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(54) **TELEMETRY ON TUBING**

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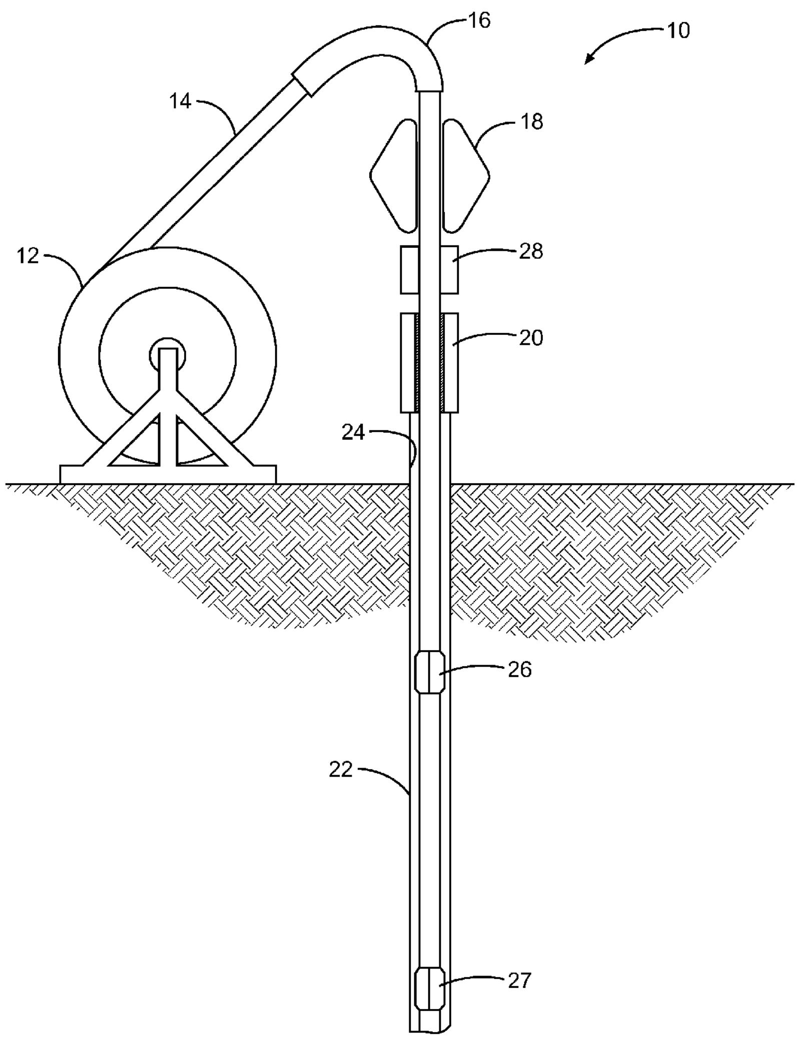
(57) **ABSTRACT**

In some embodiments, an apparatus and a system, as well as a method and an article, may operate to program a first acoustic repeater to transmit information at a first operating frequency; to couple the first acoustic repeater circumferentially around a coiled tubing portion, an inner diameter of the first acoustic repeater being about equal to an outer diameter of the coiled tubing portion; to program a second acoustic repeater to receive information transmitted by the first acoustic repeater; and to receive sensor information transmitted at the first operating frequency by the first acoustic repeater and relayed by the second acoustic repeater, the second acoustic repeater being coupled to the coiled tubing portion uphole from the first acoustic repeater. Additional apparatus, systems, and methods are disclosed.



