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2010/07921 4 November 2010 (04.11.2010) ZA(71) Applicant (for all designated States except US): **DET-NET SOUTH AFRICA (PTY) LTD** [ZA/ZA]; AECI Place, The Woodlands, Woodlands Drive, Woodmead (ZA).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **SCHLENTER, Craig, Charles** [ZA/ZA]; c/o AECI Place, The Woodlands, Woodlands Drive, Woodmead (ZA).(74) Agents: **MCCALLUM RADEMEYER & FREIMOND** et al.; 390 Kent Avenue, 2125 Randburg (ZA).

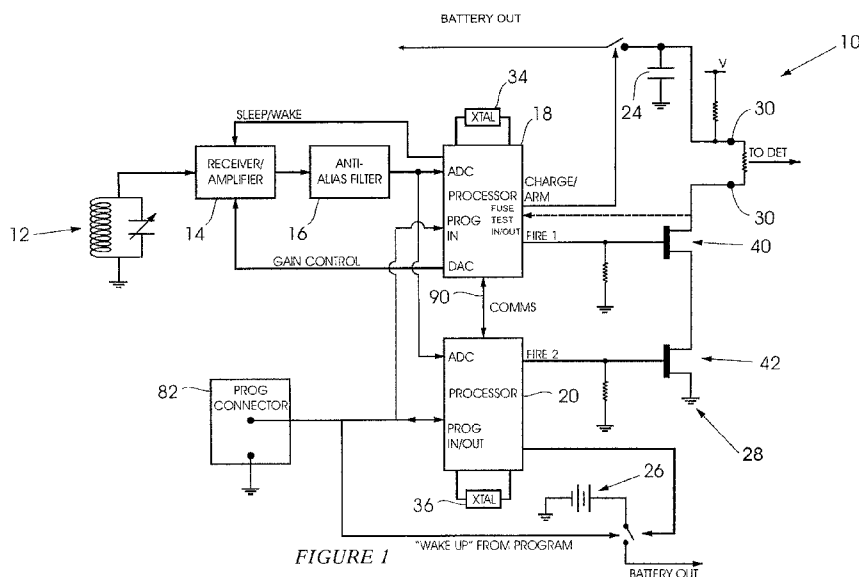
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(54) Title: WIRELESS BLASTING MODULE



(57) Abstract: A wireless blasting module which includes dual processors (18, 20) which process an output signal, produced in response to reception of a magnetic control signal, to control the connection of an energy source (26) to a detonator (DET) component.

WIRELESS BLASTING MODULE

BACKGROUND OF THE INVENTION

[0001] This invention relates to a wireless blasting module for detonating an explosive charge.

5 **[0002]** An electronic blasting system offers better timing accuracy than a pyrotechnic or shock tube-based system. This is particularly important so in an application in which improved rock fragmentation and low vibration are dependent upon accurate timing. Nonetheless, an electronic blasting system suffers from a disadvantage in that it is normally based on the use of an insulated electrical conductors or wires to
10 interconnect electronic detonators to one another and to a control device. The wires can be broken, for example when priming the blasting holes or during stemming procedures. Damage to the insulation on the wires can result in current leakage which, in turn, can impair communication capability. The wires, when positioned on an exposed surface, are also prone to damage by personnel and machinery.

15 **[0003]** A blasting system based on wireless techniques avoids the need for electrical conductors. However a wireless system can be expensive and there is an ongoing concern about safety levels inherent in this type of technology.

[0004] US2008/0307993A1 proposes wirelessly coupling blasting energy into detonators at blast time so that wireless blasting modules can function at low
20 voltages and currents before blast time. This technique does require a high power transmitter which is capable of transferring energy at the required level, through the rock which is to be blasted, to the blasting modules.

[0005] US4685396 is based on the use of a low voltage or low current power supply for a wireless module. Voltage step-up, amplification or charging circuitry is used to charge a firing capacitor prior to blasting. This approach does provide protection against directly connecting a wireless detonator battery to an initiating element but remains dependent on the circuitry not charging the firing capacitor inadvertently. This is an adverse safety factor.

