



- (51) International Patent Classification:  
*E21B 47/12* (2006.01)    *G02B 6/02* (2006.01)  
*E21B 33/12* (2006.01)
- (21) International Application Number: PCT/US2015/055755
- (22) International Filing Date: 15 October 2015 (15.10.2015)
- (25) Filing Language: English
- (26) Publication Language: English
- (71) Applicant: **HALLIBURTON ENERGY SERVICES, INC.** [US/US]; 3000 N. Sam Houston Parkway E, Houston, Texas 77032-3219 (US).
- (72) Inventor: **NITSCHKE, Wolfgang Hartmut**; 8235 Wooded Terrace Lane, Humble, Texas 77338-2058 (US).
- (74) Agents: **PERDOK, Monique M.** et al.; P.O. Box 2938, Minneapolis, Minnesota 55402 (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, BN, 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, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, 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.

[Continued on next page]

(54) Title: SAFETY WAVEGUIDE SEGMENTS

(57) Abstract: A safety waveguide apparatus includes a waveguide segment body sealed by a respective dielectric plug on each end of the waveguide body. The waveguide segment body, or at least one of the dielectric plugs, are configured to divert an oil flow from within the waveguide segment body.

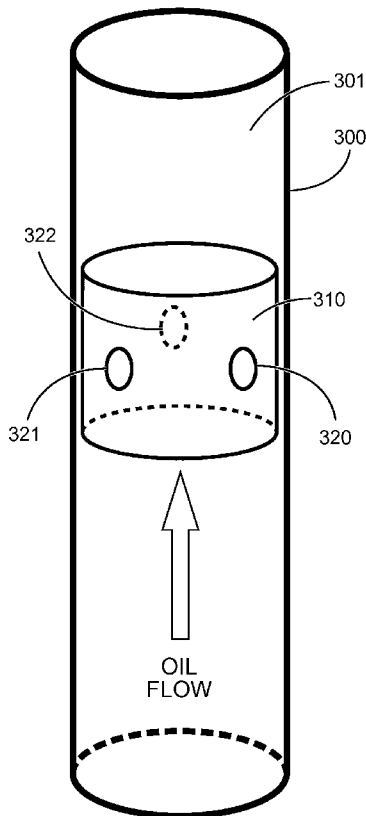


Fig. 3

WO 2017/065777 A1

**(84) Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, 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, KM, ML, MR, NE, SN, TD, TG).

**Declarations under Rule 4.17:**

— *as to non-prejudicial disclosures or exceptions to lack of novelty (Rule 4.17(v))*

**Published:**

— *with international search report (Art. 21(3))*

## SAFETY WAVEGUIDE SEGMENTS

### BACKGROUND

[0001] In drilling wells for oil and gas exploration, understanding the structure and properties of the associated geological formation provides information to aid such exploration. Measurements may be performed in a borehole to obtain this information. However, the environment in which the drilling tools operate and where measurements are made may be located at significant distances below the surface. It may be desirable to transmit downhole measurements to the surface for analysis and control purposes.

[0002] Electrical cables have been investigated for high speed communications to and from downhole tools. Use of electrical cables for such communication, however, has drawbacks due to limitations with information bandwidth. Optical fibers have also been investigated for high speed communications to and from downhole tools to overcome the information bandwidth limitations of electrical cables. Optical fibers have the drawback of typically needing near perfect optical alignment at their connections in order to achieve low signal loss.

[0003] Hollow waveguides may also be used to propagate signals between the downhole environment and the surface. However, if a hollow waveguide breaks, a path may be created through the waveguide for high pressure oil to flow to the surface.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. 1 is a diagram showing a waveguide or waveguide segment apparatus, according to various embodiments.

[0005] FIG. 2 is a cross-sectional diagram showing a breakable waveguide connection, according to various embodiments.

[0006] FIG. 3 is a cross-sectional diagram showing vent holes covered by a dielectric plug in a waveguide or waveguide segment, according to various embodiments.

- [0007] FIG. 4 is a cross-sectional diagram showing waveguide segments coupled by a breakable dielectric plug, according to various embodiments.
- [0008] FIGs. 5-7 are cross-sectional diagrams showing multiple piece waveguide segments held together by external pressure, according to various embodiments.
- [0009] FIG. 8 is a cross-sectional diagram showing external lips on a waveguide or waveguide segment, according to various embodiments.
- [0010] FIG. 9 is a diagram showing a drilling system, according to various embodiments.
- [0011] FIG. 10 is a flowchart of a method for constructing a waveguide, according to various embodiments.
- [0012] FIG. 11 is a cross-sectional diagram showing a waveguide constructed of a plurality of waveguide segments, according to various embodiments.

#### DETAILED DESCRIPTION

- [0013] Some of the challenges noted above, as well as others, may be addressed by using a waveguide incorporating breakable segments or connections that are configured to fail when relatively high pressure oil enters the waveguide. Similar to a fuse in an electrical circuit, when the safety waveguide segment experiences a particular internal pressure beyond that for which it is designed, the segment body or at least one of the dielectric plugs are configured to divert an oil flow from within the waveguide segment body.
- [0014] FIG. 1 is a diagram showing a waveguide or waveguide segment apparatus, according to various embodiments. In an embodiment, a plurality of waveguide segments may be coupled together to form a waveguide. In another embodiment, the waveguide may be one continuous segment that includes one or more of the subsequently described embodiments of FIGs. 2-8. The waveguide and waveguide segment apparatus are configured to internally propagate a signal.
- [0015] The segment includes a substantially cylindrical body 101 that encloses a chamber 100. The chamber is sealed from the ambient atmosphere by two

dielectric plugs 103, 104 (e.g., windows, dielectric windows) on either end of the substantially cylindrical body 101.

[0016] The body 101 of the segment may comprise any material that enables the waveguide to propagate relatively high frequency signals. For example, the body 101 may comprise a metal pipe (e.g., copper). In another embodiment, the body 101 may be any material (e.g., steel or nonmetallic material) and the inner surface of the body 101 may be lined with a metal (e.g., gold).

[0017] The body 101 is shown and described as “cylindrical”. The “cylindrical” description may include any shape that is approximately cylindrical such as, for example, oval, or any other shape that is configured to propagate signals.

[0018] The chamber 100 of the waveguide segment is sealed from the ambient atmosphere by the dielectric plugs 103, 104 coupled to their respective ends of the axial length of the body 101. The dielectric plugs 103, 104 are made of a material that is transparent to any frequencies being propagated through the waveguide.

[0019] Moisture in the atmosphere is known to limit the propagation of some relatively high frequency signals. Thus, the chamber 100 of the waveguide may be at an approximate vacuum, a partial vacuum (e.g., less than 1 atmosphere) with a gas having a refractive index of approximately 1, a gas atmosphere at approximately atmospheric pressure, or a combination of any of these. For example, the gas may be nitrogen, argon, and/or helium and the partial vacuum may include one or more of these gases. Subsequent reference to a vacuum is also defined to include a partial vacuum with one or more gases.

[0020] Since the waveguide or waveguide segments are constructed such that a vacuum or gas is sealed within the chamber, it is assumed that no oil is naturally present within the waveguide. Thus, the presence of an oil pressure is an indication that a portion of the waveguide downhole has been breached by oil and the oil has begun to flow upward (i.e., from downhole toward the surface). Each of the following described embodiments assumes that an upward oil flow occurs through the waveguide or the waveguide segment body 101 in order to trigger the safety waveguide segment.

[0021] FIG. 2 is a cross-sectional diagram showing a breakable waveguide connection, according to various embodiments. Only two waveguide segments 220, 221 are illustrated in the figure. However, the concept can be used in one or more locations of an entire waveguide.

[0022] One of the segments 221 may comprise an end 200 having a recess 201 into which another adjacent waveguide segment 220 is insertable. The inserted segment 220 is then adjacent to or sits on a ledge 202 within the recess.

