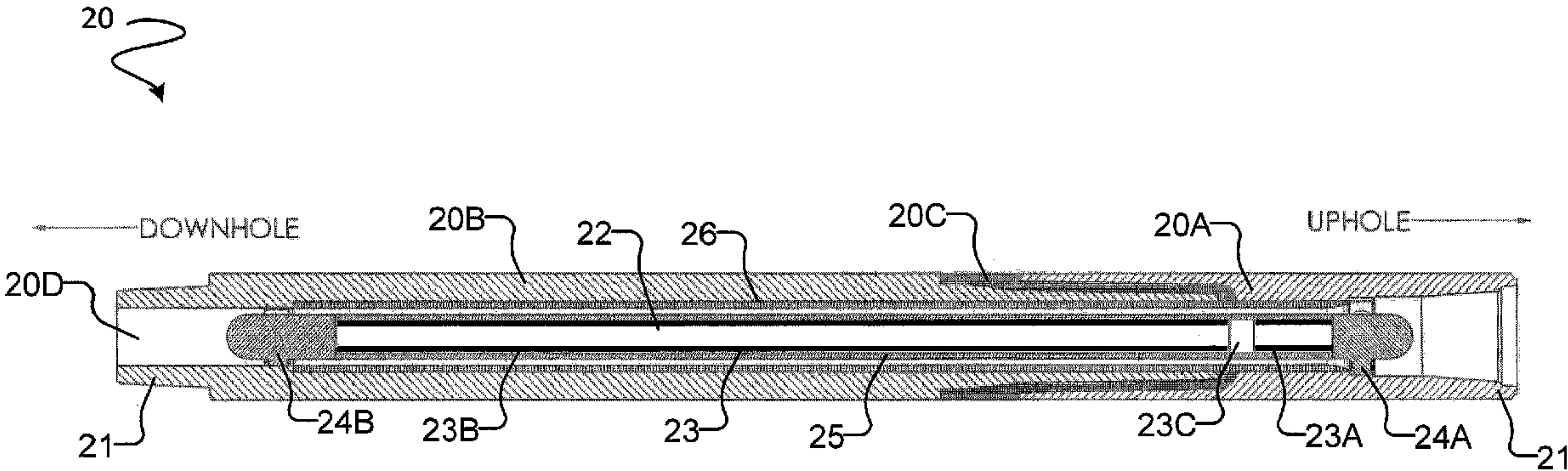




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(54) **Titre :** APPAREIL DE TELEMETRIE ELECTROMAGNETIQUE DE FOND DE Puits
(54) **Title:** DOWNHOLE ELECTROMAGNETIC TELEMETRY APPARATUS



(57) **Abrégé/Abstract:**

An assembly for use in subsurface drilling includes a downhole probe having an EM telemetry signal generator and electrical contacts for carrying telemetry signals from the EM telemetry signal generator to first and second parts of a gap sub in a drill string. An outside surface of the probe and an inside surface of the gap sub are covered with layers of electrically-insulating material. Electrical conduction paths internal to the gap sub are removed, thereby increasing efficiency of EM telemetry.

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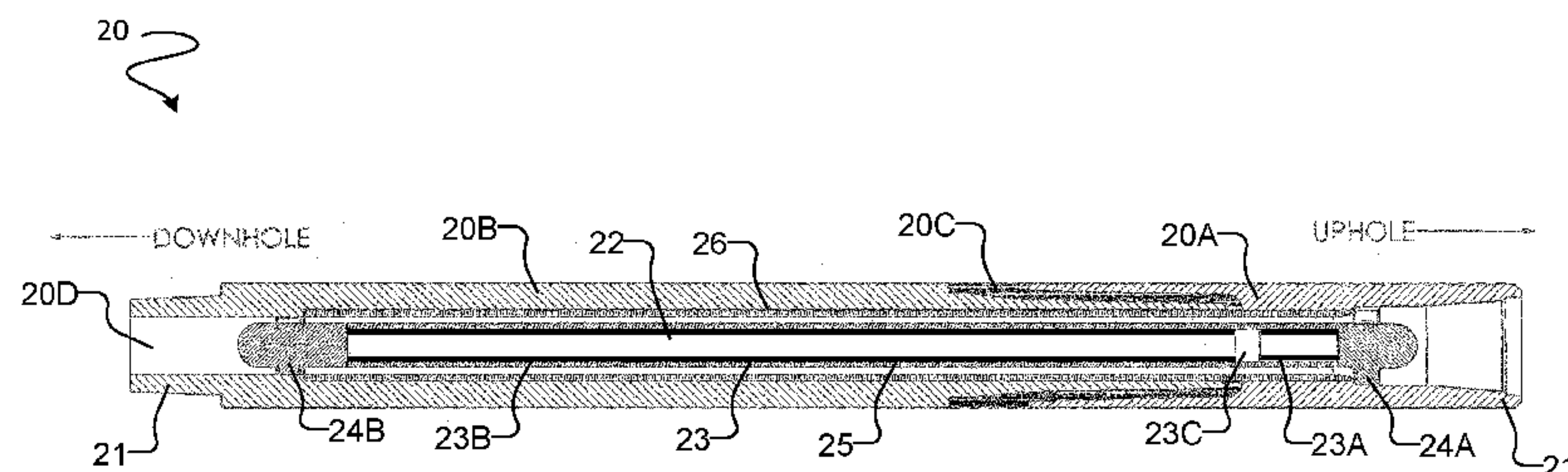


FIG. 2

(57) Abstract: An assembly for use in subsurface drilling includes a downhole probe having an EM telemetry signal generator and electrical contacts for carrying telemetry signals from the EM telemetry signal generator to first and second parts of a gap sub in a drill string. An outside surface of the probe and an inside surface of the gap sub are covered with layers of electrically-insulating material. Electrical conduction paths internal to the gap sub are removed, thereby increasing efficiency of EM telemetry.

DOWNHOLE ELECTROMAGNETIC TELEMETRY APPARATUS

[0001]

5

Technical Field

[0002] This application relates to subsurface drilling, specifically to apparatus for
10 telemetry of information from downhole locations. Embodiments are applicable to
drilling wells for recovering hydrocarbons.

Background

[0003] Recovering hydrocarbons from subterranean zones relies on the process of drilling
wellbores.

15 **[0004]** Wellbores are made using surface-located drilling equipment which drives a drill
string that eventually extends from the surface equipment to the formation or subterranean
zone of interest. The drill string can extend thousands of feet or meters below the surface.
The terminal end of the drill string includes a drill bit for drilling (or extending) the
wellbore. Drilling fluid usually in the form of a drilling “mud” is typically pumped
20 through the drill string. The drilling fluid cools and lubricates the drill bit and also carries
cuttings back to the surface. Drilling fluid may also be used to help control bottom hole
pressure to inhibit hydrocarbon influx from the formation into the wellbore and potential
blow out at surface.

[0005] Bottom hole assembly (BHA) is the name given to the equipment at the terminal
25 end of a drill string. In addition to a drill bit a BHA may comprise elements such as:
apparatus for steering the direction of the drilling (e.g. a steerable downhole mud motor or

rotary steerable system); sensors for measuring properties of the surrounding geological formations (e.g. sensors for use in well logging); sensors for measuring downhole conditions as drilling progresses; systems for telemetry of data to the surface; stabilizers; heavy weight drill collars, pulsers and the like. The BHA is typically advanced into the
5 wellbore by a string of metallic tubulars (drill pipe).

[0006] Telemetry information can be invaluable for efficient drilling operations. For example, telemetry information may be used by a drill rig crew to make decisions about controlling and steering the drill bit to optimize the drilling speed and trajectory based on numerous factors, including legal boundaries, locations of existing wells, formation
10 properties, hydrocarbon size and location, etc. A crew may make intentional deviations from the planned path as necessary based on information gathered from downhole sensors and transmitted to the surface by telemetry during the drilling process. The ability to obtain real time data allows for relatively more economical and more efficient drilling operations.

