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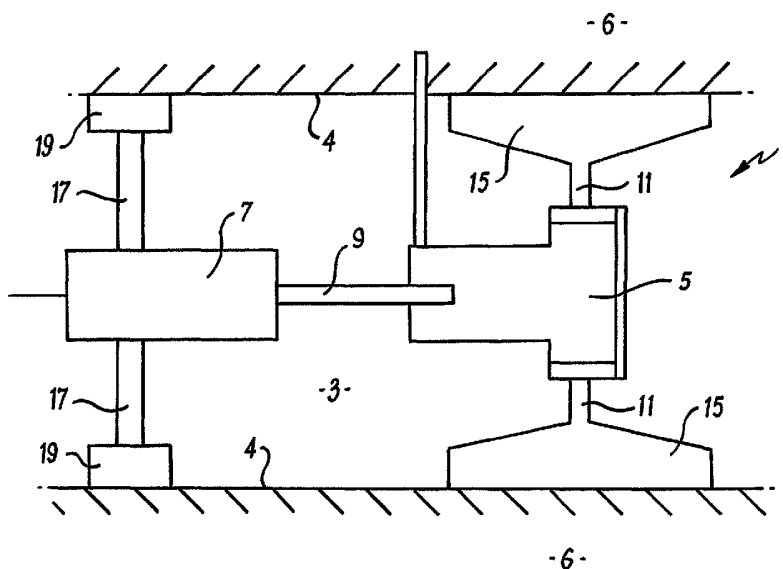
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[Continued on next page]

(54) **Title:** A MAGNETOSTRICTIVE DOWNHOLE SEISMIC SOURCE



(57) **Abstract:** There is disclosed a downhole seismic source which uses a magnetostrictive transducer (7) that is hydraulically coupled to contact members (15) in contact with the wall of a borehole. In one embodiment, there is disclosed a system for use in a borehole (3) in an earth formation (6), the system comprising a downhole assembly conveyed in the borehole; a magnetostrictive transducer (7) on the downhole assembly which produces a mechanical displacement of a coupling member (9) when activated by an electrical signal from a source thereof; at least one contact member (15) in contact with a wall (4) of the borehole and hydraulically coupled to the transducer, the at least one contact member producing a seismic signal in the formation in response to the mechanical displacement of the coupling member.

WO 2006/051298 A1



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1 **A Magnetostrictive Downhole Seismic Source**

2

3 The present invention relates to improvements in seismic
4 source devices, and in particular to but not restricted
5 to magnetostrictive sources for use during in borehole
6 investigations of the sub-surface in oil and gas
7 exploration.

8

9 Seismic sources are used to propagate an acoustic signal
10 into the earth, which is to be subsequently detected at
11 appropriately designed receivers that record the signal.
12 The purpose of seismic source/receiver systems is to
13 determine properties of the earth in the region between
14 the source and receivers. Typically, the characteristic
15 velocity of a rock formation, the acoustic impedance, or
16 other reflection characteristics are investigated. Such
17 investigations reveal information regarding the structure
18 of the earth local to the source and receiver.

19

20 Seismic investigations can be conducted on a number of
21 scales. In many cases it is desirable to deploy seismic
22 sources and receiver arrays together in a single well to

1 investigate the formation properties near to the
2 wellbore. Upon drilling of a well, data may be
3 interpreted to assist and guide drilling of the well.
4 Specifically, a recorded signal that has been reflected
5 back from a particular target can provide early warning
6 of a problematic structure that should not be drilled.

7

8 A seismic source is driven in a manner that enables a
9 signal with a particular form to be generated and
10 transmitted. In general, it is desirable to have
11 accurate control of the source signal. An accurate and
12 reproducible source signal facilitates processing of the
13 receiver signal into an interpretable form. Signals may
14 be constructed to have a particular frequency content or
15 amplitude and phase attributes selected for a given task.
16 In the case of sub-surface imaging, the ability to
17 resolve sub surface structures at various ranges from the
18 source is a major consideration for designing an
19 appropriate source signal.

20

21 In downhole applications, a number of different sources
22 have been used, but they suffer from a number of
23 deficiencies and drawbacks. A common type of seismic
24 source is an electro-mechanical source, which produces a
25 seismic signal from a mechanical impact generated in
26 response to an electrical input signal. These sources
27 rely on the impact between components which, in general,
28 is difficult to accurately repeat. For example, each
29 time there is an impact, differing amounts of energy are
30 dissipated as friction. Such unclean impacts make it
31 difficult to generate a well-defined pulse. These
32 sources operate over a limited frequency band, typically

1 up to about 400 Hz. This compromises resolution and the
2 ability to process the data effectively.

3

4 Piezo-electric sources have been used in sonar
5 applications for looking ahead of the bit whilst
6 drilling. However, in general, such systems do not
7 transfer energy efficiently to the source and into the
8 earth.

9

10 A further type of seismic source is a magnetostrictive
11 source, which contains an electric coil/magnet transducer
12 for turning electric input pulses into mechanical pulses.
13 These devices have been developed to generate signals
14 over a wide frequency range. The best known
15 magnetostrictive device is a reaction-mass source
16 developed by Sandia National Laboratories, which was
17 designed for environmental applications. In this source,
18 the transducer displaces a large mass in order to create
19 the seismic signal. As a result, a significant current
20 must be generated in the transducer coil in order to move
21 the mass. This requirement causes difficulties when
22 generating a signal because as the current is switched, a
23 significant back EMF results, which can burn out the
24 transducer coils.

25

26 Another disadvantage of this system is that strong
27 resonances are generated in the borehole which interfere
28 with transmission of the primary signal. Furthermore,
29 this source is designed to be deployed alone in a
30 borehole separate without other downhole instruments
31 deployed during drilling. Thus, in order that this
32 source can be used for seismic imaging during drilling,
33 the existing downhole tool string must be removed from

1 the borehole, prior to deploying the source. This
2 generates significant expense and poses practical
3 problems particularly where there is a jointed pipe
4 system already in place.

5

6 Other problems are manifest in downhole source
7 arrangements where the sources are attached to and
8 suspended from individual wire lines, or, are attached to
9 the tool strings, which are typically deployed for
10 investigations in connection with the drilling process.
11 Such source arrangements inhibit effective coupling into
12 the source signal into the earth, and, as a result, a
13 significant portion of the transmitter signal may become
14 trapped in the well, for example, as a standing wave
15 providing unwanted secondary coherent noise sources.
16 Much of the transmitted signal power is also lost in
17 these situations.

18

19 It is one aim of the invention to provide a downhole
20 seismic source that mitigates or at least obviates
21 limitations of prior art systems.

22

23 It is another aim of the invention to provide a downhole
24 seismic source capable of transmitting a broadband
25 acoustic signal during deployment of tool strings in the
26 borehole.

