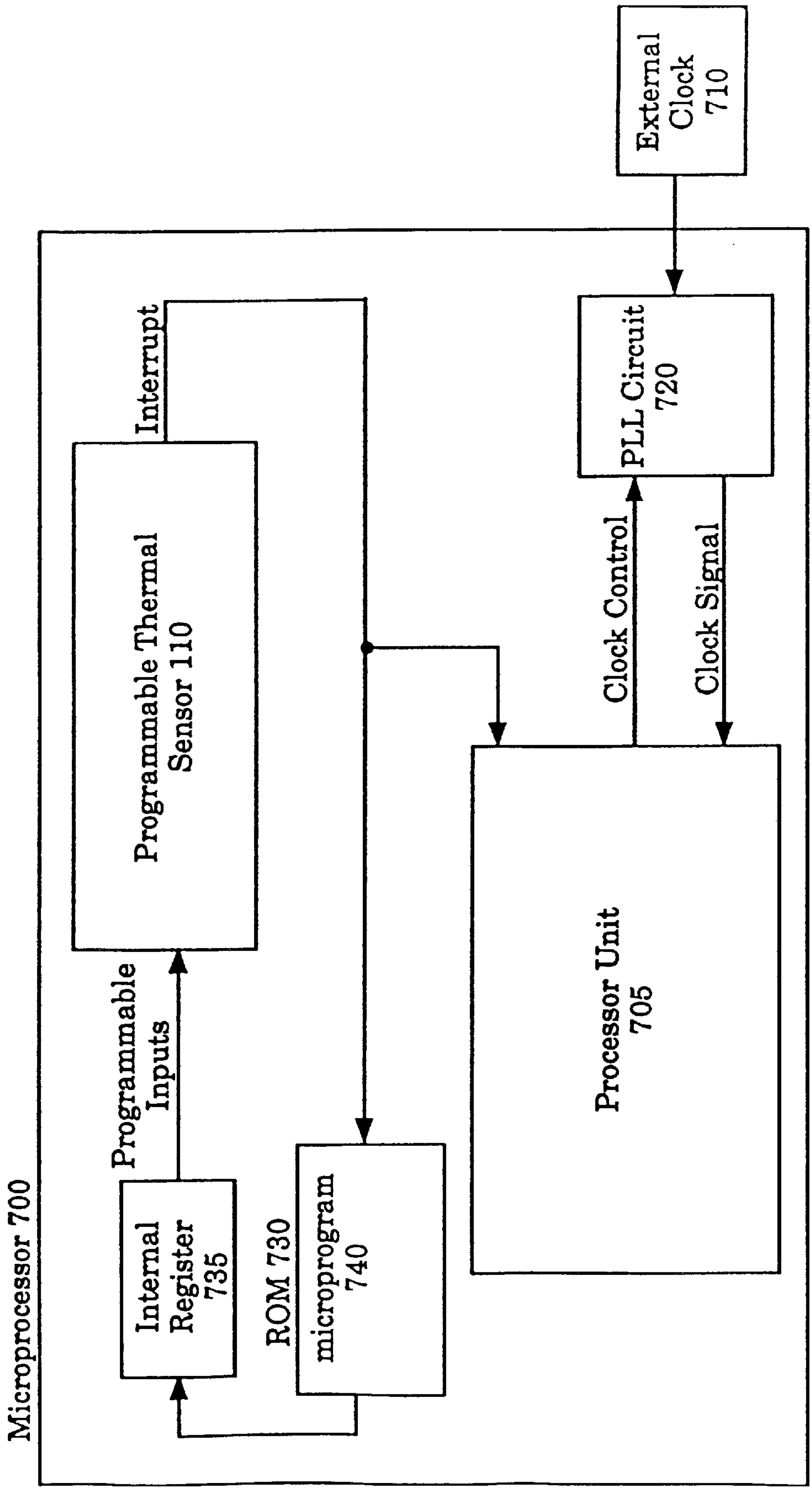

External Clock 710
Microprocessor 700
Interrupt
PLL Circuit 720
Programmable Thermal Sensor 110
Clock Control
Clock Signal
Programmable Inputs
Processor Unit 705
Internal Register 735
ROM 730
microprogram 740

Figure 7

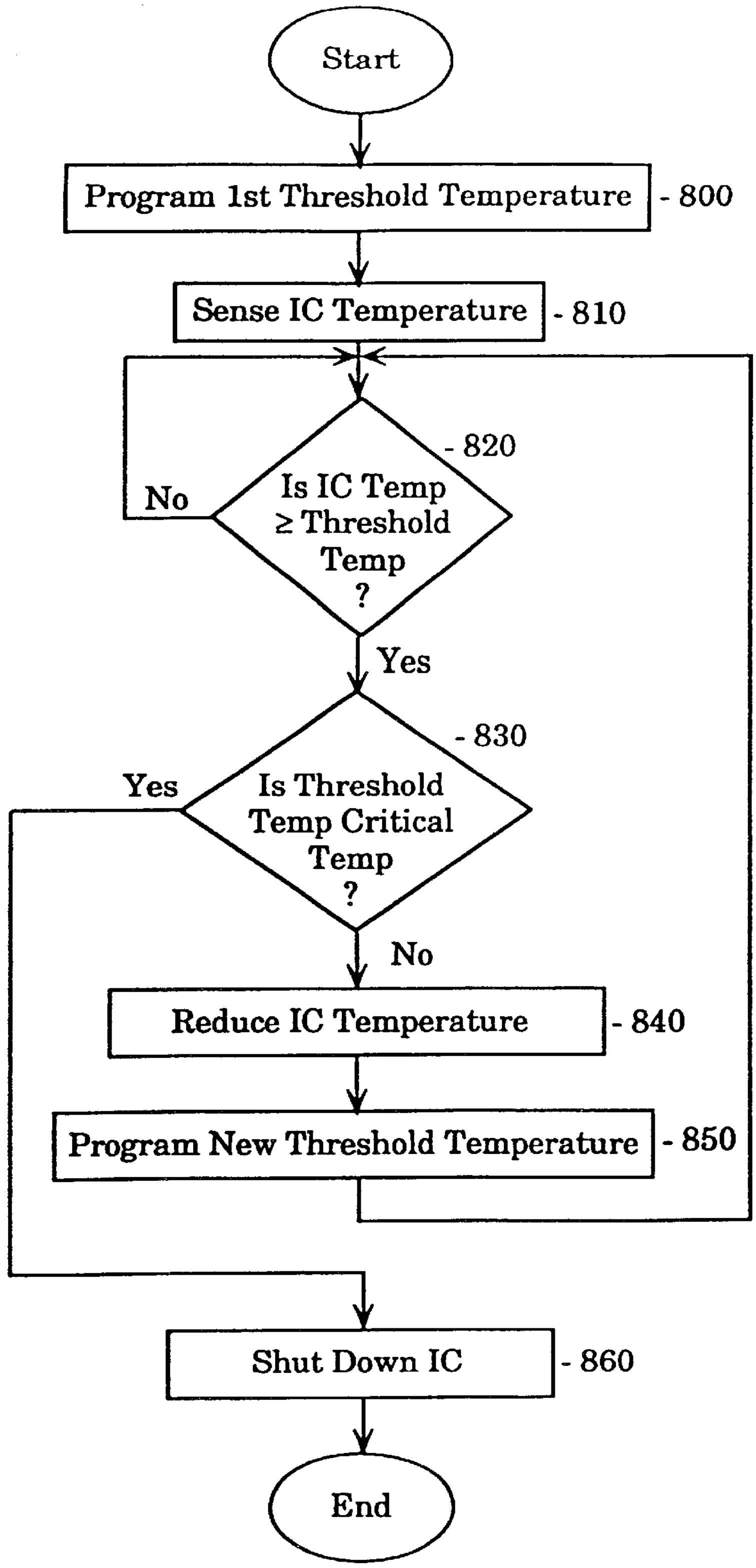

Start
Program 1st Threshold Temperature
800
Sense IC Temperature
810
820
Is IC Temp ≥ Threshold Temp ?
No
Yes
830
Is Threshold Temp Critical Temp ?
Yes
No
Reduce IC Temperature
840
Program New Threshold Temperature
850
Shut Down IC
860
End

