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(54) Title: FIBER TELEMETRY SYSTEMS FOR WELLS

(57) Abstract: In accordance with at least one aspect of this disclosure, an apparatus for downhole telemetry includes a fiber optic cable sized and configured to be connected to and/or disposed within a downhole tubular, the fiber optic cable comprising a first optical connector or a second optical connector, and a fiber optic amplifier operatively associated with the fiber optic cable to amplify a signal in the fiber optic cable.

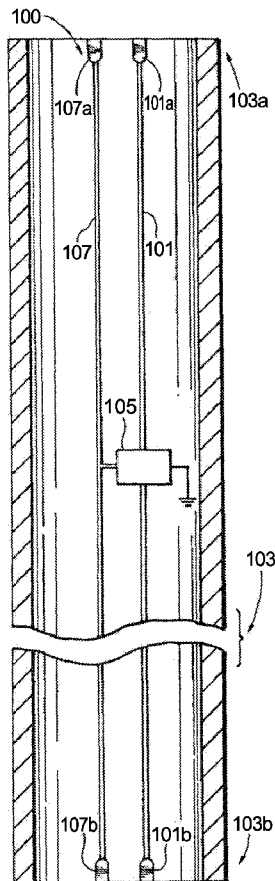


Fig. 1A



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FIBER TELEMETRY SYSTEMS FOR WELLS

BACKGROUND

1. Field

The present disclosure relates to drilling, more specifically to telemetry systems for wells
5 (e.g., hydrocarbon wells).

2. Description of Related Art

The standard option for telemetry during drilling operations is mud pulsing, which
unfortunately is limited to a data rate of a few bits per second. Standard optical fibers can
achieve a data rate which is many orders of magnitude faster and they are useful for wireline
10 applications, but they are not reasonable for drilling operations.

Drilling operations would require fiber optic connections for each added downhole
tubular, each connection causing losses in the fiber optic signal. For example for a 10 km deep
oil well, where 30m lengths of downhole tubular (e.g., three 10m drill pipes in a 30m drill stand)
are used, there would be about 333 connections. If each connection has losses of about 3 dB,
15 then the total losses are around 1000 dB for a 10 km oil well, an amount that is too high for data
transmission.

Copper cables can be used to send electrical telemetry signals, and copper cables do not
suffer from connection losses like fiber optic cables do. However, a 10 km long copper wire will
have an electrical inductance and capacitance so large that a high data rate cannot be achieve.

20 Such conventional methods and systems have generally been considered satisfactory for
their intended purpose. However, there is still a need in the art for improved telemetry systems.
The present disclosure provides a solution for this need.

BRIEF DESCRIPTION OF THE DRAWINGS

So that those skilled in the art to which the subject disclosure appertains will readily understand how to make and use the devices and methods of the subject disclosure without undue experimentation, embodiments thereof will be described in detail herein below with
5 reference to certain figures, wherein:

Fig. 1A is a schematic cross-sectional elevation view of an embodiment of an apparatus disposed in a downhole tubular in accordance with this disclosure;

Fig. 1B is a schematic cross-sectional elevation view of an embodiment of an apparatus disposed in a downhole tubular in accordance with this disclosure;

10 Fig. 2 is a perspective view of a plurality of electrical wires and fiber optic cables combined together in an embodiment of a sheath;

Fig. 3 is a perspective view of a first end connector and a second end connector in accordance with this disclosure;

15 Fig. 4 is a perspective view of an embodiment of a fiber optic amplifier in accordance with this disclosure disposed between upper and lower portions of a fiber optic cable; and

Fig. 5 is a cross-sectional elevational view of an embodiment of a system in accordance with this disclosure, shown disposed in a well.

DETAILED DESCRIPTION

Reference will now be made to the drawings wherein like reference numerals identify similar structural features or aspects of the subject disclosure. For purposes of explanation and illustration, and not limitation, an illustrative view of an embodiment of an apparatus in accordance with the disclosure is shown in Fig. 1A and is designated generally by reference character 100. Other embodiments and/or aspects of this disclosure are shown in Figs. 1B-5. The systems and methods described herein can be used to improve telemetry systems and data transfer rates for drilling assemblies.

Referring to Fig. 1A, an apparatus 100 for downhole telemetry includes at least one fiber optic cable 101 sized and configured to be connected to and/or disposed within a downhole tubular 103. The downhole tubular 103 can be any suitable tubular for well operations with at least one connection (e.g., production tubing, drill pipe, drill collars, surface casing, marine risers, and/or coiled tubing). In certain embodiments, the fiber optic cable 101 can be the same length as a downhole tubular 103 (e.g., 10 meters) and/or drill stand (e.g., 30 meters of assembled downhole tubulars 103), however, any suitable length is contemplated herein. The fiber optic cable 101 includes a first optical connector 101a and a second optical connector 101b, which can be hard wire connections or wireless connections as would be appreciated by those having ordinary skill in the art.

The apparatus 100 also includes at least one fiber optic amplifier 105 operatively associated with the fiber optic cable 101 to amplify a signal in the fiber optic cable 101. The fiber optic amplifier 105 can include any suitable fiber optic amplifier (e.g., to actually amplify the fiber optic signal) and/or regenerator (e.g., to convert the fiber optical signal to an electrical signal and reconvert the electrical signal into a new fiber optic signal with predetermined

intensity). For example, as shown in Fig. 4, an embodiment of a fiber optic amplifier 105 can be operatively disposed between an upper portion 101c and a lower portion 101d of a fiber optic cable 101. An example of a fiber optic amplifier 105 is sold by Thorlabs of Newton, New Jersey and can be about 1 millimeter in size.