27

28 It is another aim of the invention to provide a
29 magnetostrictive downhole seismic source that couples
30 effectively to the walls of the well.

31

32 Other aims and objects of the invention will become
33 apparent upon reading the following description.

1

2 According to a first aspect of the present invention,
3 there is provided a system for use in a borehole in an
4 earth formation comprising:

- 5 (a) a downhole assembly conveyed in the borehole;
6 (b) a magnetostrictive transducer on the downhole
7 assembly which produces a mechanical
8 displacement of a coupling member when
9 activated by an electrical signal from a source
10 thereof;
- 11 (c) at least one contact member in contact with a
12 wall of the borehole and hydraulically coupled
13 to the transducer, the at least one contact
14 member producing a seismic signal in the
15 formation in response to the mechanical
16 displacement of the coupling member.

17

18 Preferably, the magnetostrictive transducer comprises an
19 alloy of terbium, dysprosium, and iron.

20

21 The electrical signal may be selected from the group
22 consisting of (i) a pseudo-random binary sequence, and
23 (ii) a swept frequency signal.

24

25 The system may further comprise a plurality of extension
26 devices which maintain the transducer substantially in a
27 fixed position in the borehole.

28

29 The hydraulic coupling may be provided by:

- 30 (i) a master cylinder having an axis substantially
31 parallel to an axis of the borehole, and
32 (ii) at least one slave cylinder coupled through an
33 extension device to the at least one contact

1 member, the at least one slave cylinder
2 oriented substantially orthogonal to the master
3 cylinder.

4

5 The signal may further comprise a pseudo-random binary
6 sequence, and the source of the electrical signal may
7 further comprise a shift register provided with a
8 negative feedback loop.

9

10 The at least one contact member may further comprise a
11 pair of opposed contact members.

12

13 Conveniently, the system further comprises a conveyance
14 device which conveys the downhole assembly into the
15 borehole, the conveyance device selected from (i) a
16 wireline, (ii) a slickline, and (iii) a drilling tubular.
17 The system may further comprise a receiver which produces
18 an output responsive to the propagation of the seismic
19 signal through the earth formation. Conveniently, the
20 system further comprises a processor which determines
21 from the output of the receiver and the electrical signal
22 a travel time of the seismic signal from the at least one
23 contact member to the receiver.

24

25 According to a second aspect of the present invention,
26 there is provided a method of evaluating an earth
27 formation comprising:

- 28 (a) conveying a downhole assembly into a borehole
29 in the earth formation;
30 (b) providing an electrical signal to a
31 magnetostrictive transducer in the
32 downhole assembly and producing a mechanical

1 displacement of a coupling member coupled to
2 the transducer; and

3 (c) hydraulically coupling at least one contact
4 member in contact with a wall of the borehole
5 to the coupling member and producing a seismic
6 signal in the formation in response to the
7 mechanical displacement.

8

9 The step of providing the electrical signal may further
10 comprise using at least one of (i) a pseudo-random binary
11 sequence, and (ii) a swept frequency signal.

12

13 The method may further comprise using a plurality of
14 extension devices for maintaining the transducer
15 substantially in a fixed position in the borehole.

16

17 Conveniently, the step of hydraulically coupling the at
18 least one contact member in contact with the wall of the
19 borehole further comprises using a master cylinder and at
20 least one slave cylinder coupled through an extension
21 device to the at least one contact member.

22

23 The signal may comprise a pseudo-random binary sequence,
24 and the step of providing the electrical signal may
25 further comprise using a shift register provided with a
26 negative feedback loop.

27

28 Conveniently, the at least one contact member may further
29 comprise a pair of opposed contact members.

30

31 The method may further comprise conveying the
32 magnetostrictive transducer into the borehole on one of

1 (i) a wireline, (ii) a slickline, and (iii) a drilling
2 tubular.

3

4 Conveniently, the method further comprises the step of
5 detecting the propagation of the seismic signal through
6 the earth formation.

7

8 The method may also comprise determining from the
9 detected signal a travel time of the seismic signal
10 through the formation.

11

12 According to a third aspect of the present invention,
13 there is provided a computer readable medium for use with
14 a system for use in a borehole in an earth formation, the
15 system comprising:

16 (a) a downhole assembly conveyed in the borehole;

17 (b) a magnetostrictive transducer on the downhole
18 assembly hydraulically coupled to at least one
19 contact member in contact with a wall of the
20 borehole;

21 the medium comprising instructions which enable
22 a processor to provide a signal to the
23 magnetostrictive transducer which causes the at
24 least one contact member to produce a seismic
25 signal in the formation.

26

27 Preferably, the medium further comprises at least one of
28 (i) a ROM, (ii) an EPROM, (iii) an EAROM, (iv) a flash
29 memory, and (v) an optical disk.

30

31 According to a fourth aspect of the invention there is
32 provided a seismic source comprising a magnetostrictive
33 transducer, and coupling means for coupling the

1 transducer to a formation, wherein the coupling means
2 includes a hydraulic coupling arrangement.

3

4 Preferably, the seismic source is adapted to be run in
5 and coupled to a borehole.

6

7 More preferably, the seismic source is adapted to be run
8 on a drill string.

9

10 Preferably, the magnetostrictive transducer comprises an
11 alloy of terbium, dysprosium, and iron.

12

13 More preferably, the magnetostrictive transducer is a
14 Terfenol-D [™] transducer.

15

16 Terfenol-D is a trade mark of Etrema Products, Inc of
17 Indiana, USA.

18

19 Preferably, the coupling arrangement comprises a
20 hydraulic master cylinder coupled to the transducer.

21

22 More preferably, the hydraulic master cylinder is coupled
23 to the transducer on a substantially longitudinal axis of
24 the borehole.

25

26 Preferably, the coupling arrangement comprises a
27 plurality of slave cylinders coupled to the master
28 cylinder and the borehole.

29

30 More preferably, the coupling arrangement is adapted to
31 transmit a substantially non-directional signal in the
32 formation.

33

1 More preferably, the coupling arrangement comprises
2 pressure pads adapted to transmit an output signal from
3 the slave cylinders to the formation.

4

5 Preferably, the slave cylinders are oriented
6 substantially radially in the borehole.

7

8 More preferably, two slave cylinders are provided
9 oriented substantially in the same axis.

10

11 Optionally, the coupling means comprises a pair of fixing
12 cylinders adapted to fix the transducer radially within
13 the wellbore.

14

15 Preferably, activating means is provided for activating
16 the coupling arrangement by moving it from a first
17 position in which it is free from the borehole to a
18 second position in which it is coupled to the borehole.

19

20 More preferably, the fixing means increases the hydraulic
21 pressure in the slave cylinders and the fixing cylinders.

