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(54) **METHOD AND APPARATUS FOR THERMAL SENSITIVITY BASED DYNAMIC POWER CONTROL**

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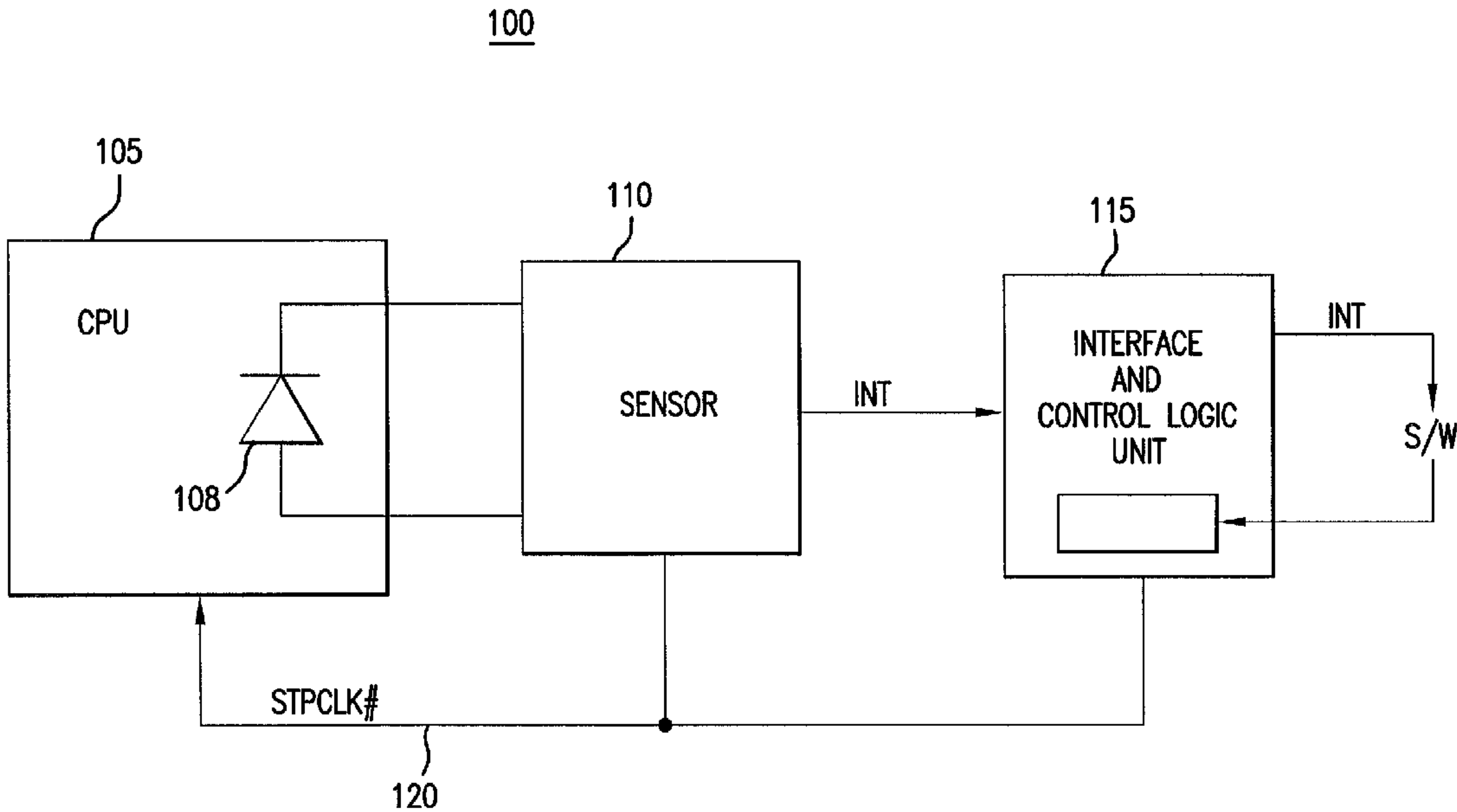
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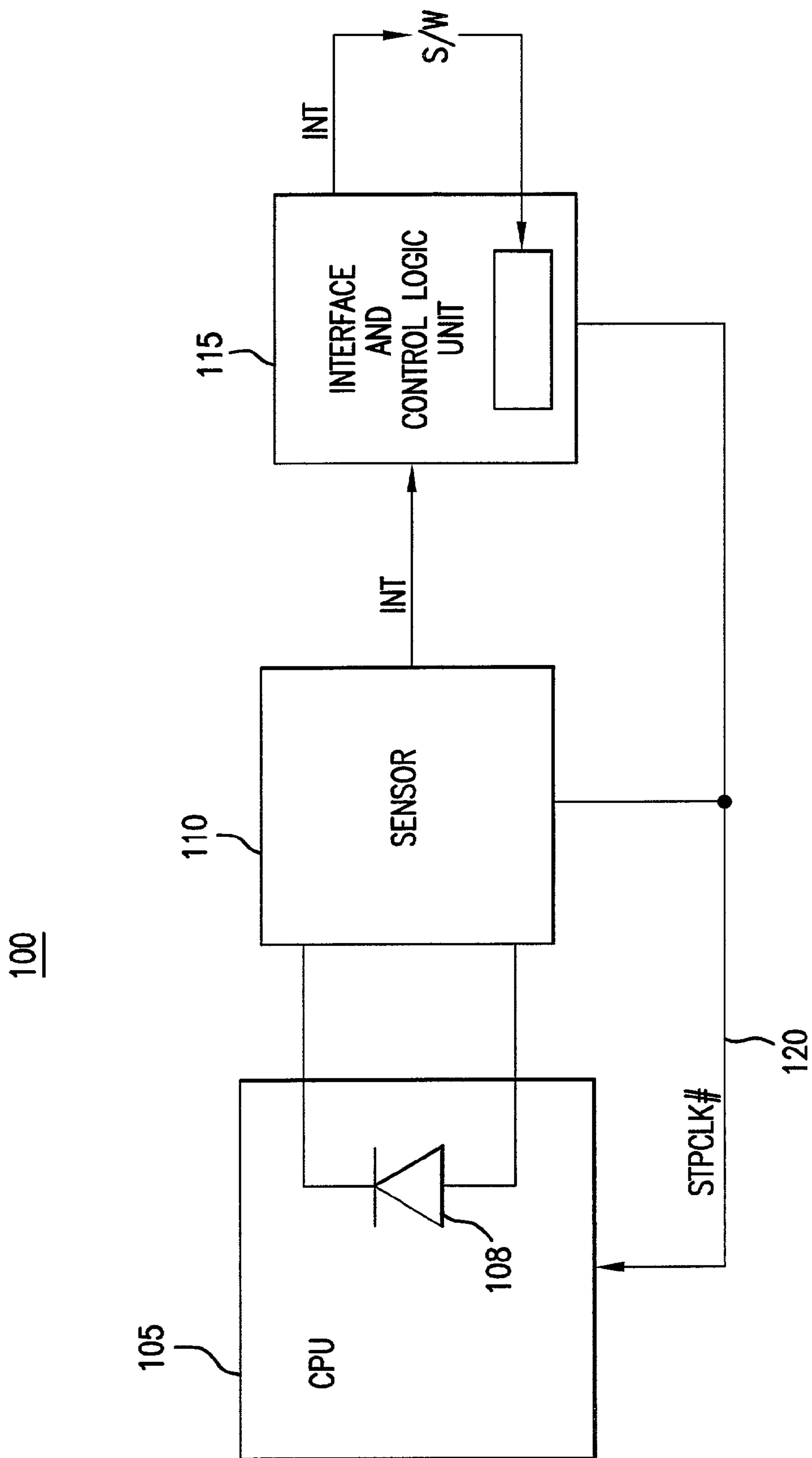
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(57) **ABSTRACT**