Figure 8

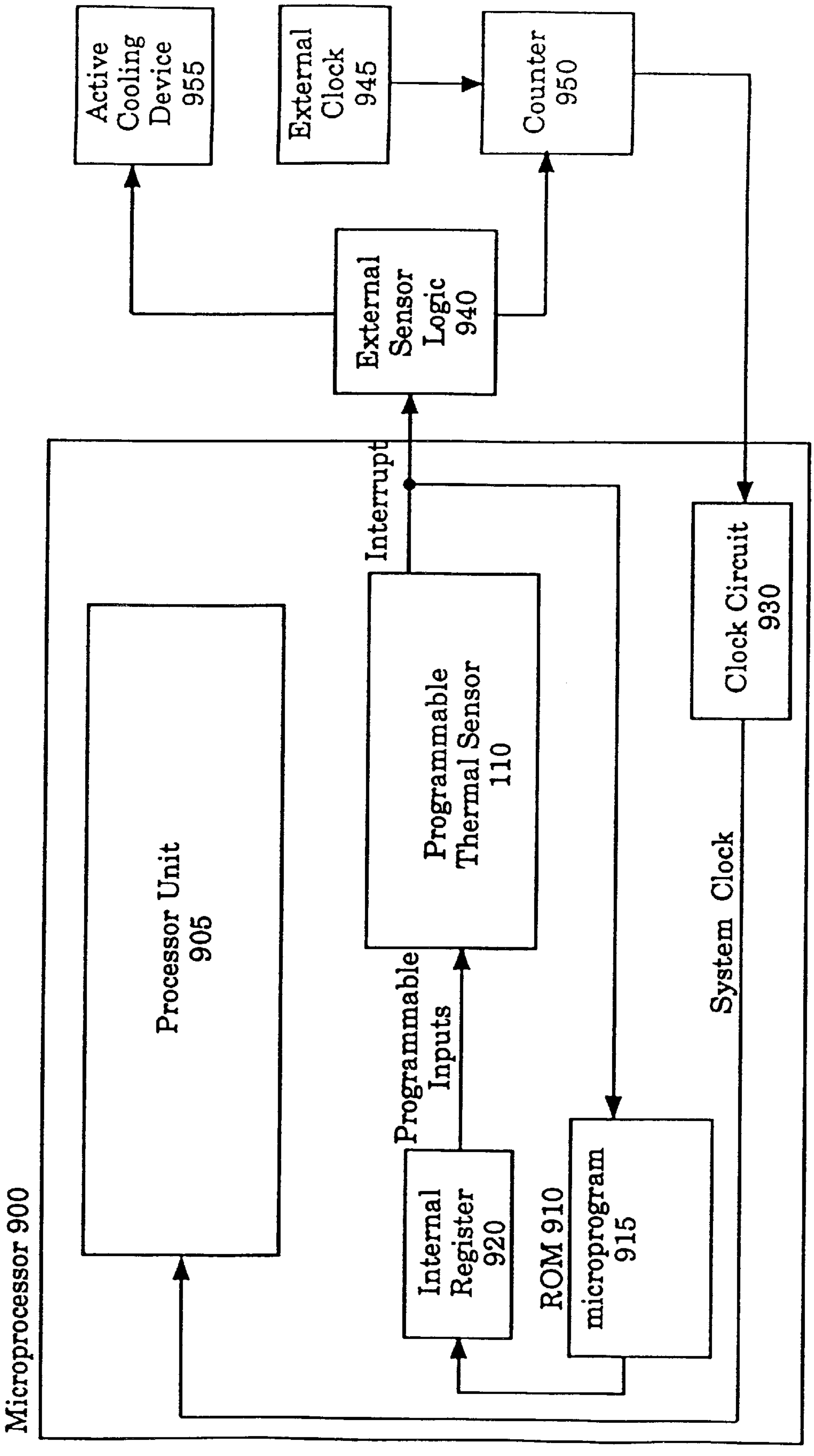

Active Cooling Device 955
External Clock 945
Counter 950
External Sensor Logic 940
Interrupt
Microprocessor 900
Processor Unit 905
Programmable Thermal Sensor 110
Clock Circuit 930
Programmable Inputs
System Clock
Internal Register 920
ROM 910
microprogram 915

Figure 9

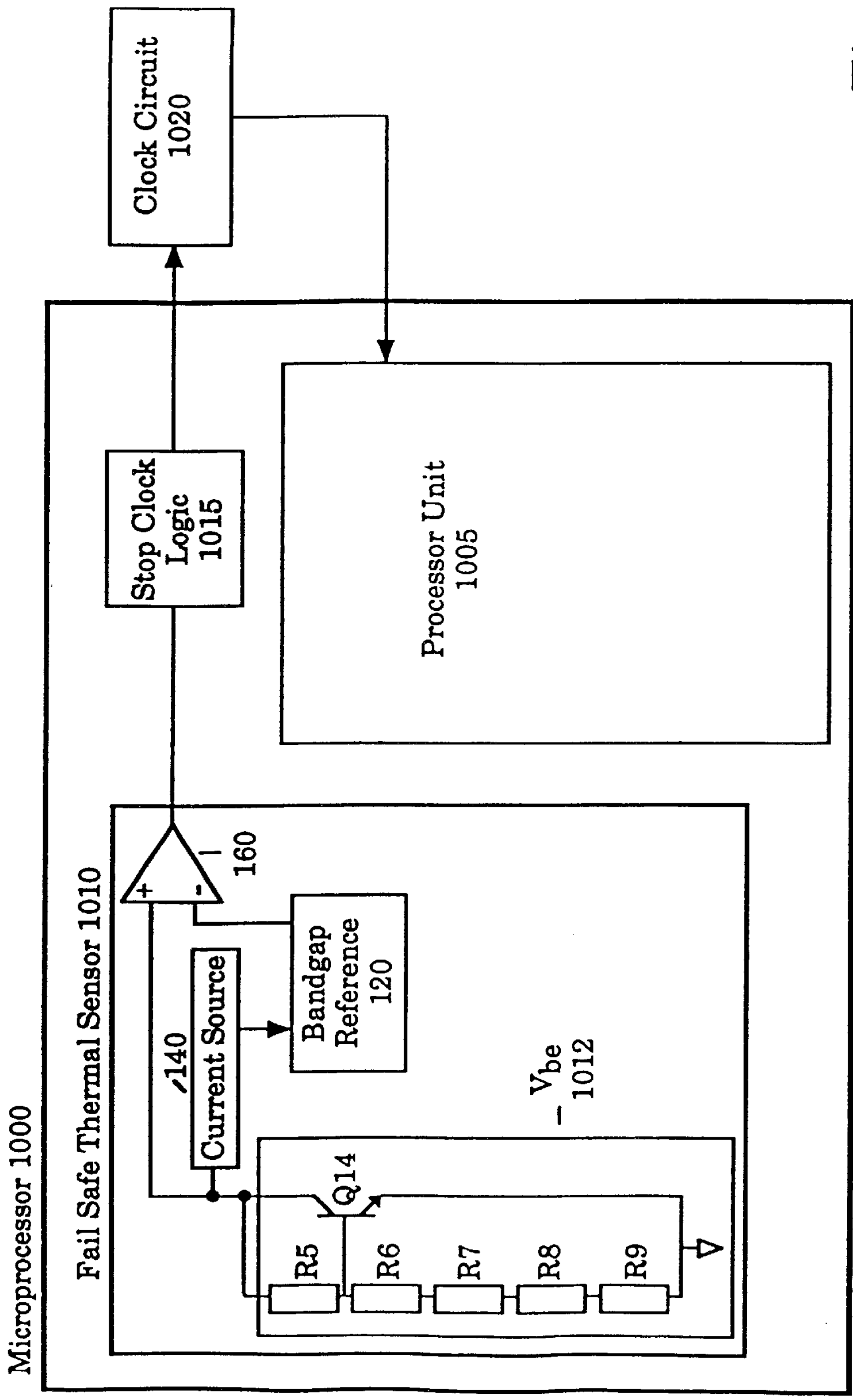

Clock Circuit
1020
Stop Clock
Logic
1015
Processor Unit
1005
Microprocessor 1000
Fail Safe Thermal Sensor 1010
+
-
160
Bandgap
Reference
120
Current Source
140
V_{be}
1012
Q14
R5
R6
R7
R8
R9