22

23 The seismic source may be adapted to be driven by a
24 digital binary electronic signal.

25

26 The digital binary electronic signal may be a pseudo-
27 random binary sequence (PRBS).

28

29 Preferably, the PRBS is provided at low voltages.

30

31 Preferably, the PRBS is a maximal length (ML) sequence,
32 providing broadband frequency signal characteristics.

33

1 Preferably, the ML PRBS can be generated using a 10-stage
2 negative feedback shift register, having two feedback
3 taps combined into an XOR logic gate and modulo-2 summed.
4

5 According to a fifth aspect of the invention there is
6 provided a seismic source comprising a magnetostrictive
7 transducer, and coupling means for coupling the
8 transducer to a formation, wherein the seismic source is
9 adapted to be driven by a pseudo-random binary sequence
10 (PRBS).

11

12 Preferably, the PRBS is provided at low voltages.

13

14 Preferably, the PRBS is a maximal length (ML) sequence,
15 providing broadband frequency signal characteristics.

16

17 Preferably, the ML PRBS is generated using a 10-stage
18 negative feedback shift register, having two feedback
19 taps combined into an XOR logic gate and modulo-2 summed.
20

21 According to a sixth aspect of the invention there is
22 provided a seismic source comprising a transducer and
23 coupling means for coupling the transducer to a
24 formation, wherein the coupling means includes a
25 hydraulic coupling arrangement.

26

27 Preferably, the seismic source is adapted to be run in
28 and coupled to a borehole.

29

30 More preferably, the seismic source is adapted to be run
31 on a drill string.

32

1 According to a seventh aspect of the invention there is
2 provided a seismic signal transmission system comprising;
3 - a seismic source coupled to a formation,
4 - means for driving the seismic source using a
5 pseudo-random binary sequence (PRBS) to cause a
6 signal to propagate in a formation,
7 - means for receiving a signal from the formation.

8

9 Preferably, the PRBS is provided at low voltages.

10

11 Preferably, the PRBS is a maximal length (ML) sequence,
12 providing broadband frequency signal characteristics.

13

14 Preferably, the ML PRBS is generated using an nth stage
15 negative feedback shift register, having two feedback
16 taps combined into an XOR logic gate and modulo-2 summed.

17

18 Preferably, the seismic source is adapted to be run in
19 and coupled to a borehole.

20

21 More preferably, the seismic source is adapted to be run
22 on a drill string.

23

24 According to an eighth aspect of the invention there is
25 provided a method of transmitting an acoustic signal in a
26 formation the method comprising the steps of;

27

a. providing a seismic source,

28

b. coupling the seismic source to the
29 formation by a hydraulic coupling
30 arrangement,

31

c. driving the seismic source to cause an
32 acoustic signal to be transmitted in the
33 formation.

1

2 Preferably, step a. involves running the seismic source
3 on a drill string.

4

5 Preferably, the step c. is carried out using a pseudo-
6 random binary sequence (PRBS).

7

8 Preferably, the seismic source is the seismic source of
9 any of the fourth, fifth or sixth aspects of the
10 invention.

11

12 There will now be described, by way of example only,
13 embodiments of the invention with reference to the
14 following drawings, of which:

15

16 Figure 1 is a side view line drawing of a downhole
17 magnetostrictive seismic source in accordance with
18 an embodiment of the invention;

19

20 Figure 2A is a state transition diagram for a Finite
21 State Machine (FSM) in accordance with an embodiment
22 of the invention;

23

24 Figure 2B is a schematic representation of a
25 downhole magnetostrictive seismic signal generation
26 and interpretation system in accordance with an
27 embodiment of the invention;

28

29 Figure 3 is a line graph of a processed output
30 signal in accordance with an embodiment of the
31 present invention; and

32

1 Figure. 4 illustrates the arrangement of source and
2 sensors using the source of the present invention;

3
4

5 With reference firstly to Figure 1, there is depicted a
6 downhole magnetostrictive seismic source at 1. The
7 source 1 is located within the wellbore 3. The source 1
8 comprises a master cylinder 5 at an operational end, and,
9 a magnetostrictive transducer 7 is located at an input
10 end. The transducer 7 and the master cylinder 5 are
11 connected along a longitudinal axis by a push rod 9,
12 which displaces relative to the master cylinder 5 in
13 accordance with mechanical displacement generated by the
14 transducer 7. The transducer 7 converts electrical
15 pulses into mechanical motion along the longitudinal axis
16 of the transducer 7. The push rod 9 is attached to the
17 transducer such that an electrical signal in the coil is
18 transferred to a mechanical movement of the push rod 9.
19 The push rod may be referred to as a coupling member.
20 For the purposes of the present invention, the geometry
21 of the coupling member is not important.

22

23 In this example, the source is a Terfenol-D™ transducer,
24 marketed by Etrema Products, Inc of Indiana, USA.

25

26 In this embodiment, a set of slave cylinders 11 are
27 attached to the master cylinder 5 and are provided with
28 large-area pressure pads 15 that are located against the
29 walls 4 of the well bore 3. A set of fixing cylinders 17
30 attached to the transducer 7 have a set of pressure pads
31 19 located against the well bore wall 4. The individual
32 cylinders of the slave cylinders 11 and the fixing
33 cylinders 17 substantially oppose each other and are

1 positioned perpendicularly to the longitudinal axis of
2 the source.

3

4 The above arrangement provides means for securing and
5 locating the source in the borehole. The slave pistons
6 11 and fixing pistons 17 displace radially away from the
7 main cylinder 5 and transducer 7 according to forces
8 imposed on them due to the pressure exerted on the walls
9 of the cylinder 5. In turn, this force is transferred to
10 the pressure pads 15 and 19 and is applied against the
11 borehole walls 4. In this case, the master cylinder 5 is
12 a hydraulic cylinder containing hydraulic fluid. In a
13 test environment (which will be described in more detail
14 below), initial pressurisation is provided manually by a
15 hand operated pump. It will be appreciated, however,
16 that pressure may be supplied in the downhole environment
17 via control line or the like, or utilising wellbore
18 pressure, through a control valve assembly. Pressurising
19 the master cylinder 5 simultaneously attaches the slave
20 cylinders and fixing cylinders via pressure pads 15 and
21 19. Once the source is attached, the hydraulic link
22 between the fixing cylinder set 17 and the master
23 cylinder 5 is terminated by sealing a valve between them.
24 This removes the possibility of pressure variations
25 occurring in the fixing cylinder set 17 as a result of
26 mechanical displacement of the push rod 9 into the master
27 cylinder 5.

28

29 Upon increasing the pressure within cylinder 5 by
30 insertion of the push rod 9 into the master cylinder 5,
31 the slave pistons 11 exert a force through pressure pads
32 15 to the wellbore walls 3. Through this mechanism there

1 is transmitted an acoustic signal to the rock formation
2 6.