5 The fiber optic amplifier 105 can include any suitable circuitry ensure that a constant power is drawn from each amplifier regardless of how much laser amplification is needed (e.g., a capacitor, a resistor to convert energy to heat), which can allow the use of DC power. Also, instead of using discrete amplifiers 105 as depicted, however, it is contemplated that the entire fiber 101 can be used as a gain medium which is pumped either electrically or optically (e.g.,
10 through electrically produced light) to amplify the signal therein.

 The fiber optic amplifier 105 can be configured to amplify the signal in the fiber optic cable 101 by an amount equal to or greater than a connection loss of the first and second optical connector ends 101a, 101b. In certain embodiments, this can be about 3 decibels per fiber optic cable (e.g., both connectors 101a, 101b combined), thus the amplifier 105 can amplify the signal
15 by 3 or more decibels. As is appreciated by those having ordinary skill in the art, the amplifier 105 can be selected to be of any suitable amplification (e.g., less than losses) so that it cancels out a suitable amount of losses due to any design parameter of a fiber optic cable and/or connectors.

 The apparatus 100 can further include at least one electrical wire 107 (e.g., one or more
20 copper wires) operatively connected to the fiber optic amplifier 105 and configured to supply the fiber optic amplifier 105 with electrical energy to power the fiber optic amplifier 105. It is appreciated by those having skill in the art that the at least one electrical wire 107 can include a positive and negative wire, and/or a single wire (e.g., with ground used as the electrical return

path) for providing electricity to the amplifier 105 and/or other downhole electronics. It is contemplated that the electrical wire 107 can also supply energy to a wireless fiber optic connector for receiving and/or transmitting data signals from/to another wireless connector.

In certain embodiments, the electrical wire 107 can be the same length as downhole tubular 103 and/or fiber optic cable 101 (e.g., 10 meters, 30 meters) or any other suitable length. The electrical wire 107 can include a first electrical connector 107a and a second electrical connector 107b. As shown, the amplifier 105 can be disposed in parallel between the first electrical connector 107a and the second electrical connector 107b, however, any other suitable arrangement is contemplated herein. For example, it is contemplated herein that the amplifier 105 can be disposed within one or more of a first end connector 311a or a second end connector 311b.

In this regard, in certain embodiments, the amplifier 105 is embodied as regenerators at the first end connector 311a or a second end connector 311b. This way, the optical signal arrives at one side of the connection, then it is detected and converted into an electrical signal, then the electrical signal is sent across the connection (which could be through an electrical wire or through wireless radio waves), then the electrical signal is received at the second side of the connection, and there finally a new optical signal is created.

In certain embodiments, referring to Fig. 1B, the apparatus 100 can include a battery 108 disposed in electrical communication with the amplifier 105 in addition to or alternative to an electrical wire 107. The battery 108 can be any suitable battery for powering the amplifier 105.

Referring to Fig. 2, it is contemplated that one or more fiber optic cables 101 can be combined with one or more electrical wires 107 in a single sheath 213. In certain embodiments, referring to Fig. 3 for example, the first optical connector 101a and the first electrical connector

107a can be coupled together (e.g., embodied therein) within a first end connector 311a.

Similarly, the second optical connector 101b and the second electrical connector 107b can additionally or alternatively be coupled together (e.g., embodied therein) within a second end connector 311b. This can allow for a single cable for easier attachment to or disposal within the downhole tubular 103/drill stand. This can also simplify the connection scheme between successive downhole tubulars 103 allowing an operator to connect a single connection for each downhole tubular 103 as opposed to a connection for each fiber optic cable and electrical wire.

The first end connector 311a can be configured to operatively mate with the second end connector 311b such that a plurality of fiber optic cables 101 and electrical wires 107 can be operatively connected in series. It is contemplated that the first end connector 311a and the second end connector 311b can be disposed on the downhole tubular 103 in such a manner that the proper assembly of two downhole tubulars 103 together would necessarily cause operative communication between a first end connector 311a and a second end connector 311b.

In certain embodiments, referring again to Fig. 1A, the apparatus 100 can be combined with the downhole tubular 103 in any suitable manner. For example, the first end connector 311a can be connected to an upper end 103a of the downhole tubular 103. The second end connector 311b can be connected to a lower end 103b of the downhole tubular 103 such that a plurality of downhole tubulars 103 can be assembled to operatively connect successive fiber optic cables 101 and electrical wires 107 in series.

In certain embodiments, at least one of the fiber optic cable 101, the electrical wire 107, and the amplifier 105 can be disposed within a wall of the downhole tubular 103. In certain embodiments, the fiber optic cable 101, the fiber optic amplifier 105, and/or the electrical wire 107 can be contained within the downhole tubular 103 (e.g., within the inner diameter).

However, it is contemplated that one or more portions of apparatus 100 can be disposed outside of the downhole tubular 103.

Referring to Fig. 5, a system 500 can include a plurality of downhole tubulars 103 including components for telemetry as described above. As shown, a plurality of fiber optic cables 101 are operatively connected to each downhole tubular 103 such that the first optical connector 101a and second optical connector 101b of each successive fiber optic cable 101 are operatively connected. At least one fiber optic amplifier 105 can be operatively associated with at least one of the plurality of fiber optic cables 101 to amplify a signal in the plurality of fiber optic cables 101. While an amplifier 105 is shown in each downhole tubular 103, it is contemplated that there may be a different number of amplifiers 105 than downhole tubulars 103 (e.g., less). Whatever the signal losses for the totality of connections of a given system 500, the amount of amplifiers 105 needed in system 500 can be modified based on amplification strength of each amplifier 105. For example, if a four connection system has losses of 12 decibels, two 6 decibel amplifiers 105 may be employed in only two of the downhole tubulars 103 instead of four 3 decibel amplifiers 105. Any suitable number of amplifiers 105 and strengths thereof are contemplated herein.