Figure 10

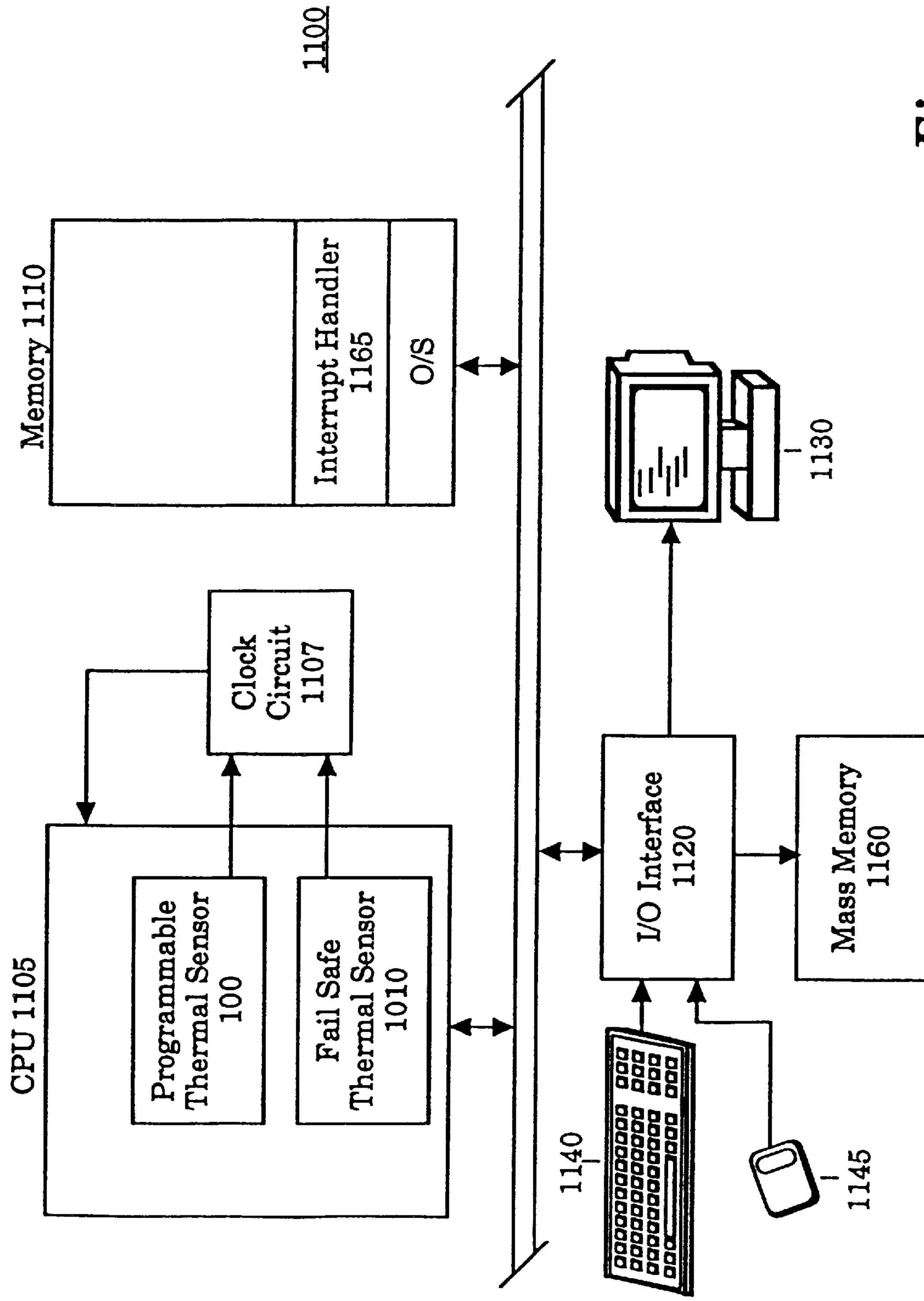

1100
Memory 1110
Interrupt Handler
1165
O/S
Clock
Circuit
1107
CPU 1105
Programmable
Thermal Sensor
100
Fail Safe
Thermal Sensor
1010
1130
I/O Interface
1120
Mass Memory
1160
1140
1145

Figure 11

TEMPERATURE-BASED COOLING DEVICE CONTROLLER APPARATUS AND METHOD

This application is a division of prior application Ser. No. 09/093,988 filed Jun. 8, 1998 which has been abandoned, which is a continuation of prior application Ser. No. 08/660,016, filed Jun. 6, 1996, issued as U.S. Pat. No. 5,838,578 on Nov. 17, 1998, which is a continuation of prior application Ser. No. 08/124,980, filed Sep. 21, 1993 which has been abandoned, all entitled "Method and Apparatus for Programmable Thermal Sensor for an Integrated Circuit" and all assigned to the assignee of the present application.

FIELD OF THE INVENTION

The present invention relates to thermal sensing, and more specifically to methods and apparatus for a programmable thermal sensor in an integrated circuit.

ART BACKGROUND

Advances in silicon process technology has lead to the development of increasingly larger die sizes for integrated circuits. The large dies sizes permit integration of millions of transistors on a single die. As die sizes for integrated circuits become larger, the integrated circuits consume more power. In addition, advances in microprocessor computing require execution of a large number of instructions per second. To execute more instructions per second, the microprocessor circuits operate at an increased clock frequency. Therefore, a microprocessor containing over one million transistors may consume over 30 watts of power. With large amounts of power being dissipated, cooling becomes a problem.

Typically, integrated circuits and printed circuit boards are cooled by either active or passive cooling devices. A passive cooling device, such as a heat sink mounted onto an integrated circuit, has a limited capacity to dissipate heat. An active cooling device, such as a fan, is used to dissipate larger amounts of heat. Although a fan cooling system dissipates heat, there are several disadvantages associated with such a system. Traditionally, fans cool integrated circuits by air convection circulated by a fan. However, when a fan is used in conjunction with a high density multi-chip computer system, a large volume of air is required for cooling thereby necessitating powerful blowers and large ducts. The powerful blowers and large ducts implemented in the computer occupy precious space and are too noisy. The removal of a cover or other casing may result in a disturbance of air flow causing the fan cooling system to fail. In addition, the fan cooling system is made up of mechanical parts that have a mean time between failure (MTBF) specification less than a typical integrated circuit. Furthermore, fan cooling systems introduce noise and vibration into the system.

In addition to cooling systems, thermal sensors are implemented to track the temperature of an integrated circuit or electronic system. Typically, thermal sensors consist of a thermocouple which is directly attached to a heat sink. In more sophisticated thermal sensing systems, a diode and external analog circuitry are used. In operation, the voltage/current characteristics of the diode change depending upon the temperature of the integrated circuit, and the external analog circuitry measures the voltage or current characteristics of the diode. The additional analog circuitry is complex and difficult to implement. In addition, employing the analog circuitry results in a thermal time delay degrading the accuracy of such a configuration. Moreover, external analog circuitry for sensing the voltage of the diode consumes a larger area than the integrated circuit being sensed. Therefore, it is desirable to provide a thermal sensor which is incorporated into the integrated circuit. In addition, it is desirable to provide a thermal sensor that can provide feedback for an active cooling system. Furthermore, it is desirable to control the temperature of an integrated circuit without the use of a fan. The present invention provides an integrated thermal sensor that detects a threshold temperature so that active cooling of the integrated circuit is accomplished through system control.

SUMMARY OF THE INVENTION

A programmable thermal sensor is implemented in an integrated circuit. The programmable thermal sensor monitors the temperature of the integrated circuit, and generates an output to indicate that the temperature of the integrated circuit has attained a predetermined threshold temperature. The programmable thermal sensor contains a voltage reference, a programmable V_{be}, a current source, and a sense amplifier or comparator. The current source generates a constant current to power the voltage reference and the programmable V_{be}. With a constant current source, the voltage reference generates a constant voltage over varying temperatures and power supply voltages. In a preferred embodiment, the voltage reference is generated with a silicon band gap reference circuit. The constant voltage from the voltage reference is one input to the sense amplifier. The programmable V_{be} contains a sensing portion and a multiplier portion. In general, the programmable V_{be} generates a voltage dependent upon the temperature of the integrated circuit and the value of programmable inputs. The programmable inputs are supplied to the multiplier portion to generate a multiplier value for use in the multiplier portion. The voltage reference is compared with the voltage generated by the programmable V_{be} in the sense amplifier. The sense amplifier generates a greater than, less than, signal.

The programmable thermal sensor of the present invention is implemented in a microprocessor. In addition to the programmable thermal sensor, the microprocessor contains a processor unit, an internal register, microprogram and clock circuitry. The processor unit incorporates the functionality of any microprocessor circuit. The clock circuitry generates a system clock for operation of the microprocessor. In general, the microprogram writes programmable input values to the internal register. The programmable input values correspond to threshold temperatures. The programmable thermal sensor reads the programmable input values, and generates an interrupt when the temperature of the microprocessor reaches the threshold temperature. In a first embodiment, the interrupt is input to the microprogram and the processor unit. In response to an interrupt, the processor unit may take steps to cool the temperature of the microprocessor, and the microprogram programs a new threshold temperature. For example, the processor may turn on a fan or reduce the clock frequency. The new threshold temperature is slightly higher than the current threshold temperature so that the processor unit may further monitor the temperature of the microprocessor.

