(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
22 April 2010 (22.04.2010)

PCT

(10) International Publication Number
WO 2010/045221 A1

(51) International Patent Classification:
H05B 1/02 (2006.01)

(21) International Application Number:
PCT/US2009/060490

(22) International Filing Date:
13 October 2009 (13.10.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/104,798 13 October 2008 (13.10.2008) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *of inventorship (Rule 4.17(iv))*

Published:
— *with international search report (Art. 21(3))*

(54) **Title**: TEMPERATURE MONITORING AND CONTROL SYSTEM FOR NEGATIVE TEMPERATURE COEFFICIENT HEATERS

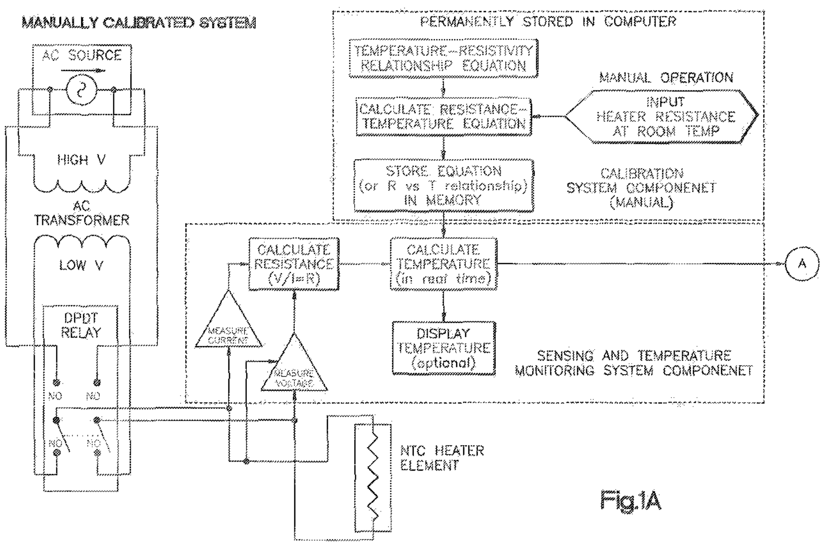


Fig.1A

(57) **Abstract**: A temperature monitoring system for a flexible, thin-film graphite heater dement includes a temperature sensing component thai uses the heater element to sense temperature. The temperature sensing component Includes a current sensor and a voltmeter circuit, A temperature control component Is associated with the heater element. The temperature control component receives at least one set point value associated with the heater anά controls the temperature of the heater element based on the at least one set point value.

WO 2010/045221 A1

Temperature Monitoring and Control System for Negative Temperature Coefficient Heaters

Field of the Invention

The present invention relates to a temperature monitoring and control system for a negative temperature coefficient ("NTC") heater element and, in particular, relates to a heater that utilizes conventional circuitry without the need for an external temperature sensing device on the heater element.

Background

A heater element having a negative temperature coefficient of resistance will decrease in resistance as it heats up. Carbon based heater elements, such as graphite and carbon fiber heaters, have a negative coefficient of resistance and, thus, can be referred to as NTC heater elements.

Summary of the Invention

In accordance with the present invention, a temperature monitoring system for a flexible, thin-film graphite heater element includes a temperature sensing component that uses the heater element to sense temperature. The temperature sensing component includes a current sensor and a voltmeter circuit. A temperature control component is associated with the heater element. The temperature control component receives at least one set point value associated with the heater and controls the temperature of the heater element based on the at least one set point value.

A method of monitoring temperature in a negative temperature coefficient heater having a heater element in accordance with the present invention includes measuring the voltage of the heater element and the current of the heater element. The resistance (y) of the heater element using Ohm's law is then calculated. The temperature (x) of the heater element based upon the calculated resistance is then calculated.

In accordance with anther embodiment of the present invention, a temperature monitoring system for a heater includes a flexible, thin-film graphite heater element. The film has a density of about 40 lbs/in^3 to about 130 lbs/in^3 and a thickness from about .001" to about .100". A temperature sensing component has current and voltage sensors for measuring the current and voltage across the heater element. A temperature control component is associated with the heater element.

Brief Description of the Drawings

Figs. 1A-1B depict a flowchart demonstrating a first example calibration system; and

Figs. 2A-2B depict a flowchart demonstrating a second example calibration system.

Detailed Description

The present invention relates to a temperature monitoring and control system for a negative temperature coefficient ("NTC") heater element and, in particular, relates to a heater that utilizes conventional circuitry without the need for an external temperature sensing device on the heater element. In one embodiment of the present invention, the system utilizes conventional circuitry in a unique manner to control and/or monitor the temperature of NTC heaters without the use of external temperature sensing devices on the heater element. The system allows a user to control an NTC heater without the need for thermocouples, Resistance Temperature Detectors (RTDs), thermistors or other sensors. This system utilizes existing technology in a new manner to measure, calculate, display values and provide calibration adjustments.

There are many benefits that the present invention provides over conventional control methodology. These benefits include, but are not limited to: the elimination of sensor placement issues, the elimination of sensor contact issues, improved protection from damaging temperatures, substantial reduction of system temperature hysteresis, possible cost savings, and simplified wiring. Other benefits may also be realized in accordance with the present invention.