A downhole tool 501 is operatively connected to a last 501b of the plurality of fiber optic cables 101. The downhole tool 501 is configured to output a fiber optic signal. A computer 503 can be operatively connected to a first 501a of the plurality of fiber optic cables 101 and is configured to receive signals from the downhole tool 501 through the plurality of fiber optic cables 101. The computer 503 can be configured to interpret the fiber optic signals as known in the art.

As shown, a power source 505 (e.g., a DC power source) can be connected to a first 507a of the electrical wires 107 to supply each amplifier 105 with energy. DC power can be beneficial because the voltage and current have some constant value which means that the high capacitance and inductance do not matter.

5 A last 507b of the electrical wires can be grounded at its lower end (for example if the amplifiers are electrically connected in series), open, or operatively connected to the downhole tool 501 to supply the downhole tool 501 with electrical energy. It is contemplated that the power source 505 and computer 503 can be together such that both the electrical wire 107 and the optical cable 101 can be operatively connected thereto (e.g., for embodiments where the
10 electrical wire 107 and the optical cable 101 are combined together).

In accordance with at least one aspect of this disclosure, a method includes connecting two or more downhole tubulars together to form at least one fiber optic connection and communicating with one or more well tools across the at least one fiber optic connection of the downhole tubulars. Connecting the two or more downhole tubulars can include connecting three
15 or more downhole tubulars to form a plurality of fiber optic connections. In certain embodiments, communicating with one or more well tools can include communicating across two or more of the plurality of fiber optic connections.

In accordance with at least one aspect of this disclosure, a method for connecting a plurality of downhole tubulars to form a data path across one or more connections thereof can
20 include connecting a plurality of fiber optic cables at a connection of each downhole tubular. In certain embodiments, the method can include amplifying a fiber optic signal within the plurality of the fiber optic cables using a fiber optical amplifier. In certain embodiments, the method can

include connecting a plurality of electrical wires at the connection of each downhole tubular to power the optical amplifier.

During well drilling or other well operation, for example, downhole tubulars 103 (e.g., drill pipes) can be successively added (e.g., in individual lengths or in stands of multiple assembled downhole tubulars). Each time when a segment of downhole tubular 103 is added during a drilling operation, an apparatus 100 as described above can also be added therewith, if not already installed in the downhole tubular 103. At each connection, the laser light in the optical fibers 101 is attenuated by a certain amount (e.g., about 3 dB in certain embodiments). Each electrically driven amplifier 105 then amplifies the light by an equal or greater amount (e.g., a multiple of the losses to account for each unamplified prior segment of fiber optic cable 101).

Traditionally, a multi-connection system would not be beneficial because the losses at each connection would amount to total losses too great to be able to pass a suitable signal down and/or up the total length of the fiber optic cable. However, utilizing the above described systems, the total power of the light in fiber optic cables 101 can be controlled to stay constant, for example, all the way down and/or up the well because the amplifiers 105 can account for any suitable amount of loss from each connection. Thus, the benefits of the above described systems include the use of a convenient multi-connection systems which allow onsite assembly of a fiber optic system of any desired length and high data rates in the multi-connection system that are unachievable through traditional well construction techniques.

ASPECTS

In accordance with at least one aspect of this disclosure, an apparatus for downhole telemetry includes a fiber optic cable sized and configured be connected to and/or disposed

within a downhole tubular, the fiber optic cable comprising a first optical connector and a second optical connector, and a fiber optic amplifier operatively associated with the fiber optic cable to amplify a signal in the fiber optic cable.

5 In accordance with at least one aspect of this disclosure, the fiber optic amplifier can be configured to amplify the signal in the fiber optic cable by an amount equal to or greater than a connection loss of the first and second optical connector ends.

10 In accordance with at least one aspect of this disclosure, the apparatus can further include an electrical wire operatively connected to the fiber optic amplifier and configured to supply the fiber optic amplifier with electrical energy to power the fiber optic amplifier, wherein the electrical wire can include a first electrical connector and a second electrical connector.

In accordance with at least one aspect of this disclosure, the first optical connector and the first electrical connector can be coupled together within a first end connector.

In accordance with at least one aspect of this disclosure, the second optical connector and the second electrical connector can be coupled together within a second end connector.

15 In accordance with at least one aspect of this disclosure, the first end connector can be configured to operatively mate with the second end connectors such that a plurality of fiber optic cables and electrical wires can be operatively connected in series.

In accordance with at least one aspect of this disclosure, the apparatus can further include a battery for providing energy to the amplifier.

20 In accordance with at least one aspect of this disclosure, the apparatus can further include the downhole tubular which can include an upper end and a lower end. The first end connector can be connected to the upper end and the second end connector can be connected to the lower

end such that a plurality of downhole tubulars can be assembled to operatively connect successive fiber optic cables and electrical wires in series.

In accordance with at least one aspect of this disclosure, at least one of the fiber optic cable or the electrical wire can be disposed within a wall of the downhole tubular.

