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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 June 2023 (15.06.2023)

WIPO | PCT

(10) International Publication Number
WO 2023/108179 A1

(51) International Patent Classification:
E21B 47/07 (2012.01) *F42B 3/00* (2006.01) *F42D 1/08* (2006.01) *F42C 11/06* (2006.01)

(21) International Application Number: PCT/ZA2022/050058

(22) International Filing Date: 18 November 2022 (18.11.2022)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2021/10056 07 December 2021 (07.12.2021) ZA

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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, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,

(54) Title: BOREHOLE TEMPERATURE MONITORING

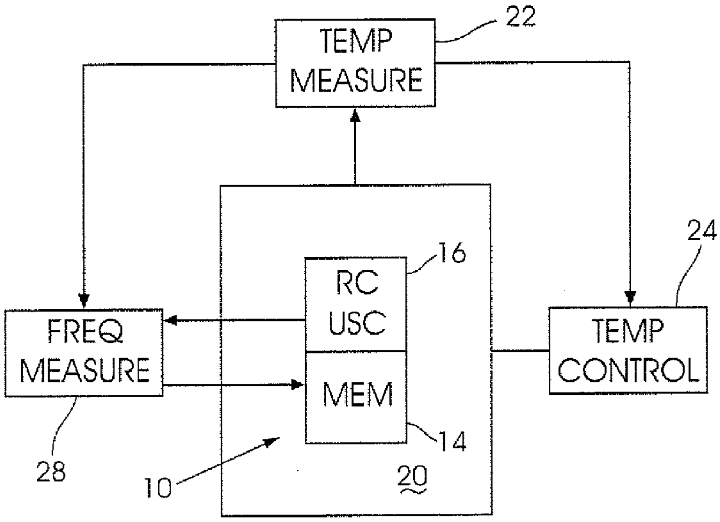

FIGURE 3

(57) Abstract: The invention provides a detonator which includes an oscillator, and a memory unit in which is stored a first measurement which is based on the frequency of oscillation of the oscillator at a first temperature and a second measurement which is based on the frequency of oscillation of the oscillator at a second temperature. The invention further extends to a method of monitoring a temperature in a borehole which includes the steps of using the first and second frequency measurements and the first and second temperatures to establish a frequency versus temperature relationship for the oscillator, placing the oscillator into the borehole, obtaining a third measurement of the frequency of oscillation of the oscillator while it is in the borehole, and using said frequency versus temperature relationship and the third frequency measurement to determine the temperature of the oscillator at the time the third frequency measurement was obtained.

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DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

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

BOREHOLE TEMPERATURE MONITORING

BACKGROUND OF THE INVENTION

[0001] This invention relates to measuring the temperature in a borehole at a blast site.

[0002] A high temperature can be generated in a borehole which is formed in reactive or hot ground when the borehole is charged with explosives.

[0003] "Reactive ground" is rock or other ground material which includes sulphide-containing minerals, typically pyrite, that react spontaneously with an ammonium nitrate-based explosive (ANFO). This reaction results in an exothermic decomposition of the explosive. As a result the temperature prevailing in the explosive can rise rapidly and significantly and cause the explosive to be ignited.

[0004] Hot ground holes can be due to geothermal heating, volcanic activity, burning coal seams, cement-fills in stopes, heating of rocks by solar radiation and the like. Reactive ground in which sulphur oxidation occurs, as described, is a particular case of a hot ground situation.

[0005] Figure 1 attached hereto is a curve of temperature versus time illustrating how a temperature prevailing in a borehole, formed in reactive or hot ground, could rise when the borehole is filled with ANFO.

[0006] During an initial induction stage the temperature variation is minimal. However the temperature can rise by about 100°C over a few minutes during a following intermediate stage. Nitrogen dioxide fumes may be visible during this stage. The intermediate stage could be succeeded by an ignition stage during which the rate at which the temperature increases, is extremely rapid. If sufficient fuel (ANFO) is present, and provided physical parameters such as confinement and critical diameter are met, then the ignition stage can result in detonation of the explosive. If these parameters are not present then deflagration of the ANFO, or pyrite fires, can result.