3

4 Mechanical displacement of the rod 9, caused by the
5 transducer 7, into the cylinder 5, exerts a fluid
6 pressure force on the hydraulic fluid within the cylinder
7 5 and in turn causes an increase in pressure within the
8 cylinder 5. The pressurised fluid exerts a force against
9 the walls of the master cylinder 5, which is transferred
10 to the slave cylinders 11 of the master cylinder 5, to
11 the pressure pads 15 acting against the well formation 6.
12 In accordance with this mechanism, a signal generated by
13 mechanical displacement of the transducer 7 and push rod
14 9, leads to increases and decreases in force applied to
15 the walls of the master cylinder 5, and, in turn, leads
16 to pressure pulses applied to the well bore through the
17 pressure pads 15. As a result a seismic signal is
18 transmitted through the pads 15 into the well formation
19 6.

20

21 Hydraulic attachment of the source to the borehole
22 provides advantages. Because the pressure pads are in
23 contact with the rock formation, the applied source
24 signal has an effective coupling to the formation. This
25 coupling minimizes any source energy trapped within the
26 borehole, thus, reducing the occurrence of tube standing
27 waves and resonances, which are otherwise susceptible to
28 occur.

29

30 In addition, this source arrangement provides a method
31 through which relatively small displacements of the push
32 rod 9 into the cylinder 5 yield the production of
33 significant pressure at the pressure pads 11.

1 Furthermore, this system is considerably lighter than
2 existing magnetostrictive downhole sources/systems,
3 making it easier to deploy. The clamp design and
4 relatively low power requirements for driving the source
5 allows attachment of the source to the tool string
6 deployed in connection with drilling of a well. This
7 prevents any need to remove the tool string prior to
8 carrying out a seismic borehole investigation, for
9 example, for sub-surface structural investigations for
10 use in the direction of the drilling process.

11

12 Furthermore, the source couples effectively with the well
13 formation and tends not to damage the interior of the
14 borehole, which otherwise would occur for a single pulse
15 electromechanical source.

16

17 In this operational configuration the source signal from
18 the transducer 7 may generally be considered a varying
19 signal around the DC pressure required for attaching the
20 source to the borehole walls 6.

21

22 With reference to Figures 2A and 2B, there is depicted a
23 signal generation and interpretation system depicted at
24 41 for use with the downhole magnetostrictive seismic
25 source 1 that was described in the above embodiment.

26 In this system, the input signal to the source and
27 consequently the signal output into the well formation 49
28 is derived from a digital negative feedback shift
29 register 43. The purpose of the shift register 43 is to
30 provide the source 1 with a sequence of binary pulses
31 through electrical connection 44.

32

1 The shift register 43 is provided with a negative
2 feedback loop 47, which, upon activation, provides a
3 continuous stream of binary pulses until otherwise
4 requested. The binary state of the shift register (i.e.
5 the binary values at each flip-flop 46), is set upon
6 commencement of transmission. The transfer of binary
7 digits into and out of the shift register is governed by
8 clock pulses provided to the register 43 during
9 transmission. In this example, the shift register 43 is
10 configured to provide a maximal length, pseudo-random
11 binary sequence (PRBS) of pulses. This is achieved by
12 putting two binary feedback taps 45 through an XOR logic
13 gate and modulo-2 adding as part of the negative feedback
14 loop 47.

15

16 This configuration provides a maximal length PRBS of
17 length 2^3-1 . In this case, 7 states are cycled between
18 during transmission. The zero state, where all flip-
19 flops have binary value 0, is a locked state where
20 transmissions continue to further 0 states. This is
21 provided by a non-zero initial state upon signal
22 generation of a programmed clock and reset device 47.

23

24 The provision of a PRBS to the well formation using the
25 source 1 has a number of advantages. In this system, the
26 signal transmitted by the source propagates through the
27 rock formation to receiving instruments 50 that record
28 the signal 49. The seismic signal detected at the
29 receivers is correlated with the input signal, which is
30 known to be a PRBS signal, which reveals high correlation
31 where the input and output signals match.

32

1 The provision of a PRBS signal, allows significant
2 processing gain to be achieved as a result of the
3 inherent autocorrelation properties of such a signal.
4 Specifically, upon autocorrelation, the signal-to-noise
5 ratio of the output signal is substantially greater than
6 the signal-to-noise ratio of the input signal.

7
8 This provides the possibility of a signal being detected
9 and retrieved at the receiver despite being originally
10 transmitted as a sequence of pulses below the ambient
11 noise level. This feature of the PRBS signal, used in
12 this embodiment, permits the use of a low-voltage current
13 input to the source transducer. Thus, the switching of
14 the electrical current in the transducer coil can take
15 place safely without the risk of coil burnout due to back
16 EMFs upon switching. This mechanism provides for
17 maintaining prolonged use of the source components thus
18 saving maintenance costs.

19
20 Use of a PRBS signal also provides for transmission of a
21 broadband signal into the earth. This provides
22 significant resolution benefits, with high-frequencies
23 used for detection over short length scales.

24
25 In an alternate embodiment of the invention, instead of
26 pulsing the source with a PRBS signal, a chirp signal is
27 used. A chirp pulse that is a linear frequency modulated
28 pulse with a start frequency f_s and chirp rate γ is
29 denoted as:

30
$$x_{chirp}(t) = e^{j(\pi\gamma t^2 + 2\pi f_s t)}, \quad 0 \leq t < T_{chirp} \quad (6).$$

31

32

1 A particular advantage of using a chirp signal downhole
2 is that if the frequency band is sufficiently large, the
3 autocorrelation is a unit spike in the time domain. For
4 band limited chirp signals, the autocorrelation is the
5 *sync* function. Like the PRBS, a chirp signal has
6 relatively low power requirements but is able to get a
7 relatively large amount of energy into the formation.

8

9 For the case where a chirp signal is used, or even for
10 the case where a PRBS is use, instead of the circuitry
11 illustrated in Figures 2A, 2B, a processor may be used.

12

13 The principles of the present invention were demonstrated
14 in a laboratory environment, in which a 10cm diameter, 1m
15 deep hole was cored in a 5 ton granite block. The
16 transducer arrangement as described with reference to
17 Figure 1 was used, and six accelerometers were placed on
18 the surface of the block to monitor the performance of
19 the transducer.

20

21 Figure 3 is a graph of the autocorrelation of an output
22 signal with the input signal at 60. The graph reveals a
23 substantial amplitude peak at 62 corresponding to the
24 time at which the signal arrives at the receiver. At
25 earlier times, in the region 64, the autocorrelated
26 signal 60 remains within the ambient noise. In this
27 case, the receiver is an accelerometer is located in a
28 granite block away from the magnetostrictive source.