15 [0007] Various techniques have been used to transmit information from a location in a bore hole to the surface. These include transmitting information by generating vibrations in fluid in the bore hole (e.g. acoustic telemetry or mud pulse telemetry) and transmitting information by way of electromagnetic signals that propagate at least in part through the earth (EM telemetry). Other telemetry systems use hardwired drill pipe or fibre optic
20 cable to carry data to the surface.

[0008] A typical arrangement for electromagnetic telemetry uses parts of the drill string as an antenna. The drill string may be divided into two conductive sections by including an insulating joint or connector (a “gap sub”) in the drill string. The gap sub is typically placed within a bottom hole assembly such that metallic drill pipe in the drill string above
25 the BHA serves as one antenna element and metallic sections in the BHA serve as another antenna element. Electromagnetic telemetry signals can then be transmitted by applying electrical signals between the two antenna elements. The signals typically comprise very low frequency AC signals applied in a manner that codes information for transmission to the surface. The electromagnetic signals may be detected at the surface, for example by
30 measuring electrical potential differences between the drill string and one or more ground

rods. A challenge with EM telemetry is that the generated signals are significantly attenuated as they propagate to the surface. Further, the electrical power available to generate EM signals may be provided by batteries or another power source that has limited capacity. Therefore, it is desirable to provide a system in which EM signals are generated
 5 efficiently.

[0009] Design of the gap sub is an important factor in an EM telemetry system. The gap sub must provide electrical isolation between two parts of the drill string as well as withstand the extreme mechanical loading induced during drilling and the high differential pressures that occur between the center and exterior of the drill pipe. Drill string
 10 components are typically made from high strength, ductile metal alloys in order to handle the loading without failure. Most electrically-insulating materials suitable for electrically isolating different parts of a gap sub are weaker than metals (e.g. rubber, plastic, epoxy) or quite brittle (ceramics). This makes it difficult to design a gap sub that is both configured to provide efficient transmission of EM telemetry signals and has the mechanical
 15 properties required of a link in the drill string.

[0010] The following references describe various telemetry systems: US 3323327; US 4176894; US 4348672; US 4496174; US 4684946; US 4676773; US 4739325; US 5130706; US 5138313; US 5236048; US 5406983; US 5467832; US 5520246; US 5749605; US 5883516; US 6050353; US 6098727; US 6158532; US 6404350; US
 20 6446736; US 6515592; US 6727827; US 6750783; US 6926098; US 7151466; US 7243028; US 7255183; US 7252160; US 7326015; US 7387167; US 7573397; US 7605716; US 7836973; US 7880640; US 7900968; US 8154420 US 2004/0104047; US 2005/0217898; US 2006/0202852; US 2006/003206; US 2007/0235224; US 2007/0247328; US 2009/0023502; US 2009/0065254; US 2009/0066334; US
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[0011] Despite work that has been done to develop systems for subsurface telemetry there remains a need for practical subsurface telemetry systems and there remains a need to provide such systems that offer improved efficiency and/or greater range.

Summary

5 [0012] The invention has several aspects. One aspect provides EM telemetry apparatus for downhole applications. Another aspect provides methods for subsurface drilling.

[0013] Apparatus according to one aspect provides a subsurface drilling assembly comprising a downhole probe and a gap sub. The gap sub comprises an electrically-conducting uphole part comprising an uphole coupling for coupling into a drill string, an
10 electrically-conducting downhole part comprising a downhole coupling for coupling into the drill string, a bore extending through the gap sub from the uphole coupling to the downhole coupling and an electrically-insulating gap portion electrically isolating the uphole part of the gap sub from the downhole part of the gap sub. The probe extends within the bore. The probe comprises an elongated housing enclosing electronics
15 including a signal generator. The probe comprises first and second electrical contacts spaced apart longitudinally on an outside of the housing. The apparatus comprises a fluid-carrying channel bypassing the probe. Walls of the fluid-carrying channel are electrically-insulating at least in a section of the channel extending longitudinally from a location above the electrically-insulating gap portion to a location below the electrically-
20 insulating gap portion.

[0014] Apparatus according to another aspect provides a probe for use in subsurface drilling. The probe comprises an elongated metallic housing. The housing encloses electronics, including a telemetry signal generator. The housing comprises first and
25 second electrical contacts spaced apart longitudinally on the outside of the housing and an electrically-insulating gap comprising an electrically-insulating material providing electrical isolation between first and second parts of the metallic housing. The gap is located between the first and second electrical contacts. The probe also comprises an electrically-insulating layer on an outside surface of the metallic housing. The electrically
30 insulating layer at least partially covers the electrically-insulating gap and extends

continuously to cover an outside surface of the metallic housing on at least one side of the gap. In some embodiments the covering extends for a distance of at least 1 meter. In some embodiments the probe is combined with a gap sub. The gap sub (which may comprise one component or a plurality of separable components comprises an electrically-
5 conducting uphole part comprising an uphole coupling for coupling into a drill string, an electrically-conducting downhole part comprising a downhole coupling for coupling into the drill string, a bore extending through the gap sub from the uphole coupling to the downhole coupling and an electrically-insulating gap portion electrically isolating the uphole part of the gap sub from the downhole part of the gap sub. In the combination, the
10 probe is located within the bore of the gap sub and the first electrical contact is in electrical contact with the uphole part of the gap sub and the second electrical contact is in electrical contact with the downhole part of the gap sub.

[0015] Apparatus according to another aspect provides a subsurface drilling assembly comprising a gap sub. The gap sub comprises an electrically-conducting uphole part
15 comprising an uphole coupling for coupling into a drill string, an electrically-conducting downhole part comprising a downhole coupling for coupling into the drill string, a bore extending through the gap sub from the uphole coupling to the downhole coupling and an electrically-insulating gap portion electrically isolating the uphole part of the gap sub from the downhole part of the gap sub. An EM telemetry signal generator is housed within a
20 wall of the gap sub. The EM telemetry signal generator has output leads electrically coupled to the uphole and downhole parts of the gap sub. An electrically-insulating sleeve lines at least a portion of the bore of the gap sub adjacent to the electrically-insulating gap. The electrically insulating sleeve covers at least one interface between the electrically insulating gap portion of the gap sub and one of the uphole and downhole parts of the gap
25 sub and extends continuously along the one of the uphole and downhole parts of the gap sub.

[0016] A method according to a further aspect provides a subsurface drilling method performed using a drill string comprising a gap sub and an electronics package located in a bore of the gap sub. The electronics package comprises electrical contacts that are in
30 electrical contact with electrically-conductive parts of the gap sub. The method

comprises passing a drilling fluid down a bore of the drill string and, at the location of the electronics package, channeling the drilling fluid into a channel that is electrically insulated from both the electrically conductive parts of the gap sub and electrically conductive parts of the housing of the electronics package.

5

[0017] Further aspects of the invention and features of example embodiments are illustrated in the accompanying drawings and/or described in the following description.

Brief Description of the Drawings

[0018] The accompanying drawings illustrate non-limiting example embodiments of the invention.

10

[0019] Figure 1 is a schematic view of a drilling operation according to an example embodiment.

[0020] Figure 2 is a longitudinal cross sectional view of a gap sub according to an example embodiment.

[0021] Figures 3A-3D are cutaway views of a portion of a gap sub according to an example embodiment.

15

[0022] Figure 4 is a schematic view of an equivalent electrical circuit for a telemetry signal generator and gap sub according to an example embodiment.

[0023] Figure 5 is a cutaway view of a gap sub with radially-inwardly extending parts according to an example embodiment.

20

[0024] Figure 5A is an axial cross sectional view of a gap sub with radially-inwardly extending parts according to an example embodiment.

[0025] Figure 6 shows schematically an example embodiment in which an electronics package is located in a cavity in a wall of a gap sub.

Description

[0026] Throughout the following description specific details are set forth in order to provide a more thorough understanding to persons skilled in the art. However, well known elements may not have been shown or described in detail to avoid unnecessarily obscuring the disclosure. The following description of examples of the technology is not intended to be exhaustive or to limit the system to the precise forms of any example embodiment. Accordingly, the description and drawings are to be regarded in an illustrative, rather than a restrictive, sense.