5 In accordance with at least one aspect of this disclosure, the fiber optic cable, the fiber optic amplifier, and the electrical wire can be contained within the downhole tubular.

In accordance with at least one aspect of this disclosure, a system can include a plurality of downhole tubulars for drilling a well, a plurality of fiber optic cables operatively connected to each downhole tubular, the fiber optic cables each comprising a first optical connector and a
10 second optical connector, wherein the first optical connector and second optical connector of each successive fiber optic cable are operatively connected, at least one fiber optic amplifier operatively associated with at least one of the plurality of fiber optic cables to amplify a signal in the plurality of fiber optic cables, a downhole tool operatively connected to a last of the plurality of fiber optic cables, and a computer operatively connected to a first of the plurality of fiber optic
15 cables and configured to receive signals from a downhole tool through the plurality of fiber optic cables.

In accordance with at least one aspect of this disclosure, all the fiber optic amplifiers can be collectively configured to amplify the signal in the fiber optic cable by an amount equal to or greater than a connection loss of all of the first and second optical connector ends.

20 In accordance with at least one aspect of this disclosure, the system can further include an electrical wire operatively connected to each fiber optic amplifier and configured to supply each fiber optic amplifier with electrical energy to power each fiber optic amplifier, wherein the electrical wire can include a first electrical connector and a second electrical connector.

In accordance with at least one aspect of this disclosure, each first optical connector and each first electrical connector can be coupled together within a first end connector of each downhole tubular.

5 In accordance with at least one aspect of this disclosure, each second optical connector and each second electrical connector can be coupled together within a second end connector of each downhole tubular.

In accordance with at least one aspect of this disclosure, each first end connector can be configured to operatively mate with each second end connector such that a plurality of fiber optic cables and electrical wires can be operatively connected in series.

10 In accordance with at least one aspect of this disclosure, the system can further include a battery for providing energy to an amplifier.

In accordance with at least one aspect of this disclosure, the first end connector can be connected to an upper end of each downhole tubular and the second end connector can be connected to a lower end of each downhole tubular such that a plurality of downhole tubulars can
15 be assembled to operatively connect successive fiber optic cables and electrical wires in series.

In accordance with at least one aspect of this disclosure, at least one of the fiber optic cable or the electrical wire can be disposed within a wall of each downhole tubular.

In accordance with at least one aspect of this disclosure, each fiber optic cable, each fiber optic amplifier, and each electrical wire can be contained within each downhole tubular.

20 In accordance with at least one aspect of this disclosure, a downhole tubular includes an upper end, a lower end, a fiber optic cable disposed within the downhole tubular, the fiber optic cable comprising a first optical connector coupled to the upper end and a second optical connector coupled to the lower end, and a fiber optic amplifier disposed within the downhole

tubular and operatively associated with the fiber optic cable to amplify a signal in the fiber optic cable.

In accordance with at least one aspect of this disclosure, the fiber optic amplifier can be configured to amplify the signal in the fiber optic cable by an amount equal to or greater than a connection loss of the first and second optical connector ends.

In accordance with at least one aspect of this disclosure, the downhole tubular can further include an electrical wire disposed within the downhole tubular and operatively connected to the fiber optic amplifier and configured to supply the fiber optic amplifier with electrical energy to power the fiber optic amplifier, wherein the electrical wire can include a first electrical connector and a second electrical connector.

In accordance with at least one aspect of this disclosure, the first optical connector and the first electrical connector can be coupled together within a first end connector and the second optical connector and the second electrical connector can be coupled together within a second end connector.

In accordance with at least one aspect of this disclosure, a method includes connecting two or more downhole tubulars together to form at least one fiber optic connection and communicating with one or more well tools across the at least one fiber optic connection of the downhole tubulars.

In accordance with at least one aspect of this disclosure, connecting two or more downhole tubulars can include connecting three or more downhole tubulars to form a plurality of fiber optic connections.

In accordance with at least one aspect of this disclosure, communicating with one or more well tools can include communicating across two or more of the plurality of fiber optic connections.

5 In accordance with at least one aspect of this disclosure, a method for connecting a plurality of downhole tubulars to form a data path across one or more connections thereof can include connecting a plurality of fiber optic cables at a connection of each downhole tubular.

In accordance with at least one aspect of this disclosure, the method can include amplifying a fiber optic signal within the plurality of the fiber optic cables using a fiber optical amplifier.

10 In accordance with at least one aspect of this disclosure, the method can include connecting a plurality of electrical wires at the connection of each downhole tubular to power the optical amplifier.

15 The methods and systems of the present disclosure, as described above and shown in the drawings, provide for drilling telemetry systems with superior properties including high data rate during drilling operations. While the apparatus and methods of the subject disclosure have been shown and described with reference to embodiments, those skilled in the art will readily appreciate that changes and/or modifications may be made thereto without departing from the spirit and scope of the subject disclosure.

What is claimed is:

1. An apparatus for downhole telemetry, comprising:

a fiber optic cable sized and configured be connected to and/or disposed within a downhole tubular, the fiber optic cable comprising a first optical connector and a second optical connector; and

a fiber optic amplifier operatively associated with the fiber optic cable to amplify a signal in the fiber optic cable.

2. The apparatus of claim 1, wherein the fiber optic amplifier is configured to amplify the signal in the fiber optic cable by an amount equal to or greater than a connection loss of the first and second optical connector ends.

3. The apparatus of any of the preceding claims, further comprising an electrical wire operatively connected to the fiber optic amplifier and configured to supply the fiber optic amplifier with electrical energy to power the fiber optic amplifier, wherein the electrical wire includes a first electrical connector and a second electrical connector.

