

**(12) STANDARD PATENT**  
**(19) AUSTRALIAN PATENT OFFICE**

(11) Application No. **AU 2011217960 B2**

(54) Title  
**Apparatus and methods for providing information about one or more subterranean variables**

(51) International Patent Classification(s)  
**G01V 1/40** (2006.01) **G01V 3/18** (2006.01)

(21) Application No: **2011217960** (22) Date of Filing: **2011.02.18**

(87) WIPO No: **WO11/103422**

(30) Priority Data

(31) Number	(32) Date	(33) Country
<b>61/306,478</b>	<b>2010.02.20</b>	<b>US</b>

(43) Publication Date: **2011.08.25**

(44) Accepted Journal Date: **2015.04.02**

(71) Applicant(s)  
**Baker Hughes Incorporated**

(72) Inventor(s)  
**Brannon, Harold Dean**

(74) Agent / Attorney  
**Freehills Patent Attorneys, Level 43 101 Collins Street, Melbourne, VIC, 3000**

(56) Related Art  
**WO 2009/047781 A2**  
**US 2003/0205376 A1**  
**US 2009/0288820 A1**

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

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
25 August 2011 (25.08.2011)

(10) International Publication Number  
**WO 2011/103422 A3**

- (51) **International Patent Classification:**  
*G01V 1/40* (2006.01) *G01V 3/18* (2006.01)
- (21) **International Application Number:**  
PCT/US2011/025431
- (22) **International Filing Date:**  
18 February 2011 (18.02.2011)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**  
61/306,478 20 February 2010 (20.02.2010) US
- (71) **Applicant** (for all designated States except US): **BAKER HUGHES INCORPORATED** [US/US]; 2929 Allen Parkway, Suite 2100, Houston, TX 77019 (US).
- (72) **Inventor; and**
- (75) **Inventor/Applicant** (for US only): **BRANNON, Harold, Dean** [—/US]; 32207 Edgewater Drive, Magnolia, TX 77354 (US).
- (74) **Agent:** **SMITH, Ernest, Randall;** Jones & Smith, LLP, 2777 Allen Parkway, Suite 1000, Houston, TX 77019 (US).
- (81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ,

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

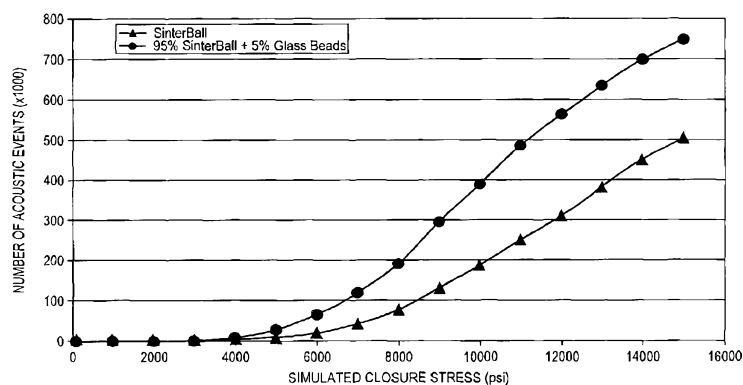
- (84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR,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

**Published:**

- with international search report (Art. 21(3))
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

- (88) **Date of publication of the international search report:**  
3 May 2012

(54) **Title:** APPARATUS AND METHODS FOR PROVIDING INFORMATION ABOUT ONE OR MORE SUBTERRANEAN VARIABLES



**FIG. 2**

(57) **Abstract:** In some embodiments, a method of obtaining information about at least one variable existing at a target location in an underground well bore and/or surrounding subterranean formation includes delivering a plurality of signal generating devices to the target location(s), emitting at least one detectable signal from the target location and receiving at least one such signal. Information about the variable(s) is derived from at least some of the received signals.

WO 2011/103422 A3

**APPARATUS AND METHODS FOR PROVIDING INFORMATION  
ABOUT ONE OR MORE SUBTERRANEAN VARIABLES**

**[0001]** This application claims priority to U.S. Provisional Patent Application Serial No. 61/306,478 filed February 20, 2010 and Entitled “Apparatus and Methods for Using Nano-Devices to Provide Information About one or More Subterranean Variables”, the disclosure of which is hereby incorporated by reference herein in its entirety.

**FIELD OF THE INVENTION**

**[0002]** The present disclosure relates generally to providing information about one or more variables in, or proximate to, an underground well or subterranean formation.

**BACKGROUND OF THE INVENTION**

**[0003]** In various operations conducted via underground wells, it is often advantageous to be able to gain information about one or more variables existing in the well bore or subterranean formation. In the arena of hydrocarbon exploration and production, example operations during which it may be beneficial to gain such information are drilling, cementing, completion, stimulation (including well treatment) and workover. The variables could be any measurable condition, parameter or property, such as one or more geometric dimension, the location of a particular object or geometric feature, temperature, pressure, flow, chemical composition, in-situ stresses in the well bore or formation, or the like. Note, the present disclosure is not limited by the type of operation, the target location in the well bore or formation or the type of variable.

**[0004]** In one example in the hydrocarbon recovery arena, it is often of significant benefit to learn about the geometry of an area within an underground well or subterranean formation, such as the location or dimensions of propped hydraulic fractures. Hydraulic fracturing is a widely used process for stimulating oil and gas wells and which typically involves injecting fluid into

the well bore at a higher pressure than the surrounding reservoir pressure. The higher pressure of the injected fluids causes the formation to fracture, exposing the surface area through which oil or gas may flow.

[0005] Once a hydraulic fracture is formed, proppant is typically delivered into the fracture during well treatment to effectively increase the conductivity of the fracture and provide a flow path of hydrocarbons between the reservoir and the producing well bore. Proppants ensure the created flow path remains open and conductive after the treating pressure is relieved. Proper placement of the proppant is often considered one of the most critical facets of fracture stimulation. The propped fracture area is believed to directly correlate with stimulated well potential and productivity, whereby the larger the propped fracture, the more productive the well. It is thus typically advantageous to know the location and/or dimensions of propped fractures or proppant packs within conductive fractures. For example, knowledge of the location of proppant in fractures and/or the dimensions of propped fractures can, in some instances, assist in optimizing and improving fracturing efforts and proppant distribution, well placement and production strategies.

[0006] Existing techniques for mapping or visualizing underground geometries (e.g. micro-seismic fracture mapping, tilt-meter fracture mapping, use of tracers) are believed to have one or more limitations. For example, some of these techniques provide information on only one dimension or feature (e.g., length, height, depth or azimuth). For another example, some of these techniques only provide information about the formation in close proximity to the well bore. For other examples, some current technologies require the use of one or more offset wells, which may dramatically increase costs, and/or radioactive material, which may be environmentally damaging.

[0007] It should be understood that the above-described discussion is provided for illustrative purposes only and is not intended to limit the scope or subject matter of this disclosure, the appended claims or the claims of any related patent application or patent. Thus, none of the appended claims or claims of any related patent application or patent should be limited by the above discussion or required to address, include or exclude the above-cited examples, features and/or disadvantages merely because of their mention above.