[0027] While a number of exemplary aspects and embodiments have been discussed above, those of skill in the art will recognize certain modifications, permutations, additions and sub-combinations thereof. It is therefore intended that the following appended claims and claims hereafter introduced are interpreted to include all such modifications, permutations, additions and sub-combinations as are within their true spirit and scope.

[0028] Figure 1 shows schematically an example drilling operation. A drill rig 10 drives a drill string 12 which includes sections of drill pipe that extend to a drill bit 14. The illustrated drill rig 10 includes a derrick 10A, a rig floor 10B and draw works 10C for supporting the drill string. Drill bit 14 is larger in diameter than the drill string above the drill bit. An annular region 15 surrounding the drill string is typically filled with drilling fluid. The drilling fluid is pumped through a bore in the drill string to the drill bit and returns to the surface through annular region 15 carrying cuttings from the drilling operation. As the well is drilled, a casing 16 may be made in the well bore. A blow out preventer 17 is supported at a top end of the casing. The drill rig illustrated in Figure 1 is an example only. The methods and apparatus described herein are not specific to any particular type of drill rig.

[0029] Drill string 12 includes a gap sub 20. An EM signal generator 18 located inside the drill string (for example in an electronics probe contained within the bore of the drill string) is electrically connected across the electrically-insulating gap of the gap sub 20. The signals from the EM signal generator result in electrical currents 19A and electric fields 19B that are detectable at the surface. In the illustrated embodiment a signal receiver 13 is connected by signal cables 13A to measure potential differences between

electrical grounding stakes 13B and the top end of drill string 12. A display 11 may be connected to display data received by the signal receiver 13.

[0030] Figure 2 shows an example arrangement of a gap sub 20. Gap sub 20 has an electrically-conducting uphole portion 20A and an electrically conducting downhole portion 20B separated by gap 20C filled with an electrically-insulating material. Couplings 21 for coupling to adjacent elements of the drill string are provided at the uphole and downhole ends of gap sub 20. An electronics package 22 comprising an EM telemetry signal generator (not shown in Figure 2) is supported in a bore 20D of gap sub 20.

[0031] Electronics package 22 has a metal housing 23 comprising first and second parts 23A and 23B that are electrically insulated from one another by an electrically-insulating gap 23C. First and second electrodes 24A and 24B are connected to the telemetry signal generator and are respectively in contact with the uphole portion 20A and the downhole portion 20B of gap sub 20. Electrode 24A may be, but is not necessarily, in electrical contact with first part 23A of the housing of electronics package 22. Electrode 24B may be, but is not necessarily in electrical contact with second part 23B of the housing of electronics package 22.

[0032] An electrically-insulating layer 25 at least partially covers electrically-insulating gap 23C of electronics package 22. Electrically insulating layer 25 extends over the outside surface of electronics package 22 and continuously covers the outside surface of conductive housing 23 of electronics package 22 for a distance beyond electrically-insulating gap 23C on one or both sides of electrically-insulating gap 23C. In some embodiments the length of continuous coverage of electrically-insulating layer 25 is at least 1 meter and preferably at least 1 ½ meters or 2 meters. In some example embodiments the length of continuous coverage of electrically-insulating layer 25 is 3 to 4 meters.

[0033] In some embodiments, electrically-insulating layer 25 continuously covers at least 60% or 70% or 80% of that portion of the outside surface of electronics package 22 that lies between electrodes 24A and 24B. In some embodiments electrically insulating layer

25 continuously covers substantially all of that portion of the outside surface of electronics package 22 that lies between electrodes 24A and 24B. Here, 'substantially all' means at least 95%.

[0034] In some embodiments, electrically-insulating layer 25 comprises a coating applied to electronics package 22, a sleeve or tube extending around electronics package 22, or the like. The material of layer 25 may be any electrically insulating material suitable for exposure to downhole conditions. Some non-limiting examples are suitable thermoplastics, epoxies, ceramics, elastomeric polymers, and rubber. Layer 25 may comprise a coating that is applied to, or bonded to electronics package 22 or a pre-formed component (formed e.g. by extrusion, injection molding, or the like which is subsequently attached to, affixed around, or supported around electronics package 22. The material of layer 25 should be capable of withstanding downhole conditions without degradation. The ideal material can withstand temperature of up to at least 150C (preferably 175C or 200C or more), is chemically resistant or inert to any drilling fluid to which it will be exposed, does not absorb fluid to any significant degree and resists erosion by drilling fluid. An example of a suitable material is PET (polyethylene terephthalate) or PEEK (polyether ether ketone).

[0035] A second electrically-insulating layer 26 is provided between electronics package 22 and the inner surfaces of the electrically-conducting uphole and/or downhole parts 20A and 20B of gap sub 20. Electrically insulating layer 26 extends to at least partially cover the inner side of electrically-insulating gap 20C and extends continuously to cover electrically-conductive parts of the bore wall on at least one side of electrically-insulating gap 20C. In some embodiments electrically insulating layer 26 continuously covers a part of the bore wall that includes the inner side of electrically-insulating gap 20C and extends continuously to cover parts of both uphole and downhole parts 20A and 20B of gap sub 20. In some embodiments electrically insulating layer 26 comprises a coating applied to the inside of gap sub 20, a sleeve or tube extending around the inside of gap sub 20, or the like.

[0036] As with layer 25, the material of layer 26 may be any electrically insulating material suitable for exposure to downhole conditions. Some non-limiting examples are

suitable thermoplastics, epoxies, ceramics, elastomeric polymers, and rubber. Layer 26 may comprise a coating that is applied to, formed on or bonded to the inner wall of gap sub 20 or a pre-formed component (formed e.g. by extrusion, injection molding, or the like) which is subsequently attached to, affixed around, supported around the inside of the bore of gap sub 20. An example of a suitable material is PET (polyethylene terephthalate) or PEEK (polyether ether ketone).

[0037] The inventors have determined that low impedance paths within the bore of a gap sub can provide a significant source of inefficiency in the transmission of EM telemetry signals. The provision of electrically insulating layer 25, especially in combination with the provision of electrically insulating layer 26 has been found to dramatically reduce losses arising from conduction currents within the bore of the gap sub. With electrically-insulating layers 25 and 26 lining electrically-conductive surfaces within bore 27, the shortest path through the fluid in bore 27 electrically connecting parts 20A and 20B of gap sub 20 is at least the length of the shorter one of electrically-insulating layers 25 and 26.

[0038] Figures 3A to 3D illustrate possible electrical conduction paths through which current originating from electrodes 24A and 24B could pass. It can be seen that all of these possible electrical conduction paths are blocked by at least one of electrically-insulating layer 25, electrically-insulating layer 26, electrically-insulating gap 23C, and electrically-insulating gap 20C.

[0039] By providing electrically insulating barriers on conductive surfaces of electronics package 22 and/or gap sub 20 that would otherwise be exposed to the drilling fluid in the bore of gap sub 20, considerable improvements in the efficiency of EM transmission may be achieved. The lengths of insulating layers 25 and 26 should be sufficient to raise the impedance of the conductive paths through the bore fluid to a desired degree. Providing electrically insulating layers 25 and 26 that are at least approximately 2 meters (6 feet) long has been shown to reduce power lost as a result of current flowing inside the borehole by 90% or more in some cases.

[0040] In example embodiments, insulating layers 25 and 26 are at least 1 meter in length (although they could be shorter in some embodiments). In some embodiments insulating

layer 26 extends for a length that is at least 75% of the length of electrically insulating layer 25. In preferred embodiments, electrically insulating layer 26 is at least as long as electrically insulating layer 25. In some embodiments, electrically insulating layer 26 covers substantially the entire inside of that portion of the bore of gap sub 20 lying
5 between electrodes 24A and 24B.