4. The apparatus of claim 3, wherein the first optical connector and the first electrical connector are coupled together within a first end connector.

5. The apparatus of any of claims 3 and 4, wherein the second optical connector and the second electrical connector are coupled together within a second end connector.

6. The apparatus of claims 4 and 5, wherein the first end connector is configured to operatively mate with the second end connectors such that a plurality of fiber optic cables and electrical wires can be operatively connected in series.

5 7. The apparatus of any of the preceding claims, further comprising a battery for providing energy to the amplifier.

8. The apparatus of any of claims 6 and 7, further comprising the downhole tubular comprising an upper end and a lower end, wherein the first end connector is connected to the upper end and the second end connector is connected to the lower end such that a plurality of downhole tubulars can be assembled to operatively connect successive fiber optic cables and electrical wires in series.

10

9. The apparatus of claim 8, wherein at least one of the fiber optic cable or the electrical wire is disposed within a wall of the downhole tubular.

15

10. The apparatus of claim 8 or 9, wherein the fiber optic cable, the fiber optic amplifier, and the electrical wire are contained within the downhole tubular.

20 11. A system, comprising:
a plurality of downhole tubulars for drilling a well;
a plurality of fiber optic cables operatively connected to each downhole tubular, the fiber optic cables each comprising a first optical connector and a second optical connector, wherein

the first optical connector and second optical connector of each successive fiber optic cable are operatively connected;

at least one fiber optic amplifier operatively associated with at least one of the plurality of fiber optic cables to amplify a signal in the plurality of fiber optic cables;

5 a downhole tool operatively connected to a last of the plurality of fiber optic cables; and

a computer operatively connected to a first of the plurality of fiber optic cables and configured to receive signals from the downhole tool through the plurality of fiber optic cables.

12. The system of claim 11, wherein all fiber optic amplifiers are collectively configured to
10 amplify the signal in the fiber optic cable by an amount approximately equal to or greater than a connection loss of all of the first and second optical connector ends.

13. The system of any of the preceding claims, further comprising an electrical wire
operatively connected to each fiber optic amplifier and configured to supply each fiber optic
15 amplifier with electrical energy to power each fiber optic amplifier, wherein the electrical wire includes a first electrical connector and a second electrical connector.

14. The system of claim 13, wherein each first optical connector and each first electrical
connector are coupled together within a first end connector of each downhole tubular.

20

15. The system of any of claims 13 and 14, wherein each second optical connector and each
second electrical connector are coupled together within a second end connector of each
downhole tubular.

16. The system of claims 14 and 15, wherein each first end connector is configured to operatively mate with each second end connector such that a plurality of fiber optic cables and electrical wires can be operatively connected in series.

5

17. The system of any of the preceding claims, further comprising a battery for providing energy to an amplifier.

10

18. The system of any of claims 16 and 17, wherein each first end connector is connected to an upper end of each downhole tubular and the second end connector is connected to a lower end of each downhole tubular such that a plurality of downhole tubulars can be assembled to operatively connect successive fiber optic cables and electrical wires in series.

15

19. The system of claim 18, wherein at least one of the fiber optic cable or the electrical wire is disposed within a wall of each downhole tubular.

20. The system of claim 19, wherein the each fiber optic cable, each fiber optic amplifier, and each electrical wire are contained within each downhole tubular.

20

21. A downhole tubular, comprising:
an upper end;
a lower end;

a fiber optic cable disposed within the downhole tubular, the fiber optic cable comprising a first optical connector coupled to the upper end and a second optical connector coupled to the lower end; and

a fiber optic amplifier disposed within the downhole tubular and operatively associated with the fiber optic cable to amplify a signal in the fiber optic cable.

22. The downhole tubular of claim 21 wherein the fiber optic amplifier is configured to amplify the signal in the fiber optic cable by an amount approximately equal to or greater than a connection loss of the first and second optical connector ends.

23. The downhole tubular of any of the preceding claims, further comprising an electrical wire disposed within the downhole tubular and operatively connected to the fiber optic amplifier and configured to supply the fiber optic amplifier with electrical energy to power the fiber optic amplifier, wherein the electrical wire includes a first electrical connector and a second electrical connector.

24. The downhole tubular of claim 23, wherein the first optical connector and the first electrical connector are coupled together within a first end connector and the second optical connector and the second electrical connector are coupled together within a second end connector.

25. A method, comprising:

connecting two or more downhole tubulars together to form at least one fiber optic connection; and

communicating with one or more well tools across the at least one fiber optic connection of the downhole tubulars.

26. The method of claim 25, wherein connecting two or more downhole tubulars includes connecting three or more downhole tubulars to form a plurality of fiber optic connections.

27. The method of claim 26, wherein communicating with one or more well tools includes communicating across two or more of the plurality of fiber optic connections.

28. A method for connecting a plurality of downhole tubulars to form a data path across one or more connections thereof, comprising;

connecting a plurality of fiber optic cables at a connection of each downhole tubular.

29. The method of claim 28, further including amplifying a fiber optic signal within the plurality of the fiber optic cables using a fiber optical amplifier.

30. The method of claim 29, further comprising connecting a plurality of electrical wires at the connection of each downhole tubular to power the optical amplifier.