[0023] As described in the embodiment of FIG. 1, the inserted segment 220 is sealed by a dielectric plug 210 that seals the bottom end of the inserted segment 220. The force necessary to break the dielectric plug 210 is greater than the force necessary to push the inserted segment 220 out of the recess 201. Thus, as the oil flow pressure builds up, the connection between the two segments 220, 221 will break (i.e., segment 220 pushed out of the recess 201) before the dielectric plug 210 breaks so that the oil is diverted out of the connection instead of up through the waveguide to the surface.

[0024] In an embodiment, an optional dielectric plug 211 seals the lower segment 221 to protect the inner chamber of that segment from dirt and moisture. This dielectric plug 211 may have a thinner composition than the dielectric plug 210 of the inserted segment 220 so that the lower dielectric plug 211 will break at approximately the same pressure or less as the pressure necessary to break the connection between the two segments 220, 221.

[0025] FIG. 3 is a cross-sectional diagram showing vent holes 320-322 covered by a dielectric plug 310 in a waveguide or waveguide segment 300, according to various embodiments. This embodiment uses one or more vent holes 320-322 through the segment body 300 and into the inner chamber 301 (i.e., connecting the chamber 301 with the ambient atmosphere) to enable the oil flow through the chamber 301 to be diverted out of the segment body 300 through the vent holes 320-322. The internal dielectric plug 310 seals the holes 320-322 from the ambient atmosphere when no oil is flowing through the segment body 300.

[0026] The plug 310 may comprise a dielectric material and/or thickness that is transparent to certain frequencies of radiation. Thus, those frequencies being propagated through the waveguide are not impeded by the plug 310.

[0027] The outside of the plug 310 that is visible through the holes 320-322 may be coated with the same material that makes up the waveguide body 300 or that is used to coat the inside surface of the waveguide body 300 or by some other conductive material. This enables the radiation to propagate through the waveguide 300 and not be affected by the holes. For example, the material may be a metal.

[0028] When oil is flowing through the waveguide 300, the oil pressure pushes the plug 310 upwards to expose the holes 320-322. Once the holes 320-322 are opened, the oil can be diverted out of the segment body 300 or drilling fluid can flow into the segment body 300 in order to prevent the pressurized oil from the bottom of the oil well from flowing to the surface through the waveguide pipe.

[0029] In another embodiment, the plug 310 may be made of a frangible material and/or extremely thin relative to the thickness of the segment body 300. In such an embodiment, the oil pressure may break the plug 310 or both move and break the plug 310 to expose the vent holes 320-322.

[0030] FIG. 4 is a cross-sectional diagram showing waveguide segments 400, 401 coupled by a breakable dielectric plug 420, according to various embodiments. The waveguide segments 400, 401 are coupled by the plug 420 at a joint 410.

[0031] The plug 420 may comprise a dielectric material and/or thickness that is transparent to certain frequencies of radiation. Thus, those frequencies being propagated through the waveguide are not impeded by the plug 420.

[0032] The outside of the dielectric plug 420 may be metal coated, especially if there is a gap at the joint 410 between the waveguide segments 400, 401. The plug 420 may be glued or otherwise fastened to the waveguide segments 400, 401. The plug 420 may also be held into the waveguide segments by a vacuum in each of the waveguide segments 400, 401.

[0033] If oil flows through one waveguide segment 401, the oil pressure either pushes the plug 420 up, breaks the plug 420, or both pushes and breaks the plug

420. When the plug 420 is removed from the joint 410 holding the two segments 400, 401 together, the two segments 400, 401 become disconnected. Thus, the flow of oil through the waveguide to the surface is diverted.

**[0034]** FIGs. 5-7 are cross-sectional diagrams showing multiple piece waveguide segments held together by external pressure, according to various embodiments. These embodiments are for purposes of illustration only as other similarly cut waveguide segments would operate as safety waveguide segments in a similar fashion.

**[0035]** Each of the illustrated waveguide segments 500 may be substantially the same as the apparatus illustrated in FIG. 1. For example, the body 500 encloses a chamber 502 that is sealed by the dielectric plugs 510, 511 at respective ends of the body 500. The chamber 502 is filled with a vacuum or partial vacuum.

**[0036]** In the illustrated embodiments of FIGs. 5-7, the body 500 of each individual segment may be cut 501, 601, 701 into two or more pieces that are held together by the pressure differential between the ambient pressure on the outside and the vacuum inside. The ability of a vacuum to keep such pieces together is well known (i.e., Otto von Guericke's Magdeburg hemispheres).

**[0037]** If there is a downhole breach of the waveguide and oil flows up, the oil pressure first breaks the dielectric plug 511 sealing the bottom of the waveguide segment 500 and flows into the segment 500. This destroys the vacuum and increases the inside pressure of the segment. When pressure from oil flowing through the segment 500 is greater than the pressure on the outside of the body 500 (i.e., ambient pressure), each individual waveguide segment will fall apart at their respective cuts 501, 601, 701. In this embodiment, the dielectric plug 511 on the end of the segment can be relatively thin since it only has to withstand atmospheric pressure so that the waveguide segment does not fall apart while it is installed into a waveguide.

**[0038]** In an embodiment, the cuts 501, 601, 701 may have a sealant lining the cut surface between the two pieces. Such a sealant may provide improved protection for the vacuum within the segment 500 so that foreign matter present on the cut surfaces does not provide microscopic pathways for the ambient



pressure to enter the segment 500. The sealant might also act as a glue holding the pieces together as long as this glue is weak enough to not prevent the pieces from being separated by the internal pressure of oil flowing through the waveguide. Thus the glue breaks in response to the internal flow of oil within the waveguide or safety waveguide segment body.

**[0039]** FIG. 8 is a cross-sectional diagram showing external lips 804, 805 on a waveguide or waveguide segment 800, according to various embodiments. The lips 804, 805 provide additional surface area for the ambient pressure to push against in order to provide a stronger force for holding two pieces of a segment together.

**[0040]** The lips 804, 805 are attached to the segment 800 such that a first lip 804 is attached to a first surface of the segment 800 on one side of the cut 801 while a second lip 805 is attached to a second surface of the segment 800 on an opposing side of the cut 801. An opening 810 between the lips 804, 805 and the interior vacuum of the segment 800 enables the vacuum to exist in a gap 830 between the lips 804, 805. An air tight seal 820 between outer edges of the lips 804, 805 protects the vacuum in the gap 830 and is held in place by the ambient atmospheric pressure working on the surface area of the lips 804, 805.

**[0041]** The lips 804, 805 are shown on a cut 801 through the body of the segment. For example, the lips 804, 805 may be located on any one of the cuts of FIGs. 5-7. In another embodiment, the lips 804, 805 may be incorporated onto other embodiments as well.

**[0042]** The lips 804, 805 may be made of the same material as the body of the segment (e.g., metal). In another embodiment, the lips 804, 805 may be made of a different material than the body of the segment.

**[0043]** Yet another embodiment may construct the waveguide or waveguide segment body from a relatively thin plastic or other material. An inside surface of the body may then be coated with metal (e.g., approximately 1  $\mu\text{m}$  thickness of coating layer). If the metal coating is thicker than the skin depth, such a waveguide will behave (with respect to electromagnetic transmission properties) like a normal metal waveguide.

[0044] The relatively thin plastic material cannot withstand high pressure inside relative to the ambient pressure. Thus if oil flows through the waveguide, the waveguide segment will burst and divert the flow of oil from the remainder of the waveguide.

[0045] In another embodiment, the relatively thin material waveguide segment may be disposed in a vacuum filled metal pipe with cuts, such as described in the embodiments of FIGs. 5-7. In such a waveguide, a traveling radiation wave sees the smooth metal coating inside of the plastic pipe so that the inside material of the segment body or the cut in the segment body do not cause any measurable signal loss in a propagated signal.