[0041] Figure 4 illustrates schematically an equivalent electrical circuit for the telemetry signal generator and gap sub 20 (neglecting capacitive and inductive effects). Resistor R_{IN} represents the available current paths within the bore 20D of the gap sub 20 and resistor R_{OUT} represents the available current paths external to the gap sub 20. Dual non-
10 conductive layers 25 and 26 provide an effectively large internal isolation path (a large value for R_{IN}) thus increasing the electrical efficiency of the gap sub 20 EM telemetry by providing an internal resistance (R_{IN}) between antenna elements of the gap sub 20 that is large compared to the resistance of the external gap (R_{OUT}).

[0042] Another advantage of providing non-conductive layers on both the inner surface of gap sub 20 and the outer surface of electronics package 22 is that layers 25 and 26 prevent
15 conductive outer surfaces of electronics package 22 from making electrical contact with inner surfaces of gap sub 20 as might possibly occur in cases where the electronics package and gap sub are subjected to high shocks and/or vibration. Such contact could damage a telemetry signal generator (e.g. by shorting its output) and/or interfere with
20 telemetry of downhole information.

[0043] A centralizer may optionally be provided to maintain electronics package 22 central in bore 20D of gap sub 20. Various centralizer designs are used. Any suitable centralizer may be used. In some embodiments one or both of layers 25 and 26 is integrated with a centralizer. For example, centralizing members such as longitudinally-
25 extending ridges or bumps or other protrusions may be provided on one or both of layers 25 and 26 to maintain electronics package 22 centered in the bore of gap sub 20. The centralizing members may comprise a resilient elastomeric or vibration dampening material such as rubber or a suitable plastic, for example.

[0044] Providing electrically-insulating layers 25 and/or 26 also allows the minimum spacing between the inner surfaces of electrically conducting parts 20A and 20B of gap sub 20 and the outer surface of the housing 23 of electronics package 22 to be reduced significantly without causing losses due to conduction through the fluid within the bore of gap sub 20 to increase significantly. This is particularly significant where the drilling fluids being used are of a type that provides relatively low electrical impedance. Water-based drilling fluids tend to have lower electrical impedance.

[0045] Providing electrically-insulating layers 25 and/or 26 also allows the width of gap 20C inside the bore of gap sub 20 and the width of gap 23C to be reduced. Reducing the widths of gaps 20C and/or 23C can result in more robust apparatus since most available electrically-insulating materials suitable for gaps 23C and 20C are less robust than the materials (most typically metals) used for other parts of gap sub 20 and housing 23.

[0046] Electrically-insulating layers 25 and 26A also alleviate any need to align gap 20C of gap sub 20 with gap 23C of electronics package 22. In some embodiments gap 20C is longitudinally spaced apart from Gap 23C. Thus the provision of electrically-insulating layers 25 and 26 allows the longitudinal position of electronics package 22 to be adjusted without causing problems that might otherwise arise from the misalignment of gaps 20C and 23C. Furthermore, the location of gap 23C on electronics package 22 may be selected for optimum mechanical properties and/or for optimum placement of electronics systems and components within electronics package 22 when it is unnecessary for gap 23C to be aligned longitudinally with gap 20C..

[0047] In some embodiments, electrically conducting parts 20A and 20B of gap sub 20 are formed to provide parts that extend radially inwardly to provide support to electronics package 22. The radially-inwardly extending parts may be integrally formed with parts 20A and 20B of the same metal.

[0048] Figure 5 illustrates an example apparatus 50 comprising a gap sub 20 that is formed to provide radially-inwardly extending parts in the form of rounded lobes 52 that extend longitudinally within bore 20D of gap sub 20. Lobes 52 may extend for

substantially the full length of electronics package 22. Lobes 52 may be formed, for example, by hobbing.

[0049] Figure 5A shows an example embodiment wherein an electrically insulating layer 25 is provided on the outside of electronics package 22. Another electrically insulating layer 26A is preferably but optionally provided on the inside of the bore of gap sub 20 covering lobes 52.

[0050] As shown in Figure 5A, lobes 52 are dimensioned such that electronics package 22 is firmly held within their inwardly-facing tips. Electrically-insulating layers 25 and/or 26A may be of materials that provide mechanical damping as well as electrical insulation. Mechanically coupling electronics package 22 to gap sub 20 continuously along its length can substantially reduce flexing and vibration of electronics package 22 caused by lateral accelerations of the drill string, flow of drilling fluid, or the like.

[0051] Apparatus as described herein may be applied in a wide range of subsurface drilling applications. For example, the apparatus may be applied to provide telemetry in logging while drilling ('LWD') and/or measuring while drilling ('MWD') applications. Providing apparatus as described herein in which electrical current flow between different antenna elements within the bore of a drill string is significantly diminished reduces the load on a telemetry signal generator. This in turn may permit the same telemetry signal generator to operate with a reduced power output and/or to provide a higher-voltage signal to the antenna elements, thereby facilitating one or more of extended battery life, reduced power consumption, improved telemetry signal strength at the surface and reduced telemetry error rate. Extended battery life in downhole applications is very significant since battery replacement or recharging may require withdrawal of the electronics package from the hole. This can be time consuming and labor intensive. Thus, increased battery life can result in a longer run length during drilling operations with fewer service intervals needed.

[0052] Another aspect of the invention provides a subsurface drilling method. The method is performed using a drill string comprising a gap sub and an electronics package located in a bore of the gap sub. The electronics package has electrical contacts that are in

electrical contact with electrically-conductive parts of the gap sub. The method involves passing a drilling fluid down a bore of the drill string and, at the location of the electronics package, channeling the drilling fluid into a channel that is electrically insulated from both the electrically conductive parts of the gap sub and electrically conductive parts of the housing of the electronics package. In some embodiments, examples of which are described above, the channel is an annular channel that surrounds that portion of the electronics package between the electrodes. This is not mandatory, however.

[0053] A wide range of alternatives are possible. For example, it is not mandatory that the gap sub be a single component. In some embodiments a gap sub comprises a plurality of components that can be assembled together into the drill string to provide electrical insulation between two parts of the drill string. A probe may extend fully or partially through one, two, three, or more coupled-together sections of the drill string.

[0054] In some embodiments, electronic systems which may include a telemetry signal generator are provided in a package located in a cavity formed in a wall of a drill collar or gap sub. Such embodiments may not have a separate probe mounted in a bore of the drill collar or gap sub. Electrical connections between an EM telemetry signal generator housed in a wall of a drill string section and uphole and downhole portions 20A and 20B of the gap sub may be made by way of conductors embedded in the wall of the gap sub. Figure 6 shows schematically an example embodiment in which an electronics package 60 is located in a cavity 61 in a wall of a gap sub 20. In such embodiments efficiency of EM telemetry may be improved by providing an electrically-insulating layer 26 that at least partially covers the inside of electrically-insulating gap 20C and extends to continuously cover parts of one or both of the inner surfaces of the electrically-conducting uphole and downhole parts 20A and 20B of gap sub 20 that are adjacent to electrically-insulating gap 20C. The electrically-insulating layer 26 covers at least one of the interfaces 62 between electrically-insulating gap 20C and uphole and downhole parts 20A and 20B. With electrically-insulating layer 26 lining bore 27, the shortest path through the fluid in bore 27 electrically connecting parts 20A and 20B of gap sub 20 is at least the length of electrically-insulating layer 26.

Interpretation of Terms

[0055] Unless the context clearly requires otherwise, throughout the description and the claims:

- 5 • “comprise”, “comprising”, and the like are to be construed in an inclusive sense, as opposed to an exclusive or exhaustive sense; that is to say, in the sense of “including, but not limited to”.
- “connected”, “coupled”, or any variant thereof, means any connection or coupling, either direct or indirect, between two or more elements; the coupling or connection between the elements can be physical, logical, or a combination thereof.
- 10 • “herein”, “above”, “below”, and words of similar import, when used to describe this specification shall refer to this specification as a whole and not to any particular portions of this specification.
- “or”, in reference to a list of two or more items, covers all of the following interpretations of the word: any of the items in the list, all of the items in the list, and any combination of the items in the list.
- 15 • the singular forms “a”, “an” and “the” also include the meaning of any appropriate plural forms.