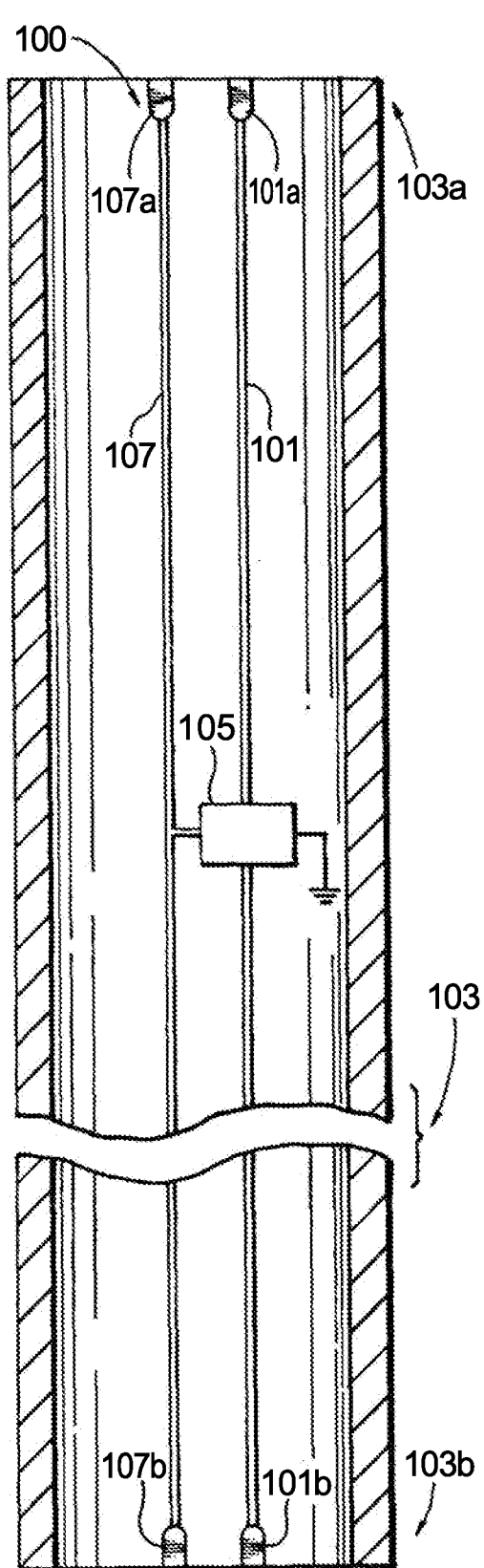


Fig. 1A

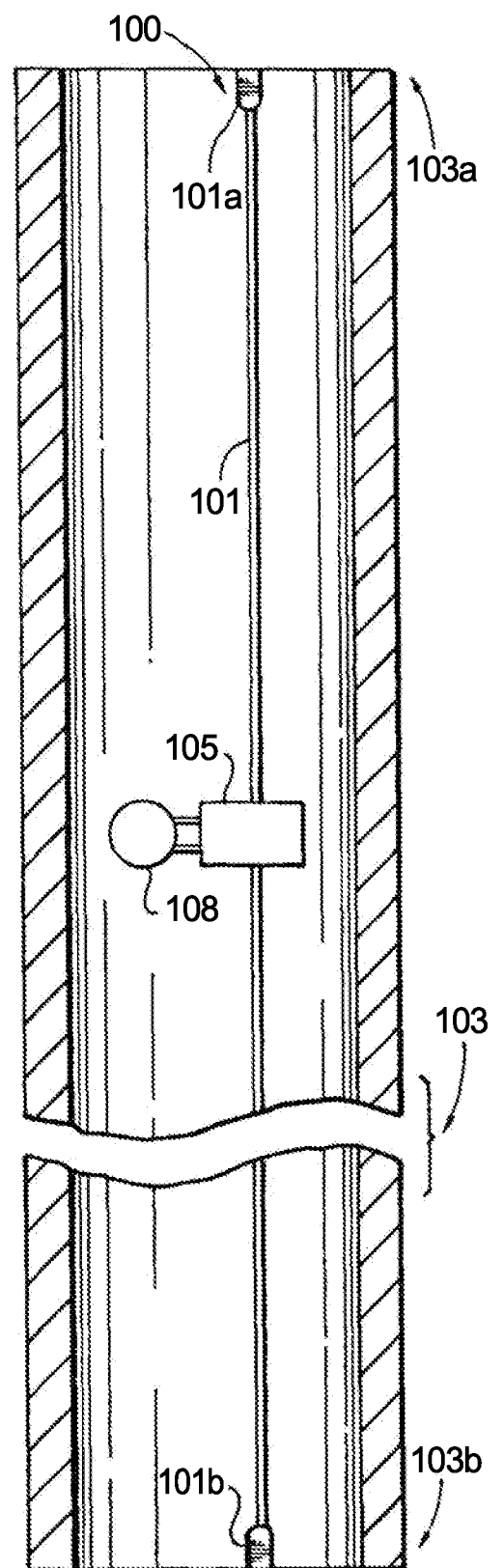


Fig. 1B

2/4

Fig. 2