The NTC heater element may be constructed of a carbon-based material, such as graphite or carbon fiber. More specifically, the heater element may be constructed of a flexible, thin-film graphite or carbon graphite material. Flexible graphite heater elements are particularly well suited to the example system because the temperature-resistance curve for such an NTC heater element (*see* graph below) has sufficient amplitude to allow accurate temperatures to be calculated from the measured data. Furthermore, the resistance of flexible graphite as a function of temperature remains stable over time provided that no mechanical damage to the heater element occurs.

Flexible graphite is also advantageous because, in contrast to heater elements formed from other materials, flexible graphite can be repeatedly produced such that every heater element has the same characteristic temperature-resistance correlation for a given graphite construction.

Using Ohm's Law (1) and the equation (2) from the trend line in the graph shown below, an equation (3) for the average heater element temperature can be written as a function of voltage and current. More specifically, the equations can be represented by:

Ohm's Law:

$$V=IR \text{ or } R=V/I \qquad (1)$$

Where R=Resistance in Ohms, V=Voltage in Volts, and I=Current in Amps

Graph Trend Line:

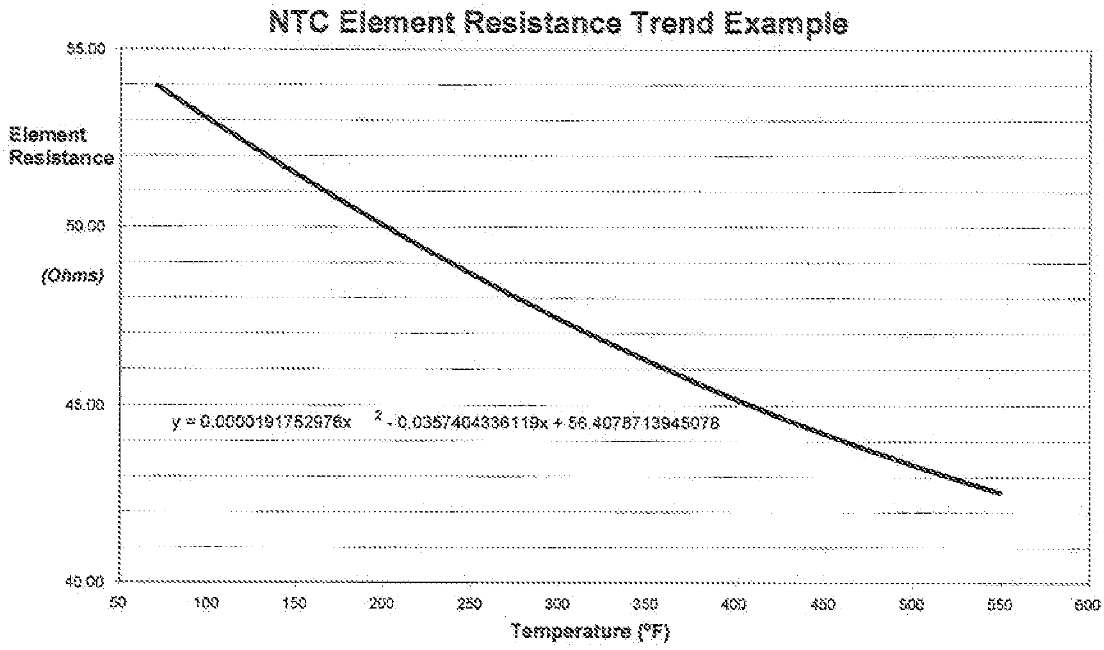
$$y = 0.0000191752976x^2 - 0.03574043336119x + 56.4078713945078 \qquad (2)$$

Where y = Resistance in Ohms, x = Temperature in Fahrenheit

Temperature as a Function of Current/Voltage:

$$0.0000191752976T^2 - 0.03574043336119T + 56.4078713945078 = V/I \qquad (3)$$

This function can be used within the system to control or monitor the heater element temperature.



<u>**System Components:**</u>

The system components include a temperature monitoring component, a temperature control component, and a system calibration component. Each component will be discussed in greater detail below.

<u>**Temperature Monitoring:**</u>

The temperature monitoring component of the example heating system includes two sensing circuits:

1) A current sensor that allows the heater's supply current to pass through a low impedance resistor. This resistor may be placed on the high voltage side or the low voltage side of the heater element. The voltage drop across this resistor is monitored to give an exact measure of the current supplied to the heater element at a given moment. Alternatively, a Hall Effect current sensor or other known sensors may be used.

2) A voltmeter circuit that monitors the DC or AC supply voltage.

The measured voltage value and current values can then be used to calculate the heater element's resistance/impedance. Using Ohm's law, the supply voltage value can then be divided by the current value to yield a value which is proportional to the resistance of the heater element. This resistance value is then used to mathematically calculate the heater element's average temperature using the element's temperature coefficient of resistance, as shown in the graph above. The circuit may include signal conditioning devices such as filters or amplifiers to process the voltage and current related readings. The signal from either sensor, i.e., the voltage sensor or current sensor, may also be used as a variable to control the amplitude or frequency of dependant signals, which themselves could be used to calculate the heater element's resistance and, thus, temperature.

<u>**Temperature Control:**</u>

The temperature control component of the system includes a means of varying set point values. These set point values may include the high limits, low limits, proportional bands, etc. needed for on/off switching. The set point values may be manually entered by the user by means of rotary dials, keypads, barcodes, RFID tags, etc. In one instance, a minimum resistance or a maximum temperature corresponding to that resistance is set as a limit. Once the prescribed limit is achieved, the circuit replaces the supply voltage with a lower voltage supply. This lower supply voltage is used as a monitoring voltage while the main supply voltage is switched off. As the heater element cools, the resistance increases. When the resistance and temperature reach a reset value relative to the high temperature limit, the heater element is again energized with the higher supply voltage and the process repeated.