[0046] The embodiment of inserting a plastic pipe (coated on its inner surface with a metal) into a strong metal pipe with bad inside surface properties may be useful as a dielectric lining even if the metal waveguide is a standard waveguide without any safety features. In such an embodiment, the flow of oil through the waveguide may not be preventable but the problems related to the smoothness and the electric and magnetic properties of the outside waveguide may be reduced or eliminated. If a dielectric lining is desired inside of the waveguide (for example to reduce mode conversion), the plastic pipe may be metal-coated on its outside so that the plastic acts as the dielectric lining.

[0047] The above-described embodiments may be incorporated in one location of a waveguide or in multiple locations. For example, in a waveguide measured in multiple kilometers, a plurality of the safety waveguide segments may be incorporated into the waveguide. The waveguide may also incorporate a combination of the various embodiments of the safety waveguide segment.

[0048] FIG. 9 is a diagram showing a drilling system, according to various embodiments. The system 964 includes a drilling rig 902 located at the surface 904 of a well 906. The drilling rig 902 may provide support for a drillstring 908. The drillstring 908 may operate to penetrate the rotary table 910 for drilling the borehole 912 through the subsurface formations 990. The drillstring 908 may include a drill pipe 918 and the bottom hole assembly (BHA) 920 (e.g., drill string), perhaps located at the lower portion of the drill pipe 918.

[0049] The waveguide 900 including one or more embodiments of the safety waveguide segment apparatus 901 described previously may be disposed in the drill string to the BHA. In another embodiment, the waveguide 900 may be external to the drill string 908. Thus, the waveguide 900 enables the BHA to communicate with the surface workstation 992 through relatively high frequency telemetry.

[0050] The BHA 920 may include drill collars 922, a down hole tool 924, stabilizers, sensors, an RSS, a drill bit 926, as well as other possible components. The drill bit 926 may operate to create the borehole 912 by penetrating the surface 904 and the subsurface formations 990.

[0051] During drilling operations within the cased borehole 912, the drillstring 908 (perhaps including the drill pipe 918 and the BHA 920) may be rotated by the rotary table 910. Although not shown, in addition to or alternatively, the BHA 920 may also be rotated by a motor (e.g., a mud motor) that is located down hole. The drill collars 922 may be used to add weight to the drill bit 926. The drill collars 922 may also operate to stiffen the bottom hole assembly 920, allowing the bottom hole assembly 920 to transfer the added weight to the drill bit 926, and in turn, to assist the drill bit 926 in penetrating the surface 904 and subsurface formations 990.

[0052] During drilling operations, a mud pump 932 may pump drilling fluid (sometimes known by those of ordinary skill in the art as “drilling mud”) from a mud pit 934 through a hose 936 into the drill pipe 918 and down to the drill bit 926. The drilling fluid can flow out from the drill bit 926 and be returned to the surface 904 through an annular area 940 between the drill pipe 918 and the sides of the borehole 912. The drilling fluid may then be returned to the mud pit 934, where such fluid is filtered. In some examples, the drilling fluid can be used to cool the drill bit 926, as well as to provide lubrication for the drill bit 926 during drilling operations. Additionally, the drilling fluid may be used to remove subsurface formation cuttings created by operating the drill bit 926.

[0053] A workstation 992 including a controller 996 may include modules comprising hardware circuitry, a processor, and/or memory circuits that may store software program modules and objects, and/or firmware, and combinations

thereof. The workstation 992 may also include modulators and demodulators for modulating and demodulating data transmitted downhole through the waveguide 900 or received through the waveguide 900 from the downhole environment.

The workstation 992 and controller 996 are shown near the rig 902 only for purposes of illustration as these components may be located at remote locations.

**[0054]** These implementations can include a machine-readable storage device having machine-executable instructions, such as a computer-readable storage device having computer-executable instructions. Further, a computer-readable storage device may be a physical device that stores data represented by a physical structure within the device. Such a physical device is a non-transitory device. Examples of a non-transitory computer-readable storage medium can include, but not be limited to, read only memory (ROM), random access memory (RAM), a magnetic disk storage device, an optical storage device, a flash memory, and other electronic, magnetic, and/or optical memory devices.

**[0055]** FIG. 10 is a flowchart of a method for constructing a waveguide, according to various embodiments. In block 1001, a waveguide may be constructed by coupling a plurality of waveguide segments together. One embodiment of a resulting waveguide is illustrated in FIG. 11 and described subsequently. The waveguide is configured to propagate a signal between a surface controller and a bottom hole assembly.

**[0056]** In block 1002, at least one of the safety waveguide segments are coupled into the waveguide. At least one safety waveguide segments is configured to divert oil out of the waveguide. In an embodiment, the safety waveguide segment may be coupled into the waveguide such that a dielectric plug that seals each waveguide segment is shared between adjacent waveguide segments, such as illustrated in FIG. 4.

**[0057]** FIG. 11 is a cross-sectional diagram showing a waveguide constructed of a plurality of waveguide segments, according to various embodiments. This waveguide is made up of a plurality of waveguide segments 1100-1102, such as illustrated in FIG. 1.

**[0058]** Adjacent waveguide segments 1100, 1101 or 1101, 1102 of the waveguide are coupled together with sleeves 1120-1122 surrounding joints

1110, 1111. For example, the window 1140 of a first segment 1100 is immediately adjacent to the window 1141 of a second segment 1101 and the sleeve 1120 surrounds a joint 1110 formed between the adjacent waveguide segments 1100, 1101. Thus, the waveguide comprises a plurality of windows 1139-1144, each window 1139-1144 may be coupled to a respective end of the waveguide such that the resulting chamber is substantially sealed from the ambient atmosphere.

**[0059]** One or more of the waveguide segments 1100-1102 may be a safety waveguide segment as described in any of the above embodiments. If more than one waveguide segment 1100-1102 is a safety waveguide segment, different embodiments of the safety waveguide segment may be combined into the waveguide.

**[0060]** Example 1 is a safety waveguide apparatus comprising: a waveguide segment body configured to internally propagate a signal and sealed by a plurality of dielectric plugs, each dielectric plug coupled to a respective end of the waveguide segment body, wherein the waveguide segment body or at least one of the dielectric plugs are configured to divert an oil flow from within the waveguide segment body.

**[0061]** In Example 2, the subject matter of Example 1 can further include wherein the waveguide segment body is insertable into a recess in a second waveguide segment such that the at least one of the dielectric plugs is disposed in the recess, the at least one dielectric plug is configured to be broken by a first pressure and the waveguide segment body is moveable from the recess by a second pressure.

**[0062]** In Example 3, the subject matter of Examples 1-2 can further include a vent hole through the waveguide segment body; and an internal dielectric plug disposed inside the waveguide segment body substantially adjacent to the vent hole such that the vent hole is sealed from an ambient atmosphere.

**[0063]** In Example 4, the subject matter of Examples 1-3 can further include wherein the internal dielectric plug comprises a thickness and/or a material that is transparent to the internally propagated signal.

[0064] In Example 5, the subject matter of Examples 1-4 can further include wherein the waveguide segment body comprises a metal or is internally coated by metal and the internal dielectric plug is coated with metal.

[0065] In Example 6, the subject matter of Examples 1-5 can further include wherein the internal dielectric plug comprises a frangible material.

[0066] In Example 7, the subject matter of Examples 1-6 can further include a vacuum or gas in the waveguide segment body, wherein the waveguide segment body is coupleable to a second waveguide segment, containing vacuum or gas, by the at least one dielectric plug, wherein the at least one dielectric plug is moveable or breakable by a pressure in the second waveguide segment.

[0067] In Example 8, the subject matter of Examples 1-7 can further include wherein the waveguide segment body comprises a plurality of pieces, wherein the plurality of pieces are held together by a pressure differential between a first pressure acting externally on the body and a second pressure sealed within the body.