A method and system provides dynamic power control based on thermal sensitivity of a processor system. The method and system includes a circuit that reduces the clock frequency for the processor system in response to thermal characteristics satisfying a pre-determined threshold that allows maximal thermal temperature limit utilization without substantially degrading processor performance.





**FIG. 1**

200

240

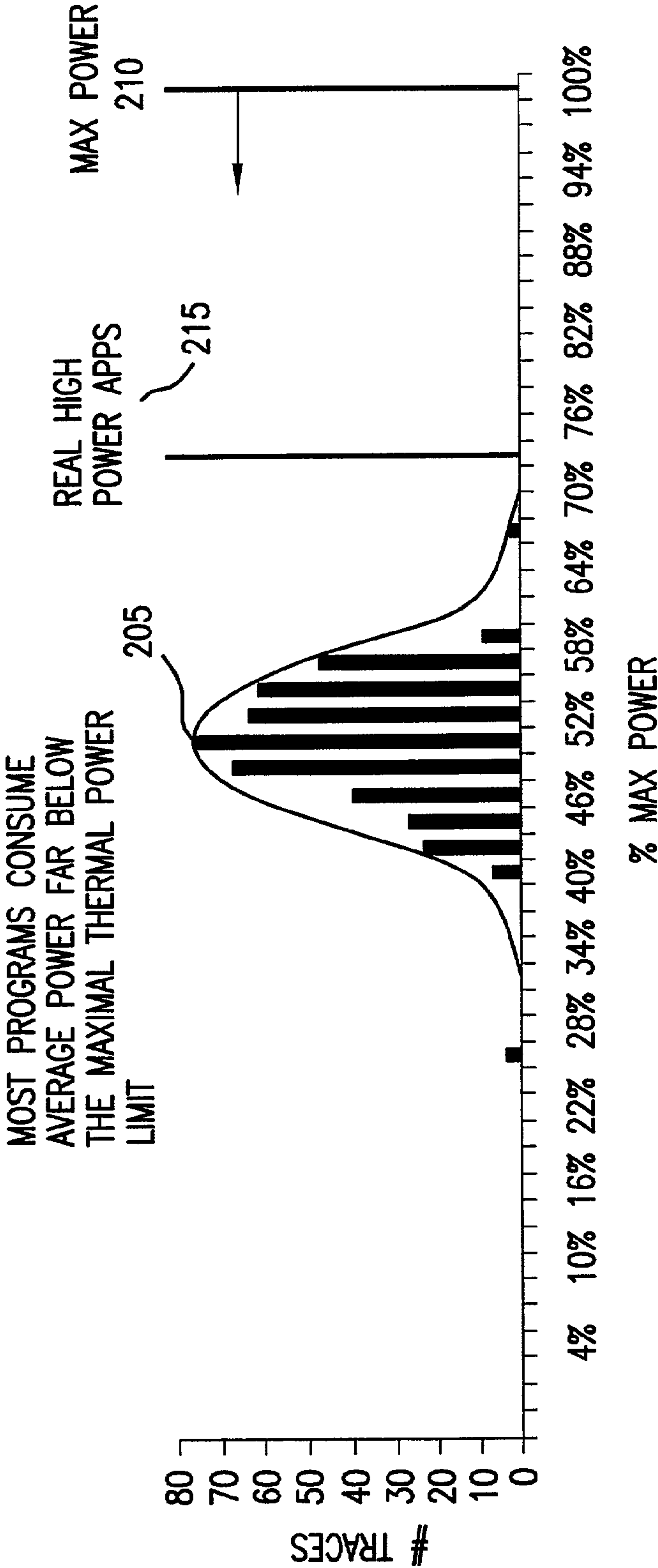


FIG.2

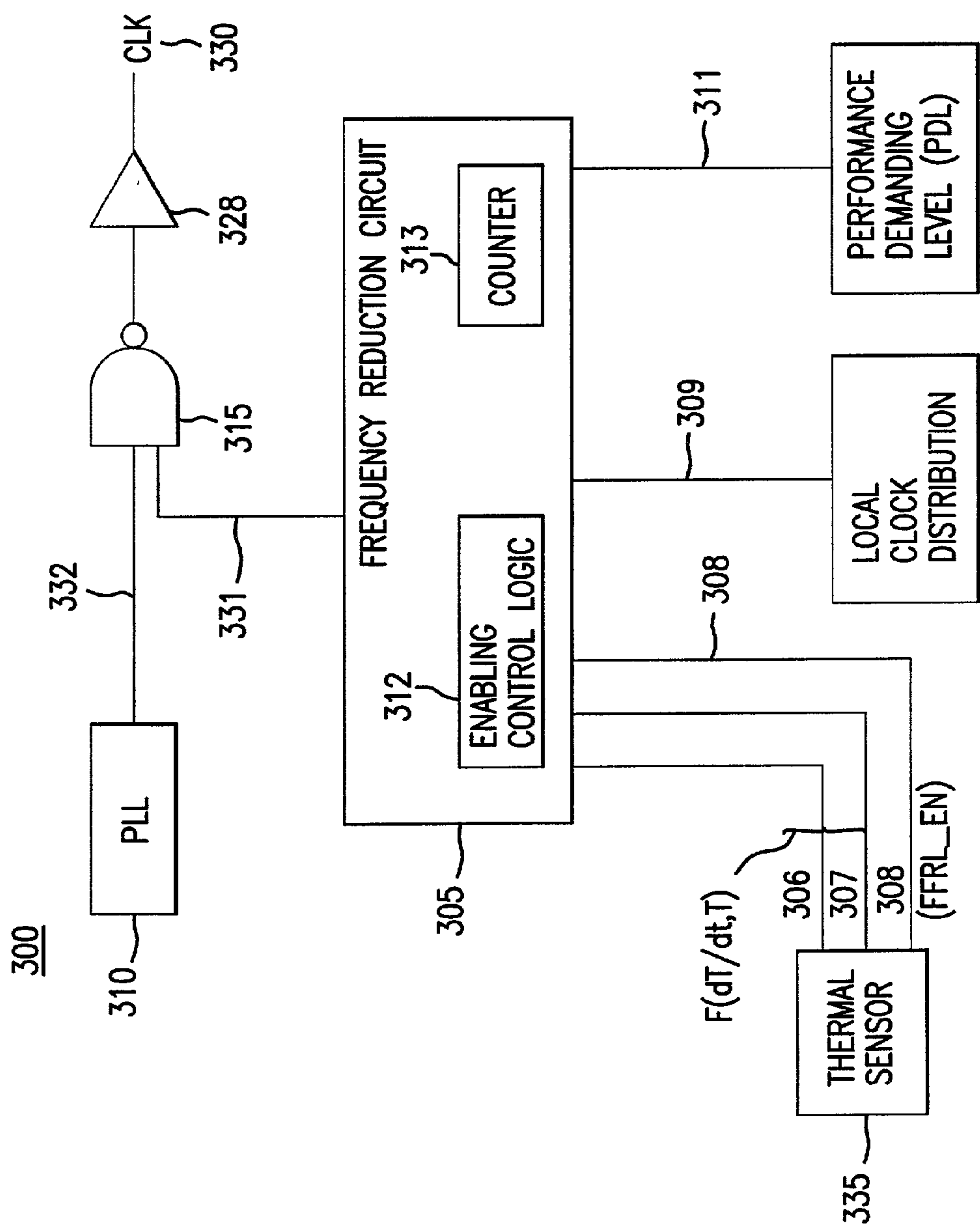


FIG.3

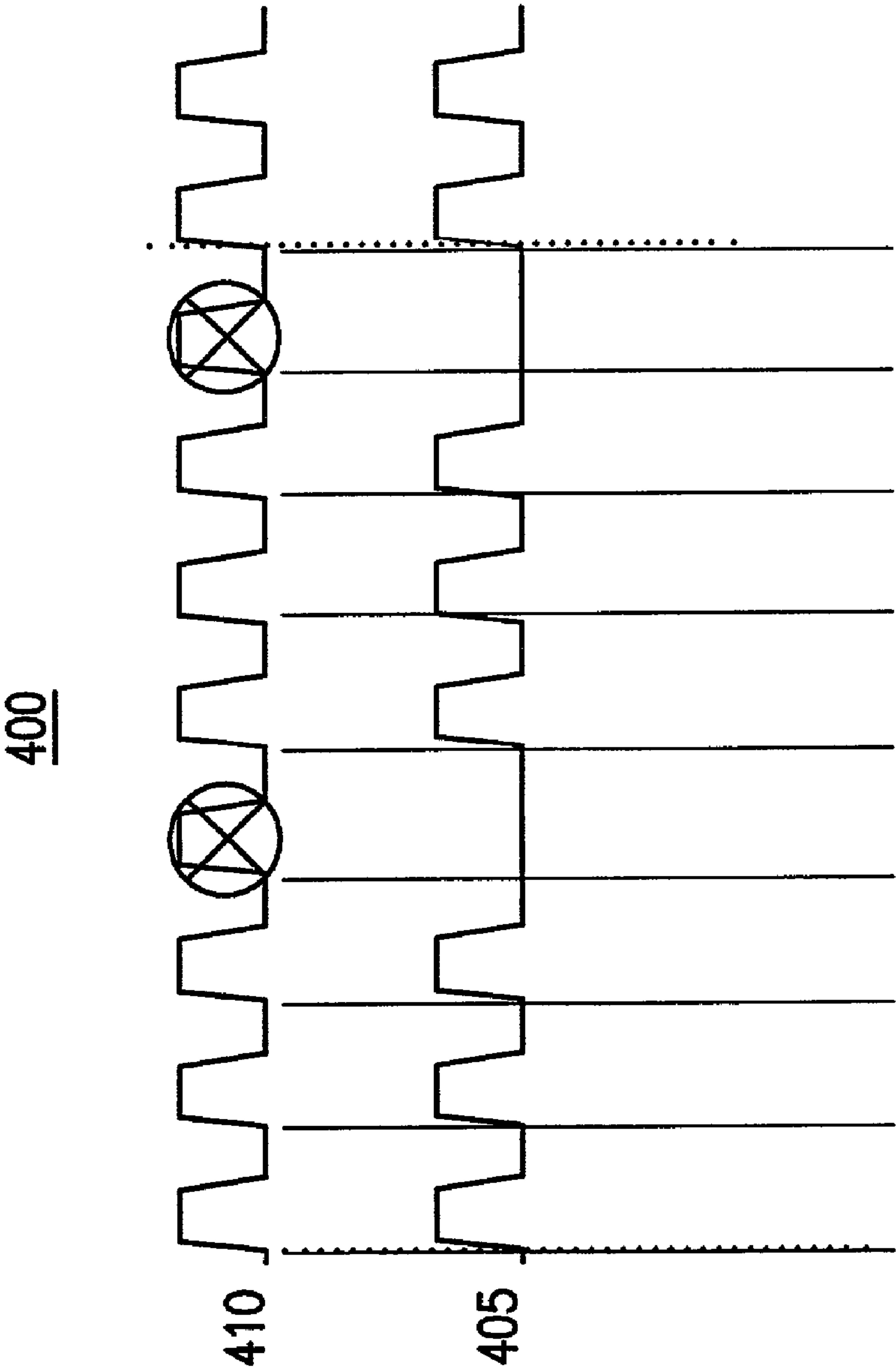


FIG. 4

500

FFRL_EN	dT/dt	THERMAL TEMPERATURE	CURRENT LOGIC STATE	PREV. LOGIC STATE