[0006] US2010170411A1 is concerned with a military wireless initiation system for firing electrical detonators immediately upon receipt of a firing command. Use is made of dual processors, in a receiver, which are responsive to signals transmitted wirelessly from a control unit. These guard against inadvertent initiation due to failure of a single processor. However the system does not include a facility for delaying the initiation of detonators relative to the receipt of a fire command and the receiver is not suitable for deployment in a blast hole. The system appears to use radio frequency rather than magnetic communications and its capability of communicating through rock is severely compromised.

[0007] An object of the present invention is to provide a wireless blasting module of enhanced capabilities.

SUMMARY OF THE INVENTION

[0008] The invention provides a wireless blasting module which includes a receiver which, in response to at least one magnetic control signal transmitted in a wireless manner from a control device, produces at least one output signal, at least first and second processors which process the at least one output signal, an energy source, terminals to which a detonator component is connectable and a switching arrangement which is operative in response to a predetermined processing

relationship between the first and second processors thereby to connect the energy source to the terminals.

[0009] The detonator component may be a detonator, or an igniter for a detonator.

[0010] The use of a magnetic control signal provides an enhanced capability of establishing effective communication through a body of rock. The receiver, in the wireless blasting module, may thus be deployed inside a blast hole.

[0011] The blasting module may include a timer which executes a timing interval of predetermined duration. The duration of the timing interval may be variable and may be programmed into the module using any suitable technique. For example the duration of the timing interval may be programmed by means of a suitable command from the control device by coupling a control signal to the module at the time of deployment of the blasting module in a blast hole.

[0012] The wireless blasting module may include a delay timer which inhibits the module from going into an operative mode in which blasting is possible for a period which is commenced after deployment of the module in a blast system.

[0013] Forward error correction techniques or any other cryptographic or coding or communication system may be employed to improve reliability of transmission of the control signal and hence to guard against unintended initiation.

[0014] The receiver may be responsive to a plurality of control signals which are repeated at intervals and which contain substantially the same information but which include time-related information which enables successive signals to be differentiated from one another.

[0015] At least one of the processors may include an oscillator. The oscillator may be a crystal or ceramic resonator or RC oscillator. The oscillator is calibrated close to actual blasting time to avoid drift, ideally in response to a command signal from the control device. Each processor may be controlled by the same oscillator.

5 Alternatively each processor includes a dedicated oscillator.

[0016] The energy source may include a battery. An energy storage device such as a capacitor may be chargeable by the battery to accumulate sufficient energy for reliable initiation of a detonator.

[0017] The module may include at least one unique identifier. This may be in any suitable form and in this connection use may be made of a bar-coded system, an rfid or any other suitable mechanism or technique. At least one processor may store a unique identifier. The identifier may be assigned to the module under factory conditions or on site.

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[0018] Generally the quantity of power available at the receiver is low and communication from the wireless blasting module, positioned inside a borehole, cannot readily and reliably be effected as a result of signal attenuation by the surrounding rock mass. Thus use of the module must be based on the premise that reliable one-way communication from an external controller to the receiver, deployed in a blast hole, can be achieved. For this reason, at least, use is made of a magnetic control signal which has the capability of propagating, at least to some extent, through a body of rock; the use of redundancy techniques such as repeated transmission of commands; and the detection and elimination of errors in a signal received by the receiver – an aspect which can be addressed to some extent at least by use of forward error correction codes and similar techniques.

