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**Declaration under Rule 4.17:**
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

**Published:**
— *with international search report*

*[Continued on next page]*

(54) Title: TEMPERATURE SENSOR WITH ADJUSTABLE TEMPERATURE COEFFICIENT

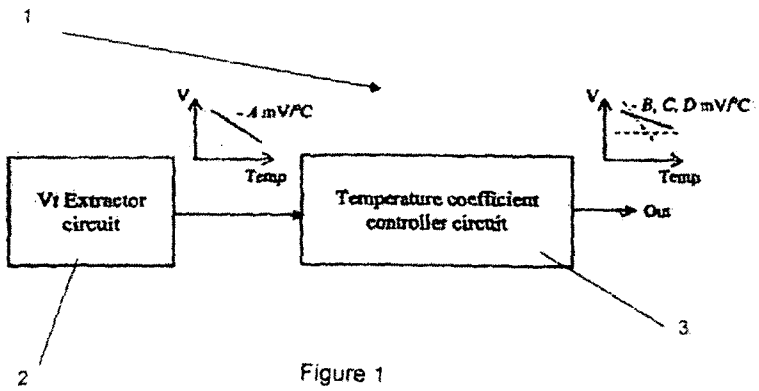


Figure 1

(57) Abstract: The invention relates to a temperature sensor (1) that comprises of a first circuit (2) adapted to generate temperature coefficient signal that corresponds linearly with respect to the temperature being sensed, and a second circuit (3) adapted to vary the generated signal for allowing operation in varied on-field temperatures condition. The second circuit (3) is a temperature coefficient controller having means for allowing adjustable circuit parameter. It is connected to the output terminal of the first circuit (2) and the temperature coefficient controller of the second circuit (3) includes an amplifier (4), a variable resistor (5) and a resistor (6) whereby the resistor (6) is connected to the input terminal of the second circuit and the variable resistor acting as feedback resistor to the amplifier. Application with respect to soil study such as pH measurement, soil-based nutrients analysis and other are some of the possible applications of the temperature sensor.

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— *the filing date of the international application is within two months from the date of expiration of the priority period*

# TEMPERATURE SENSOR WITH ADJUSTABLE TEMPERATURE COEFFICIENT

## 1. TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to temperature sensor and more particularly, to an on-chip temperature sensor that is provided with variable temperature coefficient to provide more reliable application in diverse temperature variations.

## 2. BACKGROUND OF THE INVENTION

The effect of temperature variations in the electronic field cannot be disregarded entirely because temperature has inherent effects to the characteristics and operation of any electronic devices. In the field of semiconductor devices, especially with respect to integrated circuits (IC) where high number of transistors are fabricated on a single chip, the thermal performance of the individual transistors do play important role to the devices as well to the overall system. Generally, solid states devices behave differently in different temperatures, therefore such different behavior will have definite effects to the overall operating characteristic of the devices. In critical area such security, or in highly sensitive temperature dependent scientific experimentation or some others applications, the temperature effects must be effectively considered in order to eliminate possible measurement error, data contamination and such likes.

In ion sensitive applications, especially with regard to, for example, pH, salinity and nutrients measurement of soil and liquid sample using ion sensitive field effect transistor (ISFET), when temperature changes, the electrical characteristics of the sensor device also changes significantly. Electrical characteristics including threshold voltage, sensitivity and electron mobility must be properly taken into account and calibrated for the varied temperatures especially if that monitoring and measurement are done at field. In addition, process variation in the fabrication of the device will also have an

effect to the electrical characteristic and must also be properly compensated.

It is therefore an object of the present invention to provide a means for providing accurate and reliable temperature information to compensate temperature variations in an integrated circuit temperature sensor for allowing operation in diverse temperatures, especially with regard to CMOS (complementary-metal-oxide-semiconductor) temperature sensor operating in the same. Further, since output signals with varied temperature coefficients could effectively be generated, the device has further advantage of being able to be calibrated effectively to produce appropriate temperature coefficient to mutually offset the ISFET temperature coefficient.

## 3. SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an integrated circuit temperature sensor with variable temperature coefficient setting.

It is also another object of the present invention to provide a CMOS temperature sensor with variable temperature coefficient setting.

It is yet another object of the present invention to provide an on-chip CMOS temperature sensor with variable temperature coefficient setting.