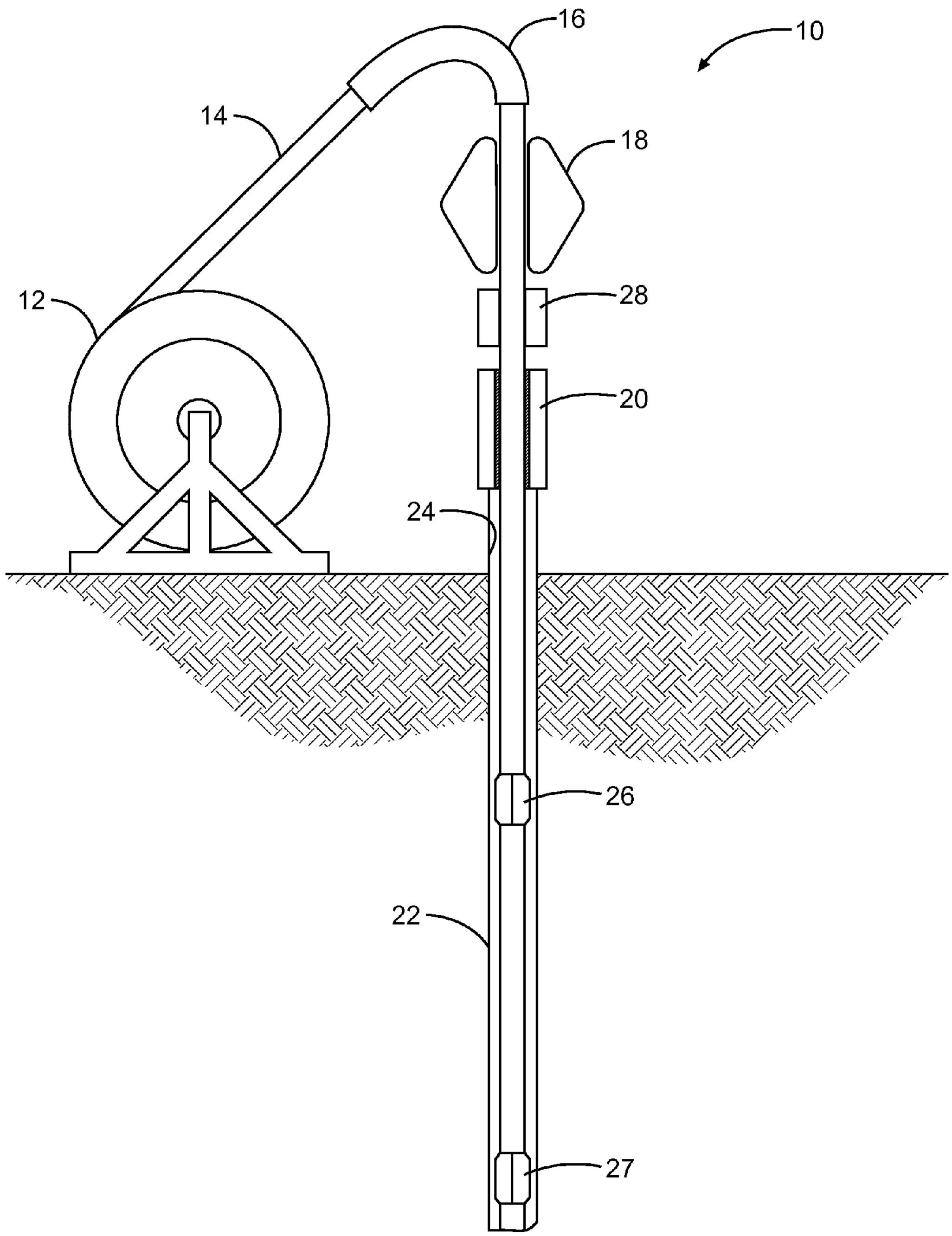


Fig. 1

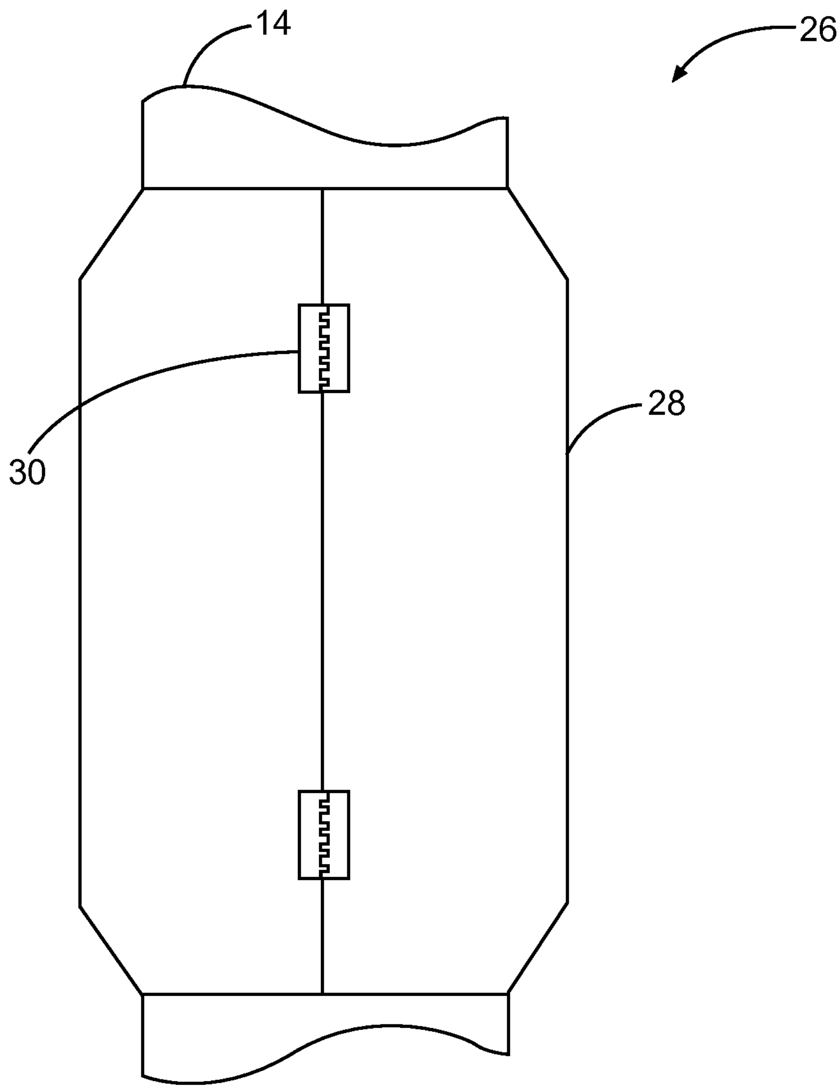


Fig. 2

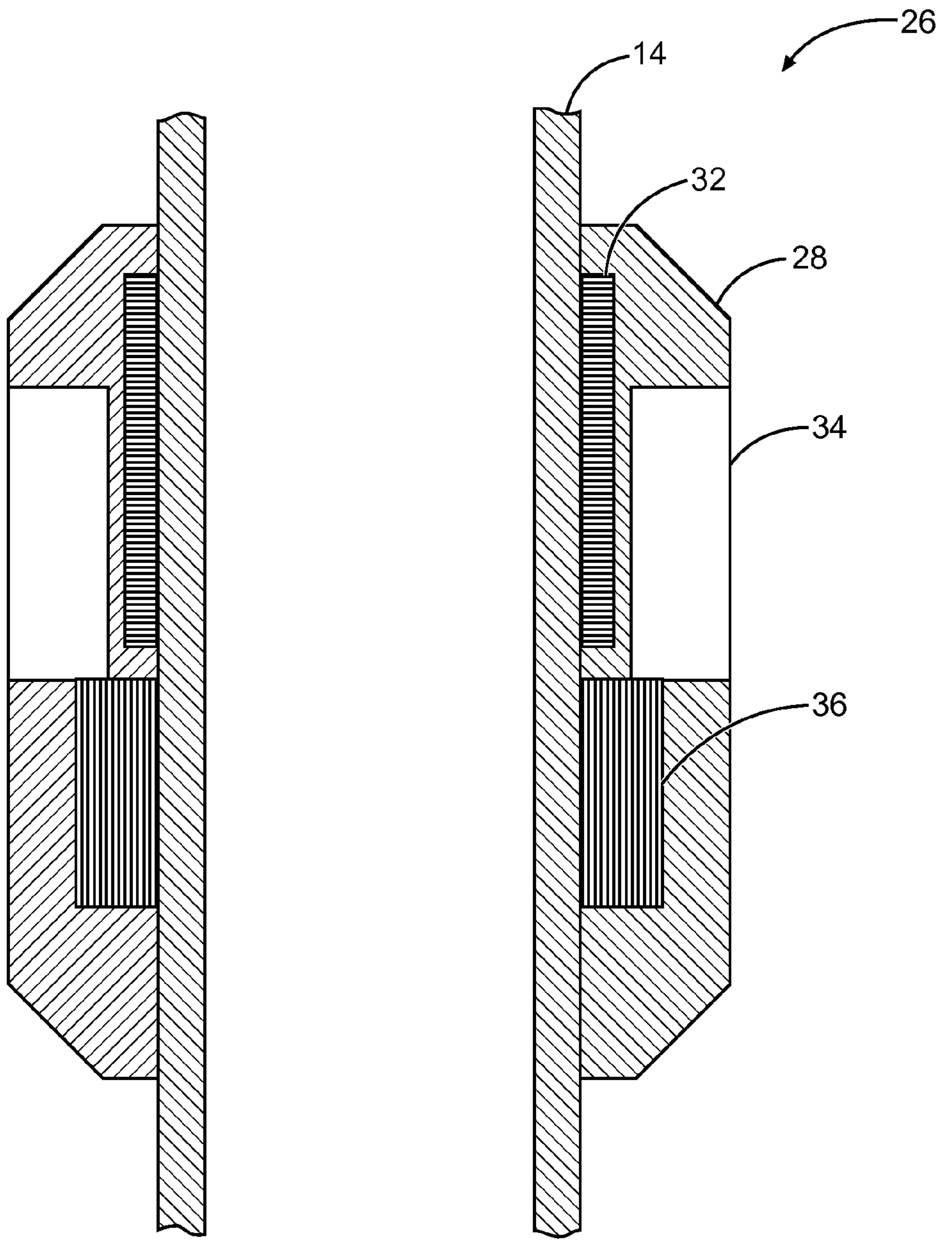


Fig. 3

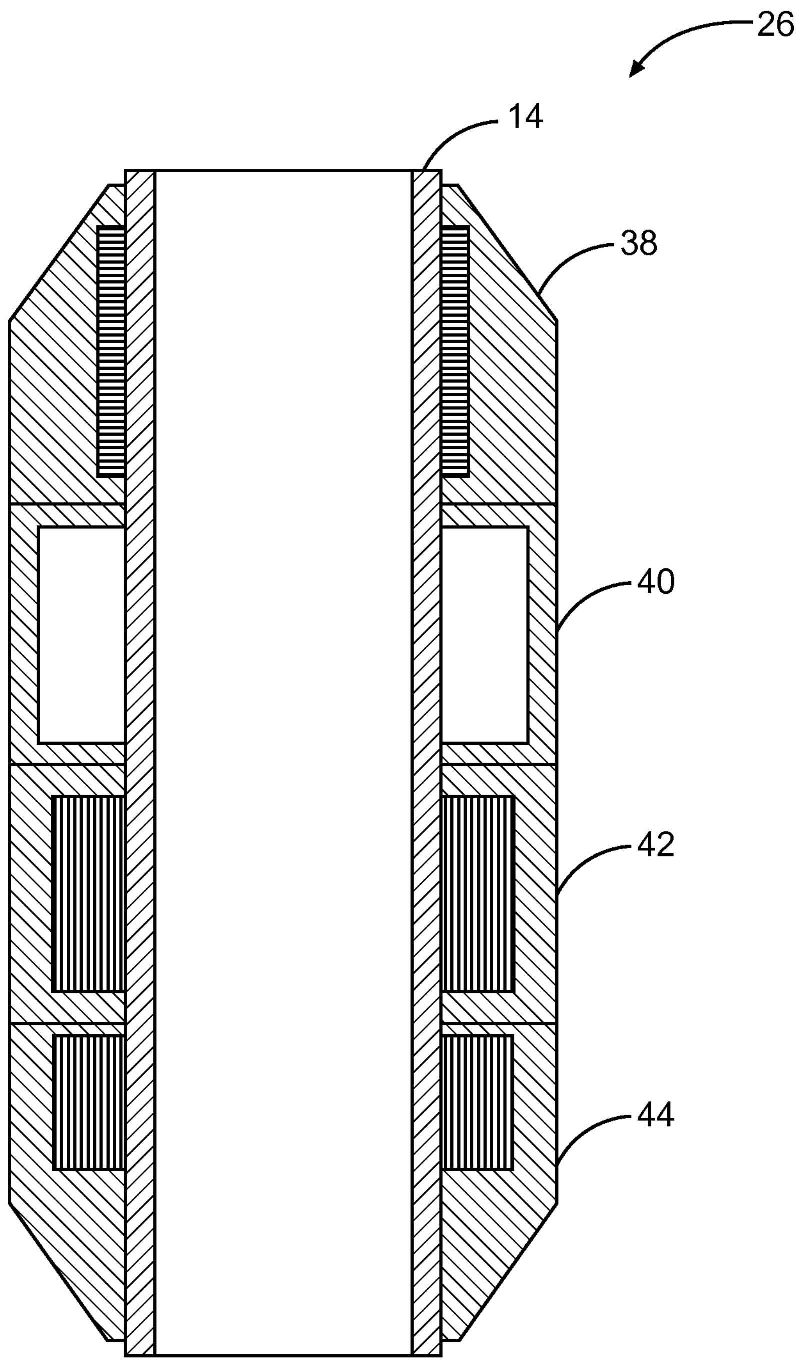


Fig. 4

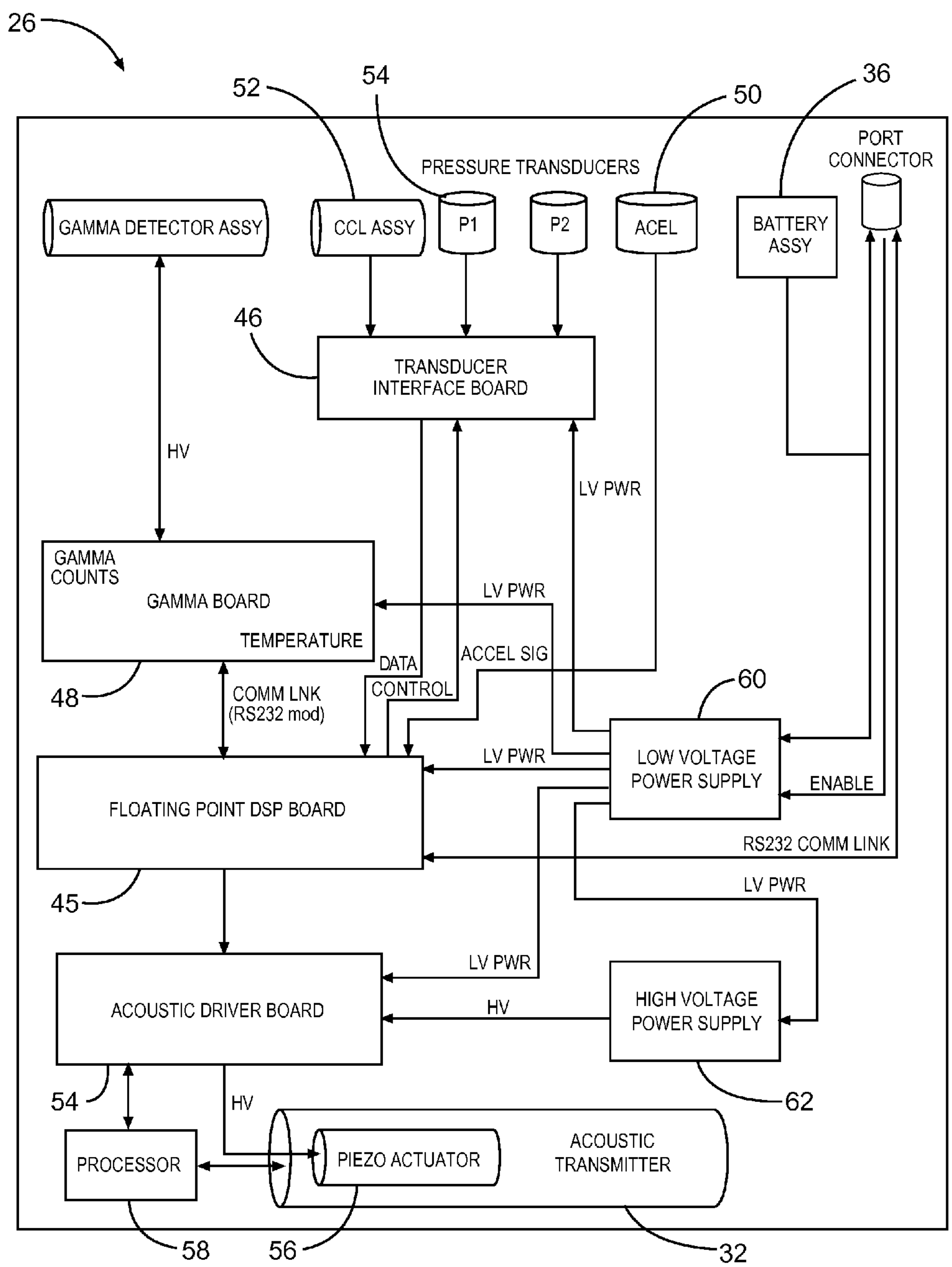

26
52
54
50
36
PRESSURE TRANSDUCERS
PORT CONNECTOR
GAMMA DETECTOR ASSY
CCL ASSY
P1
P2
ACEL
BATTERY ASSY
46
TRANSDUCER INTERFACE BOARD
HV
LV PWR
GAMMA COUNTS
GAMMA BOARD
TEMPERATURE
LV PWR
ACCEL SIG
DATA
CONTROL
48
COMM LNK (RS232 mod)
60
LOW VOLTAGE POWER SUPPLY
LV PWR
ENABLE
FLOATING POINT DSP BOARD
RS232 COMM LINK
45
LV PWR
LV PWR
ACOUSTIC DRIVER BOARD
HV
HIGH VOLTAGE POWER SUPPLY
54
HV
62
PROCESSOR
PIEZO ACTUATOR
ACOUSTIC TRANSMITTER
58
56
32