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[0019] The capability of transmitting in a reliable manner from an external controller to the receiver, deployed in a blast hole, means that a user-settable time delay can be assigned to the blasting module in an effective and reliable manner.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The invention is further described by way of example with reference to the accompanying drawings in which:

Figure 1 is a schematic representation of a wireless blasting module according to one form of the invention;

Figure 2 illustrates a possible physical relationship between the module and a detonator and booster; and

Figure 3 illustrates an established blasting system.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0021] Figure 1 of the accompanying drawings illustrates in block diagram form a circuit arrangement of a wireless blasting module 10 according to the invention. The module includes an antenna 12, a receiver/amplifier 14, a filter 16, first and second processors 18 and 20 respectively, a capacitor 24, a battery 26 and a switching arrangement 28 connected to output terminals 30. In use, a detonator or a detonator igniter of any appropriate construction, not shown, is connected to the terminals.

[0022] Each processor may be of any suitable kind and for example may be a microprocessor, an application-specific integrated circuit (ASIC), FPGA, custom-designed logic or the like. The processors may be physically separate from each other. Alternatively the processors are contained in the same package or are on the same silicon die.

[0023] In this embodiment the timing of each processor is controlled by an internal RC oscillator respectively dependent on (i.e. calibrated from) externally connected crystals 34 and 36. Such calibration techniques are known in the art. Each RC oscillator is used during a timing interval countdown to make the system insensitive to mechanical shock, for example from adjacent explosions that may influence the crystal oscillators.

[0024] The antenna 12 is a multi-directional device and modulation techniques and frequencies are chosen, as appropriate, for the specific application. The receiver 14 operates at a low frequency using through-the-earth magnetic communication techniques and pulse code modulation as are described, for example, in Microchip Application Note AN232. The receiver employs automatic gain techniques and strips noise through the use of filtering techniques implemented by means of analogue circuitry, through the use of DSP techniques implemented by means of digital circuitry, or by suitable software or firmware.

[0025] The output of the receiver 14, suitably amplified, is coupled, after passing through the filter 16, to each processor 18 and 20.

[0026] The switching arrangement 28 includes field effect transistors 40 and 42 which are respectively connected to outputs from the processors 18 and 20 and which are used to control discharge of the capacitor through a detonator or igniter connected to the terminals 30.

[0027] Referring to Figure 2 the module 10 is contained in a suitable housing 50 which carries a small eyelet or hook 52. The detonator component used, e.g. a detonator 54 embedded in a booster explosive 56, is attached to the housing 50 in any appropriate way. A cord, not shown, attached to the eyelet or hook is used as a

suspension arrangement whereby the combination of the module and the booster can be lowered into a blast hole at a blasting site. The housing 50 protects the module 10 from the ingress of liquids and against mechanical shock.

[0028] Figure 3 shows a blast site 60 which includes a plurality of boreholes 62. A control device 64 is connected to an output antenna 66 which is looped around the blast site and the boreholes. The control device, which controls the blasting process, includes a processor 68, a display 70, a keyboard or any other input device 72 connected to the processor, a key input 74 without which the processor is inoperative, a transmitting amplifier 76 which is connected to the loop antenna 66 and a radio frequency transmitter/receiver 78 for communication purposes with other blasting equipment via an antenna 80.

[0029] Each borehole 62 contains explosive material and one or more blasting modules with attendant detonators and boosters, according to requirement.

[0030] Each module is supplied to a user point in a non-powered state. Typically the module is supplied with the battery 26 separate from the other components.

[0031] The battery 26 may be disconnected from the remainder of the circuit electronically or by means of a physical switch. Alternatively the battery may be attached to the remainder of the module by a user. A battery pull tab could be used to connect the battery to a circuit or a switch in the module could be activated, when necessary, by a user.

[0032] A printed barcode, rfid or an internal identifier stored in one or both of the processors is used for tracking purposes. The identifier which is assigned to the module may be unique for a particular blast and may be assigned by a programmer.

Alternatively the identifier may be unique in an absolute sense and may be an identifier which is supplied under factory conditions.

[0033] As is shown in Figure 1 the module 10 optionally includes a programming connector 82. By connecting a suitable programming unit to the connector an electronic latching switch can be activated to power the module. It is also possible to activate the module using a radio or magnetic signal but this is less desirable for the capability of activation over a distance inherently reduces the safety characteristics of the module.