In a second embodiment of the present invention, the interrupt generated by the programmable thermal sensor is input to external sensor logic. The external sensor logic automatically controls the frequency of the microprocessor. If the temperature of the microprocessor raises, then the clock frequency is decreased. Conversely, if the temperature of the microprocessor drops, then the system clock frequency is increased. In addition to a programmable thermal sensor, the microprocessor contains a fail safe thermal sensor. The fail safe thermal sensor generates an interrupt when detecting that the microprocessor reaches predetermined threshold temperatures and subsequently halts operation of the system clock. The predetermined threshold temperature is selected below a temperature that causes physical damage to the device. The microprocessor of the present invention is implemented in a computer system. Upon generation of an interrupt in the programmable thermal sensor, a message containing thermal sensing information is generated and displayed to a user of the computer system.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects, features, and advantages of the present invention will be apparent from the following detailed description of the preferred embodiment of the invention with references to the following drawings.

FIG. **1** illustrates a block diagram of a programmable thermal sensor configured in accordance with the present invention.

FIG. **2** illustrates a graph depicting the relationship between the base-emitter voltage (V_{be}) of a bipolar transistor versus the temperature of the supply voltage.

FIG. **3** illustrates a bandgap reference circuit configured in accordance with the present invention.

FIG. **4** illustrates a programmable base to emitter voltage (V_{be}) circuit configured in accordance with the present invention.

FIG. **5** illustrates a current source, including the bandgap reference circuit, configured in accordance with the present invention.

FIG. **6** illustrates a sense amplifier for the thermal sensor configured in accordance with the present invention.

FIG. **7** illustrates block diagram of a first embodiment of a microprocessor incorporating a programmable thermal sensor configured in accordance with the present invention.

FIG. **8** illustrates a flow diagram for a method of controlling the programmable thermal sensor configured in accordance with the present invention.

FIG. **9** illustrates a block diagram of a second embodiment of a microprocessor incorporating a programmable thermal sensor configured in accordance with the present invention.

FIG. **10** illustrates a block diagram of a microprocessor incorporating a fail safe thermal sensor configured in accordance with the present invention.

FIG. **11** illustrates a computer system incorporating a microprocessor comprising thermal sensing configured in accordance with the present invention.

NOTION AND NOMENCLATURE

The detailed descriptions which follow are presented, in part, in terms of algorithms and symbolic representations of operations within a computer system. These algorithmic descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art.

An algorithm is here, and generally, conceived to be a self-consistent sequence of steps leading to a desired result. These steps are those requiring physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It proves convenient at times, principally for reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like. It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities.

Further, the manipulations performed are often referred to in terms, such as adding or comparing, which are commonly associated with mental operations performed by a human operator. No such capability of a human operator is necessary, or desirable in most cases, in any of the operations described herein which form part of the present invention; the operations are machine operations. Useful machines for performing the operations of the present invention include general purpose digital computers or other similar devices. In all cases there should be borne in mind the distinction between the method operations in operating a computer and the method of computation itself. The present invention relates to method steps for operating a computer in processing electrical or other (e.g., mechanical, chemical) physical signals to generate other desired physical signals.

The present invention also relates to apparatus for performing these operations. This apparatus may be specially constructed for the required purposes or it may comprise a general purpose computer as selectively activated or reconfigured by a computer program stored in the computer. The algorithms presented herein are not inherently related to a particular computer or other apparatus. In particular, various general purpose machines may be used with programs written in accordance with the teachings herein, or it may prove more convenient to construct more specialized apparatus to perform the required method steps. The required structure for a variety of these machines will appear from the description given below. Machines which may perform the functions of the present invention include those manufactured by Intel Corporation, as well as other manufacturers of computer systems.

DETAILED DESCRIPTION

Methods and apparatus for thermal sensing in an integrated circuit are disclosed. In the following description, for purposes of explanation, specific nomenclature is set forth to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that these specific details are not required to practice the present invention. In other instances, well known circuits and devices are shown in block diagram form to avoid obscuring the present invention unnecessarily.

Referring to FIG. **1**, a block diagram of a programmable thermal sensor configured in accordance with the present invention is illustrated. In general, a programmable thermal sensor **100** monitors the temperature of an integrated circuit, and generates an output to indicate that the temperature of the integrated circuit has attained a predetermined threshold temperature. The programmable thermal sensor **100** contains a voltage reference **120**, a programmable V_{be} **110**, a current source **140**, and a sense amplifier **160**. The current source **140** generates a constant current to power the voltage reference **120** and the programmable V_{be} **110**. With a constant current source, the voltage reference **120** generates a constant voltage over varying temperatures and power supply voltages (Vcc). In a preferred embodiment, the voltage reference is generated with a silicon bandgap reference circuit. The constant voltage from the voltage reference **120** is input to the sense amplifier **160**. The programmable

V_{be} **110** contains a sensing portion and a multiplier portion. In general, the programmable V_{be} **110** generates a voltage dependent upon the temperature of the integrated circuit and the value of programmable inputs. The programmable inputs are supplied to the multiplier portion to generate a multiplier value for use in the multiplier portion.

Referring to FIG. **2**, a graph depicting the relationship between the base-emitter voltage (V_{be}) of a bipolar transistor versus temperature is illustrated. A characteristic curve **200** on the graph of FIG. **2** shows the linear characteristics of the V_{be} voltage over a temperature range of 70 degrees Fahrenheit (70° F.) to 140° F. In addition, the graph of FIG. **2** shows a relative constant bandgap voltage curve **205** over the specified temperature range. Although the bandgap voltage varies slightly over the temperature range, the variation of the bandgap voltage is negligible compared to the variation of the V_{be} voltage over the temperature range. As shown by the curve **205** in FIG. **2**, the bandgap voltage is equal to approximately 1.3 volts (V). When the V_{be} voltage equals 1.3 volts, the temperature of the integrated circuit is 100° F. Based on the linear temperature characteristics of the V_{be} voltage, and the relatively constant bandgap voltage over the temperature range, a thermal sensor is constructed.

For the voltage/temperature characteristics of line **200** shown in FIG. **2**, the bandgap voltage equals the V_{be} voltage when the integrated circuit is at 100° F. However, the V_{be} voltage may be changed to sense additional temperature values in the integrated circuit. By shifting the linear V_{be} voltage/temperature characteristic curve **200**, any number of predetermined threshold temperature values are detected. To shift the voltage/temperature characteristic curve **200**, the V_{be} voltage is multiplied by pre-determined values to generate a new voltage for comparison to the bandgap voltage. Specifically, to shift the characteristic curve **200** to sense a voltage less then 100° F., the V_{be} voltage is multiplied by a fraction to generate a new characteristic curve, such as the characteristic curve **210** shown in FIG. **2**. The characteristic curve **210** exhibits the same slope as the original characteristic curve **200**. However, for the characteristic curve **210**, the V_{be} voltage is equal to the bandgap voltage when the integrated circuit temperature equals 90° F. Similarly, the V_{be} voltage may be multiplied by a value greater than 1 to generate a characteristic curve such as the characteristic curve **220** shown in FIG. **2**. The characteristic curve **220** also exhibits the same slope as the original characteristic curve **200**. However, the characteristic curve **220** intersects the bandgap voltage curve **205** at 120° F. Consequently, any number of threshold temperatures are detectable by multiplying the V_{be} voltage by a predetermined constant.

Referring to FIG. **3**, a bandgap reference circuit configured in accordance with the present invention is illustrated. The bandgap reference circuit **120** is powered from a voltage source, Vcc. The voltage source Vcc is regulated by a current source such that the current source **140** supplies a constant current over a wide range of Vcc voltages. A preferred embodiment of the present invention for the current source **140** is described fully below. The bandgap reference circuit **120** contains three N-P-N bipolar transistors Q**1**, Q**2** and Q**3**, and three resistive elements R**1**, R**2** and R**3**. In general, the constant bandgap reference voltage, $V_{bandgap}$ is generated at the collector of N-P-N transistor Q**3**. The bipolar transistors Q**1**, Q**2** and resistive elements R**1**, R**2** and R**3** are provided to compensate for temperature variations in the base to emitter junction voltage (V_{be}) of bipolar transistor Q**3**. Specifically, the resistive element R**1** is coupled from the current source **140** to the collector of bipolar transistor Q**1**. The collector and base of bipolar transistor Q**1** are shorted so that Q**1** is effectively a P-N junction diode. The base of transistor Q**1** and the base of transistor Q**2** are coupled together. The resistive element R**3** couples the collector of transistor Q**2** to the current source **140**, and the resistive element R**2** couples the emitter of transistor Q**2** to ground. In a preferred embodiment of the present invention, the resistive element R**1** equals 4800 ohms, the resistive element R**2** equals 560 ohms, and the resistive element R**3** equals 4800 ohms.