Fig. 5

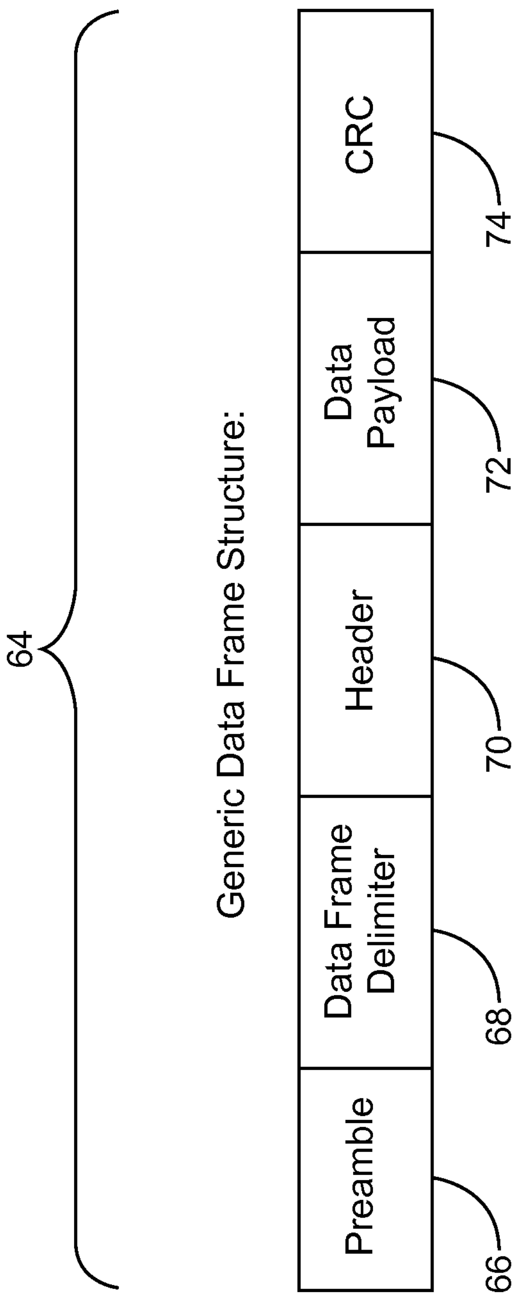

64
Generic Data Frame Structure:
Preamble
Data Frame Delimiter
Header
Data Payload
CRC
66
68
70
72
74

Fig. 6

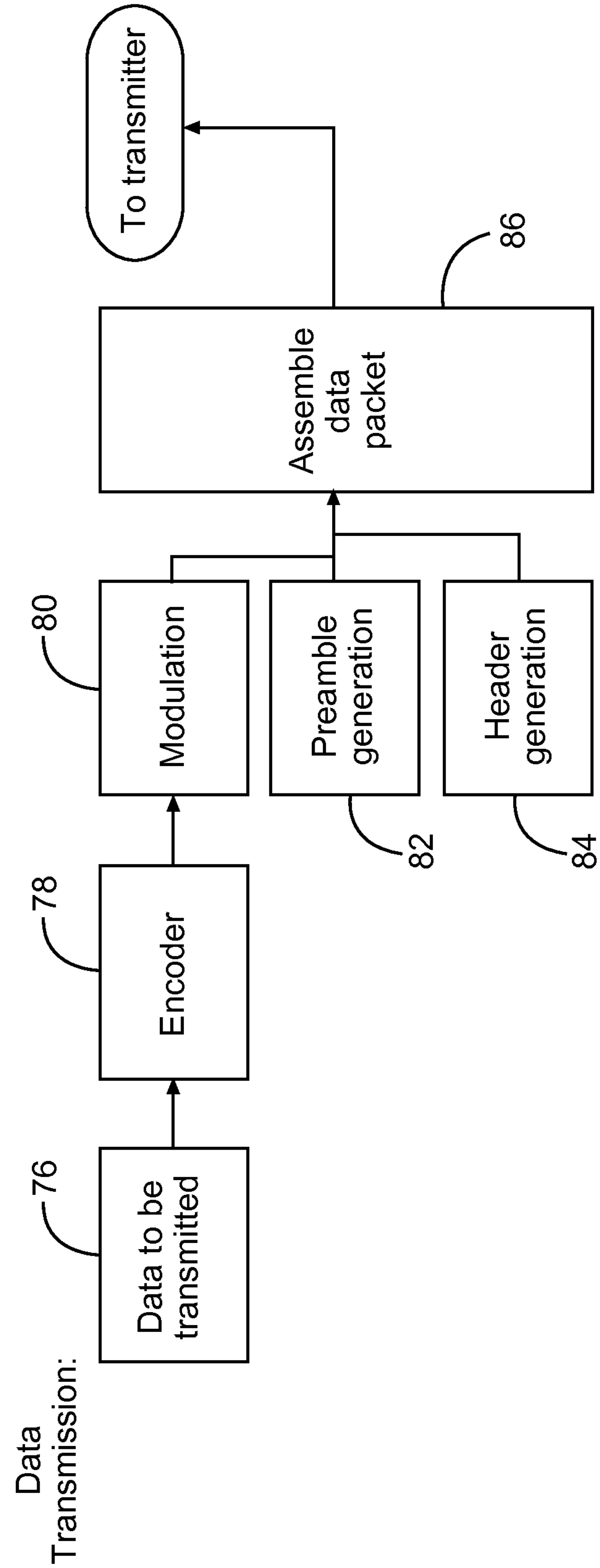

Data Transmission:
Data to be transmitted
76
Encoder
78
Modulation
80
Preamble generation
82
Header generation
84
Assemble data packet
86
To transmitter

Fig. 7

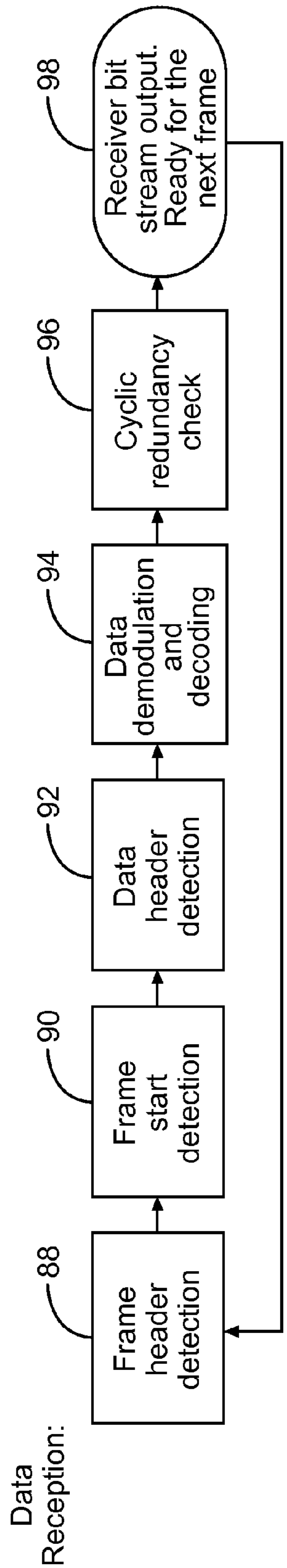

Data Reception:
Frame header detection
88
Frame start detection
90
Data header detection
92
Data demodulation and decoding
94
Cyclic redundancy check
96
Receiver bit stream output. Ready for the next frame
98

Fig. 8

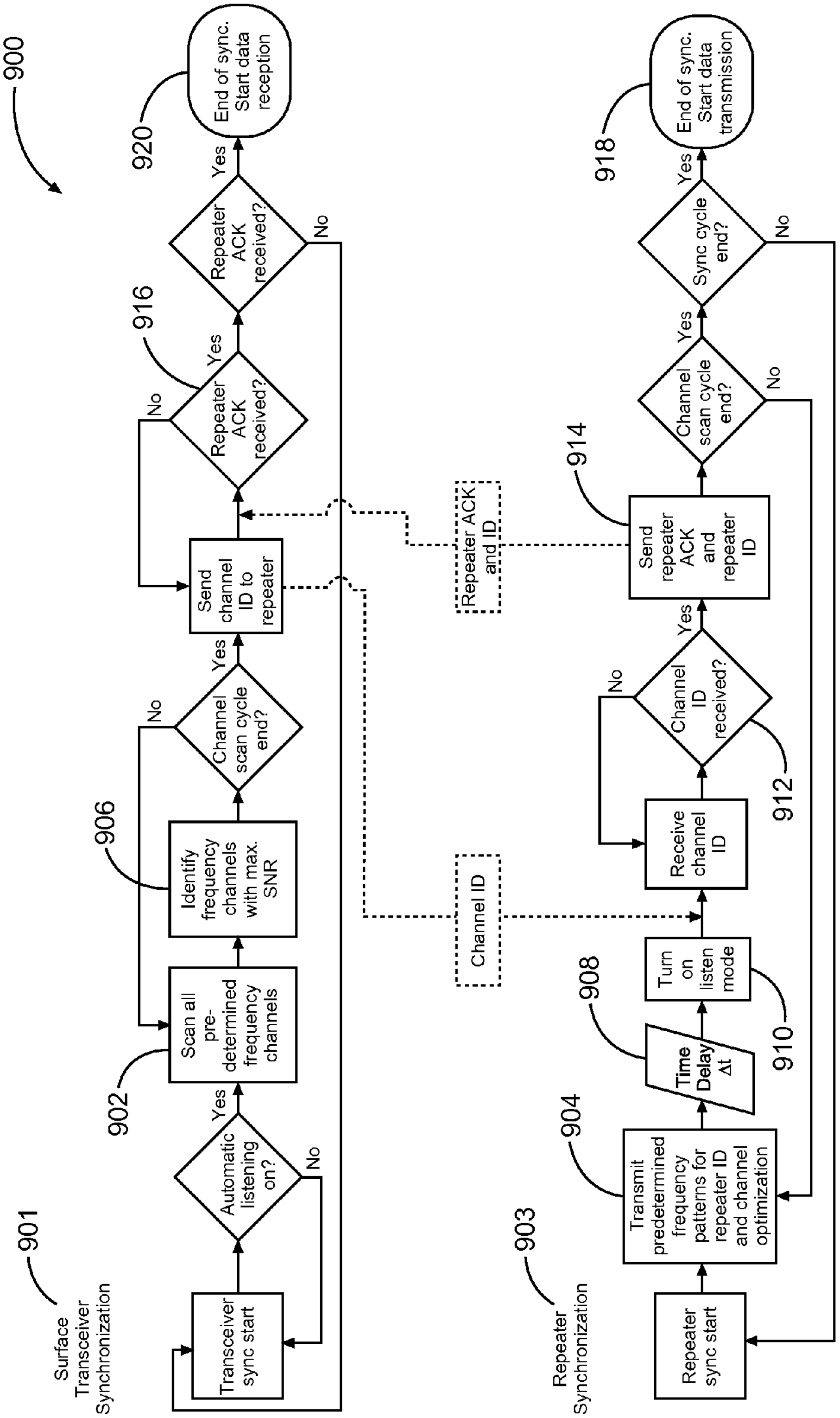

900
901
Surface Transceiver Synchronization
Transceiver sync start
Automatic listening on?
No
Yes
902
Scan all pre-determined frequency channels
906
Identify frequency channels with max. SNR
Channel scan cycle end?
No
Yes
Send channel ID to repeater
916
Repeater ACK received?
No
Yes
Repeater ACK received?
No
Yes
920
End of sync. Start data reception
Channel ID
Repeater ACK and ID
903
Repeater Synchronization
Repeater sync start
904
Transmit predetermined frequency patterns for repeater ID and channel optimization
908
Time Delay Δt
910
Turn on listen mode
Receive channel ID
912
Channel ID received?
No
Yes
914
Send repeater ACK and repeater ID
Channel scan cycle end?
No
Yes
Sync cycle end?
No
Yes
918
End of sync. Start data transmission