0 (NOT NEAR MAXIMAL THERMAL LIMIT)	NOT CARE	NOT CARE	POWER DOWN	POWER DOWN
0 (NOT NEAR MAXIMAL THERMAL LIMIT)	NOT CARE	NOT CARE	POWER DOWN	WAIT
0 (NOT NEAR MAXIMAL THERMAL LIMIT)	NOT CARE	NOT CARE	POWER DOWN	ACTIVE
1 (NEAR MAXIMAL THERMAL LIMIT)	<0.2 (SLOW RATE)	<MAX. TEMPERATURE- $\delta t$	POWER DOWN	POWER DOWN
1 (NEAR MAXIMAL THERMAL LIMIT)	>0.2 (SLOW RATE)	<MAX. TEMPERATURE- $\delta t$	WAIT	POWER DOWN
1 (NEAR MAXIMAL THERMAL LIMIT)	<0.2 (SLOW RATE)	<MAX. TEMPERATURE- $\delta t$	POWER DOWN	WAIT
1 (NEAR MAXIMAL THERMAL LIMIT)	>0.2 (SLOW RATE)	<MAX. TEMPERATURE- $\delta t$	WAIT	WAIT
1 (NEAR MAXIMAL THERMAL LIMIT)	NOT CARE	>MAX. TEMPERATURE- $\delta t$	ACTIVE	POWER DOWN
1 (NEAR MAXIMAL THERMAL LIMIT)	NOT CARE	>MAX. TEMPERATURE- $\delta t$	ACTIVE	WAIT
1 (NEAR MAXIMAL THERMAL LIMIT)	NOT CARE	>MAX. TEMPERATURE- $\delta t$	ACTIVE	ACTIVE

FIG.5

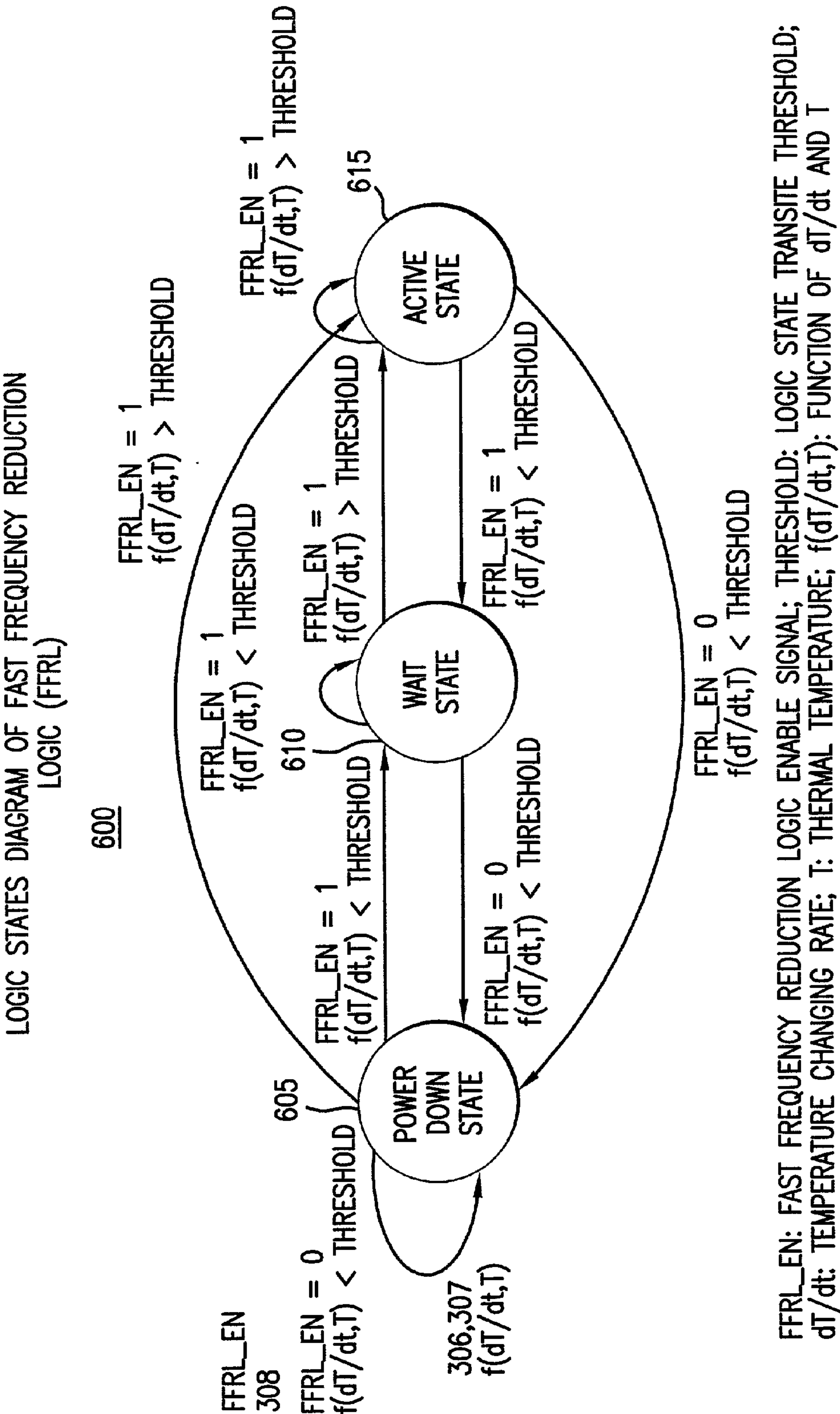


FIG.6



## METHOD AND APPARATUS FOR THERMAL SENSITIVITY BASED DYNAMIC POWER CONTROL

### BACKGROUND OF THE INVENTION

#### [0001] 1. Field of the Invention

[0002] The present invention relates generally to a processor system. It particularly relates to a method and system for processor dynamic power control based on thermal sensitivity.