[0056] Words that indicate directions such as “vertical”, “transverse”, “horizontal”, “upward”, “downward”, “forward”, “backward”, “inward”, “outward”, “vertical”, “transverse”, “left”, “right”, “front”, “back”, “top”, “bottom”, “below”, “above”, “under”, and the like, used in this description and any accompanying claims (where present) depend on the specific orientation of the apparatus described and illustrated. The subject matter described herein may assume various alternative orientations. Accordingly, these

20 directional terms are not strictly defined and should not be interpreted narrowly.

[0057] Where a component (e.g. a circuit, module, assembly, device, drill string component, drill rig system etc.) is referred to above, unless otherwise indicated, reference to that component (including a reference to a “means”) should be interpreted as including as equivalents of that component any component which performs the function of the

30 described component (i.e., that is functionally equivalent), including components which

are not structurally equivalent to the disclosed structure which performs the function in the illustrated exemplary embodiments of the invention.

[0058] Specific examples of systems, methods and apparatus have been described herein for purposes of illustration. These are only examples. The technology provided herein
5 can be applied to systems other than the example systems described above. Many alterations, modifications, additions, omissions and permutations are possible within the practice of this invention. This invention includes variations on described embodiments that would be apparent to the skilled addressee, including variations obtained by: replacing
10 features, elements and/or acts with equivalent features, elements and/or acts; mixing and matching of features, elements and/or acts from different embodiments; combining features, elements and/or acts from embodiments as described herein with features, elements and/or acts of other technology; and/or omitting combining features, elements and/or acts from described embodiments.

[0059] It is therefore intended that the following appended claims and claims hereafter
15 introduced are interpreted to include all such modifications, permutations, additions, omissions and sub-combinations as may reasonably be inferred. The scope of the claims should not be limited by the preferred embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

WHAT IS CLAIMED IS:

1. A probe for subsurface drilling comprising:
an elongated metallic housing enclosing electronics including a signal generator, the elongated housing comprising first and second electrical contacts spaced apart longitudinally on an outside of the housing and an electrically-insulating gap comprising an electrically-insulating material providing electrical isolation between first and second parts of the metallic housing, the gap located between the first and second electrical contacts; and,
a first electrically-insulating layer on an outside surface of the metallic housing, the first electrically-insulating layer continuously covers substantially all of that portion of the outside surface of the metallic housing between the first and second electrical contacts.
2. The probe according to claim 1 wherein the signal generator is an electromagnetic telemetry signal generator.
3. The probe according to any one of claims 1 and 2 wherein the first and second electrical contacts are located at opposed ends of the elongated metallic housing.
4. The probe according to any one of claims 1 to 3 wherein the first electrically-insulating layer continuously covers the outside surface of the metallic housing for a distance of at least 1 meter.
5. The probe according to any one of claims 1 to 3 wherein the first electrically-insulating layer continuously covers the outside surface of the metallic housing for a distance of at least 2 meters.
6. The probe according to any one of claims 1 to 5 wherein the first electrical contact is in electrical contact with the first part of the housing.
7. The probe according to claim 8 wherein the second electrical contact is in electrical contact with the second part of the housing.

8. The probe according to any one of claims 1 to 7 wherein the first electrically-insulating layer comprises a thermoplastic material.
- 5 9. The probe according to any one of claims 1 to 7 wherein the first electrically-insulating layer comprises a material selected from the group consisting of: thermoplastics, epoxies, ceramics, elastic polymers, and rubber.
- 10 10. The probe according to any one of claims 1 to 9 wherein the first electrically-insulating layer comprises a coating applied to an outside surface of the probe.
11. The probe according to any one of claims 1 to 9 wherein the first electrically-insulating layer comprises a pre-formed component engaged around the outside surface of the probe.
- 15 12. The probe according to claim 11 wherein the pre-formed component comprises a pre-formed tubular sleeve.
13. The probe according to any one of claims 1 to 12 wherein the first electrically-insulating layer is integrated with a centralizer.
- 20 14. The probe according to claim 13 wherein longitudinally-extending ridges or bumps are provided on an outside surface of the first electrically-insulating layer.
- 25 15. A probe combination comprising the probe according to any one of claims 1 to 14 in combination with a gap sub, the gap sub comprising an electrically-conducting uphole part comprising an uphole coupling for coupling into a drill string, an electrically-conducting downhole part comprising a downhole coupling for coupling into the drill string, a bore extending through the gap sub from the uphole coupling to the downhole coupling and an electrically-insulating gap portion electrically isolating the uphole part of the gap sub from the downhole part of the gap sub wherein the probe is located within the bore of the gap sub and the first electrical contact is in electrical contact with the uphole part of the gap sub and the
- 30

second electrical contact is in electrical contact with the downhole part of the gap sub.

- 5 16. The probe combination according to claim 15 wherein the electrically-insulating gap of the probe is longitudinally spaced apart from the electrically-insulating gap portion of the gap sub.
- 10 17. The probe combination according to any one of claims 15 and 16 comprising a second electrically-insulating layer extending around the probe within the bore of the gap sub.
18. The probe combination according to claim 17 wherein the first and second electrically-insulating layers are both at least 2 meters long.
- 15 19. The probe combination according to claim 17 wherein the second electrically-insulating layer is at least 75% as long as the first electrically-insulating layer.
- 20 20. The probe combination according to claim 17 wherein the second electrically-insulating layer covers substantially the entire portion of a wall of the bore of the gap sub lying between the first and second electrical contacts.
21. The probe combination of any one of claims 17 to 20 wherein the second electrically-insulating layer lines an inner wall of the bore of the gap sub.
- 25 22. The probe combination of claim 21 wherein the second electrically-insulating layer comprises a coating applied to the inner wall of the bore of the gap sub.
- 30 23. The probe combination of claim 21 wherein the second electrically-insulating layer comprises a tubular sleeve engaged around the inner wall of the bore of the gap sub.

24. The probe combination of any one of claims 17 to 20 further comprising a drill collar coupled to a downhole end of the gap sub wherein the second electrically-insulating layer lines an inner wall of a bore of the drill collar.
- 5 25. The probe combination of claim 24 wherein the second electrically-insulating layer comprises a coating applied to the inner wall of the bore of the drill collar.
26. The probe combination of claim 24 wherein the second electrically-insulating layer comprises a pre-formed component engaged around the inner wall of the bore of
10 the drill collar.
27. The probe combination of any one of claims 17 to 21 and 24 wherein the second electrically-insulating layer comprises a tubular sleeve formed with longitudinally-extending lobes that contact the first electrically-insulating layer on the outside
15 surface of the metallic housing.
28. The probe combination of claim 27 wherein at least one of the first electrically-insulating layer and the second electrically-insulating layer comprises a material that provides mechanical damping.
20
29. The probe combination of any one of claims 15 to 28 wherein the gap sub comprises inwardly-extending parts projecting inwardly on an inside of the bore.
30. The probe combination of claim 29 wherein the inwardly-extending parts comprise
25 longitudinally-extending ridges.
31. The probe combination of claim 30 wherein the longitudinally-extending ridges comprise rounded lobes.
- 30 32. The probe combination of any one of claims 30 and 31 wherein the longitudinally-extending ridges comprise metal ridges integrally-formed with one or both of the uphole and downhole parts of the gap sub.