Fig. 9

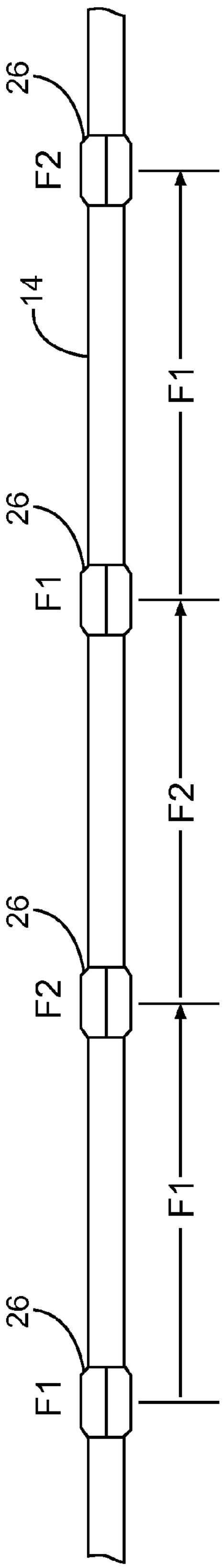


Fig. 10

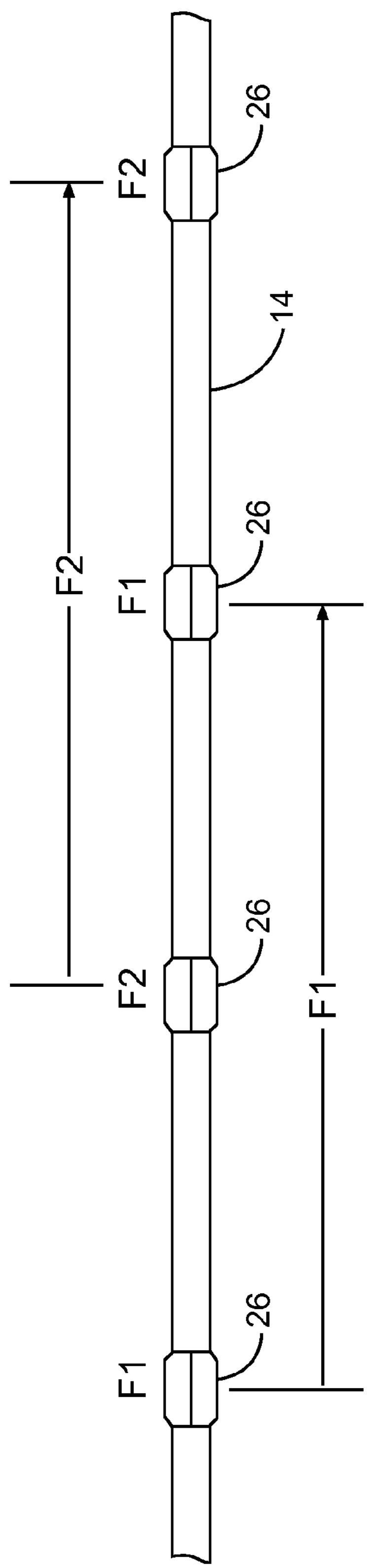


Fig. 11

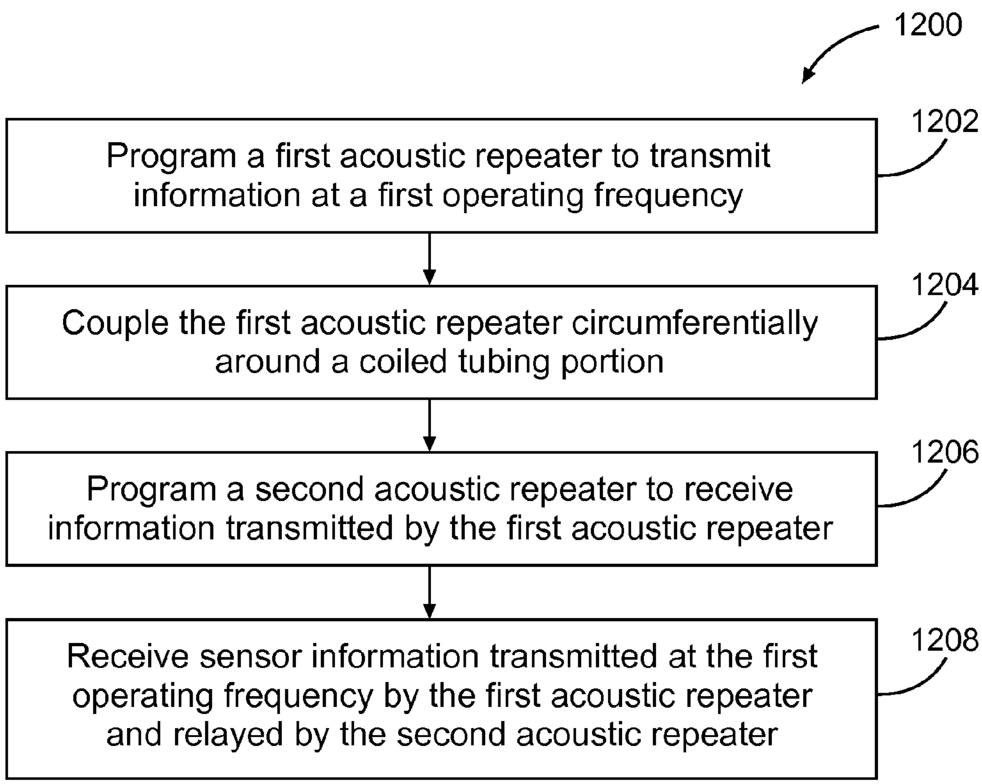

1200
Program a first acoustic repeater to transmit information at a first operating frequency
1202
Couple the first acoustic repeater circumferentially around a coiled tubing portion
1204
Program a second acoustic repeater to receive information transmitted by the first acoustic repeater
1206
Receive sensor information transmitted at the first operating frequency by the first acoustic repeater and relayed by the second acoustic repeater
1208

Fig. 12

TELEMETRY ON TUBING

BACKGROUND

[0001] Tubing, such as coiled tubing, is a natural acoustic waveguide that can serve as a telemetry channel to establish bidirectional communication between surface operators and downhole sensors and tools in a subterranean well system. An acoustic telemetry system that operates on coiled tubing can include a single transmitter at the well system bottom hole assembly (BHA) and a receiver at the surface. For operations in extended and/or horizontal wells, however, the telemetry signal from the transmitter can be adversely attenuated.

[0002] Further, as coiled tubing is tripped into a well, it is commonly passed through a stripper packer to maintain well pressure. It may be difficult to use a conventional acoustic repeater to mitigate signal attenuation, because the combination of such a repeater and the coiled tubing may not fit through the stripper packer annulus while maintaining the well seal at the surface.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] FIG. **1** illustrates an example coiled tube system including multiple acoustic repeaters in accordance with some embodiments.

[0004] FIG. **2** illustrates a front view of an example acoustic repeater in accordance with some embodiments.

[0005] FIG. **3** illustrates a section view of an example acoustic repeater in accordance with some embodiments.