As an alternative, the heater element may be re-energized after a predetermined period of time, rather than using a reset value. This scenario would allow the system to exclude the low voltage monitoring portion of the system, although without it, the temperature could not be displayed or monitored during the cooling portion of the cycle.

<u>**System Calibration:**</u>

The example system will have to be calibrated for each individual heater element either manually or automatically. For a manually calibrated system, as depicted in Figs. 1A-1B, the calibration portion of the system includes a means of varying a calibration value(s). These calibration values are used to ensure proper functioning of the temperature monitoring portion of the system. The values can correspond with the heater element's actual resistance at a given temperature or related values such as: temperature, temperature coefficient(s) of resistance, or temperature coefficients of resistivity and dimensional values of the heater element, e.g., length, width, etc. Values may be manually entered by the user by means of rotary dials, keypads, jumpers, barcodes, RFID tags or the like.

On the other hand, in an automatic calibrated system, as depicted in Figs. 2A-2B, at least two additional sensing circuits would be required, namely, a circuit to measure the heater element's resistance at ambient temperature and a circuit to measure the ambient temperature. The heater element's resistance could be measured using an ohmmeter circuit or in a manner similar to the low voltage sensing circuit mentioned above. A temperature probe and sensing circuit within the present invention would provide the ambient temperature value necessary to complete the calibration of the example system. Users could activate the calibration manually using a button, switch, or other actuating device.

Over Temperature Protection:

A simplified version of this example system may be used as an overheating protection for the heater or object(s) being heated. In particular, at a preset high temperature or low resistance limit, the power to the heater element would be removed, thereby protecting the heater or heated object(s). Breakers, switches, fuses, relays, and the like may be used to remove power from the heater and thereby turn the heater element off. In this particular construction, the low voltage temperature monitoring or time based switching portion of the system would also be excluded.

System Benefits:

The present invention eliminates the need for external temperature sensors since it uses the heater element to sense temperature. Since no external temperature sensors are used, the system wiring may be greatly simplified, thereby allowing for easier installation. The elimination of external sensors will also save money, decrease the weight, and reduce the size of the system. Eliminating external sensors will also eliminate the chance of controller damage due to high voltage feedback through a sensor wire.

One of the main benefits of the present invention is the protection of sensitive materials or heater insulation from damage due to excessive heat. The present invention can be used to control the heating of thermal insulators or materials having a low thermal conductivity or effective thermal conductivity. In temperature control, the thermal conductivity of a heated substrate or object is almost always relied upon to pass thermal energy to a sensor or thermostat. When the thermal conductivity is low, a delayed response is often experienced. This delay can result in catastrophic failure of the heater.

A similar delay can be the result of improper mounting of the heater or the use of the heater for an improper application. For example, if the heater is not held or adhered securely to the object/material to be heated, the effective thermal conductivity can be extremely low, even if the materials have a high thermal conductivity. In this case, the "effective thermal conductivity" can be defined as the material's thermal conductivity plus the thermal contact conductivity or the conductivity across the interface between the heater and the heated object/material. Often, due to thermal expansion or aging materials, the thermal transfer efficiency degrades over time. Eventually, the temperature climbs to an often dangerous level. The present invention, however, can help to prevent this temperature increase.

The thermal lag mentioned above can also cause a great deal of hysteresis about a set temperature. Often the solution to this type of problem is to use sophisticated temperature controls which use pulse-width-modulation or variable voltage to hold a temperature steady. On the other hand, the present invention can achieve tight temperature control using a much simpler On-Off methodology, since the heat source can be held at a near constant temperature due to little to no delay in temperature sensing. The present invention can also more accurately deal with variable thermal loads, since the heat is controlled from the source.

The present invention can be beneficial in many common applications as illustrated in the following table:

Application Examples	Benefits
Heated Plastic Coffee Cup	**Quickly heat insulative materials without overheating:** Heater can respond quickly without the plastic overheating. A single sensor will only accurately sense a tiny area due to the plastic's low thermal conductivity
Process Heater (Heater clamped between plates)	**Increased heater life:** Heater may lose clamp load over time. Heated system will indicate that service is required by a decrease in plate temperature (as opposed to heater failure). Original

	performance will return once fasteners are tightened.
Convective Air Heater (Thin-Film Heater Suspended in Air)	**No mounting substrate or sensors required:** No additional mass is required for sensor mounting and air flow will not be disrupted by sensors
Food Holding/Warming Panel	**Control gives a better approximation of average temperature across the entire panel or heater zone.** Temperature fluctuation is kept to a minimum. Heater is able to easily handle variable thermal loads (more/less food containers on panel).