[0008] Accordingly, there exists a need for improved systems, apparatus and methods capable of providing information about one or more variables in an underground well or subterranean formation having one or more of the attributes, capabilities or features described below or in the subsequent sections of this disclosure; provides information about one or more variable existing in a well bore, annulus or subterranean formation; provides such information during at least one among drilling, cementing, completion, stimulation and workover; provides such information without the transmission of signals to the target location; provides information about one or more geometric dimension, the location of a particular object or geometric feature, temperature, pressure, flow, chemical composition or in-situ stresses in an underground well, subterranean formation or hydrocarbon reservoir; can be used to improve well stimulation operations and well performance planning; provides information about the location of proppant disposed within a propped fracture or other area; provides multiple dimensions of an underground geometric feature; provides signal generating devices at one or more target location(s) to accomplish one or more of the above; uses signal generating devices that capture, generate or provide energy in-situ for transmitting one or more signals; incorporates nano-devices capable of generating energy and/or transmitting signals; uses piezoelectric signal generating devices; uses signal generating devices that include sound generating material capable

of emitting detectable sound waves from a subterranean location; does not require the use of offset wells or radioactive materials; is reliable; is easy to implement; requires minimal retrofitting of existing equipment; is cost-effective.

[0008A] Reference to any prior art in the specification is not, and should not be taken as, an acknowledgment or any form of suggestion that this prior art forms part of the common general knowledge in Australia or any other jurisdiction or that this prior art could reasonably be expected to be ascertained, understood and regarded as relevant by a person skilled in the art.

[0008B] As used herein, except where the context requires otherwise the term 'comprise' and variations of the term, such as 'comprising', 'comprises' and 'comprised', are not intended to exclude other additives, components, integers or steps.

### BRIEF SUMMARY OF THE DISCLOSURE

[0008C] In one aspect of the invention there is provided a method of obtaining information about at least one subterranean fracture or the location of proppant within the fracture, the method comprising: incorporating a plurality of signal generating devices in the proppant; delivering the proppant to the at least one fracture; at least some of the signal generating devices in the proppant generating a detectable signal in response to at least one down hole condition or property; at least some of the signal generating devices including sound generating material, the detectable signal generated by the signal generating devices being detectable sound waves emitted by the breaking of the sound generating material in response to at least one down hole condition or property, wherein the sound generating material breaks in response to at least one among fracture closure stress applied thereto, changes in pressure or changes in temperature; at least one receiver receiving at least one of the detectable signals; and deriving information about the fracture or location of the proppant within the fracture from at least one of the received signals.

[0008D] There is also disclosed herein a method of obtaining location and/or geometric dimension information about at least one hydraulic fracture or a proppant pack therein at a target location in an underground well bore and/or surrounding subterranean formation without the need to transmit signals to the target location, the method comprising: delivering a proppant pack that includes proppant and a plurality of signal generating devices having a particle size and density that is equal to or less than the particle size and density of the proppant into at least one hydraulic fracture at the target location; at least some of the signal generating devices transmitting at least one signal;

receiving signals from at least some of the signal generating devices; and generating information about the location and/or at least one geometric dimension of at least one hydraulic fracture or the proppant pack therein from at least some of the received signals.

[0008D] There is also disclosed herein a method of obtaining location and/or geometric dimension information about at least one hydraulic fracture or a proppant pack therein at a target location in an underground well bore and/or surrounding subterranean formation, the method comprising: mixing into a proppant pack a plurality of nano-devices having a particle size and density that is equal to or less than the particle size and density of the proppant; delivering the proppant pack into at least one hydraulic fracture at the target location; at least some of the nano-devices generating or capturing energy in-situ sufficient to power the transmission of at least one detectable signal; transmitting at least one detectable signal from the target location; receiving at least some of the transmitted signals; and deriving information about the location and/or at least one geometric dimension of at least one hydraulic fracture or the proppant pack therein from at least one of the received signals.

[0008E] There is also disclosed herein a method of obtaining information about at least one subterranean fracture or the location of proppant within the fracture the method comprising: incorporating a plurality of signal generating devices in the proppant, at least some of the signal generating devices including sound generating material; delivering the proppant to the at least one fracture; at least some of the sound generating material in the proppant generating a detectable sound wave by breaking in response to at least one among fracture closure stress applied thereto, changes in pressure or changes in temperature; at least one receiver receiving at least one of the detectable signals; and deriving information about the fracture or location of the proppant within the fracture from at least one of the received signals.

[0008F] There is also disclosed herein a method of hydraulic fracturing of a subterranean formation proximate to an underground hydrocarbon reservoir from a well bore, the method comprising: injecting fluid into the well bore at pressure that is higher than pressure in the reservoir; the injected fluids forming fractures in the formation from the well bore and through which hydrocarbons may flow from the reservoir into the well bore; preparing proppant that includes a plurality of signal generating devices, the signal generating devices including sound generating material; delivering the proppant into the fracture to increase the conductivity of the fracture and provide a flow path of hydrocarbons between the reservoir and the well bore; at least some of the sound generating material in the proppant emitting at least one detectable signal in response to fracture closure stress

applied thereto; receiving at least one of the emitted signals; and deriving information about the propped fracture or proppant from at least one of the received signals.

[0009] In some embodiments, a method of obtaining information about at least one variable existing at a target location in an underground well bore and/or surrounding subterranean formation is utilized. These methods include delivering a plurality of signal generating devices to the target location. At least some of the signal generating devices transmit at least one signal. At least some of the signals are received and information about the variable(s) is generated therefrom. These methods do not require the transmission of signals to the target location in order to obtain or generate the information.

[0010] In various embodiments, a method of obtaining information about at least one variable existing at a target location in an underground well bore and/or surrounding subterranean formation involves delivering a plurality of nano-devices to the target location. At least some of the nano-devices generate or capture energy in-situ sufficient to power the transmission of at least one detectable signal. At least one detectable signal is transmitted from the target location. At least some of the transmitted signals emitted are received. Information about the variable(s) is derived from at least some of the received signals.

[0011] Some embodiments involve a method of obtaining information about at least one subterranean fracture or the location of proppant within the fracture. These embodiments include incorporating a plurality of signal generating devices in the proppant. Delivering the proppant to at least one fracture. At least some of the signal generating devices in the proppant generate a detectable signal in response to at least one down hole condition or property. At least one



receiver receives at least one of the detectable signals. Information about the fracture or location of the proppant within the fracture is derived from at least one of the received signals.

[00012] Various embodiments include a method of hydraulic fracturing of a subterranean formation proximate to an underground hydrocarbon reservoir from a well bore. The method of these embodiments includes injecting fluid into the well bore at pressure that is higher than pressure in the reservoir. The injected fluids form fractures in the formation from the well bore and through which hydrocarbons may flow from the reservoir into the well bore. Proppant is prepared that includes a plurality of signal generating devices. The proppant is delivered into the fracture to increase the conductivity of the fracture and provide a flow path of hydrocarbons between the reservoir and the well bore. At least some of the signal generating devices in the proppant emit at least one detectable signal in response to at least one down hole condition or property. At least one of the transmitted signals is received and information about the propped fracture or proppant is derived therefrom.