33. The probe combination of any one of claims 29 to 32 wherein the inwardly extending parts extend to support the probe from a plurality of different circumferential directions.
- 5 34. The probe combination of any one of claims 15 to 23 comprising a drill collar coupled to a downhole end of the gap sub wherein the drill collar comprises a bore and inwardly-extending parts projecting inwardly on an inside of the bore of the drill collar wherein the probe extends into the drill collar.
- 10 35. A subsurface drilling assembly comprising:
- 15 a gap sub, the gap sub comprising an electrically-conducting uphole part comprising an uphole coupling for coupling into a drill string, an electrically-conducting downhole part comprising a downhole coupling for coupling into the drill string, a bore extending through the gap sub from the uphole coupling to the downhole coupling and an electrically-insulating gap portion electrically isolating the uphole part of the gap sub from the downhole part of the gap sub;
- 20 a probe extending within the bore, the probe comprising an elongated housing enclosing electronics including a signal generator, the elongated housing comprising first and second electrical contacts spaced apart longitudinally on an outside of the housing; and
- 25 a fluid-carrying channel bypassing the probe, wherein walls of the fluid-carrying channel are electrically-insulating and extend longitudinally for substantially the entire distance between the first electrical contact and the second electrical contact.
36. A subsurface drilling assembly according to claim 35 wherein the fluid-carrying channel is configured to carry all fluid flowing in the bore above the probe.
37. A subsurface drilling assembly according to claim 36 wherein the fluid-carrying channel is annular in cross-section and extends around the probe.
- 30 38. A subsurface drilling method performed using a drill string comprising a gap sub and an electronics package located in a bore of the gap sub wherein the electronics

package comprises first and second electrical contacts that are in electrical contact with electrically-conductive parts of the gap sub, the method comprising:

passing a drilling fluid down a bore of the drill string; and,

at the location of the electronics package, channeling the drilling fluid into

5 a channel extending between the first and second electrical contacts that is electrically insulated from both the electrically conductive parts of the gap sub and electrically conductive parts of the housing of the electronics package, the channel extending substantially from the first electrical contact to the second electrical contact.

10

39. The method of claim 38 wherein the channel is annular in cross section.

40. The method according to any one of claims 38 and 39 wherein the channel surrounds at least that portion of the electronics package between the electrical
15 contacts.

41. The method according to any one of claims 38 to 40 comprising carrying the drilling fluid in the channel for a distance of at least 1 meter.

42. The method according to any one of claims 38 to 40 comprising carrying the drilling fluid in the channel for a distance of at least 1 ½ meters.

20 43. The method according to any one of claims 38 to 40 comprising carrying the drilling fluid in the channel for a distance of at least 65% of a distance between the first and second electrical contacts.

44. A subsurface drilling assembly comprising:

25 a gap sub, the gap sub comprising an electrically-conducting uphole part comprising an uphole coupling for coupling into a drill string, an electrically-conducting downhole part comprising a downhole coupling for coupling into the drill string, a bore extending through the gap sub from the uphole coupling to the downhole coupling and an electrically-insulating gap portion electrically isolating the uphole part of the gap sub from the downhole part of the gap sub;

an EM telemetry signal generator housed within a wall of the gap sub, the EM telemetry signal generator having output leads electrically coupled to the uphole and downhole parts of the gap sub; and,

5 an electrically-insulating sleeve lining the bore of the gap sub, the electrically insulating sleeve covering substantially all of that portion of the bore of the gap sub from the output lead electrically coupled to the uphole parts of the gap sub to the output lead electrically coupled to the downhole parts of the gap sub.

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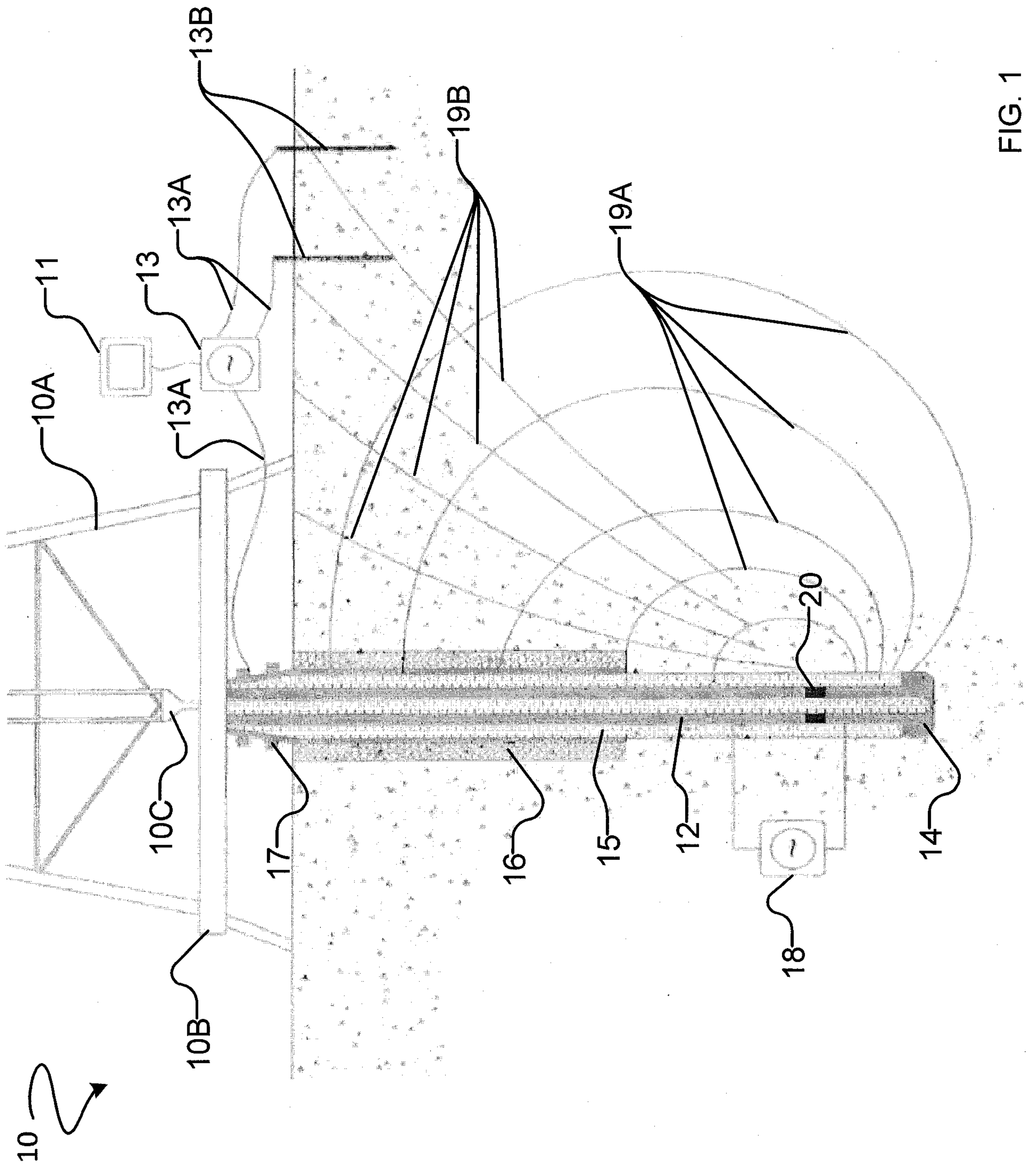
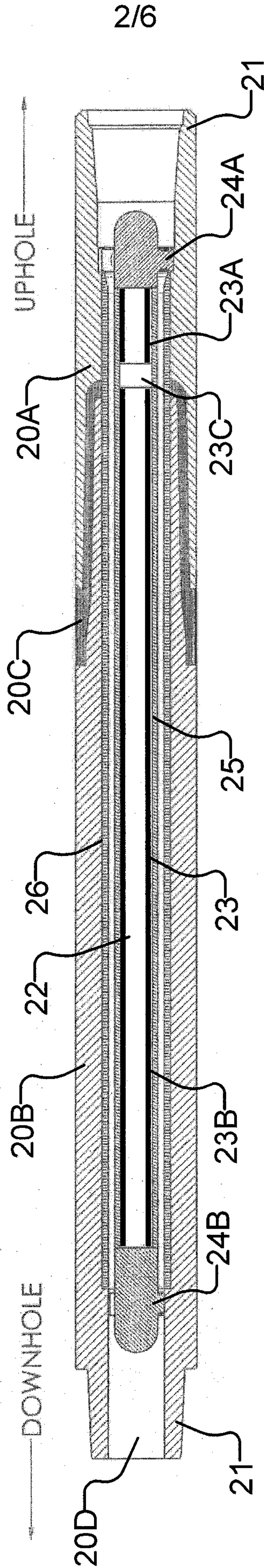