<u>Example</u>

In this example the NTC heater elements were formed from a flexible, thin-film graphite material. The raw material used to form the thin film was a flexible graphite foil having a thickness from about .001" to about .100". The density of the films ranged from about 40 lbs/in^3 to about 130 lbs/in^3. The temperature of the flexible graphite heater was calculated using the following equation:

$$Y=AX^2-BX+C \tag{4}$$

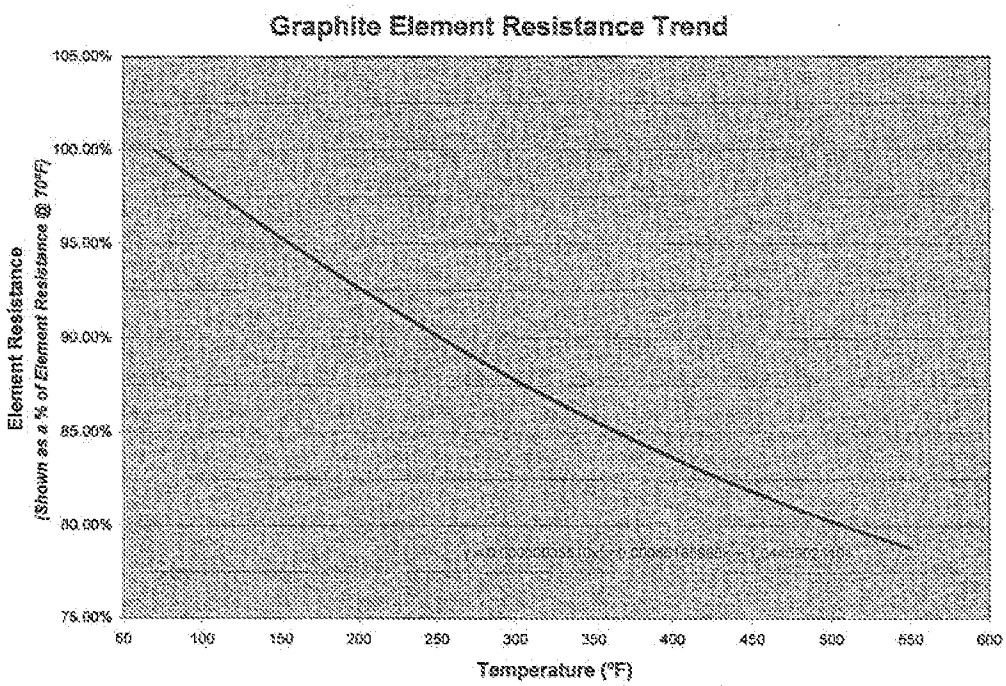
Where:

X = the average temperature of the flexible graphite element (for temperatures from about 32°F to about 600°F);

Y = the resistance of the heater element as a percentage of the element resistance at room temperature or about 70°F; and

A, B, and C are constants.

In the present example, and for most flexible graphite materials, A=0.000000355, B=0.000661860, and C=1.0446. The flexible graphite material, however, can be manipulated during manufacturing to alter the values of A, B, and C according to particular design criterion. For example, in alternate configurations, A could range from about 0.00000025 to about 0.00000045, B could range from about 0.00056 to about 0.00076, and C could range from about 1.02 to about 1.07. A graph based on the equation (4) that illustrates the relationship between the temperature of the graphite heater element based on the heater element resistance can be generated as follows:



Accordingly, during operation of the heater, the temperature monitoring system can calculate the resistance of the graphite heater element based on information received from the current sensor and the voltmeter circuit without the need for additional or external temperature sensors for sensing the temperature of the heater element. This calculated resistance, in conjunction with the known resistance of the heater element at ambient conditions, is then used to mathematically calculate the heater element's average temperature using the equation (4).

An equivalent equation can likewise be generated using the equation (4) and the following equation:

Resistance=Volume Resistivity*(element trace length/element trace cross-sectional area)

Where "Resistivity" is measured at 70°F. Additional variables representing the element trace length, width and thickness would vary from heater element to heater element.

While various features are presented above, it should be understood that the features may be used singly or in any combination thereof. Further, it should be understood that variations and modifications may occur to those skilled in the art to which the claimed examples pertain. The examples described herein are exemplary only. The disclosure may enable those skilled in the art to make and use alternative designs having alternative elements that likewise correspond to the elements recited in the claims. The intended scope may thus include other examples that do not differ or that insubstantially differ from the literal language of the claims. The scope of the disclosure is accordingly defined as set forth in the appended claims.

Having described the invention, the following is claimed:

1. A temperature monitoring system for a heater having a flexible, thin-film graphite heater element comprising:

a temperature sensing component that uses the heater element to sense temperature, the temperature sensing component including a current sensor and a voltmeter circuit; and

a temperature control component associated with the heater element, the temperature control component receiving at least one set point value associated with the heater and controlling the temperature of the heater element based on the at least one set point value.

2. The temperature monitoring system of claim 1 further comprising a calibration component for calibrating the system.

3. The temperature monitoring system of claim 1, wherein the temperature control component includes means for varying the at least one set point value.

4. The temperature monitoring system of claim 3, wherein the at least one set point value includes one or more of high limits, low limits, and proportional bands.

5. The temperature monitoring system of claim 3, further comprising means for entering the set point value.

6. The temperature monitoring system of claim 2, wherein the calibration component is either manual or automatic.

7. The temperature monitoring system of claim 6, wherein the calibration component is manual and includes means for varying a calibration value.

8. The temperature monitoring system of claim 7, wherein the calibration value includes one or more of the heater element's actual resistance at a given

temperature, the temperature of the heater element, the temperature coefficient of resistance, the temperature coefficient of resistivity, and dimensional values of the heater element.

9. The temperature monitoring system of claim 6, wherein the temperature calibration is automatic and includes a circuit for measuring the heater element's resistance at ambient temperature and a circuit for measuring the ambient temperature.