[00013] Accordingly, the present disclosure includes features and advantages which are believed to enable it to advance underground information gathering technology. Characteristics and potential advantages of the present disclosure described above and additional potential features and benefits will be readily apparent to those skilled in the art upon consideration of the following detailed description of various embodiments.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

[00014] The following figures are part of the present specification, included to demonstrate certain aspects of various embodiments of this disclosure and referenced in the detailed description herein:

[00015] Figure 1 is line graph illustrating acoustic emissions detected from the breaking of exemplary white sand proppant, glass beads, CarboLite® proppant and SinterBall Bauxite proppant during testing conducted to illustrate at least one embodiment of the present disclosure;

[00016] Figure 2 is line graph comparing the acoustic emissions detected from the breaking of SinterBall Bauxite proppant and a mixture of SinterBall Bauxite proppant and glass beads during testing conducted to illustrate at least one embodiment of the present disclosure;

[00017] Figure 3 is line graph comparing the acoustic emissions detected from the breaking of LiteProp™ 108 proppant and a mixture of LiteProp 108 and CarboLite proppants during testing conducted to illustrate at least one embodiment of the present disclosure;

[00018] Figure 4 is a photograph of a screen capture of an oscilloscope taken during testing of SinterBall proppant conducted to illustrate at least one embodiment of the present disclosure;

[00019] Figure 5 is a photograph of a screen capture of an oscilloscope taken during testing of white sand proppant conducted to illustrate at least one embodiment of the present disclosure; and

[00020] Figure 6 is a photograph of a screen capture of an oscilloscope taken during testing of CarboLite proppant conducted to illustrate at least one embodiment of the present disclosure.

#### **DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS**

[00021] Characteristics and advantages of the present disclosure and additional features and benefits will be readily apparent to those skilled in the art upon consideration of the following detailed description of exemplary embodiments of the present disclosure and referring to the accompanying figures. It should be understood that the description herein and appended drawings, being of example embodiments, are not intended to limit the claims of this patent application, any patent granted hereon or any patent or patent application claiming priority

hereto. On the contrary, the intention is to cover all modifications, equivalents and alternatives falling within the spirit and scope of the claims. Many changes may be made to the particular embodiments and details disclosed herein without departing from such spirit and scope.

[00022] As used herein and throughout various portions (and headings) of this patent application, the terms "invention", "present invention" and variations thereof are not intended to mean every possible embodiment encompassed by this disclosure or any particular claim(s). Thus, the subject matter of each such reference should not be considered as necessary for, or part of, every embodiment hereof or of any particular claim(s) merely because of such reference.

[00023] Certain terms are used herein and in the appended claims to refer to particular components. As one skilled in the art will appreciate, different persons may refer to a component by different names. This document does not intend to distinguish between components that differ in name but not function. Also, the terms "including" and "comprising" are used herein and in the appended claims in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to . . . ." Further, reference herein and in the appended claims to components and aspects in a singular tense does not necessarily limit the present disclosure or appended claims to only *one* such component or aspect, but should be interpreted generally to mean *one or more*, as may be suitable and desirable in each particular instance.

[00024] In accordance with an embodiment of the present disclosure, one or more signal generating devices are selectively provided into a well bore or subterranean formation. The signal generating devices may have any suitable form, construction, configuration and operation and may be deployed to the desired target location(s) in the well bore or subterranean formation in any suitable manner. For example, the signal generating devices may be in the form of beads, wires, pellets, spheres or other suitable items delivered in a fluid mixture or slurry with

conventional fluid delivery equipment. When providing information about propped fractures and other geometric features, the signal generating devices may be used or transported in proppant and may have one or more physical property similar to the proppant (e.g. size, shape, density, specific gravity). As used herein, the term “proppant” includes any substance, composite or fluid-particle mixture useful for assisting in propping open a fracture, crack or other area in an underground earthen formation, or other desired purpose in a well bore or subterranean formation. If desired, the signal generating devices may be clustered or agglomerated together. In preferred embodiments, it is generally desirable that the individual signal generating devices or clusters thereof are not larger than the proppant particles.

**[00025]** In some embodiments, the signal generating devices may themselves be the proppant (“signal generating device proppant”). When signal generating device proppant is used along with non-signal generating device proppant, it may be desirable for the signal generating device proppant to have a similar particulate size and specific gravity as the other proppant to ensure homogenous distribution. If desired, the signal generating device proppant may be coated for strength or other qualities.

**[00026]** In other embodiments, the signal generating devices may be included in, or provided with, other primary proppant. For example, the signal generating devices may be separate components mixed into the proppant. For another example, the signal generating devices may be bonded to or formed into the proppant particles, such as by embedding the signal generating devices within a thermoplastic proppant material or coating the signal generating devices onto the outer surface of the proppant. For cost effectiveness, it may be desirable to include a minimal effective concentration of signal generating devices.

[00027] In some embodiments, the signal generating devices include nano-devices. As used herein, the term “nano-device” includes, without limitation, one or more nano-scale sized particles, materials, devices or composites capable of being used to generate energy and/or emit a detectable signal. If desired, each nano-scale sized particle, material, device or composite may be encased or contained within another particle. The nano-scale sized particles, materials, devices or composites possess at least one feature having a nano-scale dimension, such as pore diameter, platelet length, particle mean diameter, material thickness and the like, and may be functionalized or non-functionalized. In some embodiments, the nano-scale dimension may be less than 1000 nanometers; 500 nanometers; in some embodiments, less than 200 nanometers; in some embodiments, less than 150 nanometers; in some embodiments, less than 100 nanometers; in some embodiments, less than 70 nanometers; in some embodiments, less than 50 nanometers; in some embodiments, less than 20 nanometers; in some embodiments, less than 10 nanometers; in some embodiments, less than 5 nanometers; in some embodiments, less than 1 nanometer; in some embodiments, less than .5 nanometers; and so on. In some embodiments, the nano-scale dimension may vary among multiple nano-devices being used.

[00028] In some instances, nano-devices may be used as the nano-components of nano-composite filled particulate proppant. In one particular embodiment, the nano-devices could be formed into deformable ULW (ultra-lightweight) proppant, such as LiteProp™ 108 offered by Baker Hughes Incorporated, the assignee of the present application. In this example, the nano-devices could either be used in place of a portion of the other nano-particles formed into the LiteProp™ 108 proppant, or added thereto.

[00029] After being deployed, the signal generating devices are useful to provide one or more detectable signal that can be received and processed in any suitable manner. In some

embodiments, the signal generating devices may include power generating, transmitting or sensing capabilities, or a combination thereof. For example, each signal generating devices may be capable of generating or capturing power in-situ sufficient for the transmission of one or more detectable signal (e.g. sound waves, vibrations, radio waves of a suitable frequency). In some embodiments, the signal generating devices may generate power from or react to thermal energy or bottom hole static temperature (BHST), fluid absorption (e.g. water absorption completing circuit), particle swelling, changes in temperature, mechanical stress or pressure, or other down hole properties or conditions. In various embodiments, the signal generating devices may include one or more micro-battery for providing energy.

[00030] In some embodiments, the signal generating devices may themselves emit the signal(s). In other embodiments, the power generated by the signal generating devices may be used to actuate one or more transmitters to emit the detectable signal. When included, the transmitters may have any suitable form, configuration and operation. For example, appropriate radio wave micro-transmitters may be included in the signal generating devices, associated with or in communication with the signal generating devices or otherwise disposed sufficiently proximate to the signal generating devices to be actuated by the power provided thereby.

[00031] If desired, the signal generating devices, such as nano-devices, may include piezoelectric material(s) useful for generating power. Under the theory of direct piezoelectric effect, the piezoelectric material (e.g. certain crystals, polymers, ceramics, bone, enamel, wood, combinations thereof, etc.) is capable of generating an electric potential in response to applied mechanical stresses. If the material is not short-circuited, the applied charge induces voltage across the material. Thus, piezoelectric signal generating devices can be useful to produce electricity in response to the application of stress thereto. Accordingly, in some embodiments,

piezoelectric signal generating devices may be deployed in a subterranean formation, such as in a hydraulic fracture, and activated (to generate electricity) by imposed stress on the devices caused by formation movement, such as fracture closure. The closure stress of the fracture may thus be used by the signal generating devices to create electric power.