These and other objects of the present invention are accomplished by providing,

A temperature sensor (1), comprising,

a first circuit (2) adapted to generate temperature coefficient output signal that corresponds linearly with respect to the temperature being sensed; and

a second circuit (3) electrically connected to said first circuit (2), said second circuit (3) is provided with means to change the temperature

coefficient output signal generated from said first circuit (2) so as to allow operation in varied on-field temperatures;

characterized in that :-

said second circuit (3) is a temperature coefficient controller having means for allowing adjustable circuit parameter to vary the generated temperature coefficient output signal.

Preferably, the temperature coefficient controller includes an amplifier, a resistor and a variable feedback resistor.

Also preferable, the generated temperature coefficient output signal from the temperature sensor is measured in mV/°C.

Yet, it is also preferable that the temperature sensor is fabricated as a single on-chip temperature sensor.

Yet, it is also preferable that the circuits are fabricated separately and connected together thereafter.

Preferably, the variable temperature coefficient of the temperature sensor is used in association with a pH sensor and nutrient measurement for on-field soil study.

## 4. BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments of the invention will now be described, by way of example only, with reference to the accompanying figure in which:

Figure 1 show block diagram representation of the temperature sensor of the present invention;

Figure 2 shows schematic diagram of the temperature sensor with variable

temperature coefficient according to the embodiment of the present invention;

Figures 3 and Figure 4 shows the schematic diagrams of the circuits arranged separately; and

Figure 5 shows simulated graphical results of Voltage vs Temperature signal outputs for the respective variable resistor settings.

## 5. DETAILED DESCRIPTION OF THE DRAWINGS

Referring first to Figure 1 and Figure 2 where a temperature sensor (1) with a variable temperature coefficient feature of the present invention is shown. The temperature sensor (1) is shown comprises of a first circuit (2) adapted for generating a temperature coefficient output signal that corresponds to the temperature being sensed, and a second circuit (3) adapted to vary the generated output signal from the first circuit. The first circuit may be operationally defined as a threshold voltage extraction circuit (Vt) where the output can be measured in term of voltage differential and normally decreases linearly with rising temperature. The second circuit (3) is operationally defined as a temperature coefficient controller adapted for selectively changing or varying the temperature coefficient output signal generated from the first circuit (2). Such operationally adjustable temperature coefficient output signal is preferred in order to allow temperature compensation for application in varied on-field temperature of which the sensor is to operate. The temperature compensation is crucial since electronic devices, especially semiconductor devices, behave differently in different operating temperature. Such different operating characteristics could have disastrous effects for some very crucial application such as security and the likes. Even in non-sensitive applications, for example, soil study where pH measurement, nutrient analysis and temperature measurement, error in any of the measurements will have erroneous effects to the overall study.

Still referring to the figures especially Figure 2, the first circuit (1), or also known as voltage extraction circuit (Vt), has multiplicity of transistors,

especially field effect transistors (FETs) configured in mirrored arrangement. Transistor $M_{31}$ (10) and transistor $M_{32}$ (11) provide bias voltage to transistor $M_{11}$ (12) and generate current $I_D = (K/2)(Vb - Vt)^2$ . This current is mirrored into transistor $M_{12}$ (13) and transistor $M_{13}$ (14). As transistor $M_{12}$ (13) and transistor $M_{13}$ (14) are identical and as the current flows in each transistor, they would have the same gate-to-source voltage (Vgs). In this instance, Vgs for transistor $M_{12}$ (13) is equal to Vgs for transistor $M_{13}$ (14), hence the voltage at Node A is half of $V_{HI}$. The current flowing into transistor $M_{13}$ (14) is equal to $4(K/2)(V_{HI}/2 - Vt)^2$ . Equalizing the currents, the circuit will produce $V_{HI} = Vt_{13} + Vb$ Transistor $M_{21}$ (15) and transistor $M_{22}$ (16) operate as differential amplifier. By designing them in saturation region with similar dimension, the gate-to-source voltage for transistor $M_{21}$ (15) or $Vgs_{21}$ is equal to $V_{HI} - V_{out}$. For transistor $M_{22}$ (16), the gate-to-source voltage, $Vgs_{22}$ is equal to Vb. Since transistor $M_{21}$ (15) and transistor $M_{22}$ (16) carry the same current, they must have identical Vgs. Thus, $V_{out}$ is equal to $V_{HI} - Vb$ or $V_{out} = Vt_{13}$. The above circuits are preferably fabricated using CMOS process technology and the threshold voltage in such CMOS transistor changed linearly with respect to temperature variations. Therefore, such a circuit could be used as temperature sensing device.