10. The temperature monitoring system of claim 9, wherein the circuit for measuring the heater element's resistance includes an ohmmeter circuit and the circuit for measuring the ambient temperature includes a temperature probe and sensing circuit.

11. The temperature monitoring system of claim 1, wherein the temperature sensing component calculates the temperature of the heater element based on the resistance of the heater element.

12. The temperature monitoring system of claim 11, wherein the temperature of the heater element is calculated using the following equation:

$$y = 0.00000035510x^2 - 0.00066185988x + 1.04459021101,$$

where x = the average temperature of the heater element and y = the resistance of the heater element as a percentage of the resistance of the heater element at room temperature.

13. A method of monitoring temperature in a negative temperature coefficient heater having a heater element comprising:

measuring the voltage of the heater element;

measuring the current of the heater element;

calculating the resistance (y) of the heater element using Ohm's law; and

calculating the temperature (x) of the heater element based upon the calculated resistance.

14. The method of claim 13, wherein the step of measuring the voltage of the heater element comprises measuring the voltage of a flexible, thin-film graphite heater element.

15. The method of claim 13, wherein the temperature of the heater element is calculated using the following equation:

$$y = 0.000191752976x^2 - 0.0357404336119x + 56.4078713945078,$$

where x = the average temperature of the heater element and y = the resistance of the heater element.

16. A temperature monitoring system for a heater comprising:

a flexible, thin-film graphite heater element, the film having a density of about 40 lbs/in^3 to about 130 lbs/in^3 and a thickness from about .001" to about .100";

a temperature sensing component having current and voltage sensors for measuring the current and voltage across the heater element; and

a temperature control component associated with the heater element.

17. The temperature monitoring system of claim 16 further comprising means for calibrating the system.

18. The temperature monitoring system of claim 16, wherein the resistance of the heater element decreases as the temperature of the heater element increases.