**[00032]** In other embodiments, piezoelectric signal generating devices may be useful for creating motion when an electric field is applied to it. Under the theory of reverse piezoelectric effect, stress or strain is produced by the piezoelectric material upon the application of an electric field. Accordingly, after these piezoelectric signal generating devices are deployed to the desired location, an electric field may be applied to the signal generating devices. Some methods for applying an electrical field in an underground location are disclosed in U.S. Patent Application Serial Number 12/421,061, filed on April 9, 2009, entitled "Electrolocation Apparatus & Methods for Mapping from a Subterranean Well", having a common assignee with the present application and which is incorporated by reference herein in its entirety. However, the present disclosure is not limited to the details, techniques or applications disclosed in the above reference. The resulting motion (e.g. vibration) caused by the signal generating devices may be the detectable signal, or used to generate a detectable signal.

**[00033]** In some embodiments, the signal generating devices may include sound generating material. The sound generating material may, for example, be capable of emitting detectable sound waves in response to one or more down hole property or condition, such as those described above. In preferred embodiments, the sound generating material includes glass bubbles, or glass or ceramic beads, (or an agglomeration thereof), which will break when subject to one more down hole property or condition. The breaking of these materials will generate sound waves that are detectable, such as with the use of receivers (e.g. micro-seismic) as

described further below. As used herein, the term “break” and variations thereof means at least one among crack, fail, fracture, collapse, expand, deform, separate, detach or shatter sufficient, depending upon the circumstances, to generate detectable sound in response to a down hole property or condition.

**[00034]** For example, glass or ceramic beads, as well as glass bubbles, will break under certain imposed stress caused by formation movement, such as fracture closure, sufficient to generate detectable sound emissions. In some applications, the glass or ceramic beads may sufficiently break under point-to-point stress of 7,000 – 9,000 psi applied thereto. For another example, glass bubbles may break, such as by expanding and shattering, due to a temperature change in the subterranean formation. In yet another example, glass bubbles may collapse due to a change in hydrostatic pressure.

**[00035]** The sound generating materials are not limited to the glass or ceramic beads or glass bubbles, but may be constructed of any other suitable material or combination of materials, such as certain plastics, metal alloys and other suitably brittle material, capable of sufficiently breaking and generating detectable sound in response to one or more down hole property or condition. Likewise, the sound generating materials may have any other suitable geometry and configuration, such as pellet or rods, that is capable of breaking and generating detectable sound in response to one or more down hole property or condition.

**[00036]** In the preferred embodiment, the sound generating materials are strong enough to avoid breaking during pumping, delivery and migration in the subterranean formation, possess particle size, particle density and transportability properties that are substantially the same as the proppant within which they are carried, and are mixed into the proppant in a sufficient volume to



provide the desired sound wave transmission(s). For example, in some applications, the glass beads may be provided at 5% by weight of the proppant particles.

[00037] The signal(s) generated through use of the signal generating devices may be detectable in any suitable manner. For example, signals powered by the signal generating devices may be received by appropriate receivers disposed in the well, one or more offset wells, at the surface or other locations, or a combination thereof. If desired, receivers used in conventional micro-seismic monitoring may be used. In some embodiments, the receiver(s) may be disposed in the casing (e.g. cement, casing collar) or other component mounted in the well bore, carried on a coiled or other tubing, drill string, wireline, down hole tool or other component deployed in the well bore, or a combination thereof. In some instances, multiple receivers at different locations may be useful, such as to triangulate the source of the transmitted signals to determine location, dimensions or other variables.

[00038] If desired, systems and/or techniques of the present disclosure may be used in gathering information about variables in the well bore or subterranean formation along multiple intervals or angles in the well bore. In some applications, the same receivers may be used for receiving signals from transmitters at different locations, while in other applications, multiple sets of receivers at different locations may be warranted. For example, if the receivers are lowered into the well bore on a wireline or other carrier, the multiple sets of receivers may be disposed on the same wireline or other carrier at spaced intervals. Likewise, multiple sets of receivers may be embedded in, or connected with, the casing (not shown) or other fixture in the well bore at desired intervals to receive signals from transmitters at different target locations.

[00039] After signals are received, any methods suitable for processing them and ultimately deducing or providing the desired location, dimensions, geometry, spatial relationships or other

down hole variables may be used. For example, data conversion/processing software may be used to convert transmitted radio signals into useful information. Mathematical modeling techniques, as are and become further known, may be used to formulate and apply appropriate algorithms via one or more computing device to determine the relationship between signals received and the desired variable information.

[00040] In applications where the variable includes determining one or more subterranean geometric dimension, the signals from multiple signal generating devices may be processed to determine the locations thereof. For example, the signals may be mapped in a process similar to other known micro-seismic mapping techniques. When the signal generating devices are used in proppant distributed throughout a propped fracture area, for example, such information may be used to characterize the azimuthal orientation, geometric dimensions (e.g. length, width, height, depth), underground location of all or part of the proppant pack or propped fracture area or a combination thereof. In some applications, if sufficient signal generating devices are deployed and transmissions are received, the width of the fracture may be determined. However, the present disclosure is not limited to determining the location and dimensions of hydraulic fractures. Some examples of other subterranean features that may be measured or mapped in various applications are naturally occurring fractures, wormholes or channels created by matrix stimulation and the like. If desired, other translocation technologies, such as signal reflectance and electrical resistance may be used in conjunction with apparatus, systems and/or methods of the present disclosure.

#### EXAMPLES

[00041] The following examples illustrate that sample sound generating material in the form of exemplary glass beads and ceramic proppant will emit detectable sound upon breakage due to

the application thereto of point-to-point mechanical stress of the same general magnitude expected in certain hydraulic fracturing operations. As such, the examples illustrate the practice of one or more embodiment of the present invention. Other embodiments within the scope of the claims herein will be apparent to one skilled in the art from consideration of the specification and practice of the invention as disclosed herein. It is intended that the specification, together with the example, be considered exemplary only, with the scope and spirit of the invention being indicated by the claims which follow.

**[00042]** A modified API/ISO proppant crush test (API RP19C and ISO 13503-2) was set up to demonstrate and measure the acoustic behavior of various materials during stress application. The testing used a standard ISO crush cell having a 2" diameter piston and a MTS load frame hydraulic press (500 kpsi load capacity) with data acquisition unit. An acoustic transducer, with gel couplant applied, was mounted to the plate of the load frame and connected to an HP Universal counter and a Tectronix oscilloscope. The counter was set up to monitor the total number of acoustic events (counts) and the oscilloscope displayed waveform and amplitude (loudness). A tripod-mounted digital camera was used to generate screen captures from the oscilloscope in order to document sample acoustic events.