In operation, the voltage at the base of transistors Q**1** and Q**2** are pulled to the $V_{bandgap}$ voltage through the R**1** resistance. Therefore, the transistors Q**1** and Q**2** are biased in the active region, thereby allowing current to flow from the collector to the emitter of transistors Q**1** and Q**2**. The mirrored configuration of transistors Q**1** and Q**2** tends to drive the base to emitter voltage (V_{be}) of transistors Q**1** and Q**2** equivalent. However, the resistive element R**2** increases the resistance at the emitter of transistor Q**2**, resulting in a greater current density flowing through transistor Q**1** than flowing through transistor Q**2**. As the temperature in the integrated circuit rises, the V_{be} of transistor Q**2** decreases. In turn, the decrease of V_{be} on transistor Q**2** causes a decrease in the current density flow through Q**2**. The decrease in current density through the resistive element R**2** also causes a reduction in the current density flowing through the resistive element R**3**. Because the collector of transistor Q**2** is coupled to the base of transistor Q**3**, a decrease in the current through resistive element R**3** results in an increase in the voltage at the base of transistor Q**3**. Consequently, as the temperature of the integrated circuit rises, the V_{be} across transistors Q**1**, Q**2**, and Q**3** decreases. However, the decrease of V_{be} on transistor Q**3** is compensated by the increase of voltage at the base of transistor Q**3**. Therefore, regardless of temperature fluctuations, the $V_{bandgap}$ remains at a constant silicon bandgap voltage. For a further explanation of generation of a bandgap reference, including a theoretical derivation, see A. T. Brokaw, A Simple Three-Terminal IC Bandgap Reference, IEEE J. of Solid State Circuits, December, 1974 and Karel E. Kuijk, A Precision Reference Voltage Source, IEEE J. of Solid State Circuits, June 1973.

Referring to FIG. **4**, a programmable base to emitter voltage (V_{be}) circuit configured in accordance with the present invention is illustrated. In a preferred embodiment of the present invention, a temperature varying voltage is generated from the characteristics of a base to emitter junction on a bipolar transistor. In general, the programmable V_{be} circuit generates an output voltage, V_{out}, based on the V_{be} voltage and the value of programmable input voltages V_{p1}, V_{p2} and V_{p3}. A N-P-N bipolar transistor Q**11** shown in FIG. **4** is utilized to generate the V_{be} reference voltage. As described above, the V_{be}/temperature characteristic curve may be shifted along the temperature axis to detect a desired threshold temperature. By shifting the V_{be}/temperature characteristic curve along the temperature axis, a plurality of output voltages representing different threshold temperatures are generated.

To generate the V_{out} for a particular threshold temperature, a programmable V_{be}, multiplier circuit is utilized. The programmable V_{be} multiplier circuit contains resistive elements R**5**, R**6**, R**7**, R**8**, and R**9**, and metal oxide semiconductor field effect transistors (MOSFET) Q**12**, Q**13**, and Q**14**. In a preferred embodiment, Q**12**, Q**13** and Q**14** comprise N-MOS transistors. The drain terminal of transistor Q**12** is coupled to a first input on resistive element R**7**, and the source of transistor Q**12** is coupled to a second input on resistive element R**7**. The transistors Q**13** and Q**14** are similarly coupled to resistive elements R**8** and R**9**, respectively. Programmable input voltages V_{p1} V_{p2} and V_{p3} are input to the gate of transistors **Q12**, **Q13** and **Q14**, respectively. The input voltages V_{p1} V_{p2} and V_{p3} control the current flow by selecting either a resistive element or the respective MOS transistor.

In operation, the programmable V_{be} multiplier circuit outputs a voltage, V_{out}, comprising a multiple of the base to emitter voltage on bipolar transistor **Q11**. For purposes of explanation, consider resistive elements **R6**, **R7**, **R8** and **R9** as one resistive element: **R6–R9**. The resistive element **R6–R9** is connected across the base to emitter junction of bipolar transistor **Q11**. Therefore, the voltage drop across the resistive element **R6–R9** is equivalent to V_{be} of bipolar transistor **Q11**. The current flowing through resistive element **R6–R9** is approximately equal to the current flowing through resistive element **R5** minus the current flowing into the base of transistor **Q11**. Therefore, if the value of resistive element **R5** is equal to the value of resistive element **R6–R9**, the voltage at the collector of transistor **Q11** equals $2V_{be}$. In general, the V_{out} voltage is defined by the following equation:

$$V_{out}=V_{R5}+V_{be}V_{be}=V_{R6\text{-}R9}V_{out}=V_{R5}+V_{R6\text{-}R9}$$

Therefore, V_{out} values greater than 1 V_{be} are generated by changing the ratio between resistive element **R5** and resistive element **R6–R9**.

To move the V_{be} curve **200** shown in FIG. **2** along the temperature axis via the programmable V_{be} circuit **110**, a combination of resistive elements **R7**, **R8** and **R9** are selected. To select a combination of resistive elements **R7**, **R8** and **R9**, the voltages Vp**1** Vp**2** and Vp**3** are applied to the gates of MOS transistors **Q13**, **Q12**, and **Q14**, respectively. The resistive elements **R7**, **R8** and **R9** are binary weighed resistors. Each individual resistor **R7**, **R8** and **R9** can be shorted through control by **Q12**, **Q13** and **Q14** respectively. By selecting resistive elements **R7**, **R8** and **R9** as series resistors with resistive element **R6**, the voltage V_{out} is changed. In a preferred embodiment of the present invention, the resistive element **R5** equals 6380 the resistive element **R6** equals 5880 the resistive element **R7** equals 392 the resistive element **R8** equals 787 and the resistive element **R9** equals 1568. By setting the resistive elements **R5–R9** to the above and programming the transistors **Q13**, **Q12**, and **Q14**, the voltage V_{out} is generated respond to specific threshold temperatures. Specifically, Table 1 illustrates the old temperatures programmed in response to the input voltages Vp**1**, Vp**2**, and Vp**3**.

TABLE I

Vp1	Vp2	Vp3	Threshold Temperature (Degrees C.)
0	0	0	70°
0	0	1	80°
0	1	0	90°
0	1	1	100°
1	0	0	110°
1	0	1	120°
1	1	0	130°
1	1	1	140°

Referring to FIG. **5**, a current source including the bandgap reference circuit configured in accordance with the present invention is illustrated. The bandgap reference circuit comprises resistors **R1**, **R2**, and **R3** and bipolar transistors **Q1**, **Q2**, **Q3** and **Q8**. The operation of the bandgap reference circuit **120** is described above. However, the bandgap reference circuit of FIG. **5** also incorporates a gain stage with bipolar transistor **Q8**. In order to incorporate a gain stage, the collector of bipolar transistor **Q3** is coupled to the base of bipolar transistor **Q8**. The constant bandgap reference voltage generated at the collector of bipolar transistor **Q3** controls the base of bipolar transistor **Q8** resulting in a signal at the emitter of bipolar transistor **Q8** containing a silicon bandgap voltage with increased current density. In addition to the bandgap reference circuit, FIG. **5** illustrates a constant current source **140** including a start-up circuit portion. The constant current source **140** comprises a bipolar transistor **Q4**, P-MOS transistors **Q5**, **Q7** and **Q15**, and resistor **R4**. The constant current source **140** stabilizes operation of the thermal sensor of the present invention over a range of Vcc ranges.

In general, the constant current source **140** is derived from the generation of the constant bandgap reference voltage. In operation, the constant bandgap reference voltage, $V_{bandgap}$ is coupled to the base of bipolar transistor **Q4**. The constant bandgap reference voltage drives the bipolar transistor **Q4** to generate a constant current flowing from the collector to the emitter of transistor **Q4** and through the resistor **R4**. The P-MOS transistor **Q5** is mirrored with P-MOS transistors **Q7** and **Q15**. The constant current flowing through resistor **R4** also flows through P-MOS transistor **Q5** and is mirrored through P-MOS transistors **Q7** and **Q15**. In a preferred embodiment, resistive element **R4** equals 6020. The P-MOS transistor **Q15** provides a constant current source for the programmable V_{be} circuit **110**. Similarly, P-MOS transistor **Q7** provides a constant current source to the bandgap reference circuit **120** through bipolar transistors **Q3** and **Q8**.