[0034] Firing time information for the module is supplied to the programming connector 80 by means of a programming machine. This can happen at any appropriate time before a fire command is sent to the module. The firing time (delay time) could be pre-programmed in a factory environment. Commands which are sent via the programming connector 82 make use of appropriate acknowledgement and cyclic redundancy checks to ensure proper receipt of the commands. In another approach delay time information, originated from a programming machine, is supplied to the module in a wireless manner, for example from the control device 64 to the receiver 14 using a magnetic signal – this can be done reliably and effectively using a magnetic signal which can propagate through a rock body even once the module has been deployed in a blast hole. As communication between the control unit and the module is in one direction only each signal which is transmitted to the module should make use of forward error correction techniques. Alternatively or additionally each signal should be repeated at least once to enhance reliability.

[0035] The output of the receiver 14 is directed to each processor. An important aspect of this invention is that the processors must execute a predetermined processing interactive relationship in order for reliable firing of the detonator to take

place. Various techniques can be adopted in this respect and the scope of the invention is by no means limited to the following examples. In one instance, as shown in Figure 1, each processor controls a separate, series-connected fire switch i.e. the transistors 40 and 42 respectively which are in series with the energy storage capacitor 24. Alternatively or additionally, commands between the processors 18 and 20 must be validated. A communications link 90 between the processors enables each processor to verify the state of the other processor. Another technique requires the removal of a controlled electrical short circuit over the output of the capacitor 24. Separate commands may be required for each processor so that each processor produces a predetermined output signal which leads to firing of the detonator. The commands are preferably suitably encoded but the use of a preamble, forward error correction and a cyclic redundancy check is desirable to ensure reliable command reception.

[0036] In an alternative or additional approach a command transmitted by the control device 64 is repeated at least once but preferably a number of times. When this occurs each successive command is identical to a preceding command but contains time information to enable the command to be distinguished from the preceding command. By way of example only four identical ARM commands may be transmitted at spaced time intervals. Thereafter, subject to validation and conventional control aspects, four FIRE commands may be transmitted in succession at fixed time intervals. The FIRE commands may be distinguished from one another by means of information stored in the processors beforehand. For example a first fire command may be "FIRE + 3"; a second fire command may be "FIRE + 2"; a third fire command may be "FIRE + 1"; and a fourth fire command may be "FIRE". Receipt of any of these commands, suitably interpreted by one or both processors means that firing must take place after three delay periods, two delay periods, one

delay period, and zero delay period, as the case may be. Thus receipt of only one fire command is sufficient to cause firing to take place at a desired time. The fire commands thus contain data relating to an offset time to be added to a countdown sequence upon reception. By modifying the offset time which is sent with each successive fire command receipt of any one fire command results in an accurate execution thereof i.e. in an accurately timed firing event. Similarly, substantially identical arm commands can be distinguished from each other. For calibration purposes, substantially identical START_CALIBRATE and STOP_CALIBRATE commands may respectively be distinguished from each other.

[0037] At least one of the processors 18 and 20 includes a software timer which generates a delay period during which detonator firing is prohibited and prevented. This can be done by directly connecting the terminals 30 to each other or by introducing an open circuit into the firing circuit, during the deployment period. A similar safeguard can be achieved by making use of a hardware delay timer.

[0038] If the detonator uses a fuse as an initiation element then the resistance of the fuse may be tested and reported to the programming unit which is connected to the programming connector 82, during an installation phase. Other self-tests and diagnostic tests such as the voltage of the battery 26, firmware revisions and checksums of firmware and cyclic redundancy checks, can also be implemented. If the detonator is electronic, commands may be sent to the detonator to establish the status and efficacy of the electronic detonator.