**[00043]** Tests were conducted on the following materials:

- (i) 40g Ottawa white sand proppant at 20/40 mesh having an average specific gravity (ASG) of 2.65
- (ii) 40g borosilicate glass beads at 20/40 mesh having an ASG of 2.65
- (iii) 40g CarboLite® (ceramic) proppant (Carb.) (sold by CARBO Ceramics, Inc.) at 20/40 mesh having an ASG 2.70

- (iv) 40g SinterBall Bauxite proppant (sold by Sintex Minerals & Service, Inc.) at 20/40 mesh having an ASG of 3.60
- (v) 53g (95%) SinterBall Bauxite proppant and 3g (5%) glass beads
- (vi) 16g LiteProp™ 108 (plastic) proppant (LP 108) at 14/40 mesh having an ASG 1.05
- (vii) 15g (95%) LiteProp™ 108 proppant and 1g CarboLite® proppant

**[00044]** Test results were obtained for (i) – (vii) above at loads applied to the piston of the filled crush cell from 100 psi – 15,000 psi at a rate of 2,000 psi/minute to simulate potential subterranean fracture closing stresses. The pressure on the cell was held at 15,000 psi for 2 minutes before being unloaded to 0 psi over 2 minutes. The number of acoustic events was measured at each 1,000 psi mark and shown in Table 1. Neither the counter nor the oscilloscope were calibrated to detect specific acoustic events from specific materials, thus easily detecting all acoustic emissions in each run. The detection levels were left the same for all tests, allowing for a direct comparison between the different materials tested.

**[00045]** In Figures 1-3, the number of acoustic events shown for each test run in Table 1 is graphed over the duration of the tests as the applied pressure was increased. As shown in Figure 1, the glass beads showed a most dramatic increase in counts at 7,000 psi at a magnitude of acoustic events believed to provide sufficient sound emissions to be detectable in the down hole environment. The ceramic (CarboLite®) proppant also showed a significant, though more gradual, increase around the 8,000 psi levels at count levels believed to provide detectable sound emissions. These pressures reflect typical fracture closing stresses, indicating that the glass beads and CarboLite proppant will break at the desired pressures. By comparison, the white

sand and SinterBall proppants demonstrated quantities of acoustic events less likely to be detectable during typical fracture closing events.

[00046] Figure 2 illustrates that the inclusion of 5% glass beads in a SinterBall proppant mixture provided increases in acoustic events at significant multiples. Likewise, Figure 3 shows that the inclusion of 5% CarboLite in a LiteProp 108 proppant mixture dramatically increased the number of acoustic events.

[00047] Figures 4-6 are sample screen captures of the oscilloscope during testing and illustrate sound waveforms (loudness) caused by breakage of the tested materials. The x axis represent testing time, while the y axis reflect amplitude of detected acoustic events. Figure 4 is a screen shot taken during the SinterBall test run, indicating consistently quiet sound emissions and a quantity of acoustic events (breakage) believed to be insufficient to create sufficiently detectable sound in a typical down hole environment. Figure 5 illustrates that the breaking of the white sand proppant was substantially louder, and Figure 6 reflects significant amplitudes of sound detected during breakage of the CarboLite. Figures 5 and 6 also illustrate that the amplitude of sound emissions during these test runs was greatest when the number of counts of the tested materials substantially increased, and then decreased after the number of counts reached a plateau. This data supports a finding that the CarboLite and glass beads (which showed a more dramatic increase in counts) could be ideal sound generating materials when their peak breaking pressures align with expected fracture closing stresses or other down hole events.

[00048] The percentage of crushed fines was measured through a 40 mesh screen for each run after testing. As shown in Table 1, there was significant reduction in size of the tested mass of glass beads and CarboLite proppant (as well as the white sand proppant), indicating they are susceptible to effective breakage at typical fracture closing pressures. Accordingly, the test

results indicate that the certain materials, such as glass beads and ceramic proppant, will sufficiently break under applied pressures equivalent to expected subterranean fracture closing stresses and emit sound at amplitudes believed to be detectable by currently available micro-seismic receivers. Such materials may thus be effectively employed as sound generating materials in accordance with the present disclosure.

Table 1

TIME	Pressure	NUMBER OF RECORDED ACOUSTIC EVENTS / 1000					NUMBER OF ACOUSTIC EVENTS	
		White Sand	Glass Beads	CarboLite	Sinter Ball	95% SB + 5% Glass	LP 108	95% LP108 + 5% Carb.
0.0	100	0.000	0.000	0.000	0.000	0.000	0	0
0.5	1000	0.010	0.110	0.000	0.000	0.000	0	0
1.0	2000	0.750	0.203	0.080	0.005	0.252	0	0
1.5	3000	17.000	1.222	0.700	0.141	1.560	0	0
2.0	4000	116.000	6.320	5.800	2.898	8.600	0	0
2.5	5000	425.000	17.546	21.900	8.787	28.200	0	0
3.0	6000	830.000	46.858	58.000	20.168	65.000	0	0
3.5	7000	1000.000	192.000	129.000	41.000	118.000	0	0
4.0	8000	1037.000	1060.000	330.000	77.000	191.000	0	0
4.5	9000	1052.000	1475.000	725.000	129.000	295.000	0	3
5.0	10000	1055.000	1688.000	1050.000	185.000	390.000	0	3
5.5	11000	1056.251	1832.000	1530.000	249.000	488.000	0	4
6.0	12000	1057.155	1965.000	1860.000	310.000	563.000	0	10
6.5	13000	1057.789	2060.000	2060.000	383.000	636.000	0	10
7.0	14000	1058.430	2160.000	2299.000	453.000	699.000	0	76
7.5	15000	1058.803	2223.000	2414.000	505.000	748.000	0	76
8.0	15000	1058.815	2246.000	2430.000		766.729	0	76
8.5	15000	1058.840		2443.000	530.000	772.304	0	76
9.0	15000	1058.933	2259.000	2463.000	534.621	775.756	0	76
9.5	15000	1058.933	2263.189	2469.275	536.829	777.848	0	76
11.5	0	1058.933	2263.754	2469.474	537.011	778.021	0	76
Crushed Fines (%)		53.5	41.1	32.4	6.3	11.9	n/a	n/a

[00049] Preferred embodiments of the present disclosure thus offer advantages over the prior art and are well adapted to carry out one or more of the objects of this disclosure. However, the present invention does not require each of the components and acts described above and is in no way limited to the above-described embodiments, methods of operation, variables, values or value ranges. Any one or more of the above components, features and processes may be employed in any suitable configuration without inclusion of other such components, features and processes. Moreover, the present invention includes additional features, capabilities, functions, methods, uses and applications that have not been specifically addressed herein but are, or will become, apparent from the description herein, the appended drawings and claims.

[00050] The methods that are provided in or apparent from the description above or claimed herein, and any other methods which may fall within the scope of the appended claims, may be performed in any desired suitable order and are not necessarily limited to any sequence described herein or as may be listed in the appended claims. Further, the methods of the present disclosure do not necessarily require use of the particular embodiments shown and described herein, but are equally applicable with any other suitable structure, form and configuration of components.

[00051] While exemplary embodiments have been shown and described, many variations, modifications and/or changes of the system, apparatus and methods of the present disclosure, such as in the components, details of construction and operation, arrangement of parts and/or methods of use, are possible, contemplated by the patent applicant(s), within the scope of the appended claims, and may be made and used by one of ordinary skill in the art without departing from the spirit or teachings of the invention and scope of appended claims. Thus, all matter herein set forth or shown in the accompanying drawings should be interpreted as illustrative, and

the scope of the disclosure and the appended claims should not be limited to the embodiments described and shown herein.