FIG. 1

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FIG. 2

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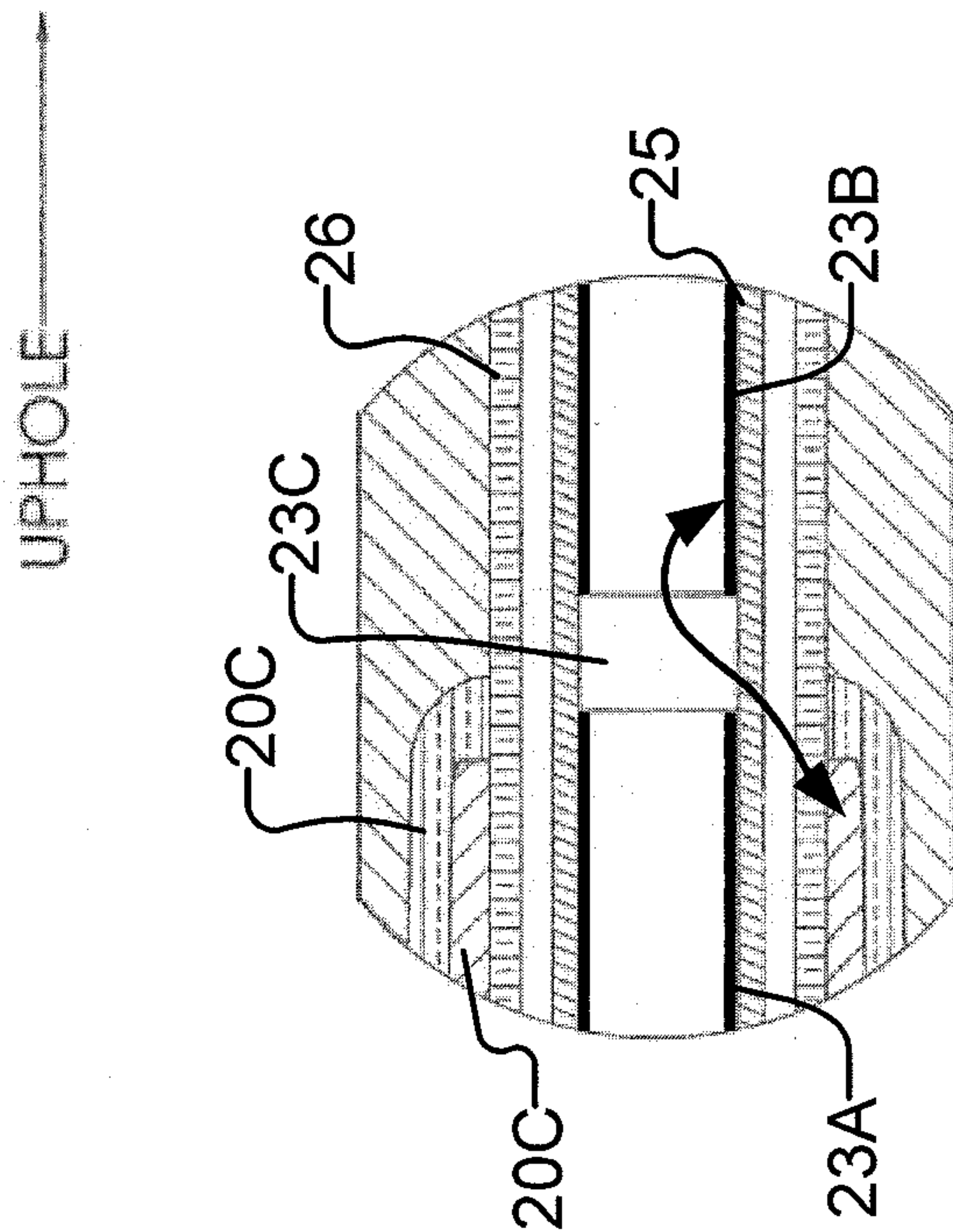