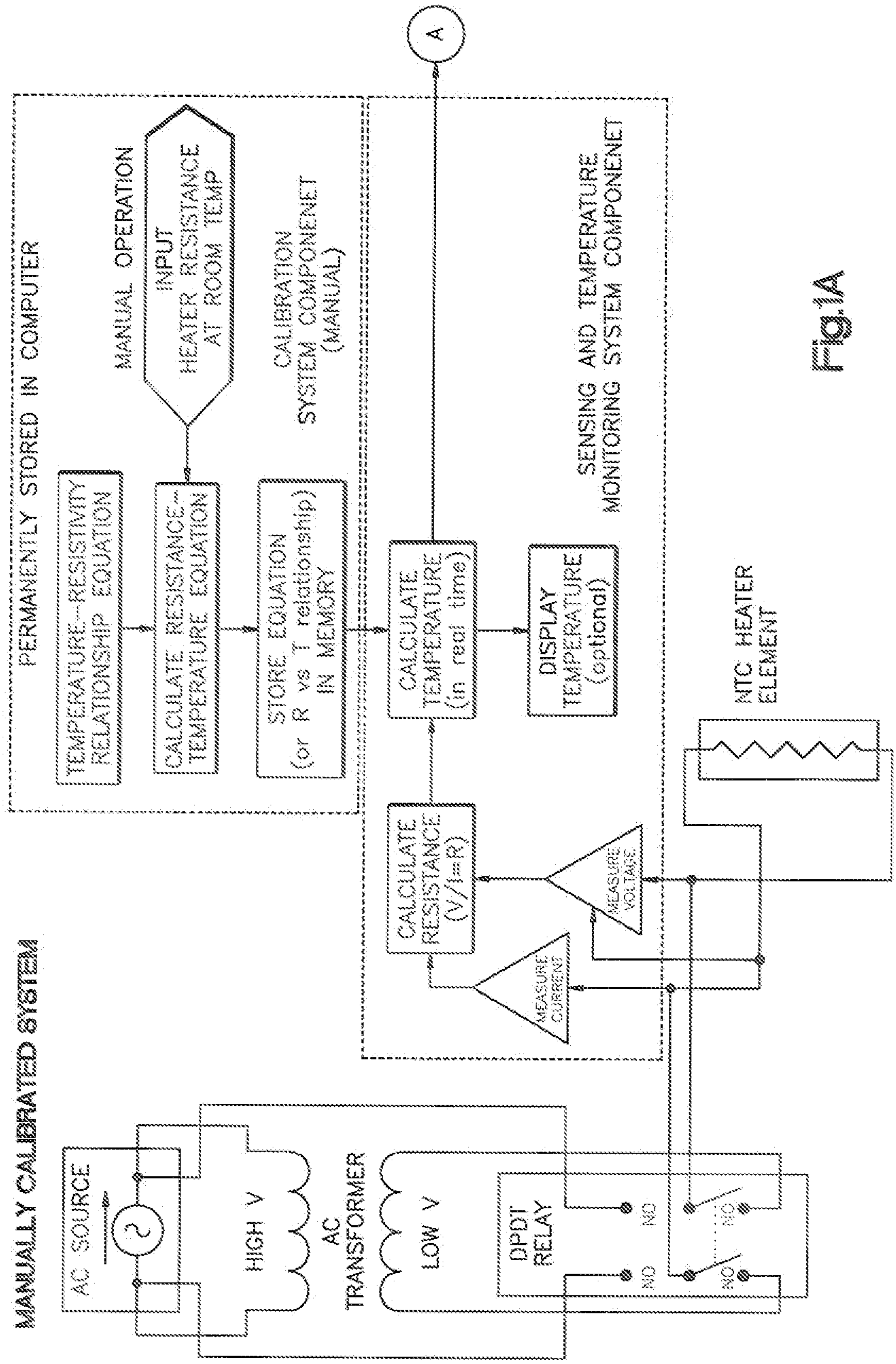

MANUALLY CALIBRATED SYSTEM
PERMANENTLY STORED IN COMPUTER
TEMPERATURE–RESISTIVITY RELATIONSHIP EQUATION
CALCULATE RESISTANCE–TEMPERATURE EQUATION
MANUAL OPERATION
INPUT HEATER RESISTANCE AT ROOM TEMP
STORE EQUATION (or R vs T relationship) IN MEMORY
CALIBRATION SYSTEM COMPONENET (MANUAL)
CALCULATE TEMPERATURE (in real time)
DISPLAY TEMPERATURE (optional)
SENSING AND TEMPERATURE MONITORING SYSTEM COMPONENET
A
CALCULATE RESISTANCE (V/I=R)
MEASURE CURRENT
MEASURE VOLTAGE
NTC HEATER ELEMENT
AC SOURCE
HIGH V
AC TRANSFORMER
LOW V
DPDT RELAY
NO
NO
NO
NO

Fig.1A

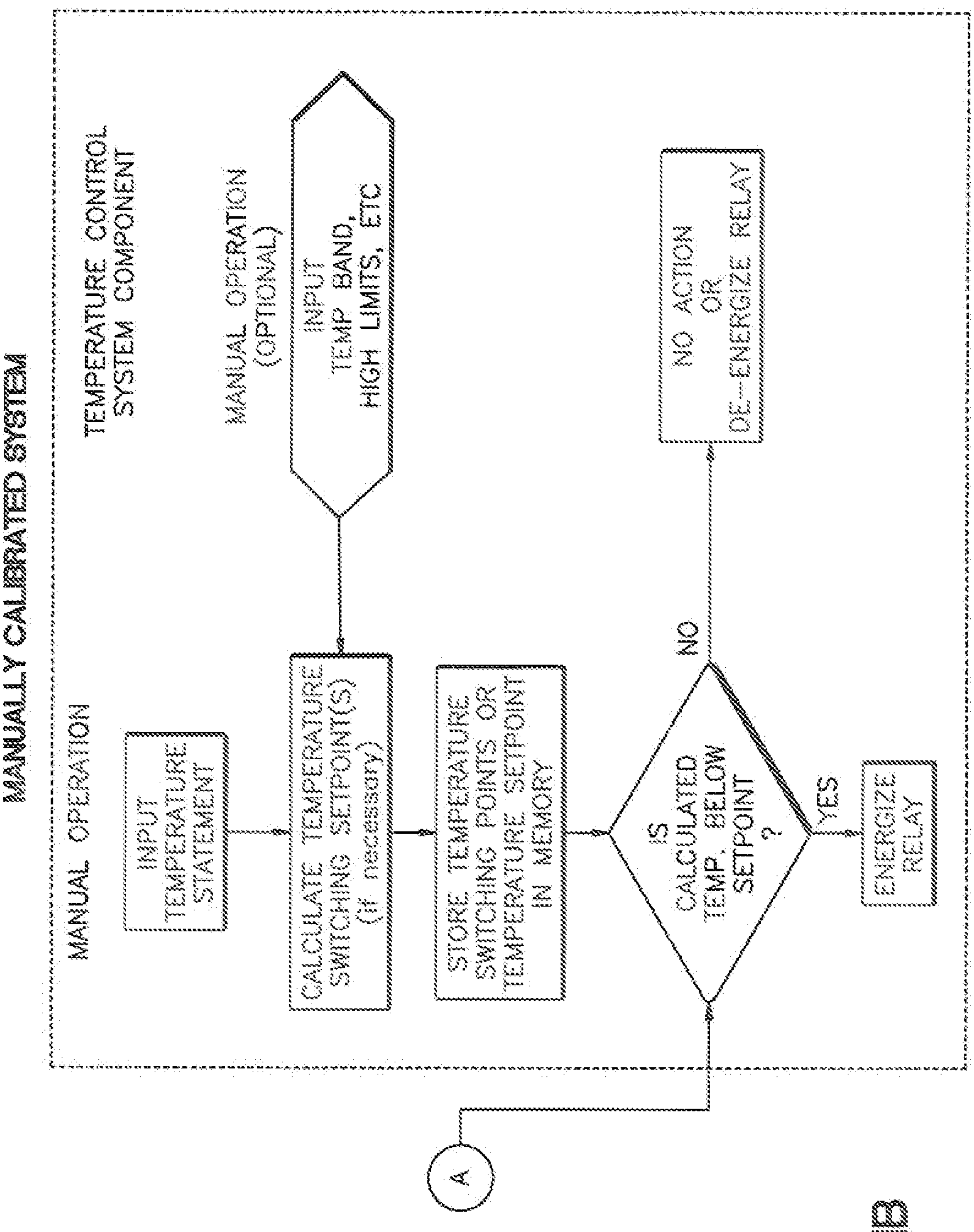

MANUALLY CALIBRATED SYSTEM
MANUAL OPERATION
TEMPERATURE CONTROL SYSTEM COMPONENT
INPUT TEMPERATURE STATEMENT
CALCULATE TEMPERATURE SWITCHING SETPOINT(S) (if necessary)
MANUAL OPERATION (OPTIONAL)
INPUT TEMP BAND, HIGH LIMITS, ETC
STORE TEMPERATURE SWITCHING POINTS OR TEMPERATURE SETPOINT IN MEMORY
IS CALCULATED TEMP. BELOW SETPOINT ?
NO
YES
NO ACTION OR DE-ENERGIZE RELAY
ENERGIZE RELAY
A