29

30 The results indicate that an improved signal-to-noise is
31 achieved by autocorrelating a PRBS signal generated by
32 the seismic source of the present invention.

33 Furthermore, it provides confirmation that the source is

1 capable of successfully transmitting a PRBS seismic
2 signal into a rock formation. This has significant
3 application to single well imaging systems in particular,
4 where tube waves generated by the source tend to obscure
5 first arrivals and reflections.

6

7 Turning now to Figure 4, an example is shown of the
8 source of the present invention conveyed in a wellbore in
9 an earth formation. The arrangement is suitable for
10 carrying out what is called a reverse Vertical Seismic
11 Profile (VSP). Shown is a drillbit 150 near the bottom
12 of a borehole 126. The drillbit is part of a bottomhole
13 assembly (BHA) conveyed in the borehole on a drilling
14 tubular such as a drillstring or coiled tubing. A
15 downhole source is denoted by 153 and a reference
16 receiver at the surface is denoted by R1. 155 shows an
17 exemplary raypath for seismic waves originating at the
18 source 153 and received by the receiver R1. The source
19 153 is usually in a fixed relation to the drillbit in the
20 bottom hole assembly. Also shown in Figure 4 is a
21 raypath 155' when the BHA (and the source) are at a
22 different position 153' near the bottom of the borehole.

23 Raypaths 155 and 155' are shown as curved. This ray-
24 bending commonly happens due to the fact that the
25 velocity of propagation of seismic waves in the earth
26 generally increases with depth. Also shown in Figure 4
27 is a reflected ray 161 corresponding to seismic waves
28 that have been produced by the source at 153, reflected
29 by an interface such as 163, and received by the receiver
30 at R1.

31

1 For the configuration shown in Figure 4, it is
2 necessary to have the downhole clock on which the
3 source operates and a surface clock where the data are
4 received and/or recorded in synchronization. Without
5 the synchronization, it is not possible to determine
6 accurate propagation times for the seismic waves from
7 the source to the receiver. Synchronization is also
8 necessary to be able to properly perform the cross-
9 correlation operations needed when a PRMS or a chirp
10 signal is used. This synchronization is not necessary
11 for looking ahead of the drillbit where the receiver(s)
12 would be on or near the BHA and could be on the same
13 bus.

14

15 The source may also be conveyed downhole on a wireline
16 as part of a string of logging tools. For the purposes
17 of this invention, the BHA and a one or more logging
18 tools are referred to as a downhole assembly.

19

20 A processor is used to determine the time of
21 propagation of the seismic waves from the source to the
22 receiver from the received and transmitted signals.
23 For looking ahead of the drillbit, a downhole processor
24 is necessary. For the example shown in Figure 4, a
25 downhole processor would be used for controlling the
26 source and typically a surface processor is used for
27 analyzing the signals.

28

29 The processing of the data may be accomplished by
30 processor. Implicit in the control and processing of
31 the data is the use of a computer program implemented
32 on a suitable machine readable medium that enables the

1 processor to perform the control and processing. The
2 machine readable medium may include ROMs, EPROMs,
3 EAROMs, Flash Memories and Optical disks.

4

5 The invention has been described with reference to a
6 logging tool conveyed on a drillstring. The method of
7 the present invention is equally applicable for use
8 with NMR logging tools conveyed on a wireline,
9 slickline or coiled tubing.

10

11 It should be appreciated that other source arrangements
12 and driving methods could be envisaged without
13 departing from the scope of the invention defined by
14 the first to fifth aspects above.

1 Claims

2

3 1. A system for use in a borehole in an earth

4 formation comprising:

5 (a) a downhole assembly conveyed in the borehole;

6 (b) a magnetostrictive transducer on the downhole

7 assembly which produces a mechanical

8 displacement of a coupling member when

9 activated by an electrical signal from a source

10 thereof;

11 (c) at least one contact member in contact with a

12 wall of the borehole and hydraulically coupled

13 to the transducer, the at least one contact

14 member producing a seismic signal in the

15 formation in response to the mechanical

16 displacement of the coupling member.

17

18 2. The system of claim 1, wherein the magnetostrictive

19 transducer comprises an alloy of terbium,

20 dysprosium, and iron.

21

22 3. The system of any preceding claim, wherein the

23 electrical signal is selected from the group

24 consisting of (i) a pseudo-random binary sequence,

25 and (ii) a swept frequency signal.

26

27 4. The system of any preceding claim, further

28 comprising a plurality of extension devices which

29 maintain the transducer substantially in a fixed

30 position in the borehole.

31

32 5. The system of any preceding claim, wherein the

33 hydraulic coupling is further provided by:

1 (i) a master cylinder having an axis substantially
2 parallel to an axis of the borehole, and
3 (ii) at least one slave cylinder coupled through an
4 extension device to the at least one contact
5 member, the at least one slave cylinder
6 oriented substantially orthogonal to the master
7 cylinder.

8

9 6. The system of any preceding claim, wherein the
10 signal comprises a pseudo-random binary sequence,
11 and wherein the source of the electrical signal
12 further comprises a shift register provided with a
13 negative feedback loop.

14

15 7. The system of any preceding claim, wherein the at
16 least one contact member further comprises a pair
17 of opposed contact members.

18

19 8. The system of any preceding claim, further
20 comprising a conveyance device which conveys the
21 downhole assembly into the borehole, the conveyance
22 device selected from (i) a wireline, (ii) a
23 slickline, and (iii) a drilling tubular.

24

25 9. The system of any preceding claim, further
26 comprising a receiver which produces an output
27 responsive to the propagation of the seismic signal
28 through the earth formation.

29

30 10. The system of claim 9 further comprising a
31 processor which determines from the output of the
32 receiver and the electrical signal a travel time of

1 the seismic signal from the at least one contact
2 member to the receiver.

3

4 11. A method of evaluating an earth formation
5 comprising:

6 (a) conveying a downhole assembly into a borehole
7 in the earth formation;

8 (b) providing an electrical signal to a
9 magnetostrictive transducer in the downhole
10 assembly and producing a mechanical
11 displacement of a coupling member coupled to
12 the transducer; and

13 (c) hydraulically coupling at least one contact
14 member in contact with a wall of the borehole
15 to the coupling member and producing a seismic
16 signal in the formation in response to the
17 mechanical displacement.

18

19 12. The method of claim 11, wherein providing the
20 electrical signal further comprises using at least
21 one of (i) a pseudo-random binary sequence, and
22 (ii) a swept frequency signal.

23

24 13. The method of claim 11 or 12, further comprising
25 using a plurality of extension devices for
26 maintaining the transducer substantially in a fixed
27 position in the borehole.