#### [0003] 2. Background

[0004] Power consumption in current high-performance processor systems often leads to high temperatures for the processor components. The high processor temperatures, especially for processors using surface-mounted technology, leads to power feedback due to failures (e.g., shorts) produced in the processor circuits. Commonly, processor systems operate with two high temperature limits, an electrical maximum power limit, and a maximal thermal design point (maximal TDP). The lower limit, the maximal TDP, is a temperature threshold where if processor thermal (relating to heat) temperature exceeds this threshold, then the processor may continue to function but could encounter problems if operating above this temperature for any substantial amount of time. The upper limit, the electrical maximum power limit, is a temperature limit where the processor will malfunction if attempting to operate above this limit. Therefore, processor systems must reduce power consumption in response to nearing these high temperature limits to avoid malfunction. A traditional method was to completely shut down the processor (stop-clock method) allowing the processor temperatures to cool below the high temperature limits before the processor is re-started. However, completely shutting down the processor and having to wait for re-start severely degrades processor system performance.

[0005] Current processor systems use a common method (measured temperature compared to threshold) for reducing power consumption (thermal throttling) in response to thermal temperature limits being neared or exceeded. FIG. 1 shows an exemplary architecture 100 for a current processor thermal throttling method that is an extension of the traditional stopclock function. The thermal throttling architecture 100 includes CPU (central processing unit) 105, intercoupled to thermal sensor 110, and intercoupled to interface and control logic unit 115. Using this architecture 100, there are two ways to stop the CPU 105 clock in response to high temperatures. A first way is to provide interface and control logic unit 115 with a software/firmware program that is called when sensor 110 detects thermal temperatures above a pre-determined threshold (e.g., maximal thermal temperature limit) on CPU 105 using an internal diode 108 and internal logic. The software/firmware routine, when called, triggers the thermal throttling mechanism by sending a stop-clock signal 120 from interface and control logic unit 115 that stops the processor clock and the internal architecture states of the microprocessor will remain in predefined states until either the thermal temperature decreases below the pre-determined threshold or the maximal thermal throttling time interval is reached. Alternatively, the stop-clock signal 120 may be generated internally by the sensor 110 to be sent directly from the sensor 110 to internal clock control logic of CPU 105 to stop the CPU clock. This drastic

measure (completely shutting down the processor clock in response to the software routine), however, generates a significant performance penalty and high processing overhead. Therefore, there is a need for an efficient power reduction method that does not generate a substantial performance penalty for the processor system

### BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 shows an exemplary prior art power reduction architecture

[0007] FIG. 2 shows an exemplary graph of average power consumption in accordance with embodiments of the present invention

[0008] FIG. 3 shows an exemplary processor system architecture for reducing power consumption in accordance with embodiments of the present invention

[0009] FIG. 4 shows a timing signal diagram in accordance with embodiments of the present invention

[0010] FIG. 5 shows a state machine chart in accordance with embodiments of the present invention

[0011] FIG. 6 shows a state machine diagram in accordance with embodiments of the present invention

### DETAILED DESCRIPTION

[0012] FIG. 2 shows an exemplary graph 200 of power consumption for processor systems in accordance with embodiments of the present invention. As shown in FIG. 2, the average power consumption 205 for processing of most programs is 52% of the maximum power limit (e.g., electrical maximum power limit) 210. Typically, the maximal thermal design point (TDP) power limit is 75%-80% of the maximum power limit 210. Therefore, high power consumption mostly results from high-power spikes (can be random or uniform) of significant power consumption, an example being the real high power application spike 215 shown at 72% of the maximum power limit 210.

[0013] A non-uniform (random) distribution of these spikes or a close distribution of these high-power spikes within a short period of time may cause the maximal thermal temperature limit (e.g., electrical maximum power limit) for a processor to be exceeded and therefore trigger thermal throttling (reduction of power consumption). However, as shown in FIG. 2, this period of high-power consumption does not occur frequently as most processor programs consume power at an average of 52% (205) of the maximum power limit 210. Therefore, only a short power-down period is necessary for the processor to return to average levels of power consumption well within the maximum power limit 210. In references to FIG. 2, assuming thermal throttling is triggered by the real high power spikes, there is a small design range 240 between the average power consumption (52%) and the real high power applications (72%) allowing processor operation within range 240 without triggering thermal throttling if higher levels of power consumption are not reached past level 215.

[0014] In accordance with embodiments of the present invention, FIG. 3 shows an exemplary processor system architecture 300 for reducing power consumption by rapidly reducing the clock frequency for the processor system during these periods of high-power spikes and then resum-



ing regular (non-reduced) clock frequency after the high (danger) temperature period has completed. The inter-coupled processor architecture **300** includes processor component (die) thermal sensor **335**, intercoupled to frequency reduction circuit **305**, phase-locked loop (PLL) circuit **310** intercoupled to frequency reduction circuit **305**, logic circuit **315** intercoupled to PLL circuit **310** and frequency reduction circuit **305**, and may optionally include inverter **328** intercoupled to logic circuit **315** for outputting a stable timing signal (the clock frequency signal—clk) **330** for the processor system **300**. Frequency reduction circuit **305** may include a counter **313** (e.g., four-bit circular counter) and enabling control logic **312**.