Fig.1B

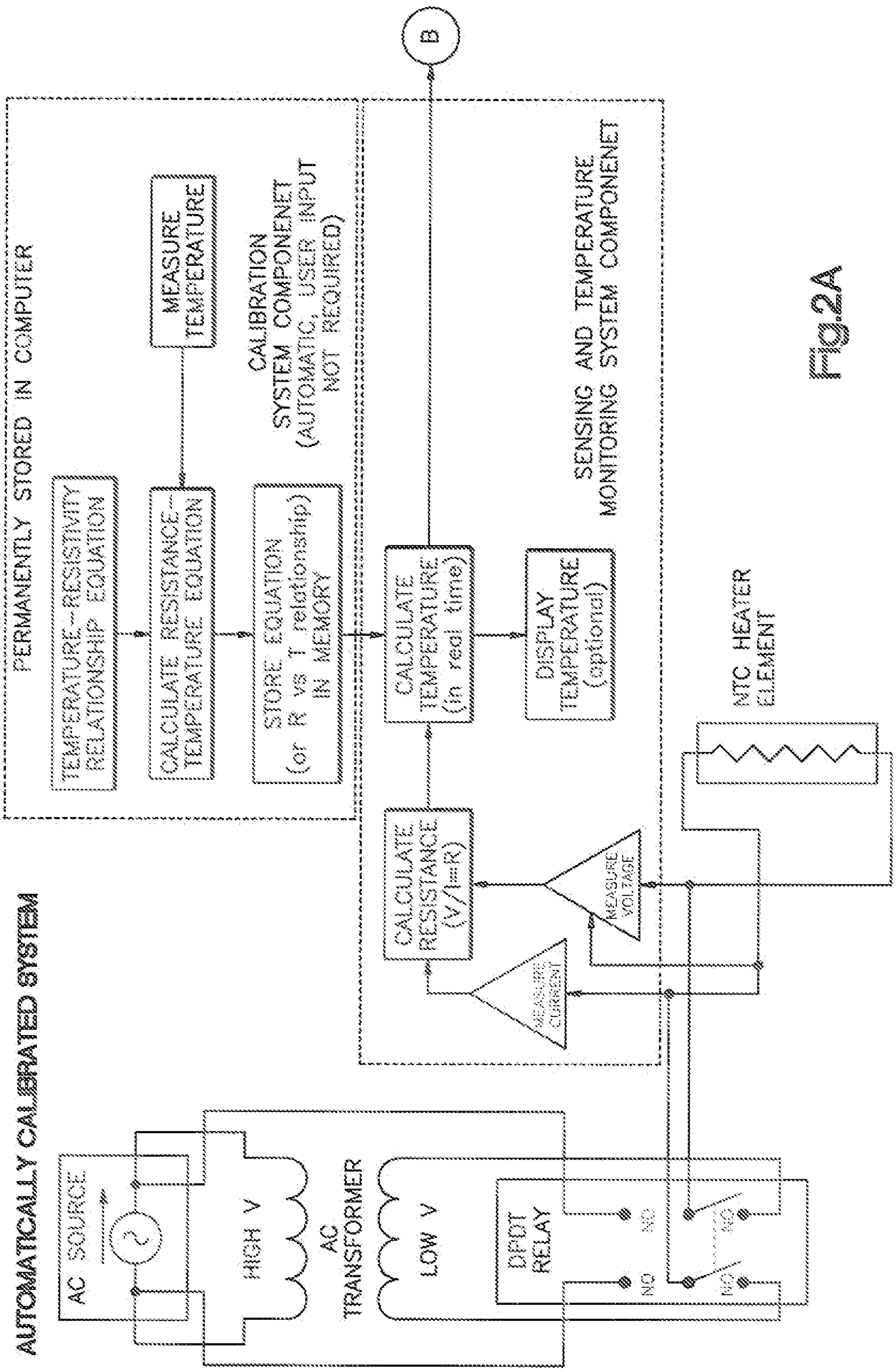

AUTOMATICALLY CALIBRATED SYSTEM
PERMANENTLY STORED IN COMPUTER
TEMPERATURE–RESISTIVITY RELATIONSHIP EQUATION
CALCULATE RESISTANCE–TEMPERATURE EQUATION
MEASURE TEMPERATURE
STORE EQUATION (or R vs T relationship) IN MEMORY
CALIBRATION SYSTEM COMPONENET (AUTOMATIC, USER INPUT NOT REQUIRED)
CALCULATE TEMPERATURE (in real time)
B
DISPLAY TEMPERATURE (optional)
SENSING AND TEMPERATURE MONITORING SYSTEM COMPONENET
CALCULATE RESISTANCE (V/I=R)
MEASURE VOLTAGE
MEASURE CURRENT
NTC HEATER ELEMENT
AC SOURCE
HIGH V
AC TRANSFORMER
LOW V
DPDT RELAY
NO
NO
NO
NO