[0007] Competent personnel at a blast site must be notified without delay if the placing of the ANFO in a borehole results in the intermediate stage. Once the reaction reaches the ignition stage developments occur too quickly to be managed safely and can be life-threatening.

[0008] Negative safety aspects or risks include the following: exposure of operators to high temperatures and to toxic vapours, ignition of vapours associated with emulsion and ANFO-type products, softening of plastic components of initiation products, melting and decomposition of bulk, packaged, and initiation, products and detonation following decomposition.

[0009] Apart from the aforementioned negative consequences, hot ground conditions can result in non-optimal blasts. The rate of degradation of the explosive product is increased and the likelihood of blast failure, e.g. a misfire or an unwanted explosion, also arises. These factors can lead to a loss in production and can increase processing costs.

[0010] Although various risk-mitigating techniques are currently employed they are dependent on identifying a blast site as a potential reactive ground, or hot ground, location. Despite this, even if hot holes are being actively monitored, at a large blast site it might not be feasible to monitor all blastholes.

[0011] An object of the present invention is to address, at least to some extent, the aforementioned situation.

SUMMARY OF THE INVENTION

[0012] The invention provides, in the first instance, a detonator which includes an oscillator, and a memory unit in which is stored a first measurement which is based on the frequency of oscillation of the oscillator at a first temperature and a second measurement which is based on the frequency of oscillation of the oscillator at a second temperature.

[0013] The memory unit is preferably a non-volatile device.

[0014] Preferably the first and second frequency measurements are determined under controlled temperature conditions prior to deployment of the detonator.

[0015] The first and second temperatures may be predetermined, or chosen according to requirement. Preferably these temperatures bridge or span what may conveniently be referred to as "room temperature" which, in this context, is a temperature at which assembly of all or a part of the detonator is done, possibly under temperature-controlled conditions.

[0016] A third measurement which is based on the frequency of oscillation of the oscillator at a third temperature may be stored in the memory unit. This third temperature may be the room temperature referred to.

[0017] In one embodiment of the invention the third temperature lies between the first temperature and the second temperature.

[0018] Through the use of appropriate curve fitting techniques a frequency versus temperature relationship for the oscillator may be established under controlled conditions using at least the first and the second frequency measurements and the first and second temperatures. Data on the relationship may be stored in the memory unit so that, if another frequency measurement is made, it is possible for a processor to use data on the another frequency measurement and the relationship thereby to obtain a measure of the temperature to which the oscillator was exposed when the another frequency measurement was made.

[0019] The invention further extends to a method of monitoring a temperature in a borehole which includes the steps of obtaining a first measurement of the frequency of oscillation of an oscillator at a first temperature, obtaining a second measurement of the frequency of oscillation of the oscillator at a second temperature, using the first and second frequency measurements and the first and second temperatures to establish a frequency versus temperature relationship for the oscillator, placing the oscillator into the borehole, obtaining a third measurement of the frequency of oscillation of the oscillator while it is in the borehole, and using said frequency versus temperature relationship and the third frequency measurement to determine the temperature of the oscillator at the time the third frequency measurement was obtained.

[0020] In a preferred embodiment the oscillator forms part of, or is otherwise associated with, a detonator which is deployed in the borehole for explosive ignition purposes.

[0021] Thus the third frequency measurement may be made once the detonator has been exposed to explosive material in the borehole.

[0022] The first and second frequency measurements may be obtained under controlled temperature conditions prior to assembly of the detonator. The first and second temperatures may be predetermined, or they may be measured at the time the respective frequency measurements are made. An additional frequency measurement may be obtained for the oscillator at a temperature which may be referred to as "room temperature" and which is between the first temperature and the second temperature.

[0023] Each frequency measurement (the first frequency measurement, the second frequency measurement and the additional frequency measurement), or data pertaining thereto, may be stored in a memory unit which is associated with the detonator.

[0024] Data on the stored frequency measurements may be extracted from the memory unit by means of a suitable controller which is in communication with the detonator when the detonator is tagged (installed in a borehole), or after the detonator is placed into a borehole.