[0015] During operation, frequency reduction circuit **305** advantageously receives five input signals **306**, **307**, **308**, **309**, and **311**. The input signals include two-bit thermal temperature change speed ( $dT/dt$ ) information (e.g.,  $F(dT/dt, T)$ ) **306**, **307** and frequency reduction enabling control signal (FFRL EN) **308** where both signals are received from processor component (die) thermal sensor **335**. The other input signals include local clock distribution signal **309**, and performance demanding level (PDL) signal **311**.

[0016] The frequency reduction enabling control signal **308** is input by the die sensor **335** and may be asserted (by the die sensor **335**) when the processor component (die) temperature has satisfied a pre-determined temperature threshold. This pre-determined temperature threshold may be a threshold close to a maximum thermal temperature limit (e.g., proportionate to electrical maximum power limit).

[0017] Advantageously,  $F(dT/dt, T)$  is a function of the rate of temperature change and thermal temperature of the processor components as measured and calculated by the thermal sensor **335** and fed (e.g., as two bits) to the frequency reduction circuit as input signals **306**, **307**. Two bits may be used for input signals **306**, **307** where one bit may indicate a pre-determined temperature threshold being satisfied or not satisfied (e.g., “0” for not satisfied, and “1” for satisfied), and the other bit indicates a rate of temperature change being satisfied or not satisfied. Alternatively, the two bits may form a two-bit code requiring decoding by the control logic **312** of the frequency reduction circuit **305**. Assuming the first two-bit method is followed,  $F(dT/dt, T)$  input signals **306**, **307** will be asserted when a pre-determined rate of temperature change/temperature threshold is satisfied. As described further with reference to FIGS. 5-6, input signals **306-308** provide three different control states for the frequency reduction circuit **305**. Temporary frequency reduction will be triggered by all the input signals **306-308** being asserted (e.g., from the pre-determined temperature and rate of temperature change/temperature thresholds being satisfied as caused by a high-power spike) and continue until the high-power spike period passes and the thresholds are no longer satisfied (e.g., not reached or exceeded).

[0018] Advantageously, in a Power Down state, the frequency reduction circuit **305** is disabled and a normal operation (non-reduced) clock frequency signal is output from logic circuit **315** and inverter **328**. Alternatively, when the input signal **308** is asserted (e.g., value of “1”), depending on the die temperature change rate as measured by the die sensor **335**, the frequency reduction circuit may be either in a Wait state or an Active state. In the Wait state, the

frequency reduction circuit **305** is in a logic ready state for frequency scaling. From this state, the frequency reduction circuit **305** can rapidly proceed to actual frequency reduction. In the Active state, the frequency reduction circuit **305** actively reduces the clock frequency output signal **330** and maintains the scaled-down frequency during execution (during the period) of this frequency reduction.

[0019] Advantageously, local clock distribution signal **309**, may be a stable local clock signal (showing low jitter) and may be generated from the PLL **310** in combination with anti-skew logic circuitry. Alternatively, local clock distribution signal **309** may be received directly from the PLL **310**. Input clock signal **309** may be used by the frequency reduction circuit **305** for determining the timing alignment of frequency reduction (e.g., level of granularity of frequency reduction) in relation to the PLL output signal **332**.

[0020] The performance demanding level signal (PDL) **311** is an input signal used by the frequency reduction circuit **305** to determine the level of sensitivity (or aggression) used for frequency reduction. If PDL signal **311** is asserted (e.g., value of “1”), then frequency reduction cannot be aggressive and instead fine granularity must be used (e.g.,  $1/15$  reduction from normal clock frequency) for reducing the normal clock frequency. Alternatively, if PDL signal **311** is not asserted (e.g., value of “0”), then frequency reduction can be aggressive and higher percentages of frequency reduction (e.g., close to 50% reduction from normal clock frequency) may be used for reducing the normal clock frequency. Advantageously, the PDL signal **311** can be used as a form of hardware performance profiling for system components interconnected to processor architecture **300**. In an exemplary scenario, during a period of frequency reduction in response to high temperatures, if a hardware component running an application (e.g., hard drive) does not require as close to possible full processor speed (e.g., 1 Gigahertz—GHz), then aggressive frequency reduction may be performed (e.g., close to 50% reduction, 550 MHz) and the PDL signal **311** is not asserted. Alternatively, if the hardware component does require as close to possible full processor speed for running its application during the high temperature period, then fine granularity of frequency reduction (e.g., 5% reduction, 950 MHz) must be performed and the PDL signal **311** is asserted.

[0021] During operation, in accordance with embodiments of the present invention, PLL **310** outputs a normal clock frequency signal **332** (e.g., 1 GHz) for the processor system **300** that is input to logic circuit **315**. In response to input signals **306**, **307**, **308**, **309**, **311** and using counter **313** and enabling control logic **312**, frequency reduction circuit **305** outputs an enabling signal **331** that is asserted (e.g., value of “0”) when frequency reduction is to be performed. Counter **313** may be used for timing alignment (granularity) of the frequency in relation to the thermal response time (e.g., delay in receiving temperature and rate of temperature change information from die sensor **335**) or some other pre-determined time interval, and enabling control logic **312** may be used to output a “0” for asserting frequency reduction. Using an exemplary NAND gate as logic circuit **315**, when enabling signal **331** is asserted (value of “0”), then the output clock signal **330**, via logic circuit **315** and inverter **328**, for the processor system **300** will be low for the period of frequency reduction. This forced low period for the output clock signal **330** effectively removes switching transitions



from the clock signal to reduce the clock frequency signal **330** by a pre-determined percentage of the normal (non-reduced) clock frequency **332**. Alternatively, when enabling signal **331** is not asserted (e.g., value of “1”), then the normal clock frequency will be output as clock signal **330** from the logic circuit **315** and inverter **328** since an input of “1” from enabling signal **331** instructs the logic circuit **315** (assuming a NAND gate) and inverter **328** to generate the normal clock frequency output signal **332** from PLL **310**.