[0068] In Example 9, the subject matter of Examples 1-8 can further include wherein the plurality of pieces are additionally held together by a glue that breaks in response to the oil flow within the waveguide segment body.

[0069] In Example 10, the subject matter of Examples 1-9 can further include a plurality of lips coupled to the waveguide segment body, wherein each lip of the plurality of lips is coupled to an opposing side of a cut that separates the plurality of pieces such that a gap between the plurality of lips is open to a vacuum in the waveguide segment body.

[0070] In Example 11, the subject matter of Examples 1-10 can further include wherein the dielectric plugs are transparent to a frequency of the signal.

[0071] Example 12 is a method comprising: constructing a waveguide by coupling a plurality of waveguide segments together; and coupling at least one safety waveguide segment into the waveguide, wherein the at least one safety waveguide segment is configured to divert, out of the waveguide, oil flowing through the waveguide.

[0072] In Example 13, the subject matter of Example 12 can further include wherein coupling the at least one safety waveguide segment into the waveguide

comprises coupling the safety waveguide segment such that a dielectric plug is shared between adjacent waveguide segments.

[0073] In Example 14, the subject matter of Examples 12-13 can further include wherein a first end of the waveguide is configured to be located at a surface controller and a second end of the waveguide is configured to be located at a bottom hole assembly and further comprising the waveguide propagating a signal between the controller and the bottom hole assembly.

[0074] Example 15 is a system comprising: a waveguide configured to propagate radiation at a frequency between a surface controller and a downhole tool; and a safety waveguide segment disposed in the waveguide, the safety waveguide segment configured to propagate the radiation at the frequency and divert oil out of the waveguide.

[0075] In Example 16, the subject matter of Example 15 can further include wherein the waveguide comprises a plurality of waveguide segments and a plurality of the waveguide segments comprise the safety waveguide segment.

[0076] In Example 17, the subject matter of Examples 15-16 can further include wherein the plurality of waveguide segments comprise a cylindrical waveguide segment body sealed on each end by a respective dielectric plug such that an inner chamber of the waveguide segment comprises a vacuum or a partial vacuum.

[0077] In Example 18, the subject matter of Examples 15-17 can further include wherein the safety waveguide segment comprises a material, lined with a metal, that is configured to break in response to the oil in the safety waveguide segment.

[0078] In Example 19, the subject matter of Examples 15-18 can further include wherein each waveguide segment comprises a chamber sealed from ambient atmosphere.

[0079] In Example 20, the subject matter of Examples 15-19 can further include wherein the waveguide is disposed in a drill string.

[0080] Although specific examples have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement that is calculated to achieve the same purpose may be substituted for the specific

examples shown. Various examples use permutations and/or combinations of examples described herein. It is to be understood that the above description is intended to be illustrative, and not restrictive, and that the phraseology or terminology employed herein is for the purpose of description. Combinations of the above examples and other examples will be apparent to those of skill in the art upon studying the above description.



## Claims

What is claimed is:

1. A safety waveguide apparatus comprising:  
a waveguide segment body configured to internally propagate a signal and sealed by a plurality of dielectric plugs, each dielectric plug coupled to a respective end of the waveguide segment body, wherein the waveguide segment body or at least one of the dielectric plugs are configured to divert an oil flow from within the waveguide segment body.
2. The apparatus of claim 1, wherein the waveguide segment body is insertable into a recess in a second waveguide segment such that the at least one of the dielectric plugs is disposed in the recess, the at least one dielectric plug is configured to be broken by a first pressure and the waveguide segment body is moveable from the recess by a second pressure.
3. The apparatus of claim 1, further comprising:  
a vent hole through the waveguide segment body; and  
an internal dielectric plug disposed inside the waveguide segment body substantially adjacent to the vent hole such that the vent hole is sealed from an ambient atmosphere.
4. The apparatus of claim 3, wherein the internal dielectric plug comprises a thickness and/or a material that is transparent to the internally propagated signal.
5. The apparatus of claim 3, wherein the waveguide segment body comprises a metal or is internally coated by metal and the internal dielectric plug is coated with metal.

6. The apparatus of claim 3, wherein the internal dielectric plug comprises a frangible material.
7. The apparatus of claim 1, further comprising a vacuum or gas in the waveguide segment body, wherein the waveguide segment body is coupleable to a second waveguide segment, containing vacuum or gas, by the at least one dielectric plug, wherein the at least one dielectric plug is moveable or breakable by a pressure in the second waveguide segment.
8. The apparatus of claim 1, wherein the waveguide segment body comprises a plurality of pieces, wherein the plurality of pieces are held together by a pressure differential between a first pressure acting externally on the body and a second pressure sealed within the body.
9. The apparatus of claim 8, wherein the plurality of pieces are additionally held together by a glue that breaks in response to the oil flow within the waveguide segment body.
10. The apparatus of claim 8, further comprising a plurality of lips coupled to the waveguide segment body, wherein each lip of the plurality of lips is coupled to an opposing side of a cut that separates the plurality of pieces such that a gap between the plurality of lips is open to a vacuum in the waveguide segment body.
11. The apparatus of claim 1, wherein the dielectric plugs are transparent to a frequency of the signal.
12. A method comprising:  
constructing a waveguide by coupling a plurality of waveguide segments together; and  
coupling at least one safety waveguide segment into the waveguide,

wherein the at least one safety waveguide segment is configured to divert, out of the waveguide, oil flowing through the waveguide.

13. The method of claim 12, wherein coupling the at least one safety waveguide segment into the waveguide comprises coupling the safety waveguide segment such that a dielectric plug is shared between adjacent waveguide segments.
14. The method of claim 12, wherein a first end of the waveguide is configured to be located at a surface controller and a second end of the waveguide is configured to be located at a bottom hole assembly and further comprising the waveguide propagating a signal between the controller and the bottom hole assembly.
15. A system comprising:  
a waveguide configured to propagate radiation at a frequency between a surface controller and a downhole tool; and  
a safety waveguide segment disposed in the waveguide, the safety waveguide segment configured to propagate the radiation at the frequency and divert oil out of the waveguide.
16. The system of claim 15, wherein the waveguide comprises a plurality of waveguide segments and a plurality of the waveguide segments comprise the safety waveguide segment.
17. The system of claim 16, wherein the plurality of waveguide segments comprise a cylindrical waveguide segment body sealed on each end by a respective dielectric plug such that an inner chamber of the waveguide segment comprises a vacuum or a partial vacuum.
18. The system of claim 15, wherein the safety waveguide segment

comprises a material, lined with a metal, that is configured to break in response to the oil in the safety waveguide segment.

19. The system of claim 15, wherein each waveguide segment comprises a chamber sealed from ambient atmosphere.
20. The system of claim 15, wherein the waveguide is disposed in a drill string.