Fig.2A

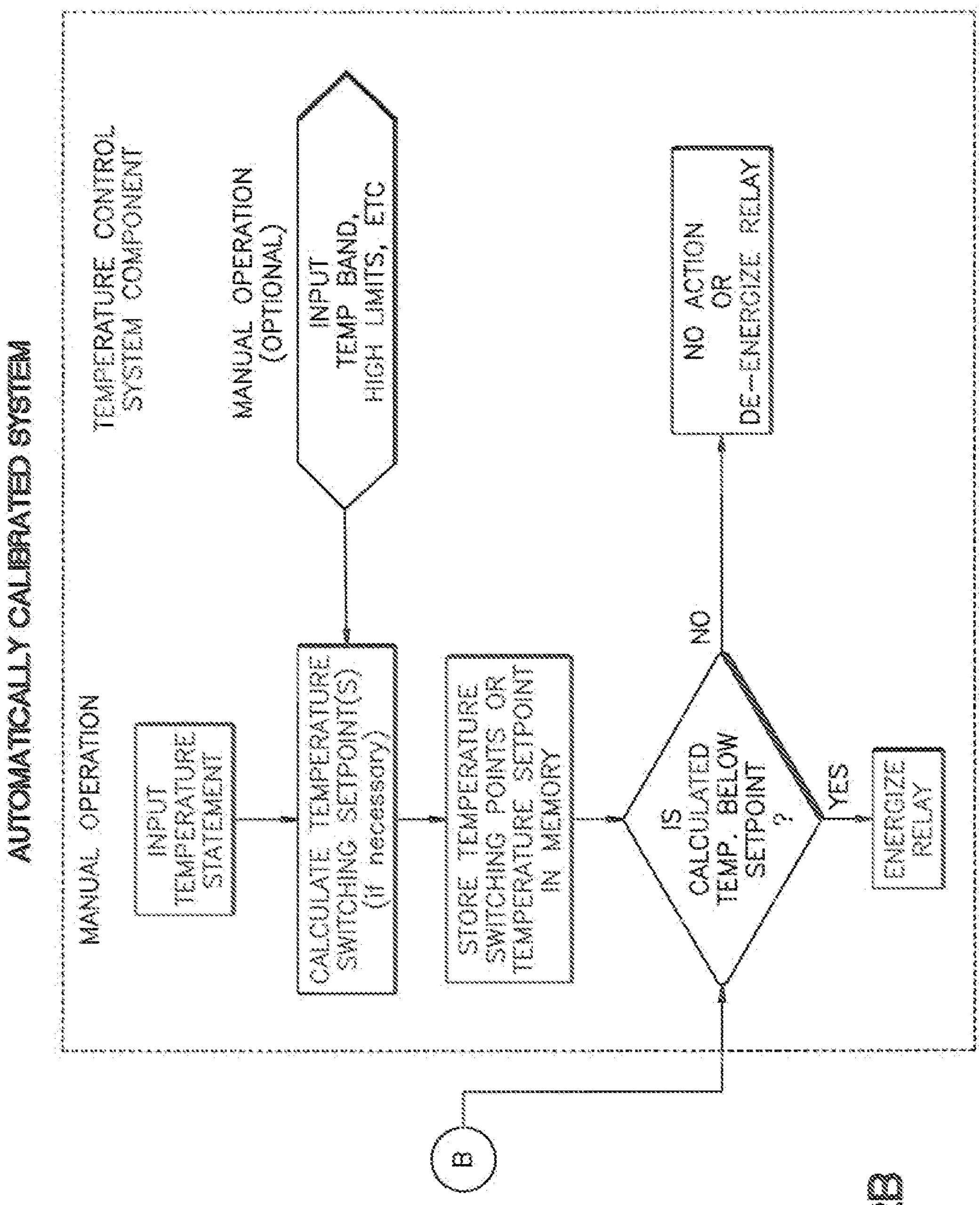

AUTOMATICALLY CALIBRATED SYSTEM
MANUAL OPERATION
TEMPERATURE CONTROL SYSTEM COMPONENT
MANUAL OPERATION (OPTIONAL)
INPUT TEMPERATURE STATEMENT
CALCULATE TEMPERATURE SWITCHING SETPOINT(S) (if necessary)
INPUT TEMP BAND, HIGH LIMITS, ETC
STORE TEMPERATURE SWITCHING POINTS OR TEMPERATURE SETPOINT IN MEMORY
IS CALCULATED TEMP. BELOW SETPOINT ?
NO
NO ACTION OR DE-ENERGIZE RELAY
YES
ENERGIZE RELAY
B

Fig.2B

INTERNATIONAL SEARCH REPORT	International application No. PCT/US 09/60490

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H05B 1/02 (2009.01)
USPC - 219/497
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
USPC: 219/497

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 219/200,482-497,549 (keyword limited - see terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST (PGPB, USPT, USOC, EPAB, JPAB); GOOGLE
Search Terms: temperature, sensing, heater, heating element, control temperature, current, voltage, calibrating, set point, resistance

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2005/0205549 A1 (Crawford et al.) 22 September 2005 (22.09.2005), entire document, especially; abstract, para. [0003], [0005], [0009], [0011], [0015], [0021], [0024], [0034], [0038], [0039], [0042], [0052], [0053], [0059], [0081], [0091]	1 - 18
Y	US 2003/0093186 A1 (Patterson et al.) 15 May 2003 (15.05.2003), entire document, especially; abstract, para. [0079]	1 - 18

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 November 2009 (24.11.2009)	09 DEC 2009

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774