[0022] An exemplary timing diagram **400** of the clock frequency signals **405**, **410** generated by the processor architecture **300** of FIG. 3 is shown in FIG. 4. The frequency reduction circuit **305** includes enabling control logic **312** to produce rapid frequency reduction, in response to processor component temperatures nearing a pre-determined maximum temperature limit, to “glide” the processor system **300** out of the thermal throttle risk region. During operation, when the rapid frequency reduction is not enabled (thresholds not satisfied), the control logic **312** of frequency reduction circuit **305** outputs a high (“1”) enabling signal **331** to produce the normal (non-reduced) operation clock frequency signal using logic circuit **315** and inverter **328**, an example being clock frequency signal **410** (e.g. 1 GHz). When the temperature and rate of temperature change thresholds are satisfied (e.g., reached or exceeded) as indicated by input signals **306-308**, then the control logic **312** of frequency reduction circuit **405** outputs a low (“0”) enabling signal **331** to rapidly switch from the normal clock frequency to a reduced frequency (using logic circuit **315** and inverter **328**), advantageously less than 50% reduced from the normal clock frequency, without a long sequence of resynchronization cycle penalty where an example is clock frequency signal **405**. As shown, reduced clock frequency signal **405** is produced by removing a pre-determined number of switching transitions (e.g., 2 transitions from every 10 cycles) from the clock frequency cycles during a given time interval which reduces the number of clock cycles in average. This method of reduction produces a fast reduction in clock frequency while still generating a high clock frequency signal not substantially reduced from the normal clock frequency. A fine granularity of frequency reduction may be produced (e.g.,  $\frac{1}{10}$ ,  $\frac{1}{16}$ ) by the frequency reduction circuit **305** where the removal of 1 switching transition from every 10 clock cycles produces a  $\frac{1}{10}$  reduction (e.g., 10%) from the normal (non-reduced) clock frequency. Advantageously, using a four-bit counter for counter **313**, various multiples of two reduction may be provided by frequency reduction circuit **305** (e.g.,  $\frac{1}{16}$ ,  $\frac{1}{8}$ , etc.).

[0023] Advantageously, in accordance with embodiments of the present invention, frequency reduction from the normal clock frequency is solely performed by reducing the number of switching transitions per number of cycles on average. Preferably, other parameters from the normal (non-reduced) clock frequency signal remain the same including, but not limited to duty cycle, rising time, and falling time, and other parameters of the normal clock frequency signal.

[0024] FIGS. 5 and 6 show the state machine chart **500** and diagram **600** followed by the control logic **312** of the frequency reduction circuit **305** in architecture **300** in FIG. 3. Advantageously, the state machine may be implemented in silicon as part of frequency reduction circuit **305**. Advantageously, during operation of the state machine, measurements (taken from die thermal sensor **335** in the processor

architecture **300**) of the thermal temperature of the processor components and rate of temperature change are being taken with input signals **306-308** (FFRL\_EN, F(dT/dt, T)) sent to the frequency reduction circuit **305**. These input signals are asserted or not asserted by the die sensor **335** in response to these measurements satisfying pre-determined thresholds for temperature (e.g., maximum temperature limit corresponding to electrical maximum power limit) and rate of temperature change/temperature.

[0025] As shown in FIG. 6, the state machine followed by control logic **312** in frequency reduction circuit **305** may proceed in either of three paths from the power down state **605** of the frequency reduction circuit **305** in FIG. 3. Firstly, if neither threshold is satisfied, the frequency reduction control logic **312** will remain in the power down state (output a “1” for enabling signal **331**) as none of the enabling signals **306**, **307**, **308** from FIG. 3 are asserted (e.g., value of “0”). The PLL **310** will continue to output the full (e.g., normal, non-reduced) clock frequency **410** from FIG. 4. Secondly, when both the die (processor components) temperature is close to a pre-determined maximum temperature limit and the rate of temperature change threshold is satisfied (as measured by thermal sensor **335**), both the frequency reduction enabling signal **308** and both the function enabling input signals **306**, **307** are asserted (e.g., value of “1”) by the thermal sensor **335** and the frequency reduction control logic **312** (state machine) may proceed to the active state **615**. When entering the active state **615**, frequency reduction occurs and the clock frequency signal output **330** is rapidly reduced by removing switching transitions as described previously using the frequency reduction circuit **305**, logic circuit **315**, and inverter **328**. Thirdly, from the power down state **605**, if the thermal temperature threshold is neared but the rate of temperature change is not satisfied, the control logic **312** may enter the wait state **610** as enabling signal **308** is asserted by the die thermal sensor **335**. The normal (non-reduced) clock frequency will be produced as output clock signal **330**.

[0026] At the wait state **610**, control logic **312** again may proceed in either of three ways. Firstly, if the rate of temperature change threshold is still not satisfied, but the enabling signal **308** is still asserted (thermal temperature threshold still satisfied), then the control logic will continue in the wait state **610** and the normal clock frequency will continue to be produced as output clock signal **330**. Secondly, if the enabling signal **308** is no longer asserted and the rate of temperature change threshold is still not satisfied, then control logic will go back to the power down state **605** and the normal clock frequency will continue to be produced as output clock signal **330**. Thirdly, if the function input signals **306**, **307** become asserted (rate of temperature change threshold is satisfied) and the enabling signal **308** is still asserted, then control logic **312** enters the active state **615** where clock frequency reduction rapidly occurs by removing switching transitions as described previously using the frequency reduction circuit **305**, logic circuit **315**, and inverter **328**. The reduced clock frequency signal is produced as output clock signal **330**.

[0027] The wait state **610** is necessary because the thermal response time (time delay in receiving a temperature reading from the die thermal sensor **335**) may be substantial (e.g., long period), especially for a GHz speed processor system. Therefore, it is necessary for the frequency reduction circuit



**305** to be enabled (at logic ready) in wait state **610** (not powered down as in power down state **605**) and ready to proceed to the active state **615** for rapid reduction of frequency in response to the rate of temperature threshold being satisfied as indicated by input signals **306**, **307**. Advantageously, in accordance with embodiments of the present invention, the control logic **312** of frequency reduction circuit **305**, from wait state **610**, provides rapid switching from the normal clock frequency **410** (as shown in FIG. 4) to the reduced clock frequency **405** (as shown in FIG. 4) to quickly reduce power consumption and avoid system malfunction from the processor system operating above maximal thermal limits.