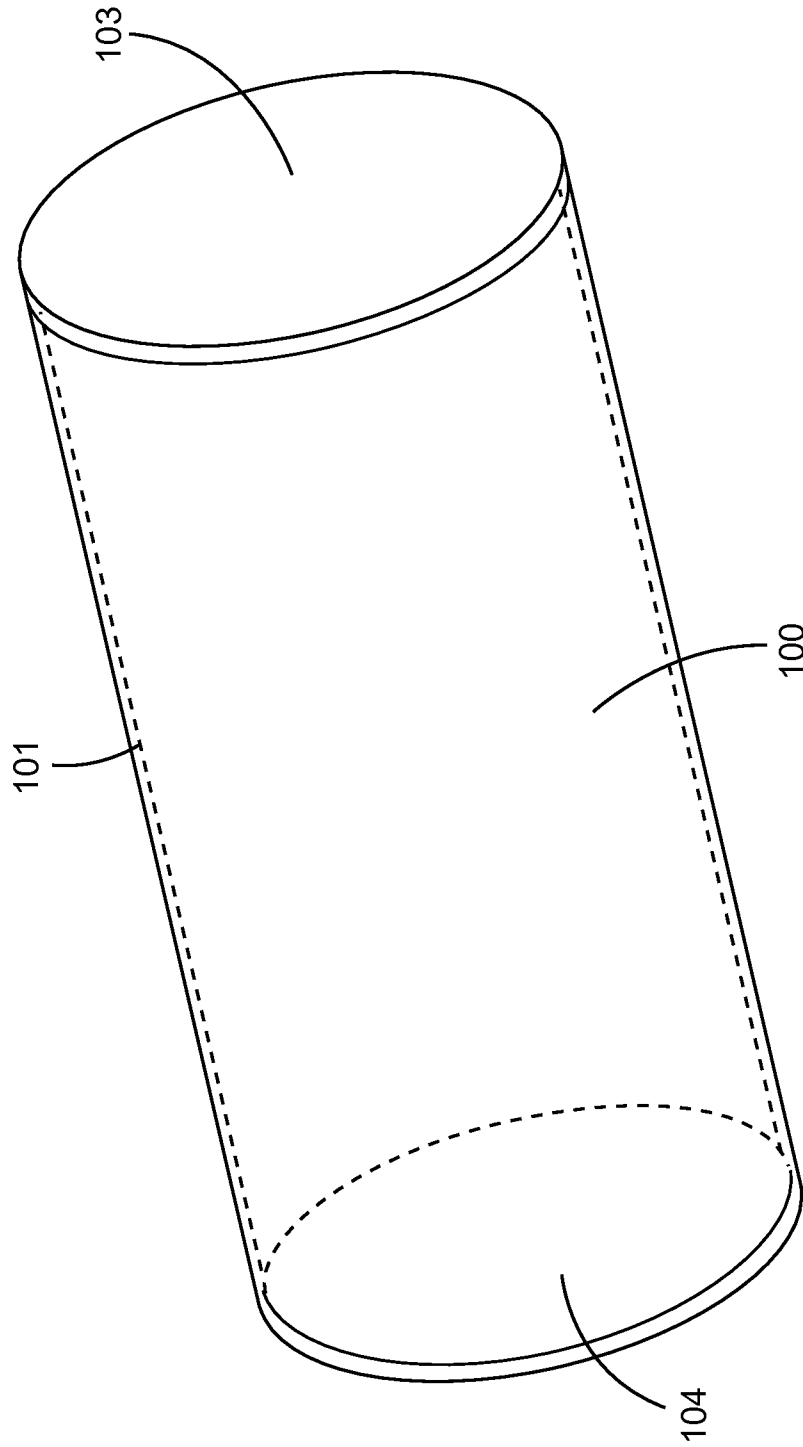


Fig. 1

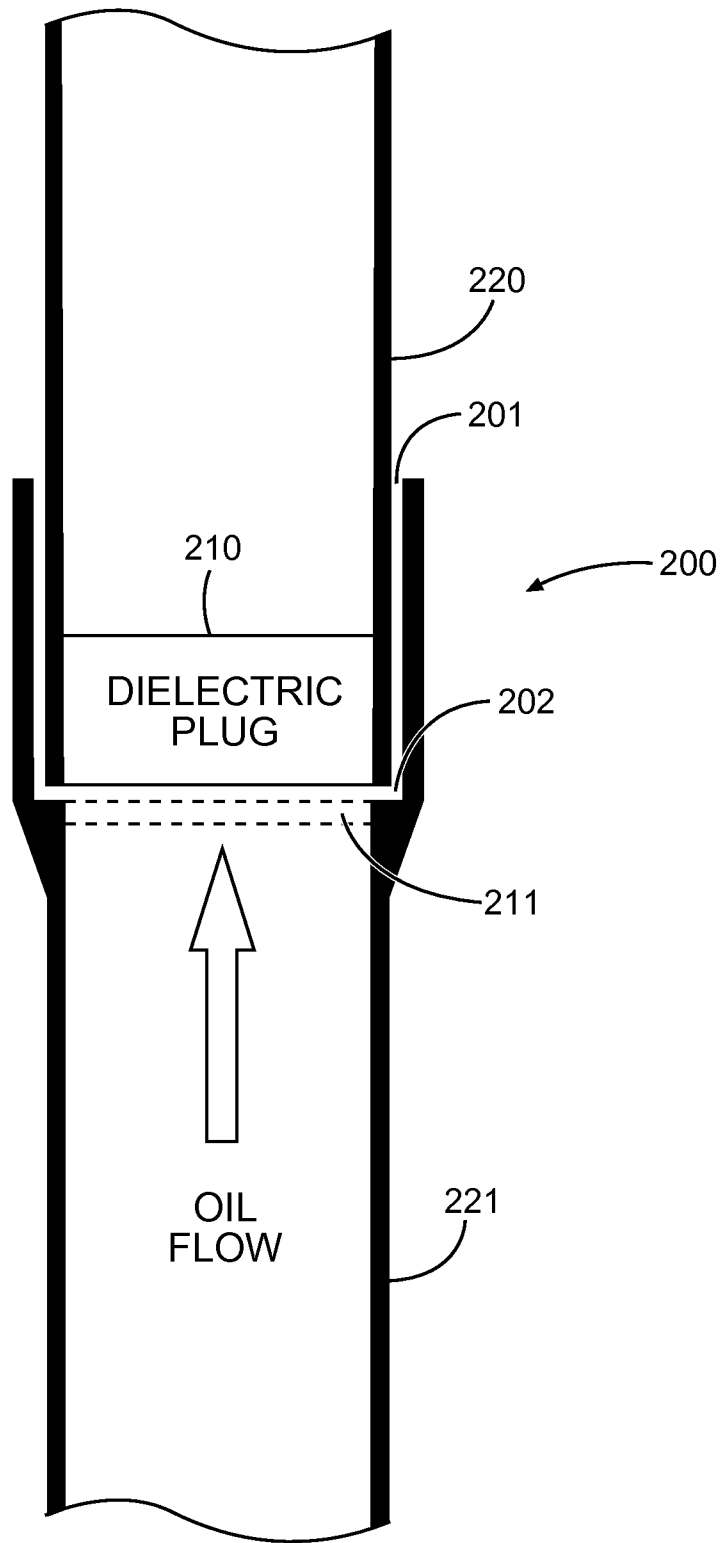


Fig. 2

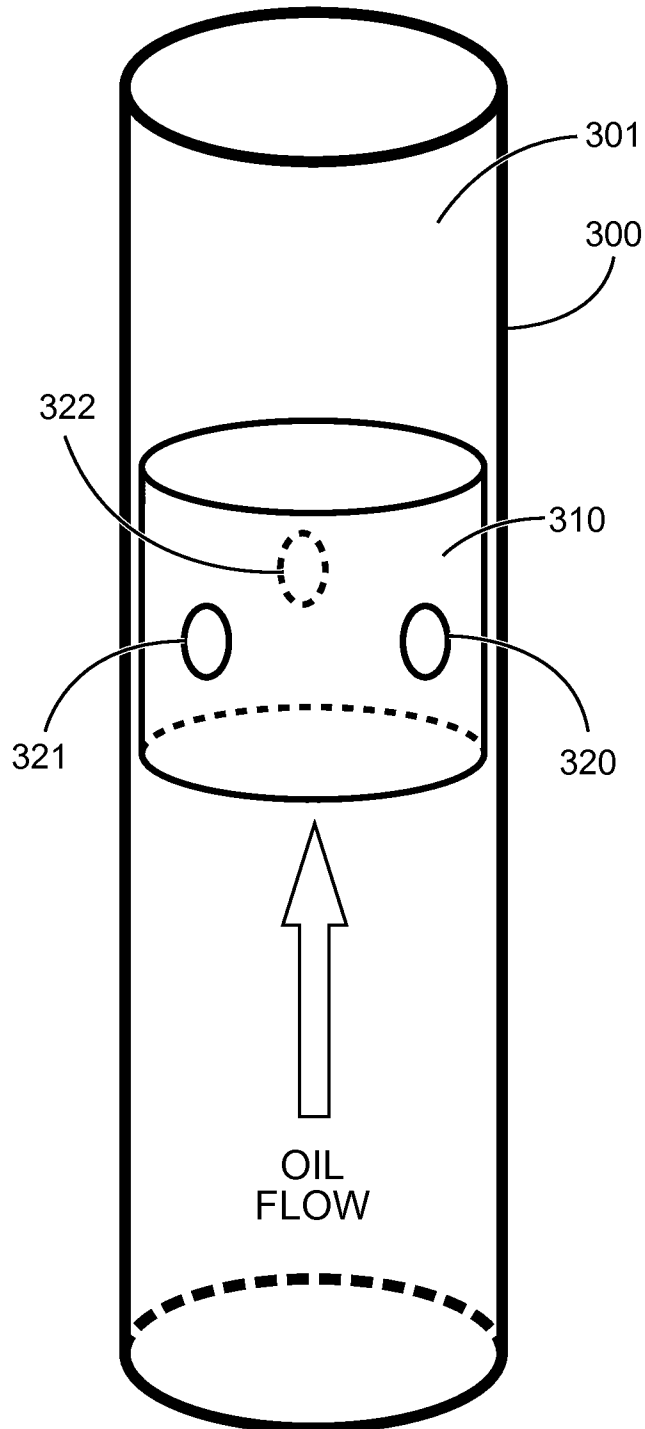


Fig. 3

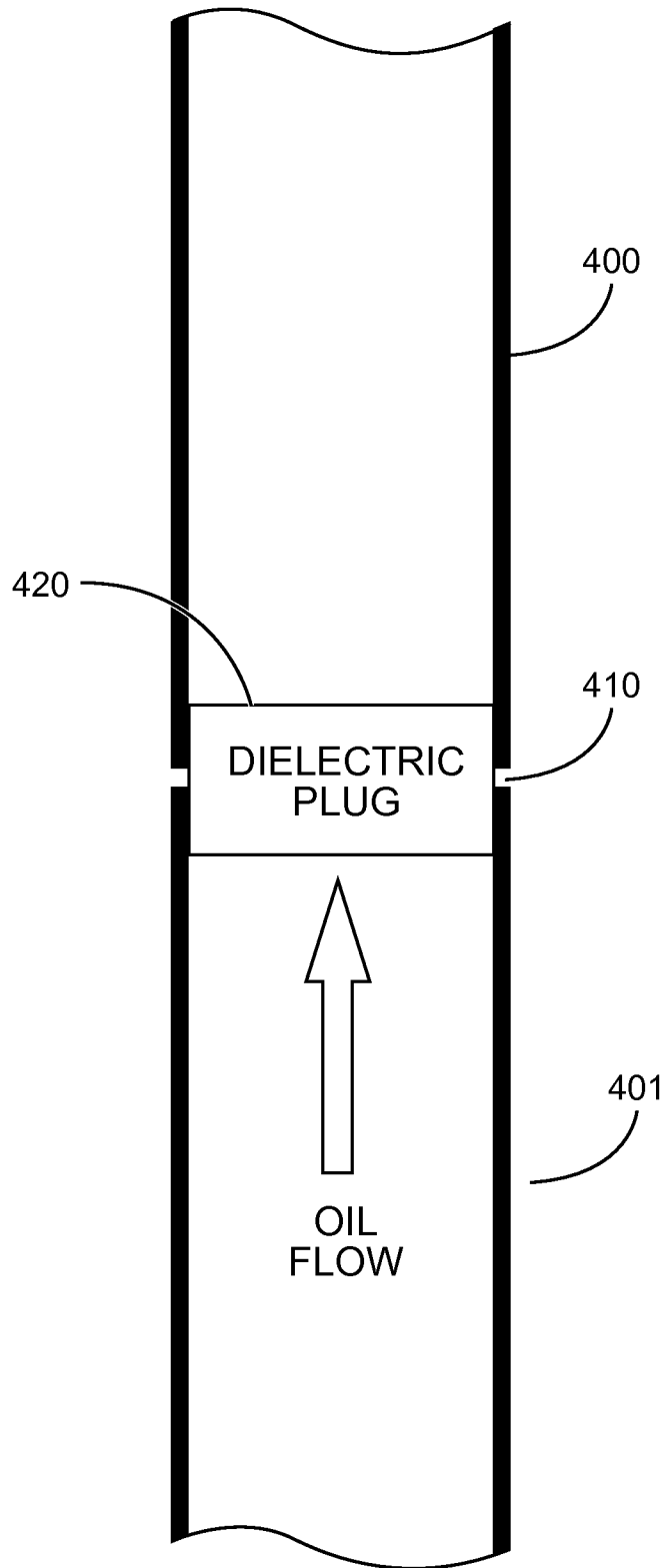


Fig. 4



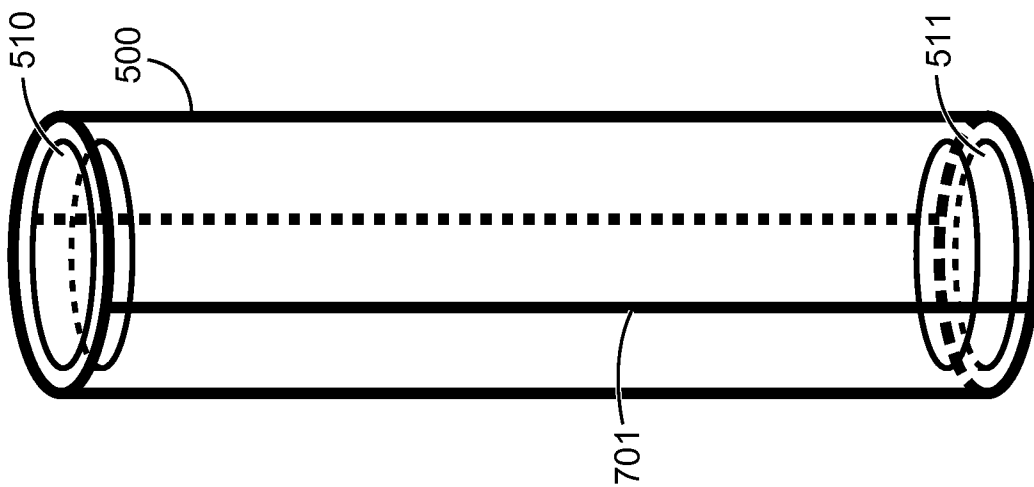


Fig. 7

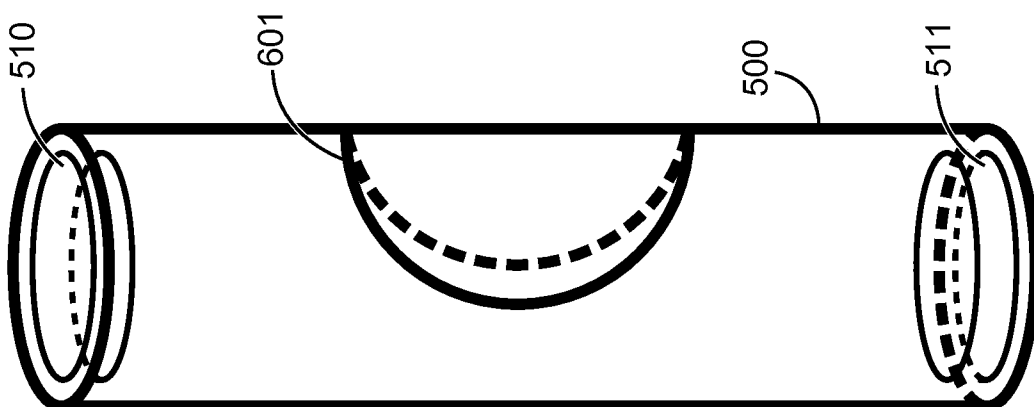


Fig. 6

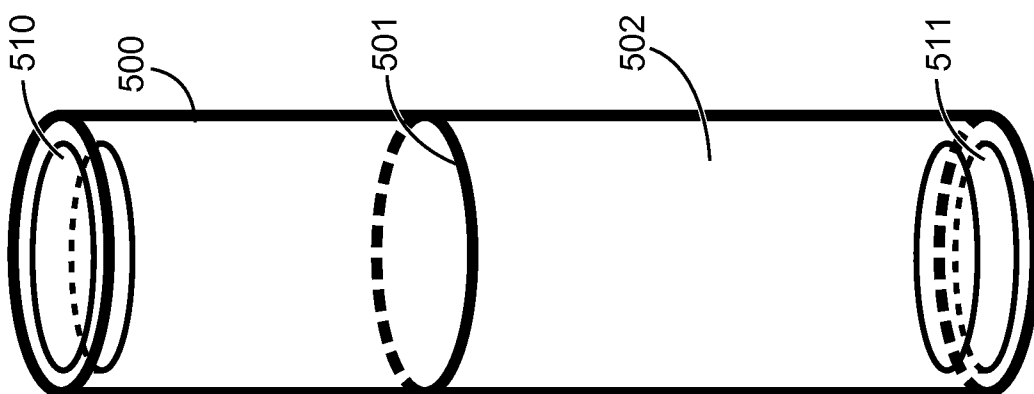


Fig. 5

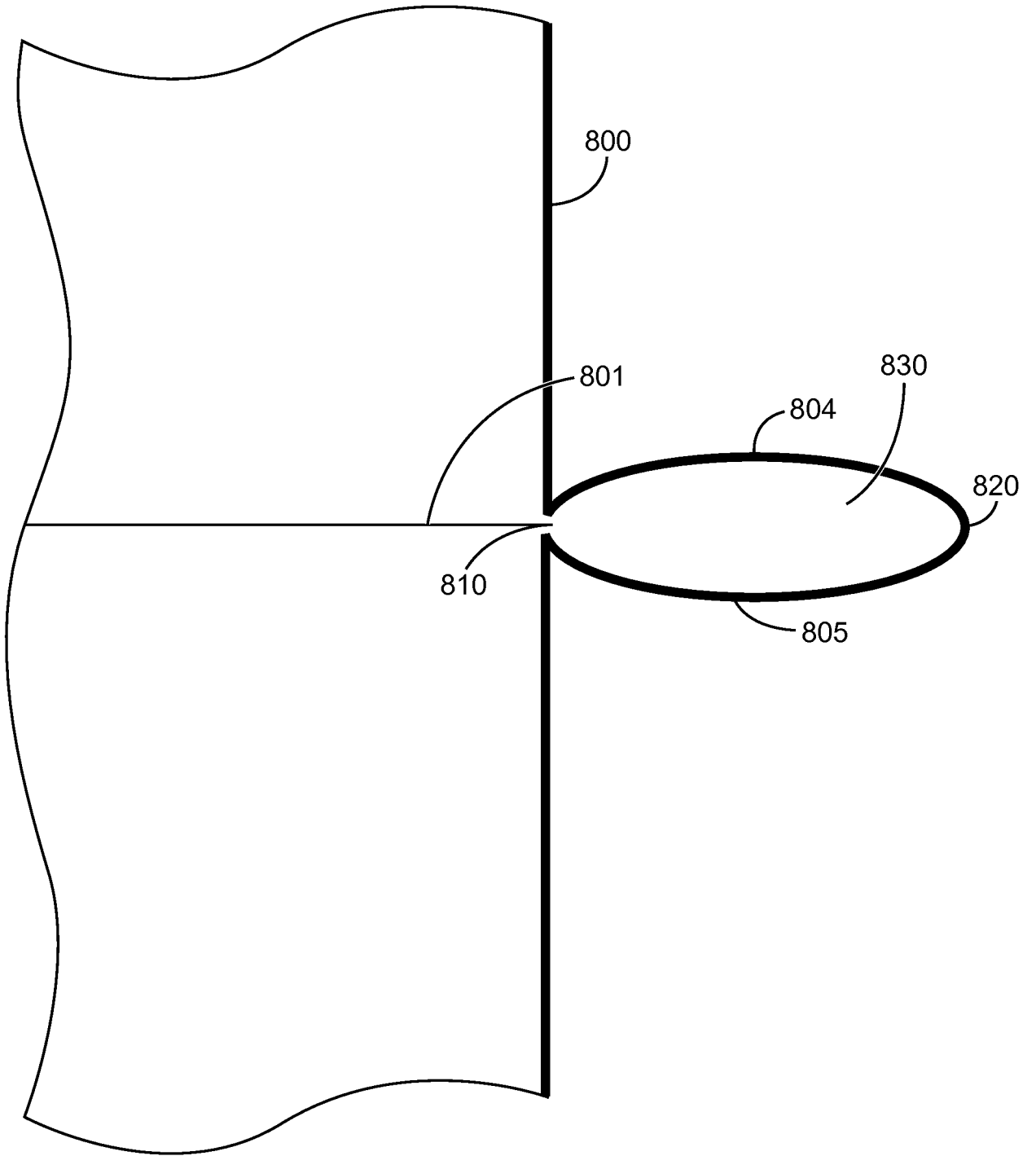


Fig. 8

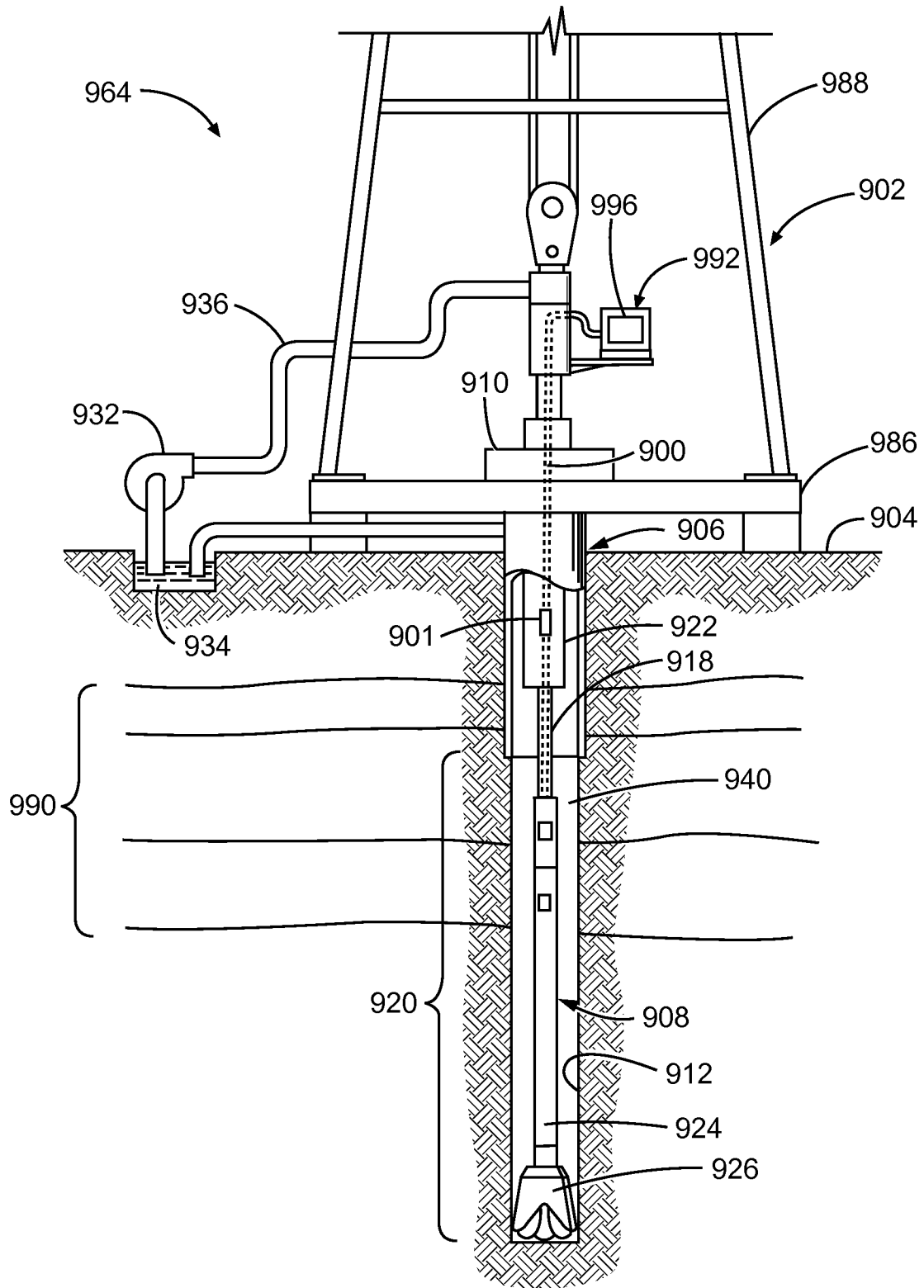


Fig. 9

8/9

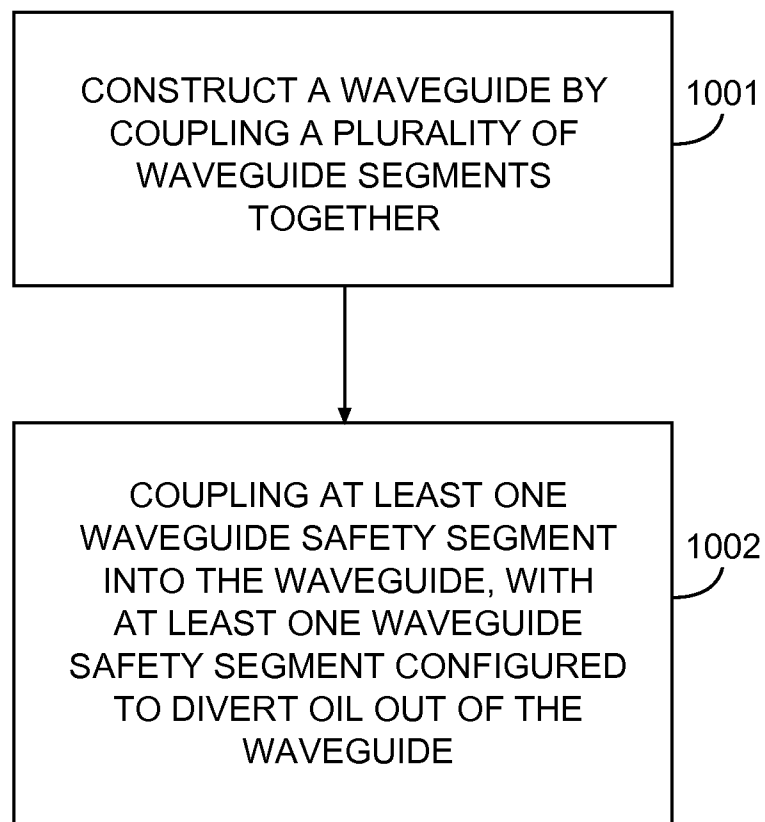


Fig. 10

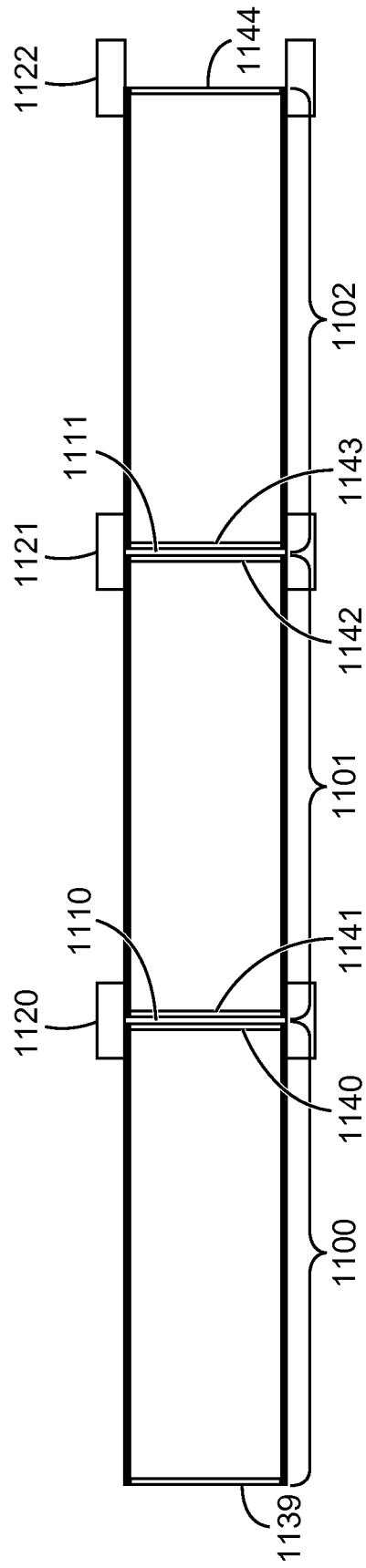


Fig. 11

## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2015/055755****A. CLASSIFICATION OF SUBJECT MATTER****E21B 