# CLAIMS

1. A method of obtaining information about at least one subterranean fracture or the location of proppant within the fracture, the method comprising:

incorporating a plurality of signal generating devices in the proppant;

delivering the proppant to the at least one fracture;

at least some of the signal generating devices in the proppant generating a detectable signal in response to at least one down hole condition or property;

at least some of the signal generating devices including sound generating material, the detectable signal generated by the signal generating devices being detectable sound waves emitted by the breaking of the sound generating material in response to at least one down hole condition or property, wherein the sound generating material breaks in response to at least one among fracture closure stress applied thereto, changes in pressure or changes in temperature;

at least one receiver receiving at least one of the detectable signals; and deriving information about the fracture or location of the proppant within the fracture from at least one of the received signals.

2. The method of claim 1, wherein the sound generating material includes at least one among glass, metal or plastic bubbles, spheres, beads, pellets or rods.

3. The method of claim 1 or 2, further including forming at least some of the signal generating devices to have a size and density about equal to the size and density of the proppant.

4. The method of claim 1, 2 or 3, further including determining at least one among the azimuthal orientation, length, width, height, depth and underground location of the fracture.

5. The method of any preceding claim, further including:

delivering the proppant and signal generating devices to multiple target locations;

at least some of the signal generating devices generating a detectable signal at each target

location;

receiving at least some of the detectable signals from signal generating devices at each target location; and

deriving information about at least one subterranean fracture or the location of the proppant therein from at least some of the received signals.

6. The method of claim 5, further including:

providing a plurality of receivers to receive the detectable signals, wherein the same receivers receive the detectable signals from the signal generating devices at multiple target locations; and

5 triangulating received signals to derive at least one among information about at least one fracture and the location of proppant within at least one fracture.

7. The method of claim 1, further including delivering the proppant and signal generating devices during hydraulic fracturing of a subterranean formation proximate to an underground hydrocarbon reservoir from a well bore.

10 8. The method of claim 7, further including:

dispersing the proppant into the least one fracture as part of a proppant pack; and

providing a plurality of receivers to receive at least some of the transmitted signals;

disposing at least some of the receivers in the well bore or at the surface; and

15 triangulating received signals to derive at least one among information about at least one fracture and the location of proppant within at least one fracture.

9. The method of claim 7 or 8, further including the sound generating materials breaking by at least one among cracking, failing, fracturing, collapsing, expanding, deforming, separating, detaching or shattering.

10. The method of claim 7 or 8, further including the sound generating materials breaking by  
20 expanding and shattering due to a temperature change in the subterranean formation.

11. The method of claim 7 or 8, further including the sound generating materials breaking under point-to-point stress of 48.3 to 62.1 MPa (7,000- 9,000 psi).

12. The method of claim 7 or 8, further including the sound generating materials collapsing due to a change in hydrostatic pressure in at least one among the well bore, the subterranean  
25 formation and the fracture.

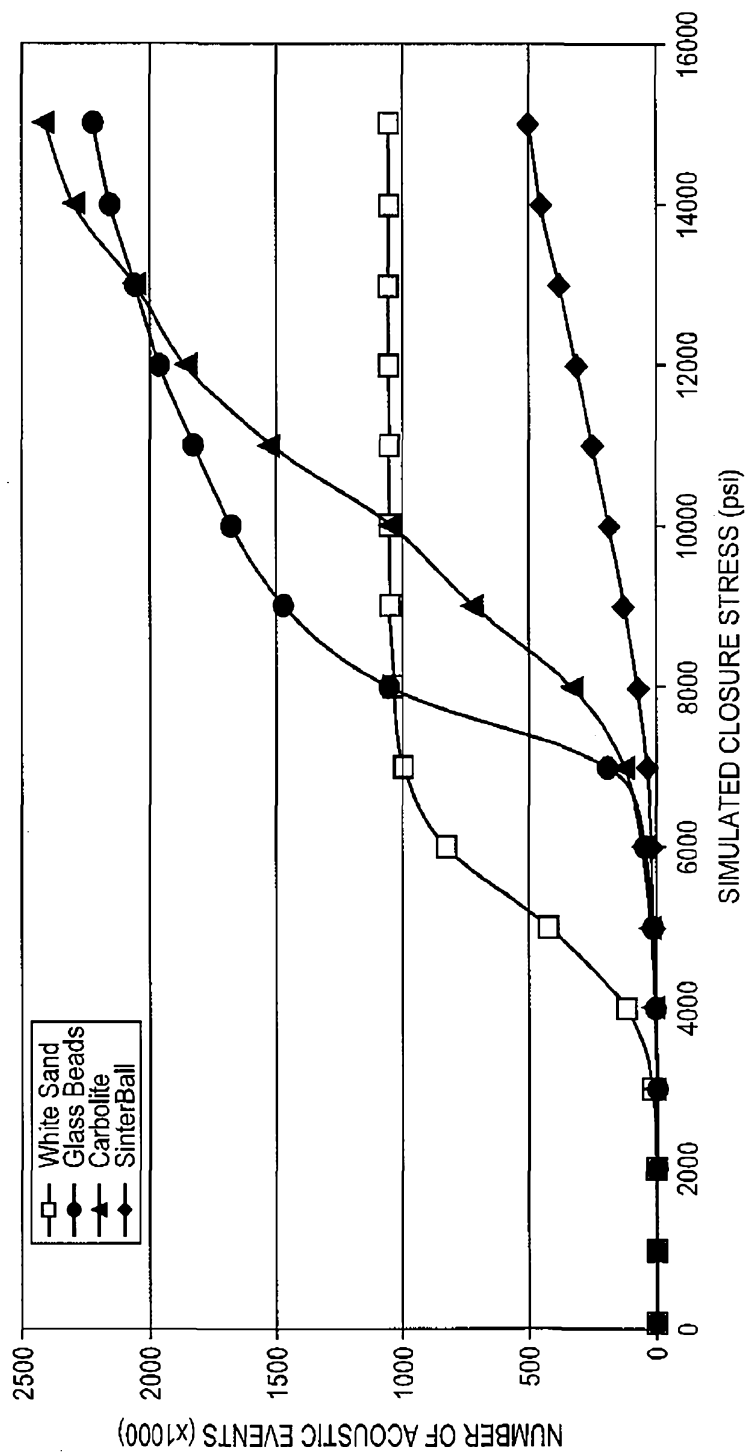
13. The method of any preceding claim, further including constructing the sound generating materials of one or more materials suitably strong to avoid breaking during pumping, delivery and migration into the subterranean fracture and capable of breaking and generating detectable

sound waves in the subterranean fracture in response to one or more down hole property or condition.