The current source and bandgap reference voltage circuit illustrated in FIG. **5** also comprises a start-up circuit. The start-up circuit within the current source is required because the bandgap reference voltage controls the current source which, in turn, controls the bandgap reference voltage. Therefore, an equilibrium between the bandgap reference voltage and the current source circuit is required to ensure the proper operation of the thermal sensor. The start-up circuit contains P-MOS transistors **Q6**, **Q9** and **Q10**. The P-MOS transistor **Q9** is configured such that the gate is coupled directly to the drain. In this configuration, the P-MOS transistor **Q9** operates as a load resistor. In general, the start-up circuit generates a voltage for the bandgap reference voltage circuit during initial power-up of the thermal sensor. Specifically, during an initial power-up of the thermal sensor circuit, transistors **Q5**, **Q7**, **Q10**, and **Q15** are biased such that no current flows through the respective devices. Also, during the initial power-up state, the P-MOS transistor **Q9** is biased to conduct current thereby supplying a low voltage level to the gate of P-MOS transistor **Q6**. A low voltage level at the gate of P-MOS transistor **Q6** biases the P-MOS transistor **Q6** such that current flows from the Vcc to bipolar transistors **Q3** and **Q8**. The P-MOS transistor **Q6** biases the base of bipolar transistor **Q8** allowing generation of the bandgap reference voltage.

An increase in the bandgap reference voltage driving the base of bipolar transistor **Q4** causes current to flow from the emitter of **Q4** through resistor **R4**. As the current density increases through transistors **Q5** and **Q10**, the voltage at the gate of transistor **Q6** also increases. The build up of charge at the gate of transistor **Q6** is facilitated by a large resistance generated by the load transistor **Q9**. As the voltage at the gate of P-MOS transistor **Q6** raises to the pinch-off threshold voltage of the device, the P-MOS transistor **Q6** conducts no current such that current is no longer supplied to bipolar transistors **Q3** and **Q8**. Because of the gain provided at the emitter of bipolar transistor **Q8**, current continues to increase in the bandgap reference voltage circuit until the collector of bipolar transistor Q3 begins to control the base of bipolar transistor Q8. At this point, the circuit has reached an equilibrium such that the constant bandgap reference voltage generated supplies a constant voltage to the current source. Also shown in FIG. 5 is a disable P-MOS transistor Q21. The P-MOS transistor Q21 powers down, or disables, the thermal sensor circuit for testing. The P-MOS transistor Q21 is utilized only for disabling, and it is not required to generate the constant current source or the bandgap reference voltage. The P-MOS transistor Q15 isolates the collector of bipolar transistor Q11 on the programmable V_{be} circuit from the Vcc on the current source circuit.

Referring to FIG. 6, a sense amplifier for the thermal sensor configured in accordance with the present invention is illustrated. In a preferred embodiment of the present invention, a sense amplifier **160** contains three stages. The first stage and the second stage are identical. The third stage comprises a current buffer **600**. The current buffer **600** is illustrated in FIG. **6** as a standard logic inverter. In general, the sense amplifier **160** operates as a comparator circuit. In operation, if the $V_{bandgap}$ is greater than the V_{out} voltage, then the output of sense amplifier **160** is a low logic level. Alternatively, if the V_{out} is greater than the $V_{bandgap}$ voltage, then the output of sense amplifier **160** is a high logic level. The second stage of sense amplifier **160** generates a voltage gain of signals on lines **S1** and **S1#**. The first stage contains PMOS transistors Q16, Q17 and Q18, and NMOS transistors Q19 and Q20. The transistors Q19 and Q20 are constructed as a current mirror.

The voltage V_{out} is input to the gate of PMOS transistor Q16, and the voltage V_{gap} is input to the gate of PMOS transistor Q17. In operation, if the voltage V_{out} is greater than the $V_{bandgap}$ then PMOS transistor Q17 is biased to conduct more current than PMOS transistor Q16. Because a greater current density flows through PMOS transistor Q17 than PMOS transistor Q16, the voltage at line **S1** rises and the voltage at line **S1 #** decreases. The source and gate of NMOS transistor Q19 are connected, and the source/gate connection is controlled by the voltage at **S1#**. Consequently, when the voltage at line **S1#** decreases, NMOS transistor Q19 is biased to reduce the current density flow. The voltage on line **S1#** is input to the gate of PMOS transistor Q18. As the voltage on line **S1#** decreases, the PMOS transistor Q18 is biased to conduct a greater current density. The increase in current density through transistor Q18 further amplifies the voltage difference between lines **S1** and **S1#**. When the V_{be} voltage is less than the V_{gap} voltage, the first stage of the sense amplifier **160** operates in an analogous manner.

The second stage of sense amplifier **160** comprises PMOS transistors Q22, Q23 and Q24, and NMOS transistors Q25 and Q26. The operation of the second stage of the sense amplifier **160** is analogous to the operation of the first stage. In addition, hysteresis is provided for the sense amplifier **160** via a feedback path from the output of sense amplifier **160** to the programmable V_{be} circuit V_{out} input of sense amplifier **160**. The hysteresis provides a more stable output signal from the sense amplifier **160** such that voltage variations on the inputs of the sense amplifier **160** after generation of a high output voltage level does not cause glitches in the output signal.

For the programmable thermal sensor of the present invention to operate well over process variations, the resistors are constructed to have a width larger than the minimum specification for the resistive value. All bipolar transistors in the programmable thermal sensor contain at least double width emitters. For the MOS transistors, long channel lengths are constructed. The long channel lengths of the MOS transistors help stabilize the programmable thermal sensor as well as provide noise immunity. For the bandgap reference circuit **120**, the bipolar transistor Q2 is constructed to be ten times greater in size than the bipolar transistor Q1. The large size differential between bipolar transistors Q1 and Q2 provides a stable bandgap voltage reference.

Referring to FIG. **7**, a first embodiment of a microprocessor incorporating a programmable thermal sensor configured in accordance with the present invention is illustrated. A microprocessor **700** contains, in part, the programmable thermal sensor **100** and a processor unit **705**. The processor unit **705** is intended to present a broad category of microprocessor circuits comprising a wide range of microprocessor functions. In general, the programmable thermal sensor **100** is programmed to detect a threshold temperature within the microprocessor **100**. If the microprocessor **700** attains the pre-programmed threshold temperature, the programmable thermal sensor **100** generates an interrupt. As described above, the programmable thermal sensor **100** detects the pre-programmed threshold temperature based on the temperature of the integrated circuit at the programmable thermal sensor **100**. The temperature across a microprocessor die can vary as much as 8° F. In a preferred embodiment of the present invention, the programmable thermal sensor **100** is located in the middle of the die of microprocessor **700** so as to provide the best thermal sensing. However, placement of the programmable thermal sensor in the middle of the die increases noise in the microprocessor. In an alternative embodiment, several thermal sensors are placed across the microprocessor die. In this configuration, each thermal sensor provides an interrupt when attaining the threshold temperature, and an average temperature is calculated based on the several thermal sensors.

In addition to the programmable thermal sensor **100** and processor unit **705**, a microprocessor **700** contains an internal register **735**, a read only memory (ROM) **730**, and a phase lock loop (PLL) circuit **720**. External to the microprocessor **700** is an external clock **710**. The external clock **710** provides a clock signal to the PLL circuit **720**. The PLL circuit **720** permits fine tuning and variable frequency adjustment of the input clock signal. Specifically, the PLL circuit **720** receives a value, and increases or decreases the frequency based on the value received. The PLL circuit **720** is intended to represent a broad category of frequency adjustment circuits, which are well known in the art and will not be described further. The output of the PLL circuit **720** is the microprocessor system clock, and is input to the processor unit **705**.

The programmable thermal sensor **100** is coupled to the ROM **730** and internal register **735**. The ROM **730** contains a microprogram consisting of a plurality of microcode instructions. The operation of the microprogram within the microprocessor **700** is described more fully below. In general, the microprogram **740** writes values representing the threshold temperature in the internal register **735**. The internal register **735** stores the threshold temperature values and is coupled to the programmable V_{be} circuit **110**. For example, in a preferred embodiment of the present invention, the Vp**1**, Vp**2** and Vp**3** voltage values stored in the internal register **735** are used to program the programmable V_{be} circuit **110** in the manner as described above. However, the present invention is not limited to three input voltage values in that any number of values may be stored in the internal register **735** to program any number of threshold temperatures. When the microprocessor **700** attains the threshold temperature, the programmable threshold sensor generates a comparator signal via sense amplifier **160** as described above. The comparison signal is labeled as "interrupt" on FIG. **7**. The interrupt is input to the ROM **730** and the processor unit **705**.