47/12(2006.01)i, E21B 33/12(2006.01)i, G02B 6/02(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; H01J 25/00; H01P 5/18; H01S 3/00; H01P 5/02; G02B 6/44; E21B 33/12; G02B 6/02

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) &amp; Keywords: downhole, safety, waveguide, fiber optic, segment, couple, dielectric, plug, divert, oil and vent hole

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4668894 A (BARNETT et al.) 26 May 1987 See column 2, line 20-column 3, line 41 and figure 1.	1-20
A	US 7671700 B1 (ROSENBERG et al.) 02 March 2010 See claims 1-9 and figures 1-2.	1-20
A	US 6127902 A (SPELDRICH et al.) 03 October 2000 See claim 1 and figure 1.	1-20
A	US 2003-0021555 A1 (TOTH et al.) 30 January 2003 See paragraphs [0023]-[0027] and figures 1-3.	1-20
A	US 8345348 B1 (SAVAGE-LEUCHS, MATTHIAS P.) 01 January 2013 See column 6, line 64-column 16, line 41 and figures 1A-3B.	1-20

 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

"&amp;" document member of the same patent family

Date of the actual completion of the international search

14 February 2016 (14.02.2016)

Date of mailing of the international search report

**15 February 2016 (15.02.2016)**

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

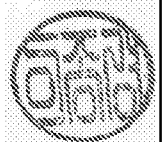
189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

Facsimile No. +82-42-472-7140

Authorized officer

LEE, Jong Kyung

Telephone No. +82-42-481-3360



**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2015/055755**

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4668894 A	26/05/1987	None	
US 7671700 B1	02/03/2010	CN 001620737 A CN 991396651 C EP 1476915 A1 EP 1476915 B1 US 2003-0145446 A1 US 6807728 B2 WO 03-063289 A1	25/05/2005 21/03/2007 17/11/2004 11/04/2007 07/08/2003 26/10/2004 31/07/2003
US 6127902 A	03/10/2000	DE 19716290 A1 EP 0872910 A2 EP 0872910 A3	29/10/1998 21/10/1998 07/07/1999
US 2003-0021555 A1	30/01/2003	US 6665477 B2	16/12/2003
US 8345348 B1	01/01/2013	US 7768700 B1 US 8089689 B1 US 8199399 B1 US 8705166 B1	03/08/2010 03/01/2012 12/06/2012 22/04/2014