[0025] The controller may implement a curve fitting technique to establish said frequency versus temperature relationship from the first and second frequency measurements and from the first temperature and the second temperature. The relationship may be established by the controller, or by using another mechanism, at any suitable time. In one approach the relationship is established under controlled conditions before deployment of the detonator and data on the relationship is stored in a memory unit, associated with the detonator, which can be accessed by a processor after the third frequency measurement is made thereby to determine the frequency of the oscillator at the time of the third frequency measurement.

[0026] The controller may be physically separate from the detonator but in communication therewith using any suitable mechanism. Alternatively the processing steps referred to in connection with the controller may be implemented using circuitry embodied in or otherwise associated directly with the detonator.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The invention is further described by way of example with reference to the accompanying drawings in which :

Figure 2 is a schematic representation depicting how the frequency of oscillation of an oscillator can vary with temperature,

Figure 3 depicts aspects of a calibration technique, and

Figure 4 shows a detonator according to the invention, in use.

DESCRIPTION OF PREFERRED EMBODIMENT

[0028] An electronic detonator may use a crystal oscillator or an RC oscillator as a timing mechanism. A crystal oscillator is accurate over time but is sensitive to shock, an event which is prevalent in a mining environment. RC oscillators are therefore in widespread use. This type of oscillator is trimmed to be accurate over a standard temperature range.

[0029] If a detonator is used outside of the standard temperature range then the frequency of oscillation of the RC oscillator can drift in a temperature-dependent manner. This aspect is illustrated in Figure 2 which has two curves, A and B respectively, of frequency versus temperature for an RC oscillator.

[0030] During fabrication the RC oscillator is trimmed to be accurate over a standard temperature range which, as is designated in Figure 2, extends from a temperature T1 to a temperature T2, bridging a temperature T3. If the temperature to which the oscillator is exposed increases then, depending on various physical characteristics of the oscillator, the frequency of oscillation can increase as is indicated by the curve A, or can decrease as per the curve B. If the temperature drops below the standard temperature range similar frequency variations take place. The temperature T3 is conveniently referred to as "room temperature".

[0031] Each curve A and B forms a respective part of what may be referred to as a general parabolic shape (in this example).

[0032] Figure 3 illustrates aspects of a calibration technique which is adopted during manufacture of an electronic detonator which typically comprises an application specific integrated circuit (ASIC) 10 which inter alia includes a non-volatile memory unit 14 and an RC oscillator 16. Other components of the detonator are not shown for they are not relevant to an understanding of the invention.

[0033] During manufacturing and testing phases the ASIC 10 is enclosed in an environment 20. The temperature prevailing in the environment 20 is measured by a measuring device 22 and this is used to regulate the operation of a temperature controller 24. At two distinct temperatures, designated T1 and T2 in Figure 2, the frequency of oscillation of the oscillator 16 is measured by a device 28 and data on each measurement is stored in the memory unit 14. The temperatures T1 and T2 are predetermined, or are otherwise measured at the time the frequencies are measured.

[0034] The curve A in Figure 2 shows that the frequency increases with a variation in temperature, while the curve B shows that the frequency decreases with a variation in temperature – in each case relative to the temperature T3 ie the room temperature– as is referred to hereinafter. The corresponding oscillator frequencies for the curve A at the temperatures T1 and T2 are respectively designated f1 and f2. The corresponding oscillator frequencies for the curve B at the temperatures T1 and T2 are respectively designated F1 and F2.

[0035] Typically T1 is 0°C and T2 is 35°C. These temperature values are preferred but however are exemplary.

[0036] At an appropriate time e.g at an intermediate or final assembly stage of a detonator which incorporates the ASIC 10, a third frequency measurement f3 or F3 is taken at the third measured and regulated, or predetermined, temperature T3 i.e at the room temperature. T3 is typically of the order of 25°C. The measured value of the frequency of oscillation f3 or F3 is stored in the memory device 14.

[0037] Figure 4 depicts a detonator 40 which includes the ASIC 10 in which the various frequency measurements, determined at the respective measured temperature values, are stored. Other components of the detonator which are known in the art are not illustrated nor described herein. The detonator 40 is deployed in a borehole 42 formed at a desired location on a blast site 44.