[0039] The module preferably enters a low power state after a user-settable time delay if no wireless commands are received. The receiver circuit may optionally be turned off at the same time. At user-settable intervals the receiver 14 is powered for a user-settable period during which the receiver is responsive to a signal from the

control device. This technique helps to conserve energy consumption. Receipt of a control signal during a powered interval might act to postpone a following sleep period or, equivalently, extend the powered interval – this is useful for example if a blast is to be commenced or a sequence of commands is to be sent to the modules and, during that interval, the modules must be responsive to all commands.

[0040] The use of an ARM command has been referred to. This signal is transmitted to the processors by the receiver if a time period is required for the charging of the capacitor 24 or if preparatory commands must be sent to the detonator (for example). Upon receipt of an ARM command one or both processors may execute a timing interval. If a FIRE command is not forthcoming during the timing interval the module may again enter a safe state, for example by sending specific commands to the detonator component, so that the detonator component cannot be fired. The capacitor 24, if charged during this period, can alternatively or additionally be discharged.

[0041] The control device may also be operable to transmit a disarm command which operates in a similar manner to place the module in a safe state.

[0042] Commands to the processors may be repeated to enhance reliability and forward error correction techniques may be employed, as appropriate.

[0043] Prior to each module/detonator assembly being placed in a blast hole a user connects each module to the programming unit to enable the module. The programming unit supplies the module with a fire command which is unique to the given blast, and a firing time. Each blast hole is loaded with explosive, as desired, and one or more modules are placed in each blast hole. Subsequently the wire loop

antenna 66 is placed around the blast zone (panel) and is connected to the control unit (blasting machine) which is in a safe location.

5 **[0044]** The control device, possibly under the control of a wired or wireless blast coordinating machine which is communication with the control unit, supplies an appropriate sequence of commands which, as indicated, may include a sequence of ARM commands followed by a sequence of FIRE commands.

10 **[0045]** Each processor, upon receipt of a first validated FIRE command, adds the supplied fire offset, in the FIRE command, to a local firing time and commences an adjusted firing countdown sequence. After receipt of one validated FIRE command no further wireless commands are processed. The antenna 12 and receiver 14 can be clamped to prevent interference that may occur during the blasting sequence.

15 **[0046]** Preferably the FIRE command includes a cryptographically secure blast identifier that must match an identifier previously loaded into the module via the programming connector 82 for the FIRE command to be considered as valid. In this way separate blasts may be programmed with different blast identifiers and initiated at different times by the control unit.

20 **[0047]** In an alternative approach the FIRE command which is required for initiation is supplied to the detonator by the programming unit which is connected to the programming connector. This allows the detonators to be shipped with no valid FIRE command. Another possibility is for the FIRE command to be randomly generated on site on a per blast basis using any suitable technique such as a cryptographically secure, pseudo random number generator in the programming unit.

[0048] The loop 66 may be tuned manually or automatically using appropriate techniques in order to achieve an appropriate output level so that effective coupling

to the wireless detonator modules results. One such technique is to switch appropriately valued capacitors into an effective LC loop resonant circuit.

[0049] The required output voltage or power of the loop 66 may be calculated based on the depth of the wireless blasting modules, the expected attenuation due to the rock medium being blasted, a safety factor and the minimum receiver level required by the wireless blasting modules. This can be used as the basis for a “go/no-go” decision as to whether the modules will all satisfactorily receive the signal to blast. This is an important criterion as the communication to the detonators is unidirectional.

CLAIMS

- 1 A wireless blasting module which includes a receiver which, in response to at least one magnetic control signal transmitted in a wireless manner from a control device, produces at least one output signal, at least first and second
5 processors which process the at least one output signal, an energy source, terminals to which a detonator component is connectable and a switching arrangement which is operative in response to a predetermined processing relationship between the first and second processors thereby to connect the energy source to the terminals.
- 10 2 A blasting module according to claim 1 which includes a delay timer which inhibits the module from going into an operative mode in which blasting is possible, for a period which is commenced after deployment of the module in a blast system.
- 15 3 A blasting module according to claim 1 or 2 wherein the receiver is responsive to a plurality of control signals which are repeated at intervals and which contain substantially the same information but which include time-related information which enables successive signals to be differentiated from one another.
- 20 4 A blasting module according to claim 1 wherein at least one of the processors includes an oscillator which is calibrated in response to a command signal from the control device.
- 5 5 A blasting module according to any one of claims 1 to 4 which includes at least one unique identifier.