[0006] FIG. **4** illustrates a section view of an example modular acoustic repeater in accordance with some embodiments.

[0007] FIG. **5** is a schematic diagram of an example electrical system for an acoustic repeater for coiled tube telemetry in accordance with some embodiments.

[0008] FIG. **6** illustrates an example data frame structure for data transmitted by the acoustic repeater in accordance with some embodiments.

[0009] FIG. **7** is a flow diagram for data transmission by the acoustic repeater in accordance with some embodiments.

[0010] FIG. **8** is a flow diagram for data reception by the surface system in accordance with some embodiments.

[0011] FIG. **9** is a flow chart illustrating a training and synchronization method in accordance with some embodiments.

[0012] FIG. **10** illustrates a single hop relay mode for acoustic repeater communication in accordance with some embodiments.

[0013] FIG. **11** illustrates a multi-hop relay mode for acoustic repeater communication in accordance with some embodiments.

[0014] FIG. **12** is a flowchart illustrating a method for providing communication between acoustic repeaters and a surface system in accordance with some embodiments.

DETAILED DESCRIPTION

[0015] To address some of the challenges described above, as well as others, systems, apparatus, and methods are described herein for using acoustic telemetry repeaters in a subterranean well system that employs coiled tubing. The acoustic repeaters may comprise a relatively thin, hinged annular housing, which can be coupled about the circumference of the coiled tubing before the stripper packer location along the tubing, as the tubing is tripped into a well. The annular housing of the acoustic repeater is configured to be concentric with the coiled tubing and symmetric about the longitudinal axis of the coiled tubing. Concentricity and symmetry combined with a relatively small radial thickness of the repeater housing enables the repeater to be attached to the coiled tubing before the tubing passes through the stripper packer into the well. Concentricity can also enable coupling of the repeater without creating discontinuities along the coiled tubing. When discontinuities are created, pressure may leak out, defeating the purpose of the stripper packer.

[0016] FIG. **1** illustrates a coiled tubing system (CTS) **10** including a reel **12**, coiled tubing (CT) **14**, a gooseneck **16**, an injector head **18**, and a stripper packer **20**. CTS **10** is configured to trip the CT **14** into and out of a wellbore **22** within a casing **24**. CTS **10** can be used for a number of interventions, and, in some cases, for production in subterranean wells.

[0017] In operation, injector head **18** draws CT **14** off of reel **12** and trips CT **14** into wellbore **22** through stripper packer **20**. Injector head **18** includes a mechanism that pushes CT **14** into and pulls CT **14** out of wellbore **22**. Injector head **18** operates in conjunction with gooseneck **16**, which acts as a curved guide beam that threads CT **14** into injector head **18**.

[0018] Below injector head **18** is stripper packer **20**. Stripper packer **20** can include rubber pack off members, which provide a seal around casing **24** to isolate the pressure within the well from the surface. Stripper packer **20** can be hydraulically opened and closed to contain wellbore pressure. By applying hydraulic pressure at stripper packer **20**, an operator at the surface of the well is able to compress rubber inserts and trip CT **14** into and out of wellbore **22** under pressure.

[0019] Although not shown in FIG. **1**, CTS **10** can also include a blowout preventer (BOP) below stripper packer **20**. The BOP can provide the ability to cut CT **14** and seal wellbore **22** (shear-blind) to hold and seal around CT **14** (pipe-slip).

[0020] Example CTS **10** also includes multiple acoustic repeaters **26**, **27** communicatively coupling a downhole transmitter (not shown) and a surface receiver **28**. The bottommost acoustic repeater **27** may serve as the downhole transmitter. As described in more detail below, acoustic repeaters **26** include a thin hinged annular housing, which can be coupled about the circumference of CT **14** before passing through stripper packer **20** as CT **14** is tripped into wellbore **22**. The annular housing of acoustic repeaters **26** is configured to be concentric with CT **14** and symmetric about the longitudinal axis of the tubing, however embodiments are not limited thereto. Concentricity and symmetry combined with a relatively small radial thickness of the housing can enable acoustic repeaters **26** coupled to CT **14** to pass through stripper packer **20**. The ability to trip acoustic repeaters **26** into wellbore **22** through stripper packer **20** enables multiple repeaters to be deployed downhole to mitigate signal attenuation in extended and/or horizontal subterranean wells.

[0021] FIG. **2** depicts a front view of an example acoustic repeater **26** in accordance with some embodiments. Acoustic repeater **26** includes an annular housing **28**. Annular housing **28** engages an outer surface of CT **14** using, for example, hinges **30**. While some example acoustic repeaters **26** may have a relatively smooth outer surface (e.g., spherical or ovoid as depicted in FIG. **2**) that can be useful in some embodiments to provide less leakage as the repeater **26**, **27** passes through the strip packet **20** and into the well, other acoustic repeaters **26**, **27** can have other shapes, such as hexagonal or rectangular shapes.

[0022] FIG. **3** depicts a section view of acoustic repeater **26** in accordance with some embodiments. Annular housing **28** encloses acoustic transmitter **32**. Acoustic transmitter **32** can also serve as an acoustic telemetry signal detector (e.g., a receiver). Acoustic transmitter **32** can include a piezoelectric actuator **56** (FIG. **5**). The piezoelectric actuator **56** may be flexible to enable the piezoelectric actuator **56** to be mounted in annular housing **28** that is concentrically mounted about CT **14**. The flexible piezoelectric actuator **56** can include a micro-fiber composite (MFC) piezoelectric actuator. Some references for MFC piezoelectric actuators quote stress generation capabilities of +/−4000 psi at temperatures up to 180 degrees Celsius. Acoustic transmitter **32** can include a plurality of flexible piezoelectric actuators (not shown in the figures) arranged in a stack to actuate together. In this manner, the actuators can generate acoustic signals with higher power than the actuators could individually generate for transmission on CT **14**.

[0023] Acoustic repeater **26** includes electrical circuitry **34**. Electrical circuitry **34** may include some of the elements described in more detail below with respect to FIG. **5** (e.g., elements **44-50** and **54**). Annular housing **28** may enclose electrical circuitry **34**, or electrical circuitry **34** may be enclosed in another separate annular housing as described below with respect to FIG. **4**. Electrical circuitry **34** and acoustic transmitter **32** may be exposed to at least some ambient pressure to permit a thinner annular housing **28** design. A thinner annular housing **28** design may enable further reduction in the profile of acoustic repeater **26**, as it appears against the outer surface of the coiled tubing. A thinner annular housing **28** may provide capability for insertion of additional electrical circuitry **34** into annular housing **28**.

[0024] Acoustic repeater **26** can include a flexible battery element **36**. Flexible battery element **36** can include a plurality of flexible battery portions, which may be housed in separate annular housing (not shown in FIG. **3**). Some references for flexible battery elements quote a thickness of about 0.5 millimeters. Flexible battery portions may be combined in series or parallel to achieve greater power capacity in acoustic repeater **26**. In some embodiments, a flexible battery such as the FLEXION (Model SF 4823-25EC) lithium polymer battery made by Solicore corporation (Lakeland, Fla., United States of America) can be used as the flexible battery element **36**.

[0025] Annular housing **28** can have an inner diameter about equal to an outer diameter of CT **14** to prevent, for example, leakage or loss of pressure between acoustic repeater **26** and CT **14**. Some references for CT quote outer diameters of about 1.2 inches to about 2.5 inches. Annular housing **28** may have an outer diameter larger than an inner diameter of stripper packer **20**. For example, annular housing **28** may have an outer diameter larger than an inner diameter of rubber inserts of stripper packer **20**, described above with respect to FIG. **1**, yet small enough that the annual housing **28** does not apply excessive stress to the rubber inserts or other elements of stripper packer **20**. Some references for the stripper packer **20** quote through-bore sizes of about 2.5 inches to about 5 inches.

[0026] FIG. **4** is a section view of acoustic repeater **26** arranged in a modular design in accordance with some embodiments. Acoustic repeater **26** can be separated into acoustic transmitter module **38**, electrical module **40**, battery modules **42** and **44**, or any combination of modules thereof. Acoustic repeater **26** may be arranged in a modular design to gain flexibility in acoustic repeater **26** configuration and for ease of maintenance. For example, operators can add or remove additional battery modules **42**, **44** to adjust to changing energy requirements or change or add electrical modules **40** to adjust to changing requirements or replace non-functioning modules of acoustic repeater **26**. The modular design as shown in FIG. **4** may also allow for a further reduced profile of the overall acoustic repeater **26**, with respect to the distance the repeater **26** rises above the outer surface of the coiled tubing.