In response to the interrupt, the microprogram **740** generates new values representing a new threshold temperature. The microprogram writes the new values to the internal register **735**. For example, if the programmable thermal sensor generates an interrupt based on a threshold temperature of 100° F., then the microprogram may write values to the internal register **735** to represent a threshold temperature of 110° F. In the first embodiment, the processor unit **705** receives the interrupt signal as a standard hardware interrupt input. In response to the interrupt, the processor unit **705** generates a clock control value for the PLL circuit **720**. The clock signal value reduces the microprocessor system clock frequency.

If the interrupt is again generated in response to the microprocessor **700** attaining the new threshold temperature value, the microprogram **740** writes a new temperature threshold value to the internal register **735**, and the processor unit **705** further reduces the microprocessor system clock frequency. In addition, the processor unit **705** may set a standard timer circuit such that if a pre-determined amount of time elapses, then the processor unit **705** increases the clock frequency. Increasing the clock frequency permits the processor unit **705** to increase performance when the temperature of the microprocessor has decreased. In addition, to detect further decreases in the microprocessor temperature, the microprogram **740** may lower the threshold temperature and the processor unit may further increase the clock frequency. Therefore, the programmable thermal sensor of the present invention is utilized to control the temperature by increasing and decreasing the microprocessor clock frequency.

Referring to FIG. **8**, a flow diagram for a method of controlling the programmable thermal sensor configured in accordance with the present invention is illustrated. The method illustrated in the flow chart of FIG. **8** may be a microprogram such as microprogram **740** stored in ROM **730**. Upon initialization of the microprocessor, a first threshold temperature is programmed into the programmable thermal sensor as shown in step **800**. Although the present invention is described in conjunction with a microprocessor integrated circuit, one skilled in the art will appreciate that the thermal sensor of the present invention may be incorporated into any integrated circuit. The temperature of the integrated circuit is sensed as shown in step **810**. The sensing of the integrated circuit may be performed by the programmable thermal sensor **110** of the present invention. The integrated circuit sensor determines whether the temperature of the integrated circuit equals the first threshold temperature. If the integrated circuit temperature is equal to or greater than the threshold temperature, then the threshold temperature is compared to a critical temperature as shown in step **830**.

The critical temperature is defined as the maximum temperature that the integrated circuit may attain before the integrated circuit is physically damaged. If the threshold temperature is equal to the critical temperature, then the integrated circuit is shut down as shown in step **860**. Alternatively, if the threshold temperature is less than the critical temperature, then steps are taken to reduce the temperature in the integrated circuit as shown in step **840**. For example, in a microprocessor integrated circuit, the microprocessor system clock frequency is reduced. In addition to reducing the system clock frequency, a message to a system user reporting the temperature of the integrated circuit is generated. By informing the user with the temperature information, the user may take steps external to the integrated circuit to facilitate cooling. Next, a new threshold temperature is programmed in the thermal sensor as shown in step **850**. The process continues wherein the thermal sensor senses the integrated circuit temperature to detect if the integrated circuit temperature reaches the new threshold temperature, and based on the threshold temperature set, either shuts down the power to the integrated circuit or executes steps to reduce the temperature.

Referring to FIG. **9**, a block diagram of a programmable thermal sensor system configured in accordance with a second embodiment of the present invention is illustrated. A microprocessor **900** comprises, in part, a programmable thermal sensor **110** and a processor unit **905**. The programmable thermal sensor **110** is configured as described above. The programmable thermal sensor **110** is connected to a ROM **910** and an internal register **920**. The programmable thermal sensor **110** is also coupled to external sensor logic **940**. The external sensor logic **940** is coupled to a counter **950** and an active cooling device **955**. An external clock **945** is input to a counter **950**, and the output of the counter **950** is input to a clock circuit **930**. The clock circuit **930** buffers the input clock frequency to generate the microprocessor clock for the processor unit **905**. In operation, a microprogram **915**, stored in ROM **910**, sets the internal register **920** to an initial threshold temperature value. If the temperature of the microprocessor **900** rises to the threshold temperature, an interrupt signal is generated to the external sensor logic **940**.

Upon receipt of the interrupt to the external sensor logic **940**, the external sensor logic **940** programs a value to the counter **950**, and activates the active cooling device **955**. The active cooling device **955** may comprise a fan or other heat dissipating device. To activate the active cooling device **955**, the external sensor logic **940** generates a signal to turn on the active cooling device **955** by any number of well known methods. The counter **950** is configured as a frequency divider such that a clock frequency, from the external clock **945**, is input. The counter **950** generates a new clock frequency based on the counter value. The programming of a counter, such as counter **950**, for use as a frequency divider is well known in the art and will not be described further. As one skilled in the art will recognize, the amount in which the clock frequency may be reduced is a function of the counter selected. The slower clock frequency is input to the clock circuit **930**. The clock circuit **930** may perform a variety of functions such as buffering, clock distribution, and phase tuning. The system clock comprises a reduced frequency to facilitate the cooling of the device. In addition to triggering the external sensor logic **940**, the programmable thermal sensor also interrupts the microprogram **915**. Upon receiving the interrupt, the microprogram **915** programs the internal register **920** to sense a new threshold temperature. If the microprocessor **900** heats up to the new threshold temperature, the external sensor logic **940** is again triggered, and the system clock frequency is further reduced. The configuration illustrated in FIG. **9** provides closed loop control of the microprocessor system clock frequency, thereby automatically reducing the temperature when overheating occurs.

Referring to FIG. **10**, a block diagram of a fail safe thermal sensor configured in accordance with the present invention is illustrated. A fail safe thermal sensor **1010** is incorporated into a microprocessor **1000**. Although the fail safe thermal sensor **1010** is incorporated into the microprocessor **1000**, one skilled in the art will appreciate the fail safe thermal sensor may be incorporated into any integrated circuit. The fail safe thermal sensor **1010** contains a V_{be} circuit **1012**, a bandgap voltage reference circuit **120**, a current source **140**, and a sense amplifier **160**. The bandgap voltage reference circuit **120**, the current source **140** and the sense amplifier **160** operate in accordance with the respective circuits described above. The V_{be} reference circuit **1012** is equivalent to the programmable V_{be} circuit **110**, except that the resistive value ratio is fixed. In the V_{be} circuit **1012**, the output V_{be} voltage is fixed based on resistive values **R5**, **R6**, **R7**, **R8** and **R9**. In a preferred embodiment of the present invention, the resistive values **R5**, **R6**, **R7**, **R8** and **R9** are fixed to the critical temperature. Consequently, the fail safe thermal circuit **1010** generates an interrupt when the temperature of the microprocessor **1000** attains the pre-programmed fixed critical temperature.

The output of the fail safe thermal sensor **1010** is connected to stop clock logic **1015**. The stop clock logic **1015** is coupled to the microprocessor clock circuit **1020**. Upon receipt of the interrupt of the fail safe thermal sensor **1010**, the stop clock logic **1015** halts operation of the microprocessor **1000** by inhibiting the microprocessor clock. In addition, the stop clock logic **1015** ensures that the microprocessor **1000** finishes a system cycle completely. The stop clock logic **1015** therefore protects loss of data when an interrupt is generated during a microprocessor clock cycle. A microprocessor clock circuit **1012** may comprise a simple clock oscillator or a more complex and controllable clock generator. The fail safe thermal sensor **1010** prohibits the microprocessor **1000** from attaining a critical temperature, thereby protecting the device without software control.

Referring to FIG. **11**, a computer system incorporating a microprocessor comprising thermal sensing configured in accordance with the present invention is illustrated. A computer system **1100** contains a central processing unit (CPU) **1105** incorporating the programmable thermal sensor **100** and the fail safe thermal sensor **1010**. In a preferred embodiment, the CPU comprises a compatible Intel microprocessor architecture, manufactured by Intel Corporation, the assignee of the present invention. The computer system **1100** also contains memory **1110** and an I/O interface **1120**. The I/O interface **1120** is coupled to an output display **1130** and input devices **1140** and **1145**. In addition, I/O interface **1120** is coupled to a mass memory device **1160**. The CPU **1105**, memory **1110**, I/O interface **1120**, output device **1130**, and input devices **1140** and **1145** are those components typically found in a computer system, and, in fact, the computer system **1100** is intended to represent a broad category of data processing devices. The memory **1110** stores software for operation of the computer system **1100**. Specifically, memory **1110** stores, in part, an operating system and an interrupt handler routine for operation in conjunction with the thermal sensor.