28

29 14. The method of any one of claims 11 to 13, wherein
30 the hydraulic coupling further comprises:
31 using a master cylinder and at least one slave
32 cylinder coupled through an extension device to the
33 at least one contact member.

1

2 15. The method of claim 11 wherein the signal comprises
3 a pseudo-random binary sequence, and wherein
4 providing the electrical signal further comprises
5 using a shift register provided with a negative
6 feedback loop.

7

8 16. The method of any one of claims 11 to 15, wherein
9 the at least one contact member further comprises a
10 pair of opposed contact members.

11

12 17. The method of any one of claims 11 to 16, further
13 comprising conveying the magnetostrictive
14 transducer into the borehole on one of (i) a
15 wireline, (ii) a slickline, and (iii) a drilling
16 tubular.

17

18 18. The method of any one of claims 11 to 17, further
19 comprising detecting the propagation of the seismic
20 signal through the earth formation.

21

22 19. The method of any one of claims 11 to 18, further
23 comprising determining from the detected signal a
24 travel time of the seismic signal through the
25 formation.

26

27 20. A computer readable medium for use with a system
28 for use in a borehole in an earth formation, the
29 system comprising:

30

(a) a downhole assembly conveyed in the borehole;

31

(b) a magnetostrictive transducer on the downhole

32

assembly hydraulically coupled to at least one

1 contact member in contact with a wall of the
2 borehole;
3 the medium comprising instructions which enable
4 a processor to provide a signal to the
5 magnetostrictive transducer which causes the at
6 least one contact member to produce a seismic
7 signal in the formation.

8

9 21. The medium of claim 20 further comprising at least
10 one of (i) a ROM, (ii) an EPROM, (iii) an EAROM,
11 (iv) a flash memory, and (v) an optical disk.

12

13 22. A seismic source comprising a magnetostrictive
14 transducer, and coupling means for coupling the
15 transducer to a formation, wherein the coupling
16 means includes a hydraulic coupling arrangement.

17

18 23. A seismic source comprising a magnetostrictive
19 transducer, and coupling means for coupling the
20 transducer to a formation, wherein the seismic
21 source is adapted to be driven by a pseudo-random
22 binary sequence (PRBS).

23

24 24. A seismic source comprising a transducer and
25 coupling means for coupling the transducer to a
26 formation, wherein the coupling means includes a
27 hydraulic coupling arrangement.

28

29 25. A seismic signal transmission system comprising;
30 a seismic source coupled to a formation,
31 means for driving the seismic source using a
32 pseudo-random binary sequence (PRBS) to cause a
33 signal to propagate in a formation,

1 means for receiving a signal from the formation.

2

3 26. A method of transmitting an acoustic signal in a

4 formation the method comprising the steps of;

5 a. providing a seismic source,

6 b. coupling the seismic source to the

7 formation by a hydraulic coupling

8 arrangement,

9 c. driving the seismic source to cause an

10 acoustic signal to be transmitted in the

11 formation.