[0038] At the time the detonator 40 is placed into the borehole 42 use is made of a controller 50 which extracts from the memory unit 14 the stored frequency measurements f1, f2 and f3, or

F1, F2 and F3, as the case may be. Sometime thereafter an emulsion explosive 52, typically ANFO at a temperature of about 65°C, is placed into the borehole 42 surrounding the detonator. The controller 50, shortly after placement of the explosive 52, measures the frequency of oscillation of the oscillator 16. In each case the controller 50 could access the data in the memory unit 14 using a wireless technique or via a conductor, not shown, which is connected to the memory unit. That frequency, due at least to the presence of the explosive 52 which is at an elevated level would move away from the value f3, F3 which prevails at the room temperature T3. At room temperature the RC oscillator is stable. However the effect of a temperature change on the temperature of oscillation (ie the frequency drift) is known from test data. For example depending on the normal oscillator frequency, a frequency variation of about 50 Hz can be expected if the temperature changes by abut 10°C.

[0039] If the frequency has increased relative to f3 then the frequency versus temperature relationship of the oscillator is indicated by the curve A. If the frequency has decreased relative to the frequency F3 then the frequency versus temperature relationship of the oscillator is represented by the curve B. In this example if the curve A follows a general parabolic shape, or if the curve B follows a general parabolic shape, then it is possible to make use of a curve fitting technique to determine from the frequency measurement made by the controller 50, the temperature prevailing in the borehole at the RC oscillator.

[0040] There are different ways of implementing curve fitting techniques and the reference to parabolic curves is exemplary and non-limiting. A typical representative curve shape for the RC oscillator is determined by preliminary test routines. The curve fitting exercise is carried out at any suitable time to establish the frequency versus temperature relationship for the detonator, and data on that relationship is stored in the memory unit 14. Thus the relationship can be determined once the detonator is installed or prior thereto. Irrespectively, that relationship allows for the temperature of the borehole to be assessed from the prevailing frequency measurement.

[0041] If deemed appropriate the frequency of oscillation of the oscillator can be measured more than once, or even continuously, to determine whether, over an extended time period, the temperature of the borehole is rising to an unacceptable value.

[0042] If the temperature in the borehole enters the intermediate stage shown in Figure 2 a warning message is generated by the controller 50. An operator is then alerted, typically by means of a radio signal, or via a signal sent on a wiring harness, depending on the technology employed for the blasting system which incorporates the detonator, that appropriate remedial action must be taken as a matter of urgency.

[0043] In the preceding description use is made of the controller 50 to interrogate the memory unit 14 to obtain the stored calibrated frequency values, and then to obtain a measure of the frequency of oscillation of the oscillator after deployment of the detonator. In a variation of the invention, a similar process is followed in that the frequency of oscillation is measured by circuitry embodied in the ASIC 10 and a processing device in the ASIC, using the stored frequency values and the measured frequency value, makes a determination of the temperature in the borehole. If the temperature rise is unacceptable, the processing device transmits a signal preferably through the medium of a top box 60, or via any other technique, to a blast control centre 62, of a hot hole condition. This approach although calling for more on-board power at the detonator and for a signal transmission capability from the detonator has the benefit that the borehole temperature can be determined repeatedly or continuously.

CLAIMS

1. A detonator which includes an oscillator, and a memory unit in which is stored a first measurement which is based on the frequency of oscillation of the oscillator at a first temperature and a second measurement which is based on the frequency of oscillation of the oscillator at a second temperature.

2. A detonator according to claim 1 wherein the memory unit is a non-volatile device.

3. A detonator according to claim 1 wherein the first and second frequency measurements are determined under controlled temperature conditions prior to deployment of the detonator.

4. A detonator according to claim 1 wherein the first and second temperatures are predetermined and bridge or span a third temperature which comprises a temperature at which assembly of all or a part of the detonator is done, under temperature-controlled conditions.

5. A detonator according to claim 4 wherein a third measurement which is based on the frequency of oscillation of the oscillator at the third temperature is stored in the memory unit.

6. A detonator according to claim 1 wherein the memory unit includes data on a frequency versus temperature relationship for the oscillator which is established using at least the first and the second frequency measurements and the first and second temperatures,

and wherein the processor is operable, using another frequency measurement, to access the relationship thereby to obtain a measure of the temperature to which the oscillator was exposed when the another frequency measurement was made.