- 6 A blasting module according to any one of claims 1 to 5 wherein the receiver operates using through-the-earth magnetic communication techniques and pulse code modulation.
- 7 A blasting module according to claim 1 which includes first and second
5 switches, which are connected in series with each other, the energy source and the detonator component, and which are operable respectively by the first and second processors.
- 8 A blasting module according to claim 1 which includes a programming
10 connector which receives firing time information from a programming machine.
- 9 A blasting module according to claim 1 wherein the receiver is responsive to a magnetic signal from the control device thereby to receive firing time information from a programming machine.
- 10 A blasting module according to claim 1 wherein the receiver is responsive to
15 each of a plurality of successive commands, wherein each command is identical to a preceding command but contains time information to enable the command to be distinguished from the preceding command whereby receipt of only one command results in an accurate execution thereof.
- 11 A blasting module according to claim 1 wherein the receiver is turned off after
20 a user-settable time delay if no wireless commands are received and thereafter, at user-settable intervals the receiver is powered for a user-settable period during which the receiver is responsive to a signal from the control device.

12 A blasting module according to claim 1 wherein upon receipt of an ARM command by the receiver at least one processor executes a timing interval and if a FIRE command is not received during the timing interval it is not possible to fire the detonator component.

5 13 A combination comprising a housing, a suspension arrangement on the housing, a detonator module according to claim 1 in the housing, and a booster explosive in which the detonator component is embedded.

14 A blasting system which includes a blast site, a plurality of boreholes at the site, an output antenna looped around the boreholes, a control device
10 connected to the looped antenna, explosive material in each borehole, and at least one respective blasting module according to claim 1 in each borehole, and wherein the control device produces a magnetic control signal to establish unidirectional communication with each receiver, in the respective blasting modules.