[0027] FIG. **5** is a schematic diagram of an electrical system for acoustic repeater **26** in accordance with some embodiments. Acoustic repeaters **26** in accordance with this disclosure can be constructed with a number of electronic components. The components described with respect to FIG. **5** can include application-specific integrated circuits (ASICs) or field programmable gated arrays (FPGAs) designed for acoustic telemetry applications. Any of the components shown in FIG. **5** may be housed separately or together in the annular housing **28** (FIG. **2-3**) or in one or more modules such as modules **38**, **40**, **42**, **44** (FIG. **4**) of the acoustic repeater **26**. While some components are shown in FIG. **5**, acoustic repeater **26** may include other components not shown in FIG. **5** or acoustic repeater **26** may include a subset of the components shown in FIG. **5**. Different acoustic repeaters **26** of system **10** may have different subsets of the components shown in FIG. **5**.

[0028] In some embodiments, acoustic repeater **26** includes a floating point digital signal processing (DSP) board **45**. DSP board **45** is configured to receive digital data from, for example, transducer interface board **46**, gamma board **48**, accelerometer **50** or other data sources over communication links, for example an RS232 communication link or other data and control lines. Transducer interface board **46** can receive and digitize data from casing collar locator assembly **52**, pressure transducers **54** or other sources within or external to the acoustic repeater **26** assembly.

[0029] Accelerometer **50** can be a single-axis accelerometer or a multi-axis accelerometer. For example, accelerometer **50** can be multi-axis to provide increased precision or sensitivity with respect to off-axis movement. Using accelerometer **50**, acoustic repeater **26** can also detect pressure pulses in the fluid within, for example, CT **14** or elsewhere. In this way, acoustic repeater **26** can detect and relay mud pulse telemetry signals to surface system **28** (FIG. **1**).

[0030] DSP board **45** compresses and packages the digital data and transmits the data over a communication link to acoustic driver board **54**. Acoustic driver board **54** can be used to drive piezoelectric stack **56** of acoustic transmitter **32**, which generates acoustic signals that are transmitted through CT **14** (FIG. **1-4**). As described above with respect to FIG. **3-4**, acoustic repeater **26** can include low profile batteries **36**. Acoustic repeater **26** can also include power supply boards **60** and **62**.

[0031] Piezoelectric stack **56**, another piezoelectric stack (not shown in FIG. **5**) or accelerometer **50** can also serve as a receiver for acoustic repeater **26**. In some embodiments, acoustic repeater **26** may include processor **58** that can be programmed to implement different modulation schemes or trained to allow acoustic receiver **26** to receive and transmit on different frequencies as described below with respect to FIG. **7**. In some embodiments, acoustic transmitter **32** can additionally or alternatively be programmed to implement different modulation schemes or trained to allow acoustic receiver **26** to receive and transmit on different frequencies.

[0032] FIG. **6** illustrates a generic data frame structure for a data frame **64** transmitted by acoustic repeater **26** in accordance with some embodiments. Data frame **64** can include preamble **66**. Preamble **66** can include a pattern of data to allow acoustic repeaters **26**, surface system **28** or other devices to detect new incoming data frames **64**. Data frame **64** can include a data frame delimiter **68** to denote the end of preamble **66**. Data frame **64** can include a header **70**. Header **70** can have identification information for data frame **64** such as type identifiers, sources of the data, etc. Data frame **64** can include a data payload **72**, which can include sensor data or other data being transmitted by acoustic repeater **26**. Data frame **64** can include a cyclic redundancy check (CRC) **74** for detection of corrupted data within data frame **64**. Data frame **64** can include all of fields **66**, **68**, **70**, **72**, and **74**, or a subset of these fields, or other fields (not shown in FIG. **6**).

[0033] FIG. **7** is a flow diagram for data transmission by acoustic repeater **26** in accordance with some embodiments. Functional elements can be performed within acoustic repeater **26** by, for example, DSP board **44**, acoustic driver board **54**, processor **58**, or acoustic transmitter **32**.

[0034] Data to be transmitted 76 may be received at acoustic transmitter **32**, or as digital data received from the acoustic driver board **54** and encoded as acoustic data in an encoder **78**. Circuitry, for example the circuitry of processor **58** or acoustic transmitter **32**, can perform modulation **80**, preamble generation **82**, and header generation **84** to assemble **86** a data packet **64** (FIG. **6**). Acoustic transmitter **32** transmits the data packet **64**. For example, piezoelectric stack **56** of the acoustic transmitter **32** can launch an acoustic signal into CT **14**, which then acts as an acoustic transmission medium.

[0035] Modulation **80** can be performed according to various modulation schemes, including at least one of pulse position modulation (PPM), on-off keying (OOK), frequency shift keying (FSK), amplitude modulation (AM), and phase shift keying (PSK).

[0036] Modulation **80** can also be performed using orthogonal frequency division multiplexing (OFDM), which is a method currently used in some broadband communication applications for encoding digital data on multiple carrier frequencies. With OFDM, a large number of closely-spaced orthogonal sub-carrier signals are used to carry the data on parallel channels. Each sub-carrier is modulated with a modulation scheme such as, for example, FSK, at a low symbol rate.

[0037] In some embodiments, OFDM may be used because the movement of CT **14** can generate loud noises or other interference. OFDM can reduce the impact of the noise at the surface, where signals may be processed, thus improving reliability of some embodiments. OFDM can reduce the impact of noise at least because OFDM's low symbol rate can permit the use of a guard interval between symbols (e.g., a representation of bits of data), thus reducing or eliminating interference between symbols and, in turn, leading to a signal-to-noise ratio improvement.

[0038] FIG. **8** is a flow diagram for data reception by surface system **28** in accordance with some embodiments. In functional blocks **88**, **90**, **92**, **94**, and **96**, surface system **28** can detect various portions of a data frame **64** (FIG. **6**). In functional block **94**, surface system **28** can perform a demodulation of the data signal that was modulated by acoustic repeater **26**. Surface system **28** can perform error checking in functional block **96**. Surface system **28** can then, in functional block **98**, receive or prepare to receive a next data frame **64**.

[0039] FIG. **9** is a flow chart illustrating a training and synchronization method **900** in accordance with some embodiments. The training and synchronization method **900** can be performed when acoustic repeaters **26**, **27** are downhole. The training and synchronization method **900** can be performed when the surface system **28** detects that downhole conditions have change, when additional acoustic repeaters **26** are coupled to CT **14**, or for other reasons. Training and synchronization may be executed by processor **58** or acoustic transmitter **32** of an acoustic repeater **26**. The training and synchronization method **900** can include functionalities **901** performed by surface system **28** and other functionalities **903** performed by acoustic repeaters **26**, **27**.

[0040] Surface system **28** can scan **902** a set of predetermined frequency channels. Acoustic repeater **26** can transmit **904** on the predetermined frequency channels. Surface system **28** can listen on the predetermined frequency channels for these transmissions of acoustic repeater **26** to identify **906** frequency channels that have at least a threshold signal-to-noise ratio (SNR). Acoustic repeater **26** can wait **908** for a certain time duration after each transmission, and then turn on **910** a listen mode to listen for a channel identifier. If a channel identifier is received **912** from the surface system **28**, acoustic repeater **26** can send an acknowledgement **914** and repeater identifier on the frequency channel identified.

[0041] If surface system **28** receives **916** a response, including an acknowledgement and an acoustic repeater identifier, to the surface system **28**'s transmission of the channel identifier, the acoustic repeater **26** can begin **918** transmissions on the determined frequency channel, and surface system **28** can receive **920** data from acoustic repeater **26** on the frequency channel. Otherwise, the synchronization process may begin anew, or other channel identifiers can be transmitted to the acoustic repeater **26**.

[0042] Instead of or in addition to the process described above with respect to FIG. **9**, acoustic repeaters can be preprogrammed to transmit on a given frequency channel. The frequency channel can be adapted at a later time using the process described above with respect to FIG. **9**.