7. A method of monitoring a temperature in a borehole which includes the steps of obtaining a first measurement of the frequency of oscillation of an oscillator at a first temperature, obtaining a second measurement of the frequency of oscillation of the oscillator at a second temperature, using the first and second frequency measurements and the first and second temperatures to establish a frequency versus temperature relationship for the oscillator, placing the oscillator into the borehole, obtaining a third measurement of the frequency of oscillation of the oscillator while it is in the borehole, and using said frequency versus temperature relationship and the third frequency measurement to determine the temperature of the oscillator at the time the third frequency measurement was obtained.

8. A method of monitoring a temperature in a borehole according to claim 7 wherein the oscillator forms part of, or is associated with, a detonator which is deployed in the borehole for explosive ignition purposes and the third frequency measurement is made once the detonator has been exposed to explosive material in the borehole.

9. A method of monitoring a temperature in a borehole according to claim 7 wherein the first and second frequency measurements are obtained under controlled temperature conditions prior to assembly of the detonator.

10. A method of monitoring a temperature in a borehole according to claim 9 wherein the first and second temperatures are predetermined, or they are measured at the time the respective frequency measurements are made.

11. A method of monitoring a temperature in a borehole according to claim 8 which includes the step of obtaining an additional frequency measurement for the oscillator at a temperature which is between the first temperature and the second temperature.

12. A method of monitoring a temperature in a borehole according to claim 11 which includes the step of storing the first frequency measurement, the second frequency measurement and the additional frequency measurement, or data pertaining thereto, in a memory unit which is associated with the detonator.

13. A method of monitoring a temperature in a borehole according to claim 12 which includes the step of extracting data on the stored frequency measurements from the memory unit by means of a controller which is in communication with the detonator when the detonator is installed in a borehole, or after the detonator is placed into a borehole.

14. A method of monitoring a temperature in a borehole according to claim 13 which includes the step of using the controller to implement a curve fitting technique to establish said frequency versus temperature relationship from at least the first and second frequency measurements and from the first temperature and the second temperature.

15. A method of monitoring a temperature in a borehole according to claim 8 wherein said frequency versus temperature relationship is established under controlled conditions

before deployment of the detonator and the method includes the steps of storing data on the relationship in a memory unit, associated with the detonator, and using a processor to access the data after the third frequency measurement is made thereby to determine the frequency of the oscillator at the time of the third frequency measurement.

16. A method of monitoring a temperature in a borehole according to claim 13 wherein the controller is physically separate from the detonator but in communication therewith.

17. A method of monitoring a temperature in a borehole according to claim 15 wherein the processor comprises circuitry embodied in or associated with the detonator.