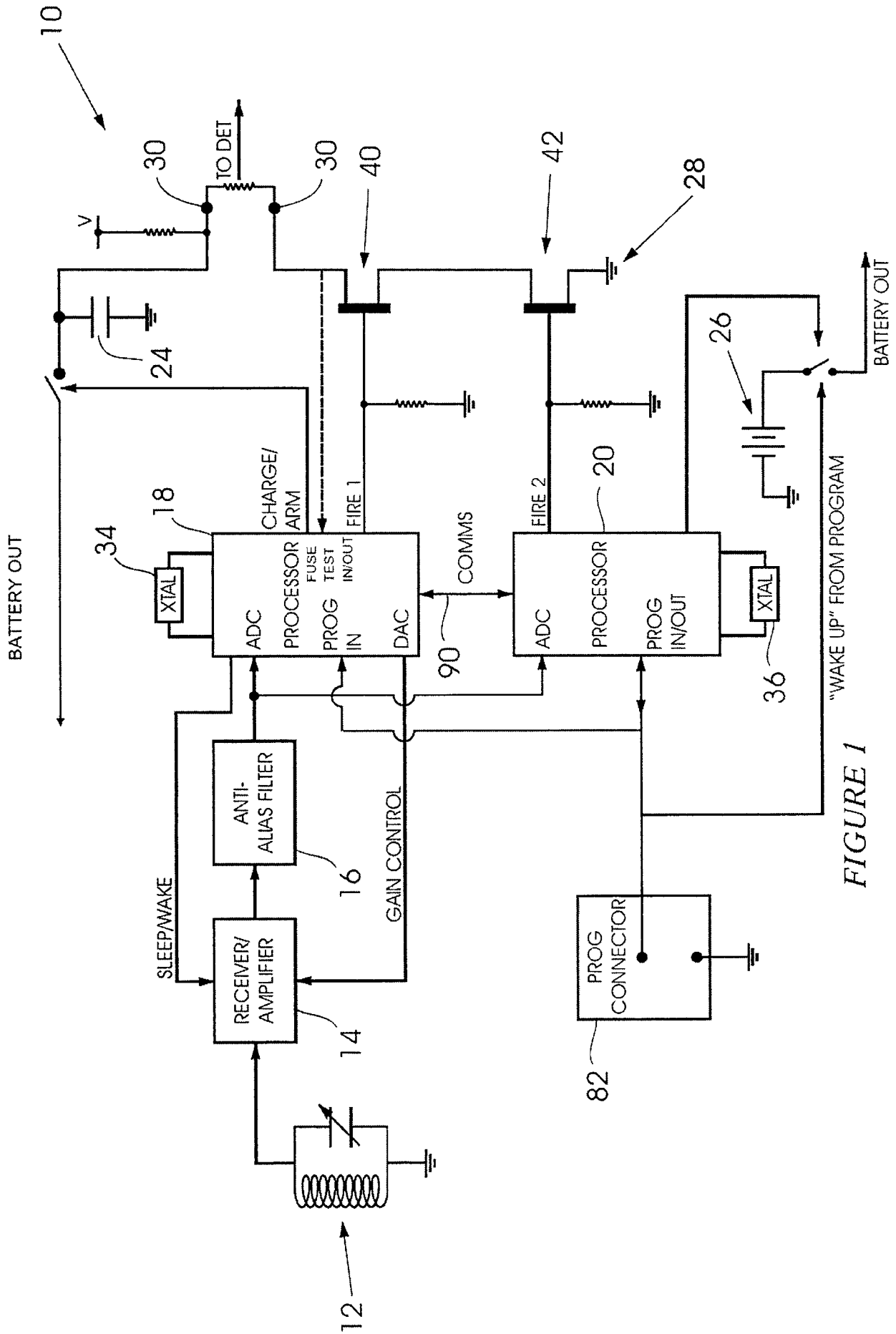


FIGURE 1

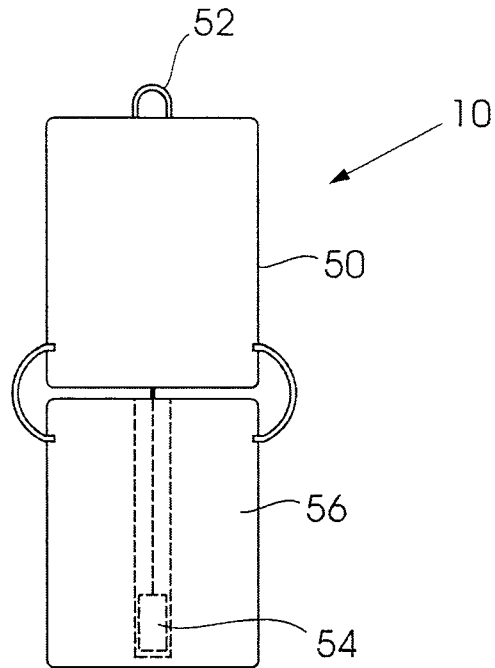


FIGURE 2

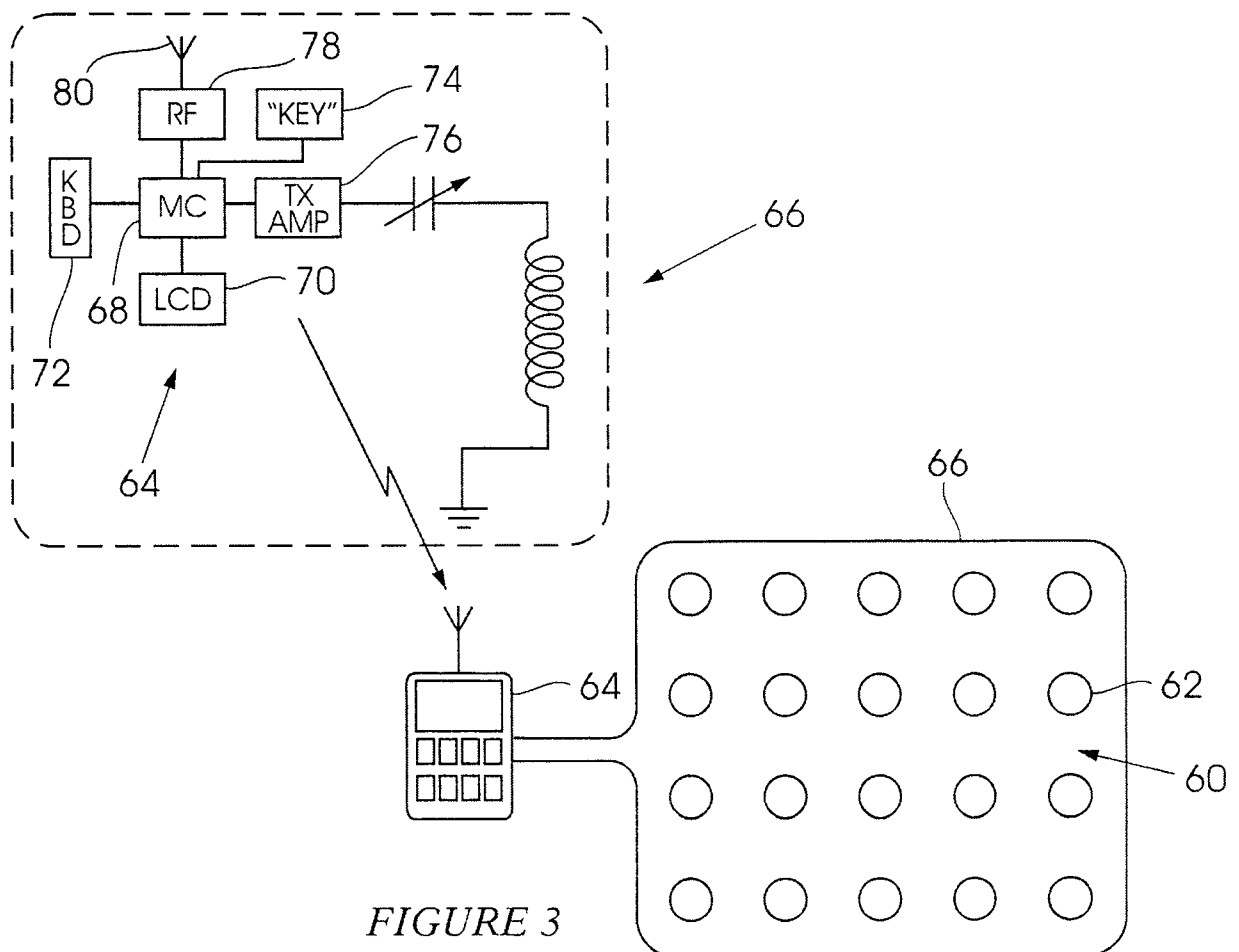


FIGURE 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/ZA2011/000072

A. CLASSIFICATION OF SUBJECT MATTER
INV. F42C15/42 F42D1/055
ADD.

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)
F42C F42D

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

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

EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	US 6 105 688 A (VAYNSHTEYN VLADIMIR [US] ET AL) 22 August 2000 (2000-08-22) column 1, lines 59-62 column 4, lines 15-38 column 6, line 49 - column 8, line 6 figure 9	1-14
A	US 4 884 506 A (GUERRERI CARL N [US]) 5 December 1989 (1989-12-05) column 5, line 50 - column 6, line 63 figure 3	1,3,10, 13,14
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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
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"P" document published prior to the international filing date but later than the priority date claimed

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"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

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Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Gex-Collet, A

INTERNATIONAL SEARCH REPORT

International application No

PCT/ZA2011/000072

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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