[0028] At the active state **615**, control logic **312** again may proceed in either of three ways. Firstly, if enabling signals **306-308** are still asserted (both thresholds still satisfied), then the control logic **312** will remain in the active state **615** and generation of the reduced clock frequency will continue. Secondly, if enabling signal **308** is still asserted, but the rate of temperature change falls under (fails to satisfy) the pre-determined threshold (function signals **306**, **307** not asserted), then control logic **312** will proceed back to the wait state **610** and normal clock frequency **410** will be produced. Thirdly, if enabling signals **306-308** become not asserted (both thresholds are no longer satisfied), then the control logic **312** will proceed back to the power down state **605** and the normal (non-reduced) clock frequency generated by PLL **310** will be produced as output clock signal **330**.

[0029] The control logic **312** of frequency reduction circuit **305** maybe implemented using a special clock gating logic to a PLL clock distribution tree which does not change clock duty cycle nor reduce the clock cycle time. Several advantages are realized using the frequency reduction circuit **305** to provide rapid frequency reduction in response to the thermal thresholds being satisfied. By reducing frequency through removing a number of pre-determined switching transitions from existing clock frequency cycles during a given time interval, a near peak clock frequency is maintained as well as high processor performance. The control logic allows for rapid switching between the peak frequency and the target (reduced) frequency which enables a controlled, dynamic maximal thermal temperature management method with fine granularity.

[0030] As shown in FIG. 2, high-power spikes corresponding to spikes of thermal temperature can occur within a short time period (e.g. from 100 to 1000 frequency cycles). If the power spikes are uniformly distributed, they will not cause any thermal throttling to occur and therefore processor performance (clock frequency) is maintained. Alternatively, if several power spikes occur close to each other in a short time period, then the previously high temperature does not have a chance to dissipate and the maximal thermal temperature may be exceeded. Use of the frequency reduction method described herein allows the clock frequency signal to be quickly reduced as soon as the high-power spike occurs while the thermal temperature is near the maximal thermal temperature limit. The control logic **312** allows the processor to continue running at the maximal achievable frequency gliding through the high-power spike period with minimal performance penalty.

[0031] Additionally, with the exemplary architecture described herein in FIG. 3, the frequency reduction logic

enabling condition can be easily modified to allow frequency scaling at different power levels and with a different reduction incremental interval (e.g., more or fewer switching transitions per number of cycles removed). Also, the exemplary architecture described herein can be easily integrated into current processor systems without abundant overhead to help meet processor system power requirements.

[0032] Additionally, embodiments of the present invention may include a machine-readable medium having stored thereon a plurality of executable instructions, the plurality of instructions including instructions to perform the method described herein to reduce sensitivity to temperature for a processor system.

[0033] Although the invention is primarily described herein using particular examples of clock frequency reduction, it will be appreciated by those skilled in the art that modifications and changes may be made without departing from the spirit and scope of the present invention. As such, the method and apparatus described herein may be equally applied to any processor system that reduces clock frequency in response to multiple thermal temperature thresholds being satisfied.

What is claimed is:

1. An apparatus for dynamic power control of a processor based on a thermal condition, comprising:

a sensor to measure a thermal characteristic of a processor with a clock frequency;

a circuit, responsive to the measured thermal characteristic satisfying a pre-determined threshold, to reduce the clock frequency of the processor.

2. The apparatus of claim 1, wherein the thermal characteristic includes temperature and rate of temperature change.

3. The apparatus of claim 1, wherein the circuit includes a frequency generator and a logic circuit.

4. The apparatus of claim 1, wherein the circuit reduces the clock frequency by less than fifty percent.

5. The apparatus of claim 1, wherein the circuit reduces the clock frequency by removing a pre-determined number of transitions from a signal producing the clock frequency.

6. The apparatus of claim 1, wherein the sensor and circuit produce a higher operating temperature for the processor.

7. A method for dynamic power control of a processor based on a thermal condition, comprising:

measuring a thermal characteristic of a processor with a clock frequency;

reducing the clock frequency in response to the measured thermal characteristic satisfying a pre-determined threshold.

8. The method of claim 7, wherein the step of measuring includes measuring temperature and rate of temperature change.

9. The method of claim 7, wherein the step of reducing includes reducing the clock frequency by less than fifty percent.

10. The method of claim 7, wherein the step of reducing includes reducing the clock frequency by removing a pre-determined number of transitions from a signal producing the clock frequency.

11. The method of claim 10, wherein the step of reducing includes reducing the clock frequency in response to the



measured thermal characteristic satisfying a pre-determined threshold to produce a higher operating temperature of the processor.

**12.** A method for using control logic to provide dynamic power control of a processor based on a thermal condition, comprising:

entering a first state from a second state in response to a measured thermal characteristic of a processor with a clock frequency failing to satisfy a first pre-determined threshold where the first state outputs the clock frequency for the processor and the second state reduces the clock frequency for the processor;

remaining in the first state in response to a measured thermal characteristic of the processor failing to satisfy the first pre-determined threshold; and

entering the second state from the first state in response to a measured thermal characteristic of the processor satisfying the first pre-determined threshold.

**13.** The method of claim 12, wherein the thermal characteristic of the processor includes temperature and rate of temperature change.

**14.** The method of claim 12, further comprising:

entering a third state from the first state in response to a measured thermal characteristic of the processor satisfying a second pre-determined threshold where the third state waits for a measured thermal characteristic of the processor to satisfy a third pre-determined threshold to reduce the clock frequency for the processor;

remaining in the third state in response to a measured thermal characteristic of the processor failing to satisfy the third pre-determined threshold; and

entering the first state from the third state in response to a measured thermal characteristic failing to satisfy the second pre-determined threshold.

**15.** The method of claim 14, wherein the second pre-determined threshold is a temperature threshold, and the third pre-determined threshold is a rate of temperature change threshold.

**16.** The method of claim 14, further comprising:

entering the second state from the third state in response to a measured thermal characteristic of the processor satisfying the third pre-determined threshold;

remaining in the second state in response to a measured thermal characteristic of the processor satisfying the third pre-determined threshold; and

entering the third state from the second state in response to a measured thermal characteristic of the processor failing to satisfy the second pre-determined threshold.

**17.** The method of claim 16, wherein the second pre-determined threshold is a temperature threshold, and the third pre-determined threshold is a rate of temperature change threshold.

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