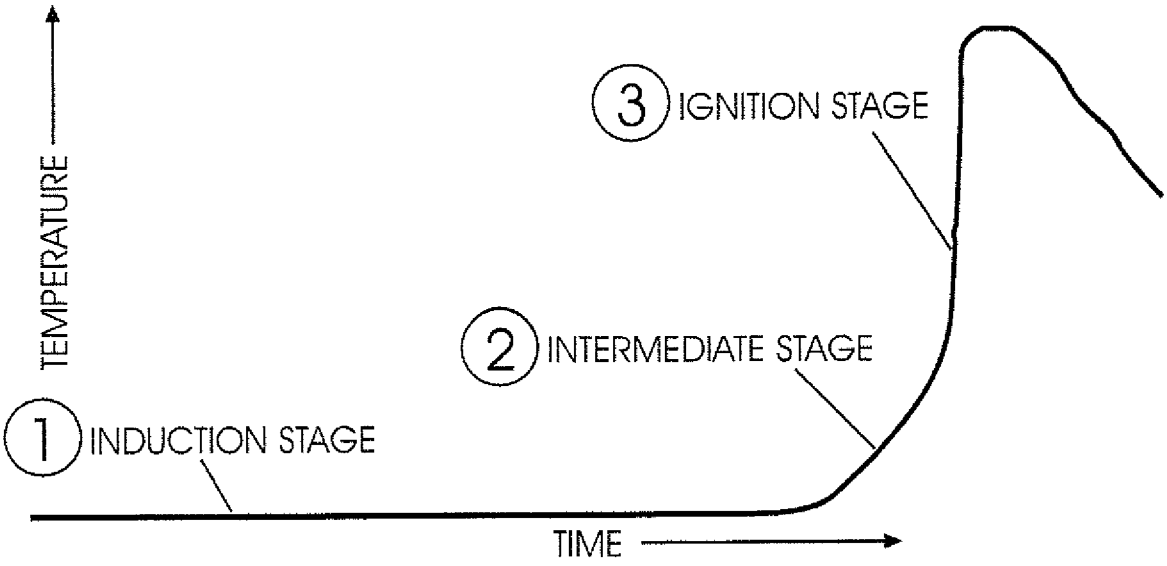

FIGURE 1

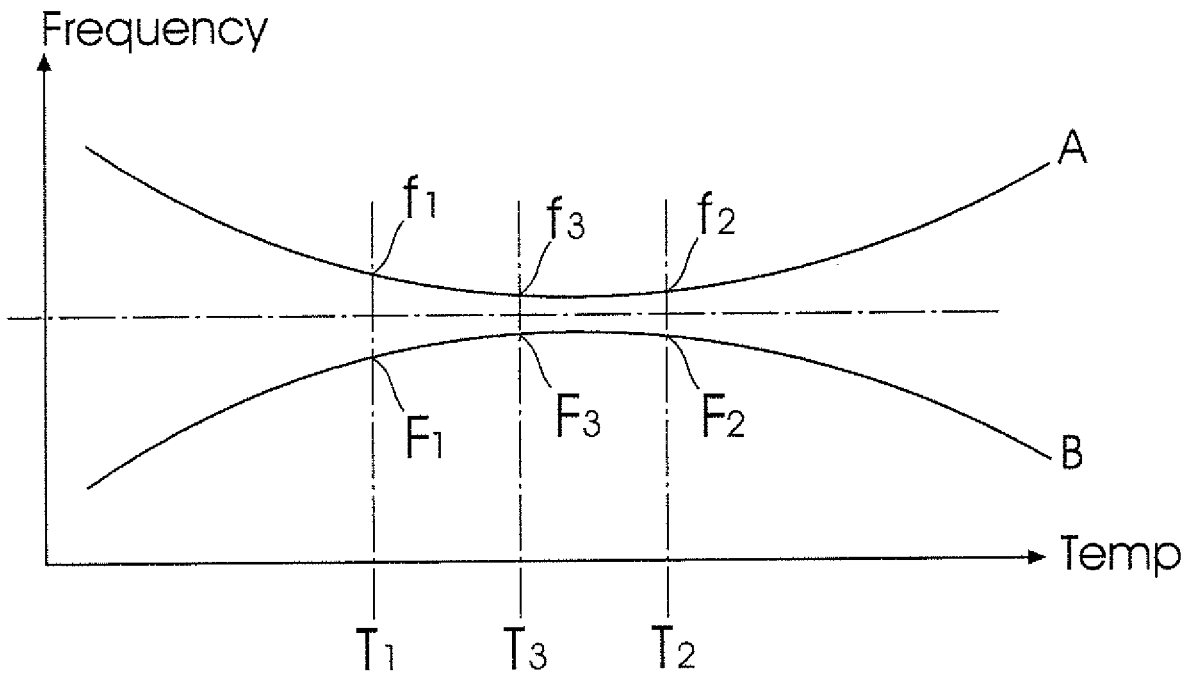

FIGURE 2