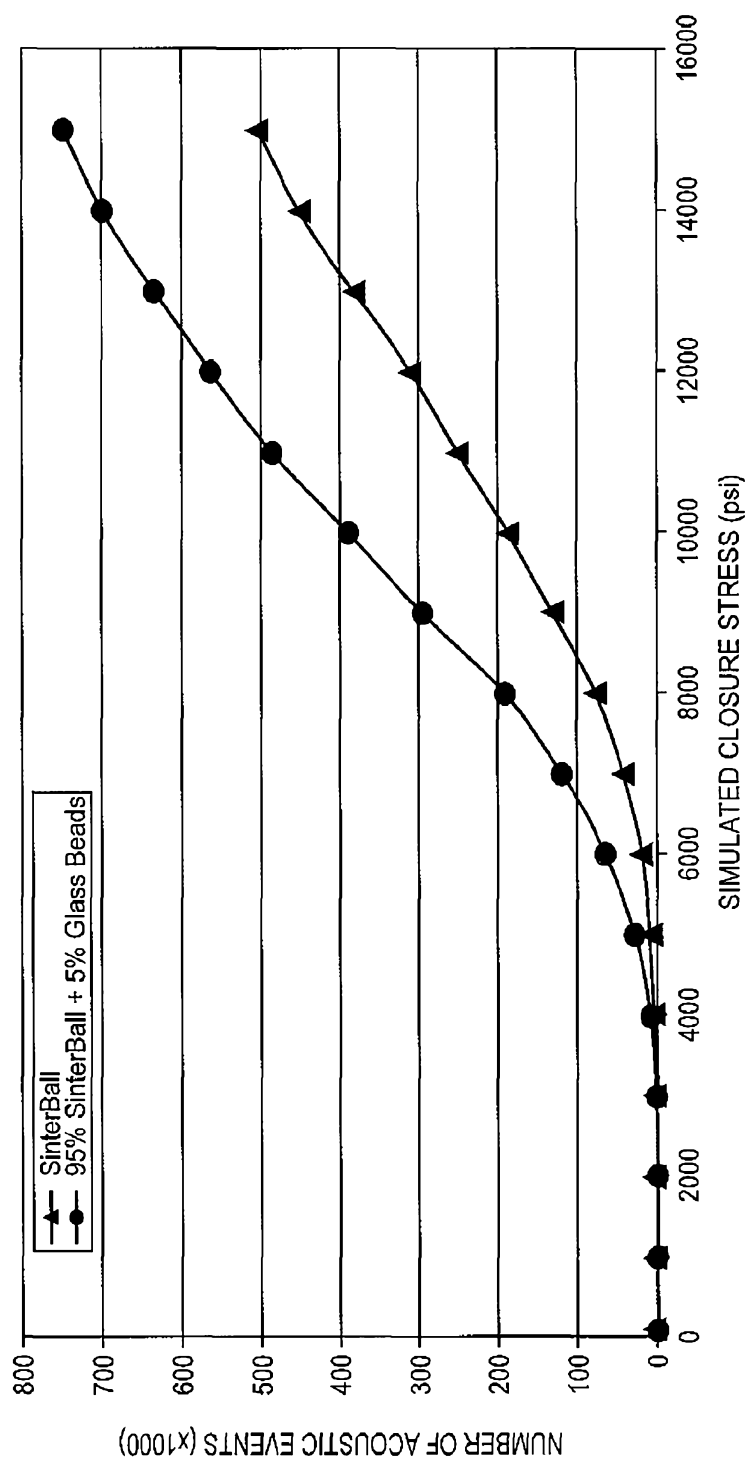
14. The method of any preceding claim, further including constructing the sound generating materials having a size, geometry, volume and particle density sufficient to avoid breaking  
 5 during pumping, delivery and migration into the subterranean fracture and able to break and generate detectable sound waves in the subterranean fracture in response to one or more down hole property or condition.

15. The method of any preceding claim, further including providing the sound generating materials at 5% by weight of the proppant particles.