Referring still to Figure 2, the output from the first circuit (2) is connected to the input of the second circuit (3). As mentioned earlier, the second circuit (3) is a temperature coefficient controller adapted for adjusting the generated temperature coefficient output signal of the voltage extraction circuit, and such feature allows accurate temperature reading in varied temperature operation in which the sensor is to operate. The temperature coefficient controller includes an amplifier (4), a variable resistor R2 (5) that act as biasing resistor to the amplifier via the input and output terminals and a resistor (6) connected to the input terminal. By varying the R2 (5), the temperature coefficient of the temperature sensor could also be varied according to the requirements. It is shown by the following equation:

$$V_{out} = Vin\left[\frac{R1 + R2}{R1}\right]$$

Simulation through use of HSPICE simulation software yields encouraging

results as shown in Figure 5. In this case, the value of R2 (5) has been chosen to be 10kΩ, 30kΩ and 50kΩ. Such variation of resistance values could be realized during the fabrication process or even after fabrication. For an on-chip option fabricated through CMOS process technology, the variable resistor could be in the form of multiple resistors connected in parallel (as shown in Figure 4) and the required resistance value of the variable resistor R2 (5) is varied by a switch controllable through a digital selector.

Figures 3 and 4 generally illustrate the same circuit as shown in Figure 2. The preferred configuration of the temperature sensor is generally an on-chip integrated circuit packaged within a single packaging where both circuits are fabricated on a single integrated circuit. However, the circuits could also be fabricated individually as separate devices but joint together during application. CMOS process technology to fabricate the integrated circuit would be sufficient to realize features of the present invention. Specifically, 0.35 μm CMOS process technology is currently utilized to fabricate the temperature sensor for application with ion sensitive field effect transistor (ISFET) for pH and nutrients measurements.

Figure 5 shows graphical representations of the simulation results using HSPICE software to gauge the operational characteristics and feasibility of the proposed invention. Varying variable resistor R2 (21) value between 10kΩ, 30kΩ and 50kΩ yielded the results as shown in the figure.

In application, the temperature sensor of the present invention would offer much improved measurement accuracy compared to the prior art as effect of temperature is duly compensated. The sensor could be used with other useful applications such soil study, liquid solution study, security application, in computer and other application. While the preferred embodiments of the present invention have been described, it should be understood that various changes, adaptations and modifications may be made thereto. It should be understood, therefore, that the invention is not limited to details of the illustrated invention shown in the figures and that variations in such minor details will be apparent to one skilled in the art.

**WHAT IS CLAIMED IS:**

1. A temperature sensor (1), comprising,

a first circuit (2) adapted to generate temperature coefficient output signal that corresponds linearly with respect to the temperature being sensed; and

a second circuit (3) electrically connected to said first circuit (2), said second circuit (3) is provided with means to change the temperature coefficient output signal generated from said first circuit (2) so as to allow operation in varied on-field temperatures;

characterized in that :-

said second circuit (3) is a temperature coefficient controller having means for allowing adjustable circuit parameter to vary the generated temperature coefficient output signal.

2. A temperature sensor (1) as claimed in Claim 1, further characterized in that said second circuit (3) is connected to the output of said first circuit (2), and said temperature coefficient controller of said second circuit (3) includes an amplifier (4), a resistor (6) and a variable resistor (5) wherein said resistor (6) is connected to the amplifier input terminal and said variable resistor (5) acts as a feedback resistor to the amplifier.

3. A temperature sensor (1) as claimed in Claim 1, further characterized in that said generated temperature coefficient output signal is in mV/°C, said varying of said generated temperature coefficient output signal is accomplished by varying the variable resistor (5) in accordance to the temperature in which the sensor is operating in.

4. A temperature sensor (1) as claimed in any of the preceding claims, further characterized in that said first circuit (2) and second circuit (3) are fabricated as an on-chip integrated circuit.

5. A temperature sensor (1) as claimed in Claim 1 or Claim 2 or Claim 3, further characterized in that said first circuit (2) and said second circuit (3) are fabricated separately and thereafter electrically connected together to provide said variable temperature coefficient temperature sensor.

6. A temperature sensor (1) as claimed in Claim 4 or Claim 5, further characterized in that said temperature sensor is utilized in association with pH measurement and/or nutrients analysis for an on-field soil study.