Upon generation of an interrupt in the programmable thermal sensor **100** or the fail safe thermal sensor **1010**, the interrupt handler routine **1165** is executed. The calling of an interrupt handler routine upon generation of a hardware interrupt in a microprocessor is well-known in the art and will not be described further. In general, the interrupt handler routine **1165** generates a message to the output display **1130**. The message informs the user of the computer system **1100** that the microprocessor **1105** has attained the threshold temperature. In response, a user may alter external environmental conditions to facilitate cooling of the CPU

1105. As described above, the CPU **1105** sets a new threshold temperature for the programmable thermal sensor. If the CPU **1105** temperature rises to the new threshold temperature, another interrupt is generated. Again, the interrupt handler routine **1165** is called to generate a message to the user on output display **1130**. If the temperature reaches a critical temperature for which the fail safe thermal sensor is programmed, then the fail safe thermal sensor generates an interrupt to shut down the CPU **1105**.

Although the present invention has been described in terms of a preferred embodiment, it will be appreciated that various modifications and alterations might be made by those skilled in the art without departing from the spirit and scope of the invention. The invention should therefore be measured in terms of the claims which follow.

What is claimed is:

1. An integrated circuit comprising:

a register to store a threshold temperature value;

a thermal sensor comprising:

a current source;

a voltage reference coupled to the current source to provide a bandgap reference voltage, wherein the bandgap reference voltage is substantially constant over a range of temperatures;

programmable circuitry providing an output voltage that varies with the integrated circuit temperature and in accordance with the register value; and

a comparator, wherein the comparator generates an interrupt signal if a difference between the output voltage and the bandgap reference voltage indicates that the threshold temperature has been exceeded; and

cooling activation logic to activate an active cooling device in response to the interrupt signal.

2. The integrated circuit of claim **1** further comprising:

threshold adjustment logic to increase the threshold temperature value to a new threshold temperature value in response to the interrupt signal.

3. The integrated circuit of claim **2** wherein the threshold adjustment logic is further to increase the new threshold temperature in response to the thermal sensor indicating that the new threshold temperature has been exceeded.

4. The integrated circuit of claim **3** wherein the threshold adjustment logic is further to lower the new threshold temperature to detect decreases in temperature.

5. The integrated circuit of claim **1** wherein the cooling system logic is to activate the active cooling device after a predetermined duration.

6. The integrated circuit of claim **1** wherein the cooling system logic is to deactivate the active cooling device in response to the thermal sensor indicating that the sensed temperature is less than the threshold temperature.

7. The integrated circuit of claim **1** wherein the thermal sensor comprises a plurality of thermal sensors placed across the integrated circuit and an averaging mechanism to calculate an average temperature from the plurality of thermal sensors.

8. The integrated circuit of claim **1** further comprising an interrupt handler to display information regarding the sensed temperature to a user of the integrated circuit.

9. The integrated circuit of claim **1** further comprising interrupt logic to generate a first interrupt if the calculated average temperature exceeds a first threshold and a second interrupt if the calculated average temperature exceeds a second threshold.

10. The integrated circuit of claim **1** wherein the cooling system logic executes instructions to activate the active cooling device of the integrated circuit in response to the thermal sensor.

11. The integrated circuit of claim **1** wherein the cooling system logic executes instructions to provide closed loop control of the integrated circuit active cooling device, thereby automatically reducing the temperature when overheating occurs.

12. The integrated circuit of claim **1** further comprising interrupt logic to activate an active cooling device in response to the thermal sensor.

13. A method comprising:

storing a threshold temperature value in a register;

sensing the temperature of an integrated circuit;

providing an output voltage that varies with the measured integrated circuit temperature and in accordance with the stored register value;

measuring a bandgap reference voltage using a current source, the bandgap reference voltage being substantially constant over a range of temperatures;

comparing the output voltage to the bandgap reference voltage to generate a first interrupt signal if a difference between the output voltage and the bandgap reference voltage indicates that the threshold temperature has been exceeded; and

activating an active cooling device for the integrated circuit in response to the sensed temperature exceeding the threshold temperature value.

14. The method of claim **13** further comprising:

increasing the threshold temperature value to a new threshold temperature value in response to the sensed temperature exceeding the threshold temperature value.

15. The method of claim **14** further comprising increasing the new threshold temperature in response to the sensed temperature exceeding the threshold temperature value.

16. The method of claim **13** further comprising lowering the new threshold temperature to detect decreases in temperature.

17. The method of claim **13** further comprising activating the active cooling device after a predetermined duration.

18. The method of claim **13** further comprising deactivating the active cooling device in response to the sensed temperature being less than the threshold temperature.

19. The method of claim **13** further comprising displaying information regarding the sensed temperature to a user of the integrated circuit.

20. The method of claim **13** further comprising executing instructions to activate the active cooling device of the integrated circuit in response to the sensed temperature.

21. The method of claim **13** further comprising executing instructions to provide closed loop control of the active cooling device, thereby automatically reducing the temperature when overheating occurs.

22. A computer system comprising:

an active cooling device;

a microprocessor comprising:

a register storing a register value corresponding to a threshold temperature; and

a programmable thermal sensor comprising:

a current source;

a voltage reference coupled to the current source to provide a bandgap reference voltage, the bandgap reference voltage being substantially constant over a range of temperatures;

programmable circuitry providing an output voltage that varies with the microprocessor temperature and in accordance with the register value; and

a comparator, wherein the comparator generates a first interrupt signal to activate a cooling device if a difference between the output voltage and the bandgap reference voltage indicates that the threshold temperature has been exceeded.

23. The computer system of claim **22** wherein the active cooling device comprises a fan.

24. The computer system of claim **22** further comprising clock circuitry for providing a clock signal for the microprocessor, wherein a frequency of the clock signal is reduced in response to the first interrupt signal.

25. The computer system of claim **24** wherein the clock circuitry further comprises:

a first clock;

a frequency divider coupled to the first clock to provide the clock signal, the frequency divider reducing a frequency of the clock signal in response to the interrupt signal; and

a second clock circuit coupled to provide the clock signal to the microprocessor.

26. The computer system of claim **25** wherein the clock circuitry further comprises a phase locked loop.

27. The computer system of claim **22** wherein the programmable circuitry further comprises:

a transistor coupled to the current source to provide the output voltage, a gain ratio of the output voltage to a junction voltage of the transistor controlled by a transistor bias, wherein the junction voltage varies in accordance with a junction temperature of the transistor, the junction temperature corresponding to the microprocessor temperature;

a bias circuit providing the transistor bias to control the gain ratio, wherein the output voltage varies with the microprocessor temperature in accordance with the register value.

28. The computer system of claim **27** wherein the bias circuit further comprises binary weighted resistors.

29. The computer system of claim **25** wherein the microprocessor further comprises:

a processor unit coupled to the second clock circuit, wherein the processor unit executes instructions to vary the activation of the active cooling device in response to the first interrupt signal.

30. The computer system of claim **22** wherein the microprocessor programs the register with another value corresponding to another threshold temperature in response to the first interrupt signal.

31. The computer system of claim **22** wherein the processor executes instructions to provide closed loop control of the active cooling device, thereby automatically reducing the temperature when overheating occurs.

32. A method of controlling a temperature of a microprocessor, comprising the steps of:

generating a temperature signal within the microprocessor corresponding to the temperature of the microprocessor by sensing the microprocessor temperature and providing an output voltage that varies with the sensed temperature and in accordance with a programmable value set in a register;

generating a first threshold temperature level using a bandgap reference voltage that is substantially constant over a range of temperatures;

comparing the temperature signal with the first threshold temperature level within the microprocessor;

generating an interrupt signal if the temperature signal indicates that the first threshold temperature level has been exceeded; and

activating an active cooling device to decrease the microprocessor temperature in response to the interrupt signal.

33. The method of claim **32** wherein the active cooling device is a fan.

34. The method of claim **32** further comprising the steps of:

comparing the temperature signal with a second threshold temperature level, wherein the second threshold temperature level represents a fail-safe temperature;

halting the microprocessor, if the temperature signal indicates that the second threshold temperature level has been exceeded.

35. The method of claim **32** further comprising providing closed loop control of the active cooling device, thereby automatically reducing the temperature when overheating occurs.

36. The method of claim **32** further comprising programming the microprocessor with a second threshold temperature in response to the interrupt signal.

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