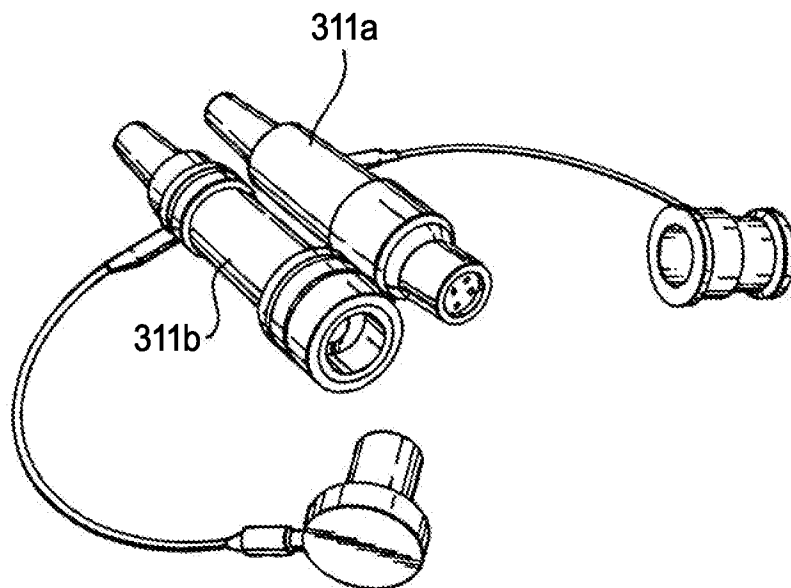
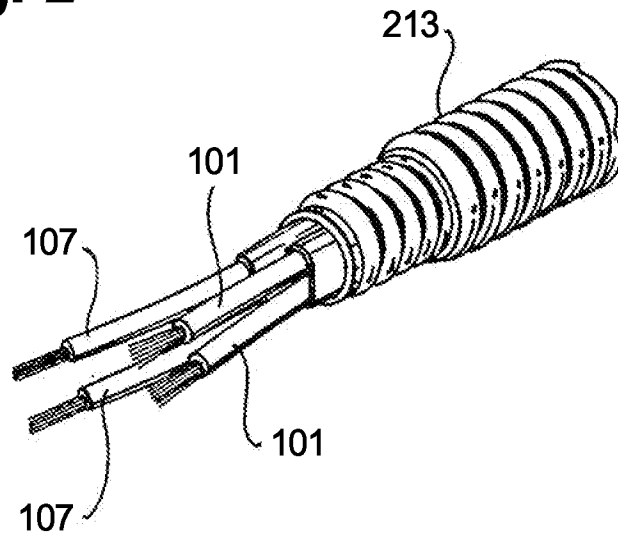
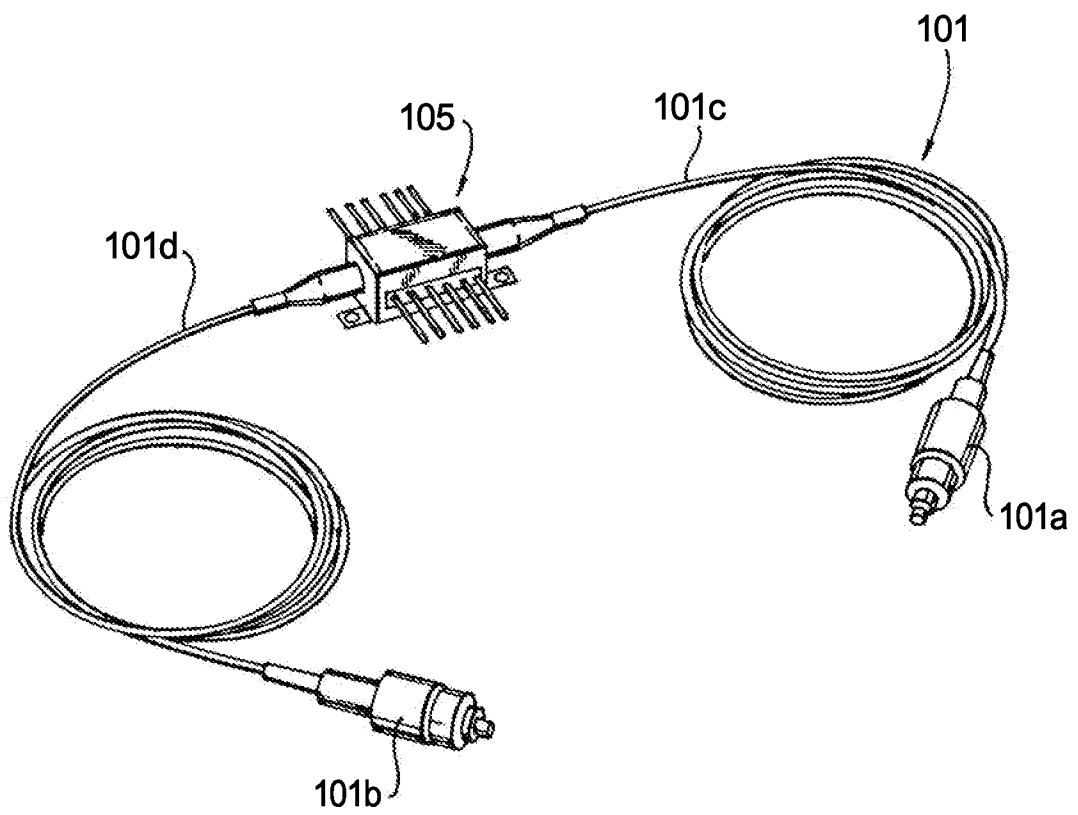