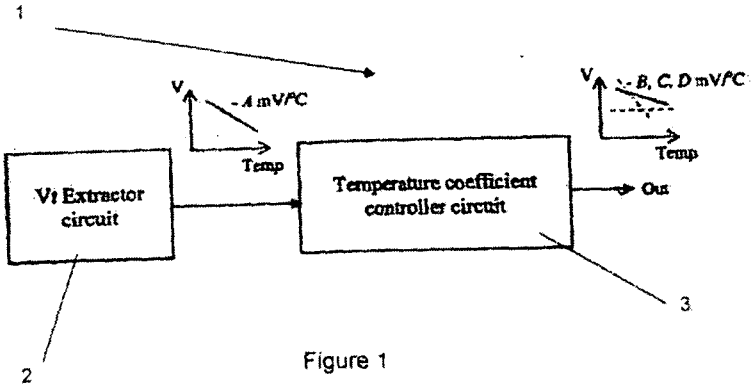


Figure 1

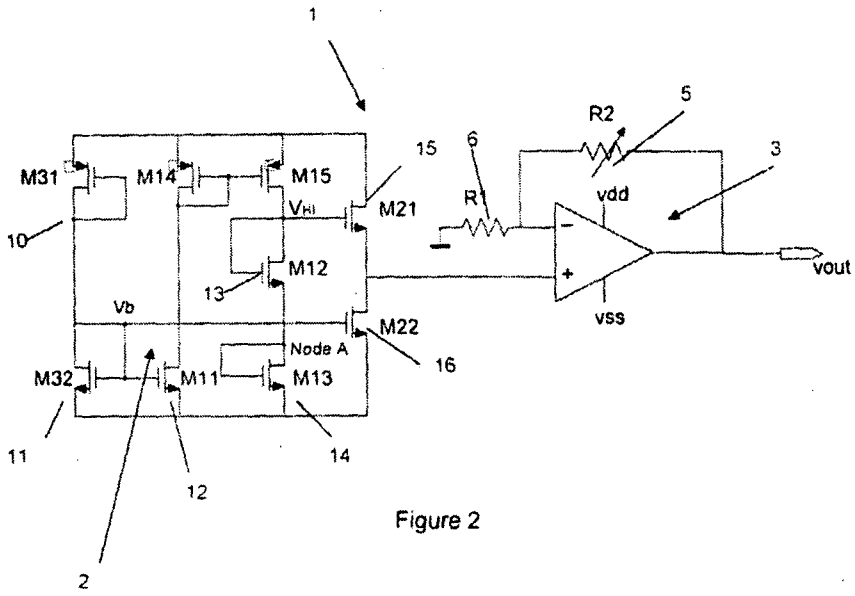


Figure 2

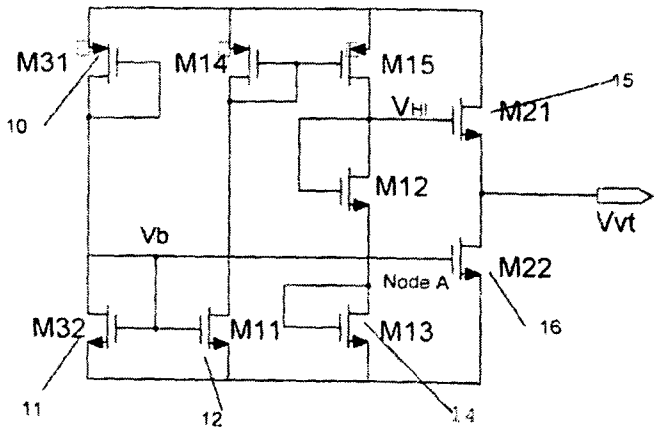


Figure 3

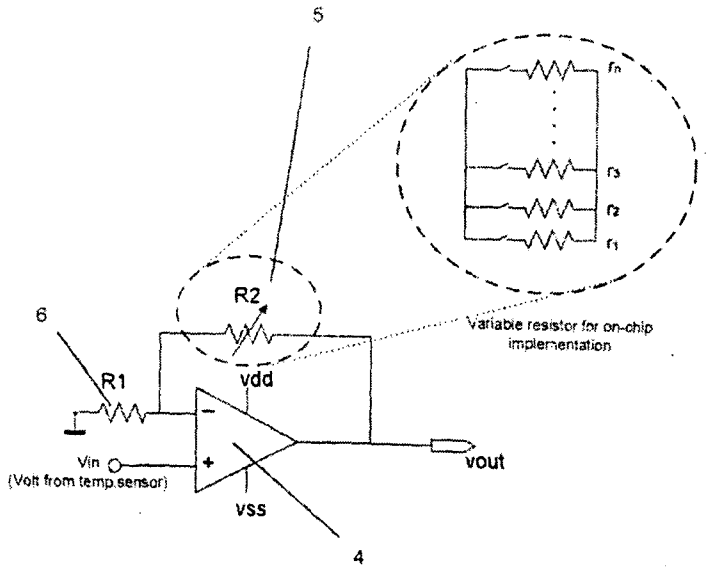


Figure 4

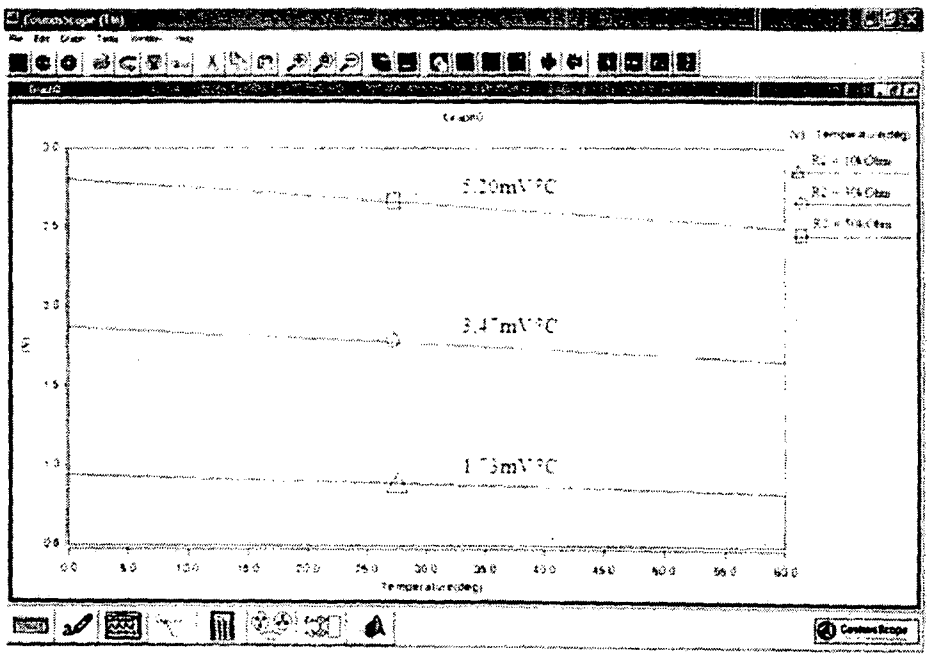


Figure 5

# INTERNATIONAL SEARCH REPORT

International application No.
**PCT/MY2009/000013**

**A. CLASSIFICATION OF SUBJECT MATTER**

***G01K 7/22(2006.01)i, H01C 7/02(2006.01)i, G01K 1/14(2006.01)i***

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)

IPC: G01K 15/00, G01F 15/00, G01K 7/00, G01K 1/08, G06F 15/00, G01K 1/20, G01K 7/12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean Utility models and applications for Utility Models since 1975

Japanese Utility models and applications for Utility Models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKIPASS (KIPO internal) & keywords: "variable resistor", "circuit", "temperature", "sensor"

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | US 7029171 B2 (TESI, D. & ZAMPIERI, U.) 18 APRIL 2006<br>See Figs.1-3; column 7, line 53 - column 8, line 35 | 1-5 |
| X | KR 10-1992-0016825 A (GOLDSTAR INSTRUMENTS CO.) 25 SEPTEMBER 1992<br>See Figs.1-4; claims | 1-5 |
| A | US 7107178 B2 (WON, M. G. et al.) 12 SEPTEMBER 2006<br>See the whole document | 1-5 |
| A | JP 15130732 A (A & D CO., LTD.) 8 MAY 2003<br>See abstract; claims | 1-5 |

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

☒ See patent family annex.

* 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 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 |
|---|---|
| 18 MARCH 2009 (18.03.2009) | **18 MARCH 2009 (18.03.2009)** |


Name and mailing address of the ISA/KR

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LEE Chang Ho

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# INTERNATIONAL SEARCH REPORT

International application No.
**PCT/MY2009/000013**

**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 6
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required addtional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/MY2009/000013**

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| US 7029171 B2 | 18.04.2006 | None | |
| KR 10-1992-0016825 A | 25.09.1992 | KR 9311170 B1 | 24.11.1993 |
| US 7107178 B2 | 12.09.2006 | US 2005-0074051 A1 | 07.04.2005 |
| JP 15130732 A | 08.05.2003 | None | |