1/4

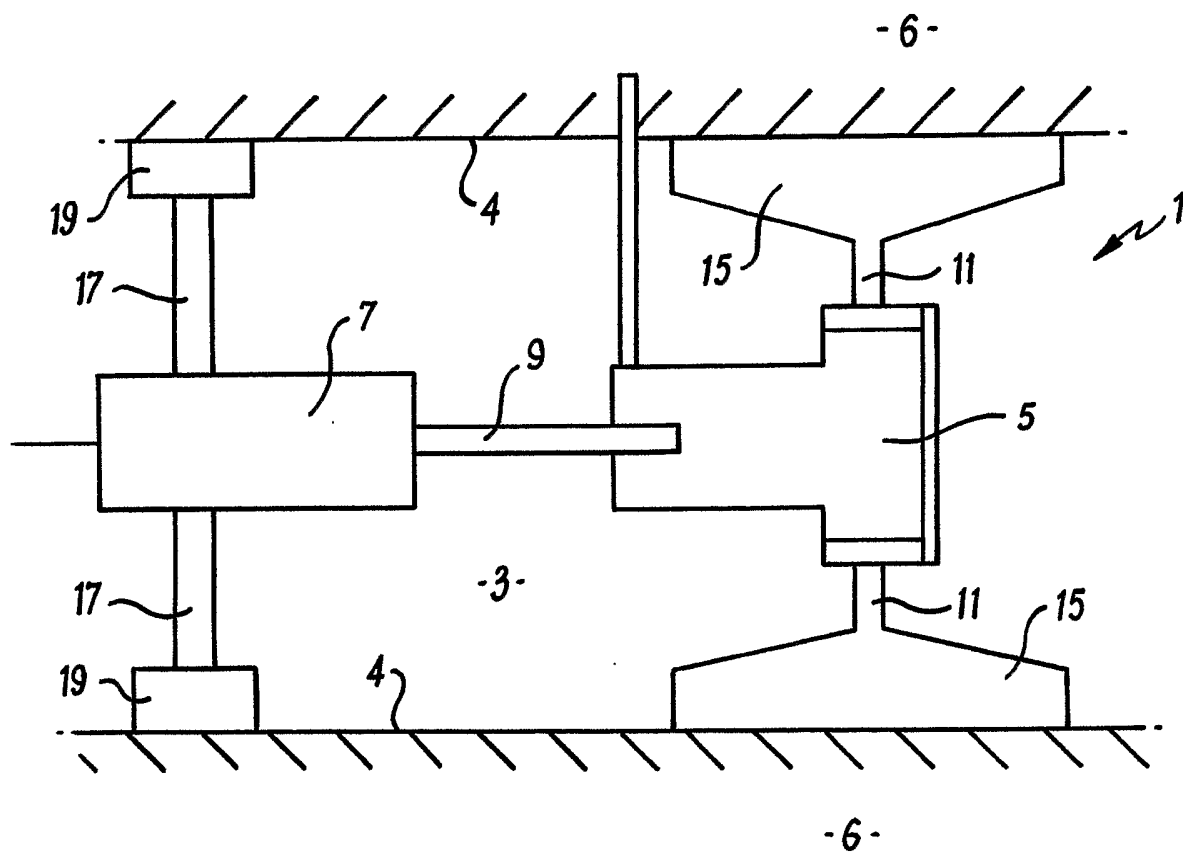
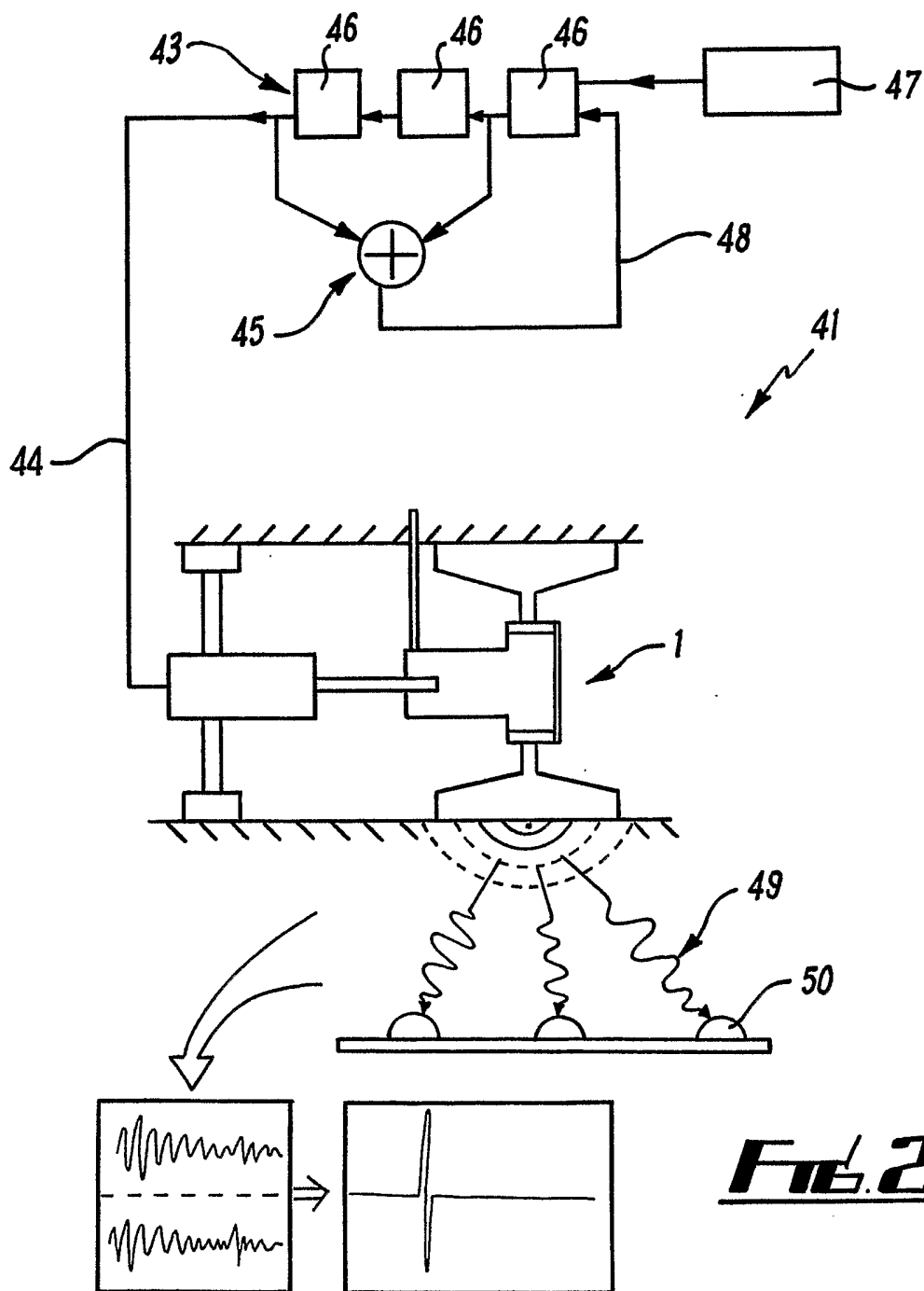
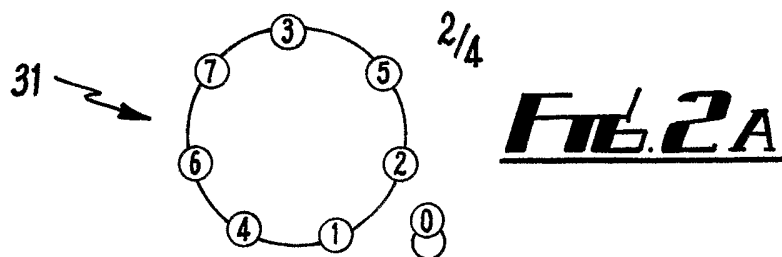