[0043] FIG. **10** illustrates an example single hop relay mode for acoustic repeater **26** communication in accordance with some embodiments. In the illustrative example, two frequency channels **f1** and **f2** are in use. At least one acoustic repeater **26** receives data on frequency channel **f1** and retransmits on frequency channel **f2**. Adjacent acoustic repeaters **26** transmit on different frequency channels **f1**, **f2** to avoid signal contamination between the channels. Frequency channels **f1** and **f2** may have been programmed into acoustic repeaters **26** when the acoustic repeaters **26** were coupled to CT **14**, or at a later time during a synchronization process as described above with respect to FIG. **9**.

[0044] FIG. **11** illustrates a multi-hop relay mode for acoustic repeater communication in accordance with some embodiments. In the multi-hop relay mode, adjacent acoustic repeaters **26** still transmit on different frequencies **f1**, **f2**. Each acoustic repeater **26** receives and retransmits on a same frequency **f1** or **f2**. Accordingly, when data is transmitted on, for example, frequency **f1**, that data is not received by a next adjacent acoustic repeater **26** but instead by a subsequent acoustic repeater **26**.

[0045] FIG. **12** is a flowchart illustrating an example method **1200** for providing communication between acoustic repeaters and a surface system in accordance with some embodiments. Some elements of method **1200** can be implemented by a surface receiver system **28** (FIG. **1**).

[0046] Example method **1200** starts at block **1210** with programming a first acoustic repeater **26** to transmit information at a first operating frequency. In some embodiments, the programming of block **1210** proceeds similarly to the training and synchronization method described above with respect to FIG. **9**. In some embodiments, first acoustic repeater **26** is preprogrammed to transmit at a first operating frequency and later trained to transmit at different operating frequencies as described above with respect to FIG. **9**. First acoustic repeater **26** can also be programmed to use a modulation scheme for modulating signals containing the sensor information. The modulation scheme can include OFDM, as described above with respect to FIG. **7**.

[0047] Example method **1200** continues at block **1220** with coupling the first acoustic repeater **26** circumferentially around a CT **14** portion, an inner diameter of the first acoustic repeater **26** being about equal to an outer diameter of the CT **14** portion.

[0048] Example method **1200** continues at block **1230** with programming a second acoustic repeater **26** to receive information transmitted by the first acoustic repeater **26**.

[0049] Example method **1200** continues at block **1240** with receiving sensor information transmitted at the first operating frequency by the first acoustic repeater and relayed by the second acoustic repeater. The second acoustic repeater is coupled to the coiled tubing portion uphole from the first acoustic repeater. The second acoustic repeater can relay the information on a second operating frequency different from the first operating frequency.

[0050] Any number of additional acoustic repeaters **26** can be coupled to CT **14**. The number can be selected based on or in response to a determination that a wellbore condition has changed. If additional acoustic repeaters **26** are added, a synchronization process as described above can be performed. This process can include at least transmitting synchronization instructions to the first acoustic repeater, subsequent to the coupling or uncoupling, to instruct the first acoustic repeater to transmit test information using another frequency different from the first frequency.

[0051] Example method **1200** can include receiving mud pulse telemetry signals from first acoustic repeater **26** based on a measurement by an accelerometer **50** (FIG. **5**) of first acoustic repeater **26**.

[0052] It should be noted that the methods described herein do not have to be executed in the order described, or in any particular order. Moreover, various activities described with respect to the methods identified herein can be executed in iterative, serial, or parallel fashion.

[0053] In summary, using the apparatus, systems, and methods disclosed herein can provide surface systems with downhole sensor data that uses the coiled tubing itself as an acoustic communication channel between a series of acoustic repeaters. As a result, real-time downhole conditions can be monitored during CT-delivered services or processes, such as fracturing processes, in extended or horizontal wells. At the same time, a surface system can send commands, through the repeaters, to instruct downhole tools to carry out desired operations. The low-profile of the repeaters makes it possible to trip them into a well, through a conventional stripper packer, without loss of pressure or other problems, and without the need to modify existing surface equipment.

[0054] The accompanying drawings that form a part hereof, show by way of illustration, and not of limitation, specific embodiments in which the subject matter may be practiced. The embodiments illustrated are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed herein. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. This Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

[0055] Such embodiments of the inventive subject matter may be referred to herein, individually and/or collectively, by the term "invention" merely for convenience and without intending to voluntarily limit the scope of this application to any single invention or inventive concept if more than one is in fact disclosed. Thus, although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to achieve the same purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of ordinary skill in the art upon reviewing the above description.

What is claimed is:

1. A coiled tubing acoustic telemetry system, comprising:

a length of coiled tubing; and

a first repeater apparatus including,

an acoustic transmitter,

electrical circuitry configured to drive the acoustic transmitter to generate acoustic signals, and

an annular housing configured to enclose the acoustic transmitter and to engage an outer surface of the coiled tubing, the annular housing having an inner diameter about equal to an outer diameter of the length of coiled tubing; and

a second repeater apparatus coupled to the coiled tubing portion and spaced at a distance downhole from the first repeater apparatus, the second repeater apparatus including an acoustic transmitter and an annular housing configured to enclose the acoustic transmitter and to engage an outer surface of the coiled tubing, the annular housing having an inner diameter about equal to an outer diameter of the coiled tubing portion.

2. The system of claim **1** wherein the annular housing has an outer diameter larger than an inner diameter of a stripper packer assembly.

3. The system of claim **1**, wherein the acoustic transmitter includes a flexible piezoelectric actuator.

4. The system of claim **1**, wherein the electrical circuitry is housed in another annular housing separate from the annular housing.

5. The system of claim **1**, wherein the first repeater apparatus further includes a flexible battery element including a plurality of battery portions.

6. The system of claim **5**, wherein a battery portion of the plurality of battery portions being enclosed in another annular housing separate from the annular housing.

7. A method for providing communication between acoustic repeaters and a surface system, the method comprising:
programming a first acoustic repeater to transmit information at a first operating frequency;
coupling the first acoustic repeater circumferentially around a coiled tubing portion, an inner diameter of the first acoustic repeater being about equal to an outer diameter of the coiled tubing portion;
programming a second acoustic repeater to receive information transmitted by the first acoustic repeater; and
receiving sensor information transmitted at the first operating frequency by the first acoustic repeater and relayed by the second acoustic repeater, the second acoustic repeater being coupled to the coiled tubing portion uphole from the first acoustic repeater.

8. The method of claim 7, wherein the second acoustic repeater relays the information on a second operating frequency different from the first operating frequency.

9. The method of claim 7, further comprising:
coupling additional acoustic repeaters to the coiled tubing portion responsive to a determination that a wellbore condition has changed; and
transmitting synchronization instructions to the first acoustic repeater, subsequent to the coupling or uncoupling, to instruct the first acoustic repeater to transmit test information using another frequency different from the first frequency.

10. The method of claim 7, further comprising:
programming the first acoustic repeater to use a modulation scheme for modulating signals containing the sensor information.

11. The method of claim 10, wherein the modulation scheme includes orthogonal frequency division multiplexing.

12. The method of claim 7, further comprising:
receiving mud pulse telemetry signals from the first acoustic repeater based on a measurement by an accelerometer of the first acoustic repeater.

13. An apparatus, comprising:
an acoustic transmitter;
electrical circuitry configured to drive the acoustic transmitter to generate acoustic signals;
an annular housing configured to enclose the acoustic transmitter and to engage an outer circumference of a section of coiled tubing; and
a receiver.

14. The apparatus of claim 13, wherein the acoustic transmitter includes a flexible piezoelectric actuator.

15. The apparatus of claim 13, wherein the electrical circuitry is enclosed in the annular housing.

16. The apparatus of claim 15, further comprising additional electrical circuitry enclosed in another annular housing separate from the annular housing, the additional electrical circuitry including one or more of a transducer interface board, a digital signal processing board, or a gamma board.

17. The apparatus of claim 16, wherein the annular housing has an outer diameter larger than an inner diameter of a stripper packer assembly.

18. The apparatus of claim 13, further comprising a flexible battery element.

19. The apparatus of claim 18, wherein the flexible battery element includes a plurality of flexible battery portions.

20. The apparatus of claim 19, wherein a battery portion of the plurality of battery portions is enclosed in a second annular housing different from the annular housing.

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