Fig. 3

**Fig. 4**

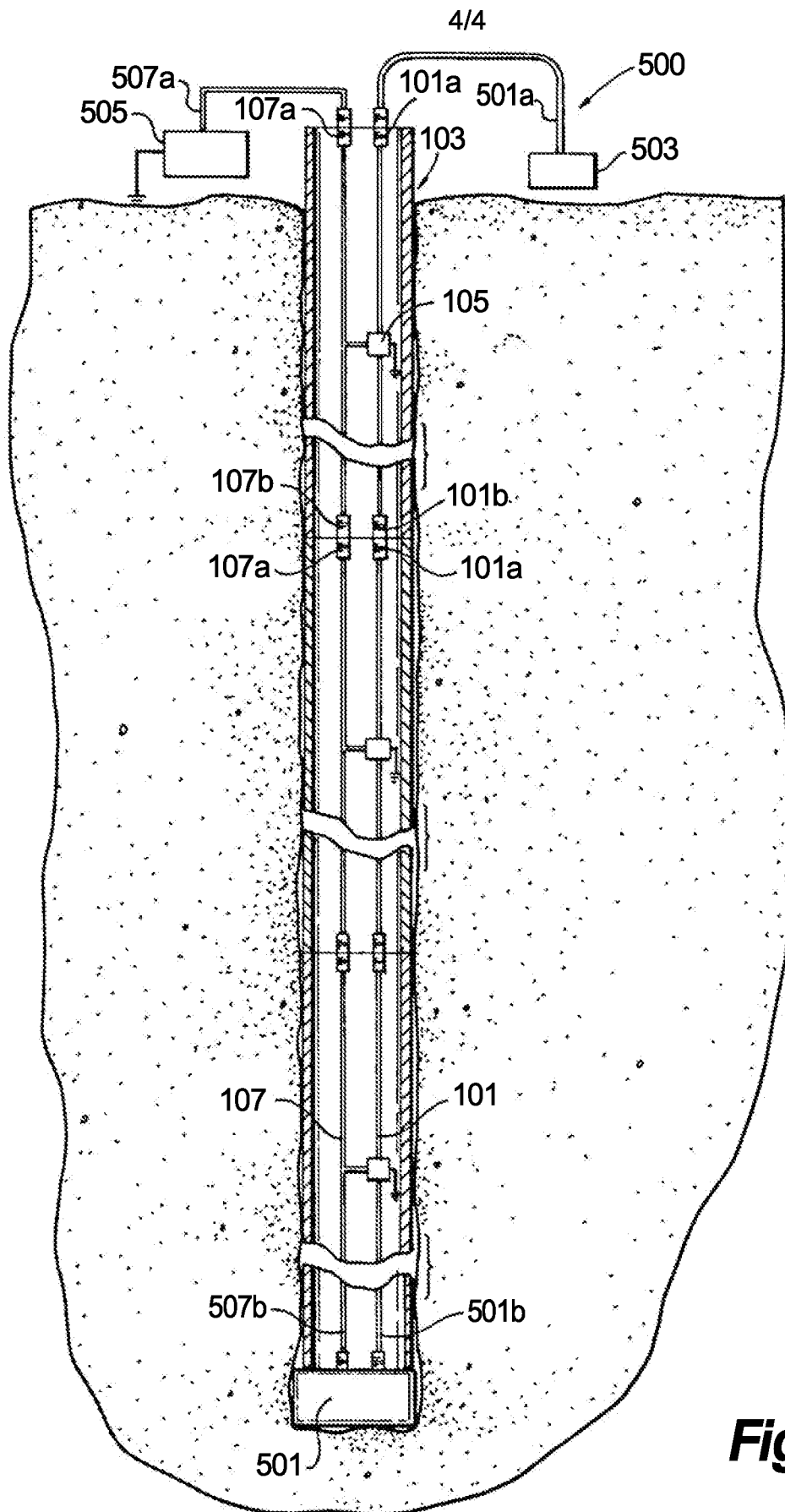


Fig. 5

A. CLASSIFICATION OF SUBJECT MATTER**E21B 47/12(2006.01)i, E21B 47/16(2006.01)i, E21B 47/01(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E21B 47/12; E21B 47/26; G01V 3/00; E21B 44/00; E21B 19/16; G01V 1/22; E21B 17/00; E21B 47/16; E21B 47/01

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & keywords: fiber optic cable, amplifier, telemetry, electrical connector, signal, and power supply

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003-0213598 A1 (HUGHES, WILLIAM JAMES) 20 November 2003 See abstract, paragraphs [0032]-[0033], [0040]-[0042], and figures 1-3, 12, 16.	25-28
Y		1-4, 11-14, 21-24 , 29-30
Y	US 2008-0159077 A1 (MADHAVAN et al.) 03 July 2008 See abstract, paragraphs [0032], [0034], [0038]-[0039], [0046], and figures 1-2, 4A.	1-4, 11-14, 21-24 , 29-30
A	WO 2014-160737 A1 (SCHLUMBERGER CANADA LIMITED et al.) 02 October 2014 See abstract, page 4, line 25 - page 5, line 25, and figure 2.	1-4, 11-14, 21-30
A	US 6934426 B2 (RICH et al.) 23 August 2005 See abstract, column 7, lines 21-34, and figure 5.	1-4, 11-14, 21-30
A	US 2011-0140907 A1 (LOUDEN, ANDREW) 16 June 2011 See abstract, paragraphs [0053]-[0054], and figure 1.	1-4, 11-14, 21-30



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

11 August 2016 (11.08.2016)

Date of mailing of the international search report

11 August 2016 (11.08.2016)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORTInternational application No.
PCT/US2015/060068**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 9,19-20
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
Claims 9, 19-20 are regarded unclear, because they refer to multiple dependent claims 8, 18 which do not comply with PCT Rule 6.4(a).
3. ☒ Claims Nos.: 5-8, 10, 15-18
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2015/060068

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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