FIG. 1



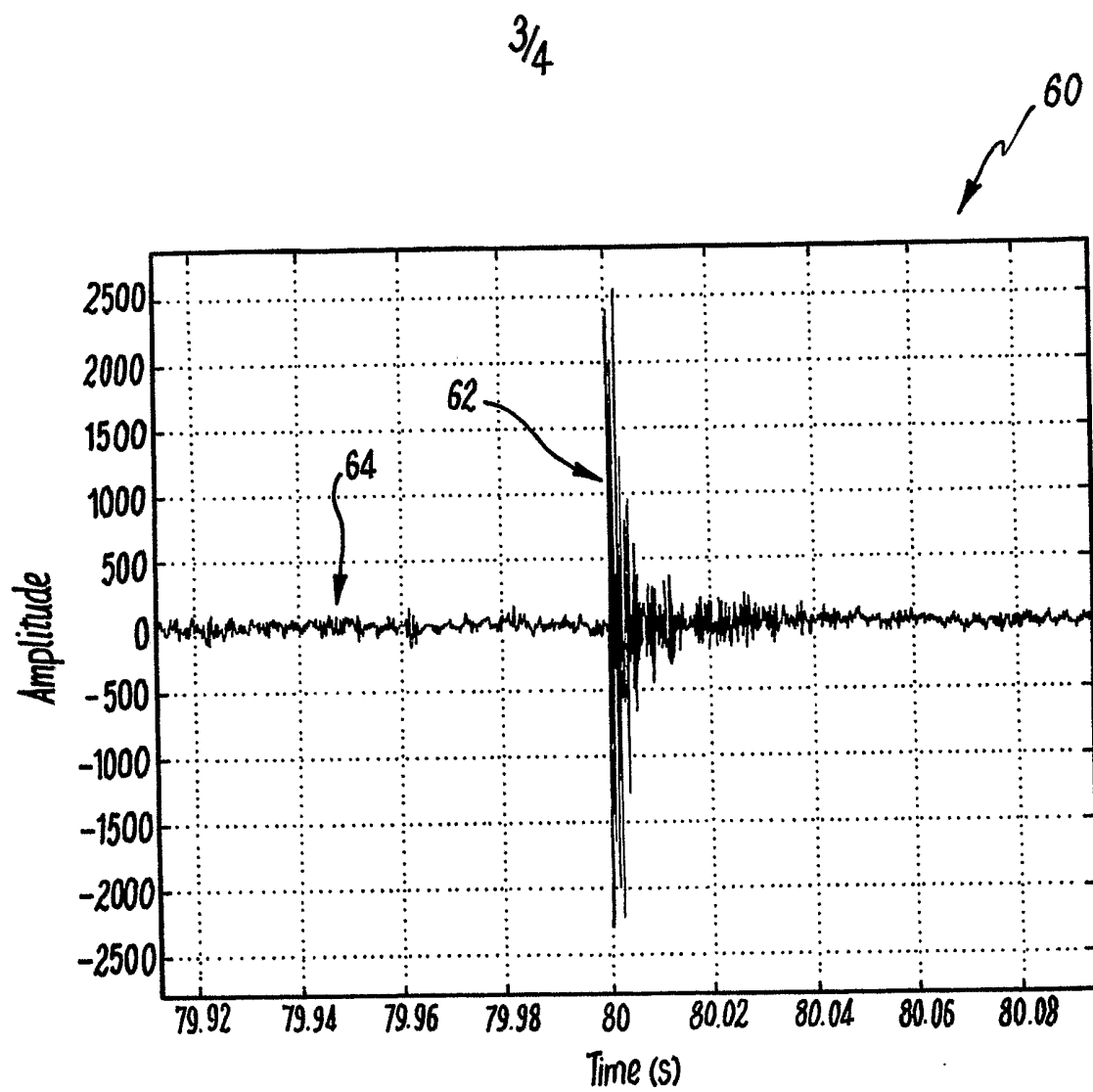


FIG. 3

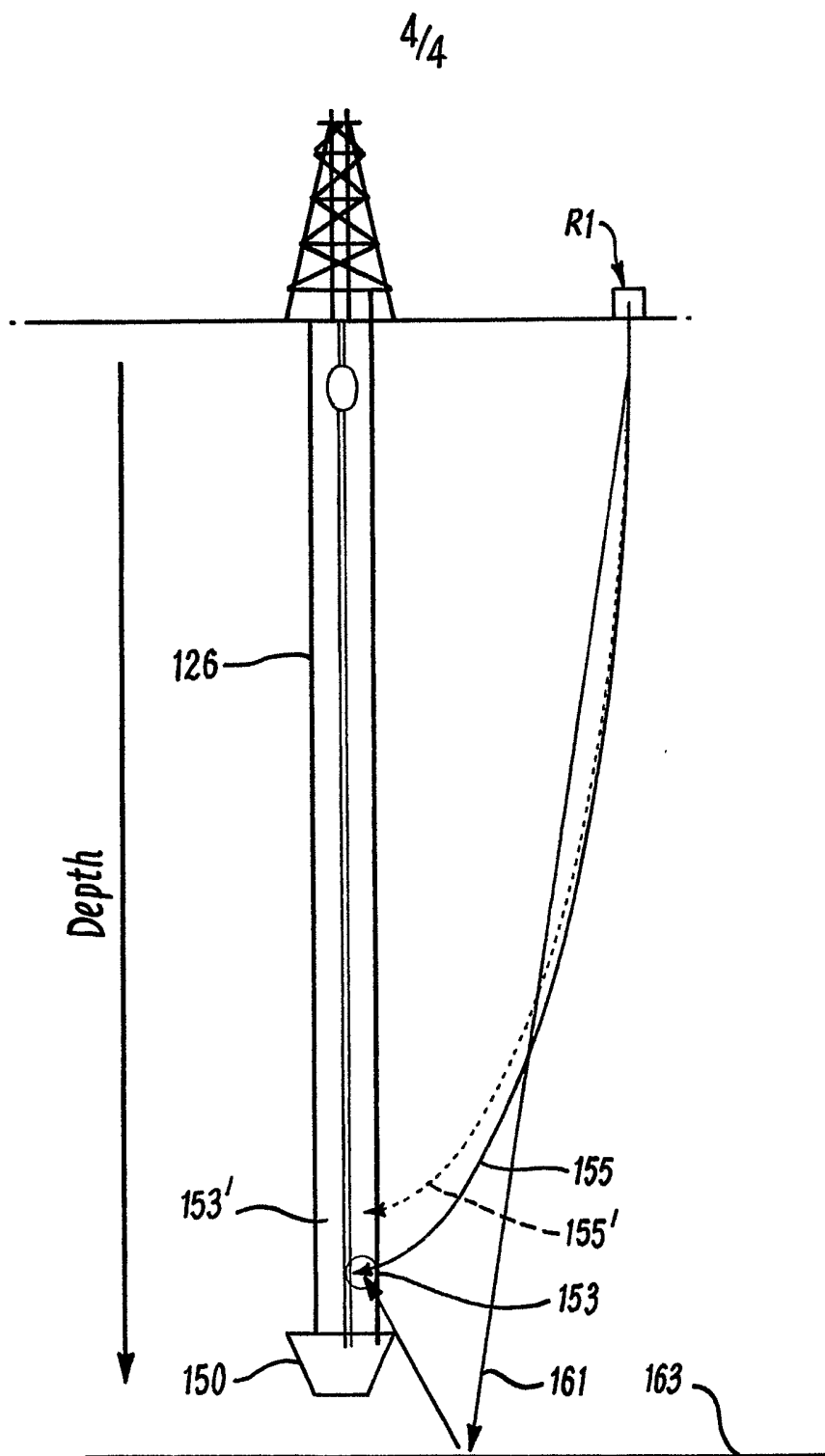


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
 /GB2005/004333

A. CLASSIFICATION OF SUBJECT MATTER
 G01V1/52

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)
 G01V

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 2 678 390 A (INSTITUT FRANCAIS PETROLE) 31 December 1992 (1992-12-31)	1,4-11, 13-22, 24,26
Y	the whole document	2,3,12
X	US 5 208 787 A (SHIRLEY ET AL) 4 May 1993 (1993-05-04) abstract	23,25
Y	US 4 700 803 A (MALLET ET AL) 20 October 1987 (1987-10-20) column 3, line 2 - line 4	2
Y	US 4 862 990 A (COLE ET AL) 5 September 1989 (1989-09-05) column 4, line 34 - line 39	3,12
	-/--	

Further documents are listed in the continuation of Box C. See patent family annex.

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A document defining the general state of the art which is not considered to be of particular relevance

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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.

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Date of the actual completion of the international search 22 February 2006	Date of mailing of the international search report 06/03/2006
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INTERNATIONAL SEARCH REPORT

International application No
 IB2005/004333

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 397 318 A (HALLIBURTON GEOPHYSICAL SERVICES, INC) 14 November 1990 (1990-11-14) column 4, line 40 - column 5, line 30; claim 1; figure 1	1, 11, 22, 24, 26
X	FR 2 667 518 A (INSTITUT FRANCAIS PETROLE) 10 April 1992 (1992-04-10)	1, 4-11, 13-22, 24, 26
Y	the whole document	2, 3, 12

INTERNATIONAL SEARCH REPORT

 International application No
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			DE	69005692 T2	28-04-1994
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