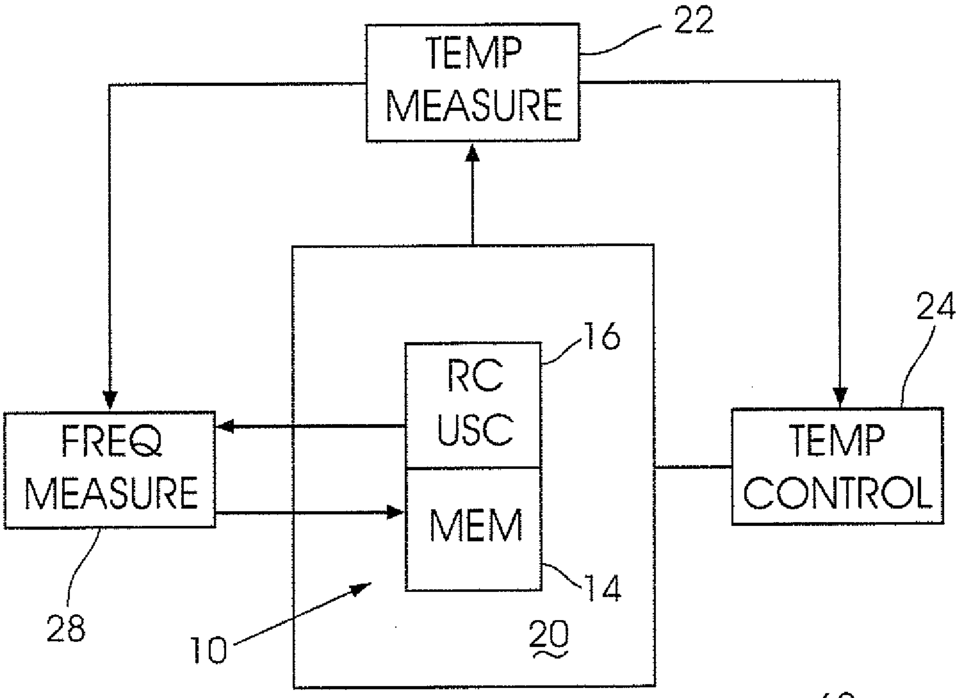

FIGURE 3

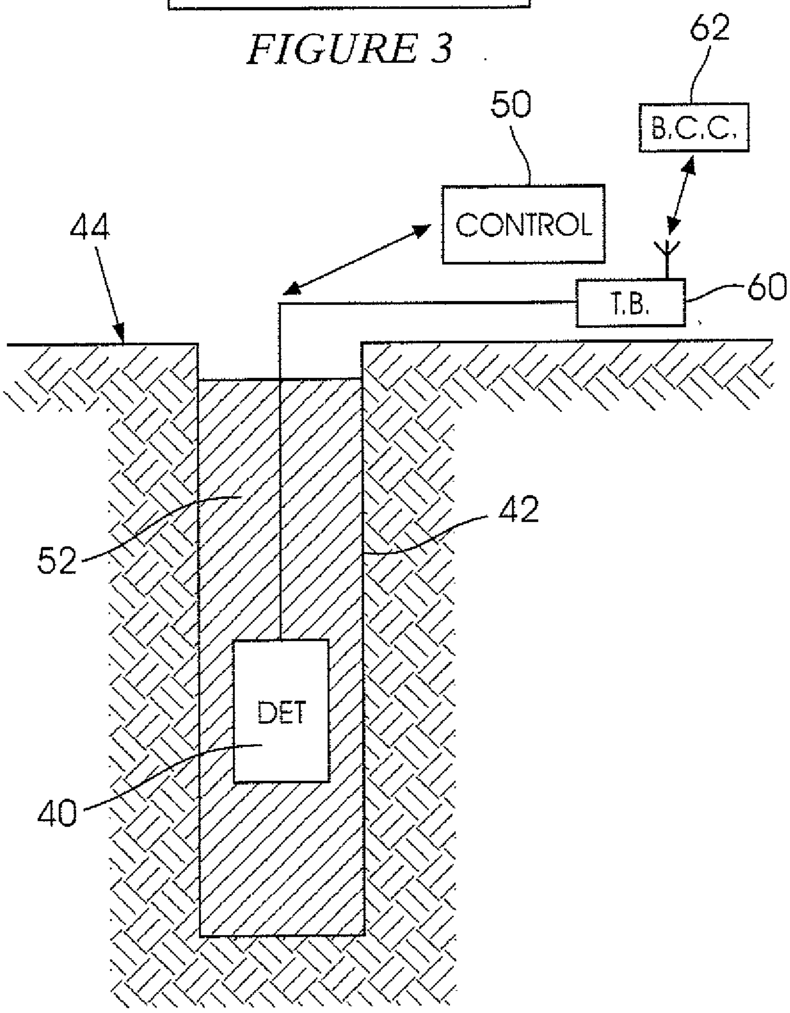

FIGURE 4