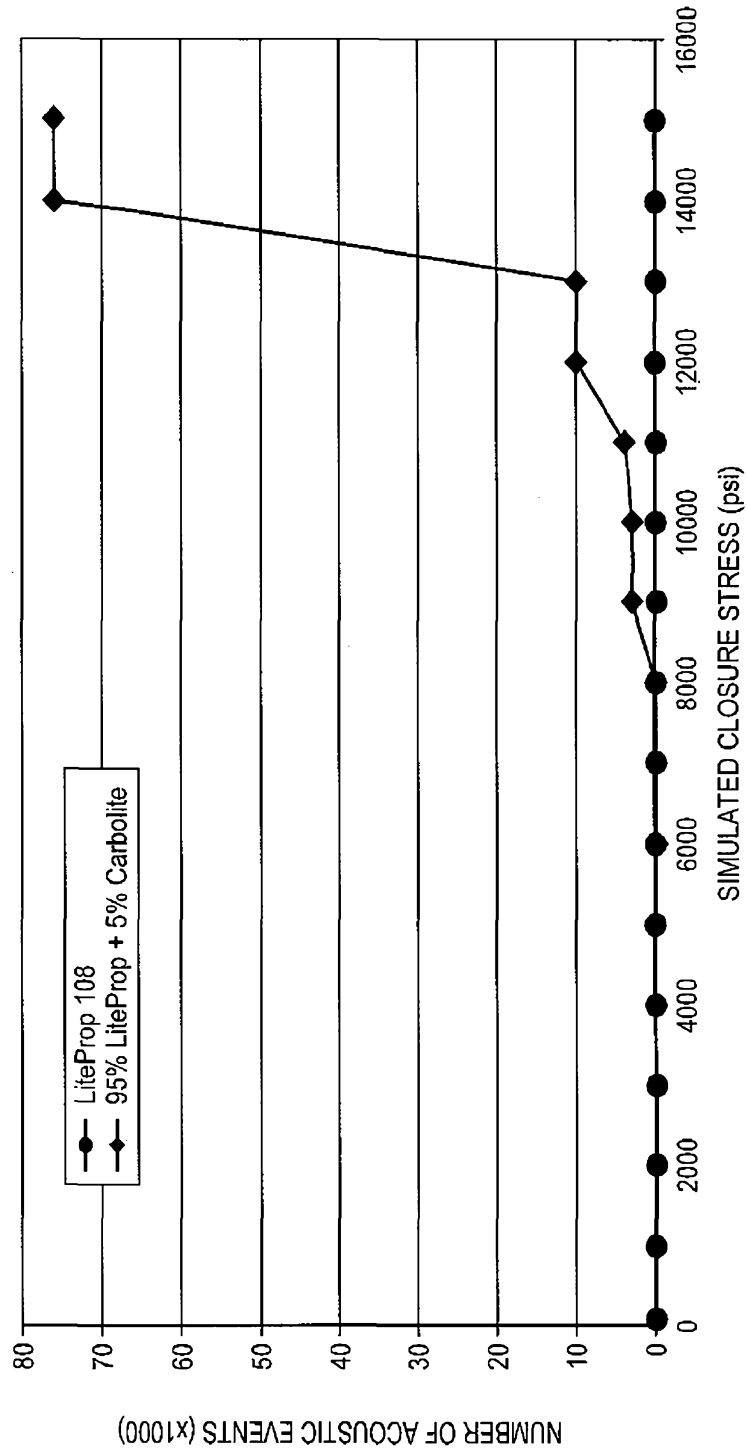
1/6

**FIG. 1**

2/6

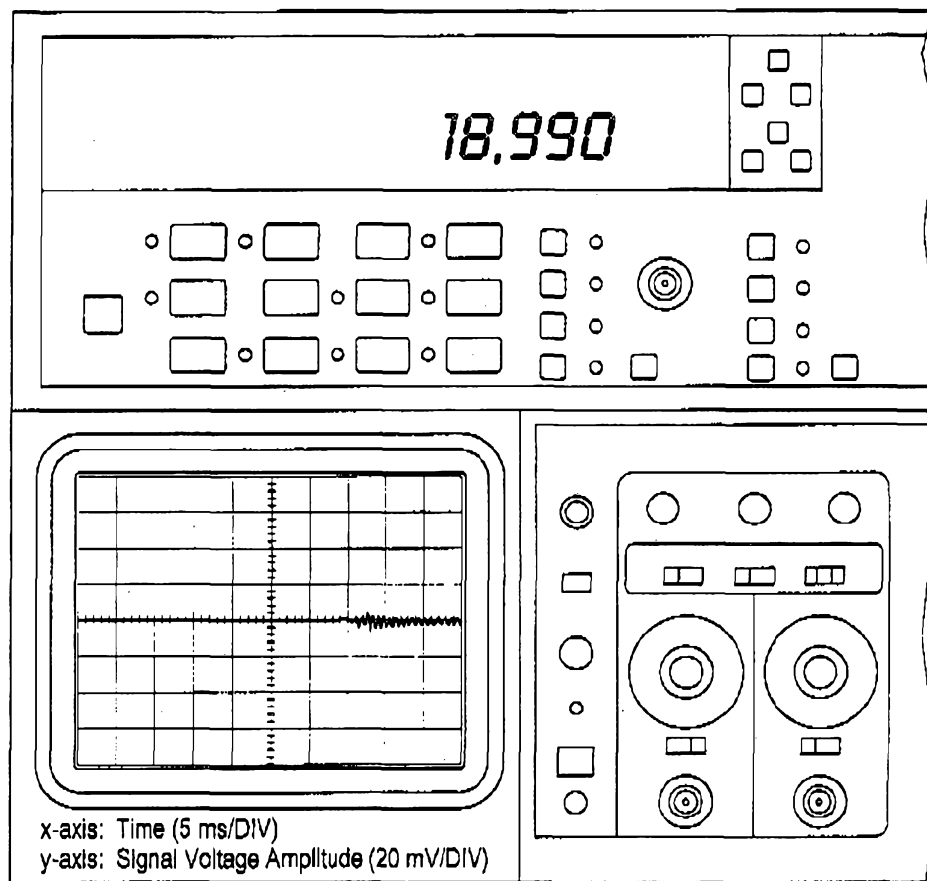
**FIG. 2**

3/6

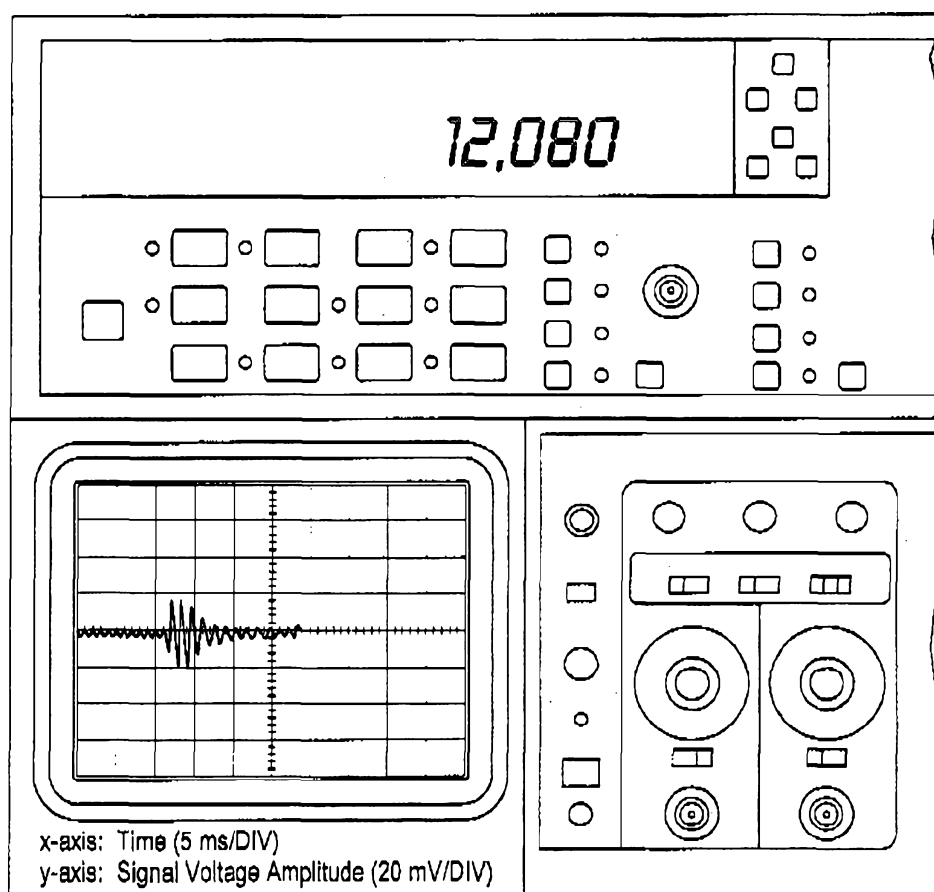


**FIG. 3**

4/6

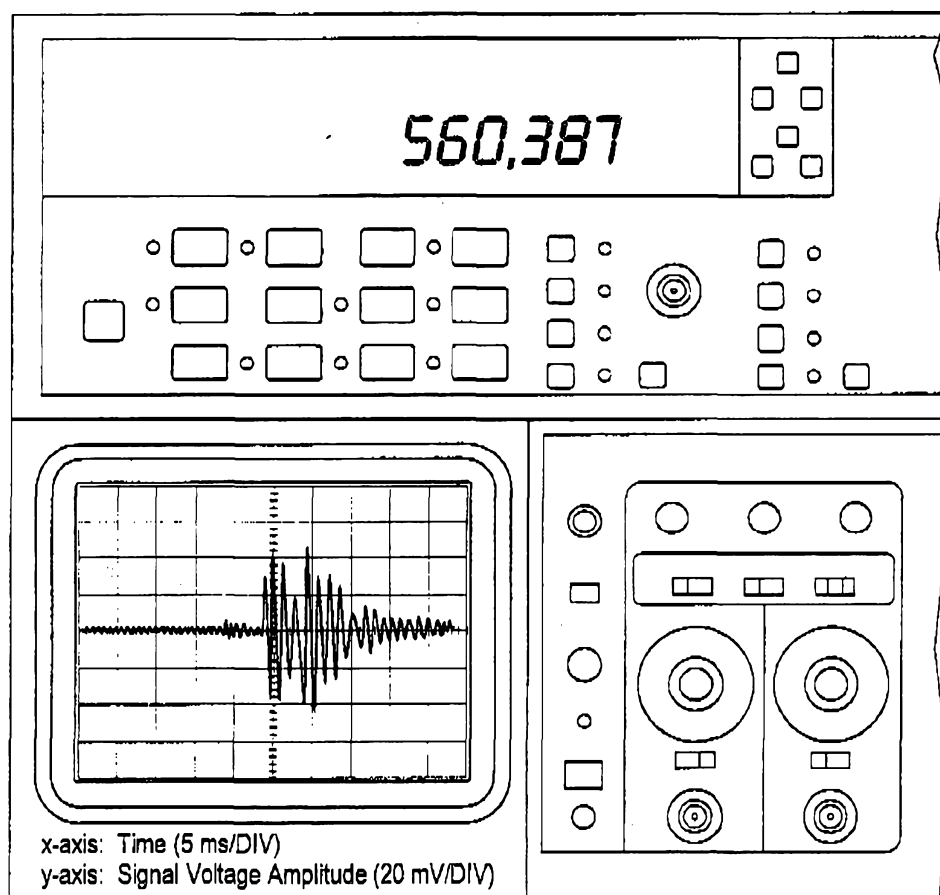
**FIG. 4**

5/6

**FIG. 5**



6/6

**FIG. 6**