FIG. 3A

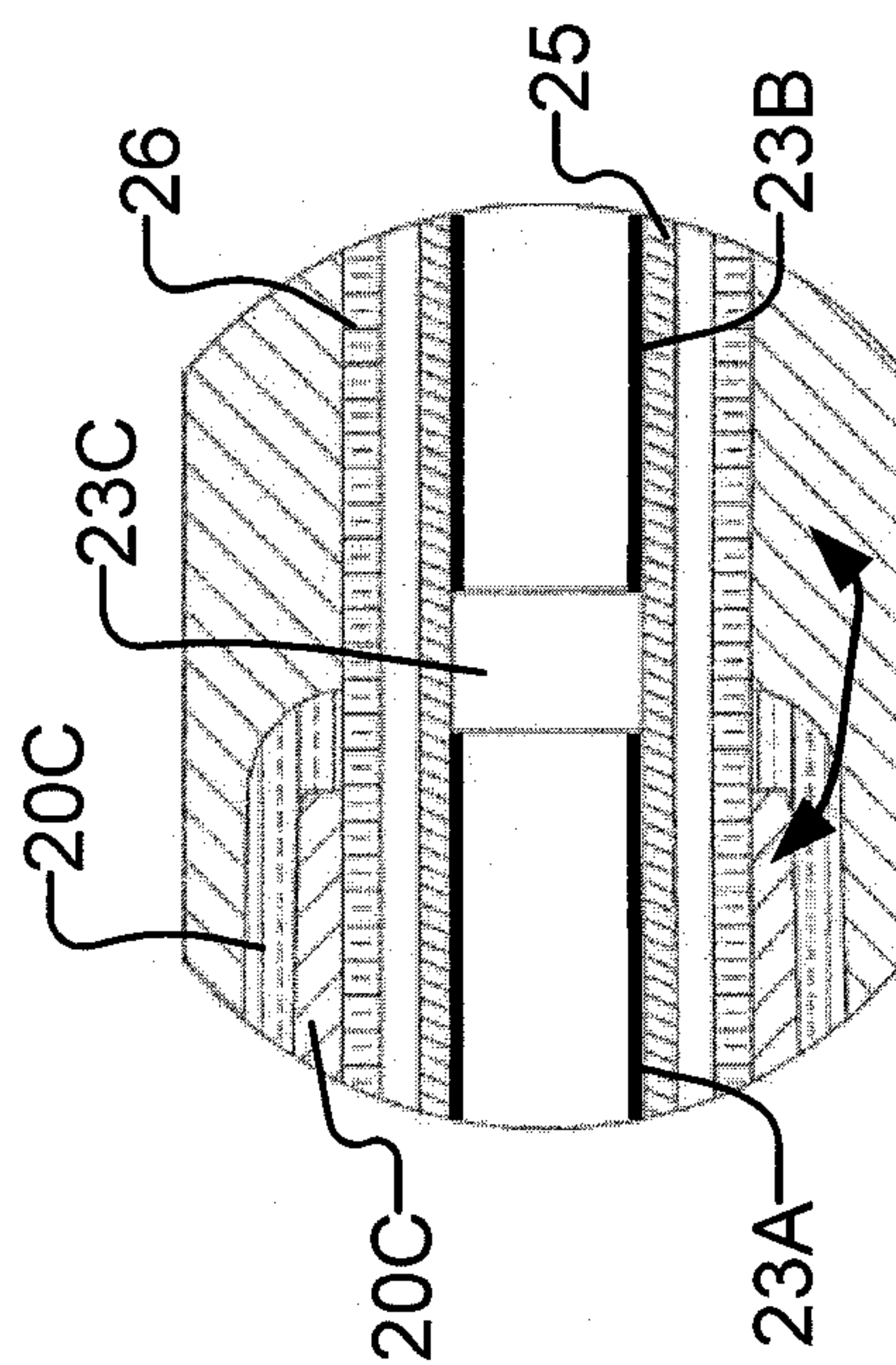


FIG. 3B

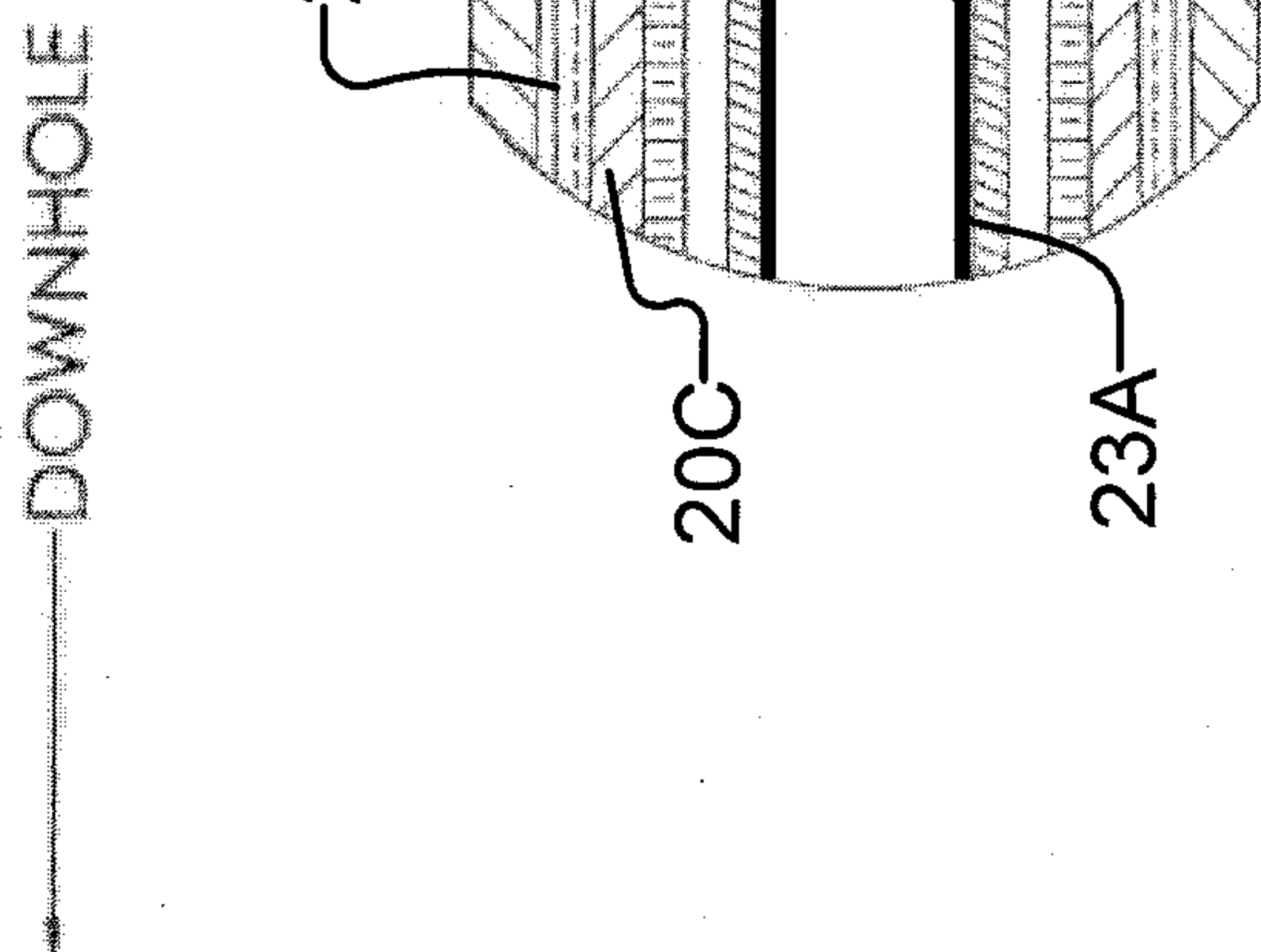


FIG. 3C

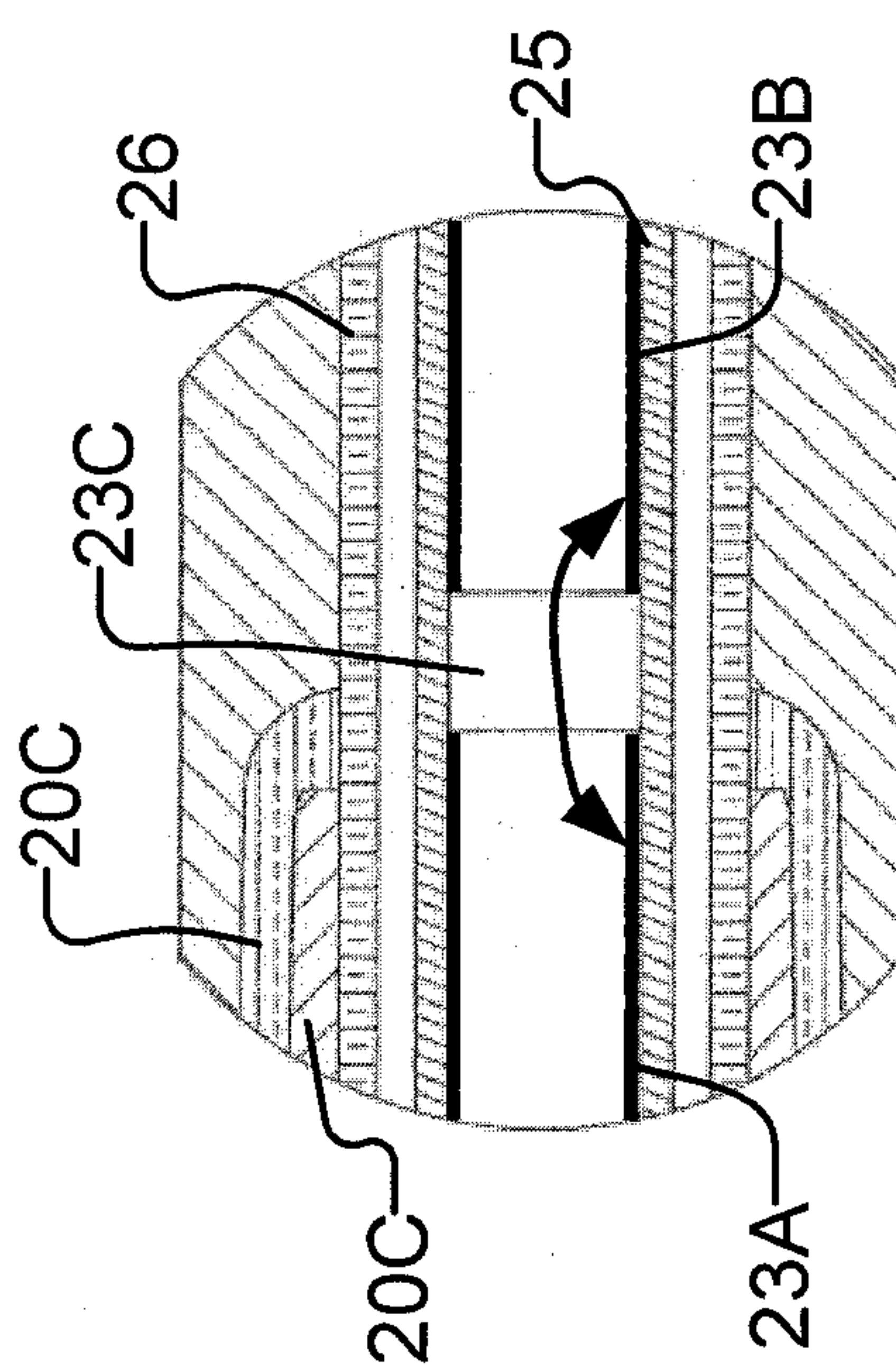


FIG. 3D

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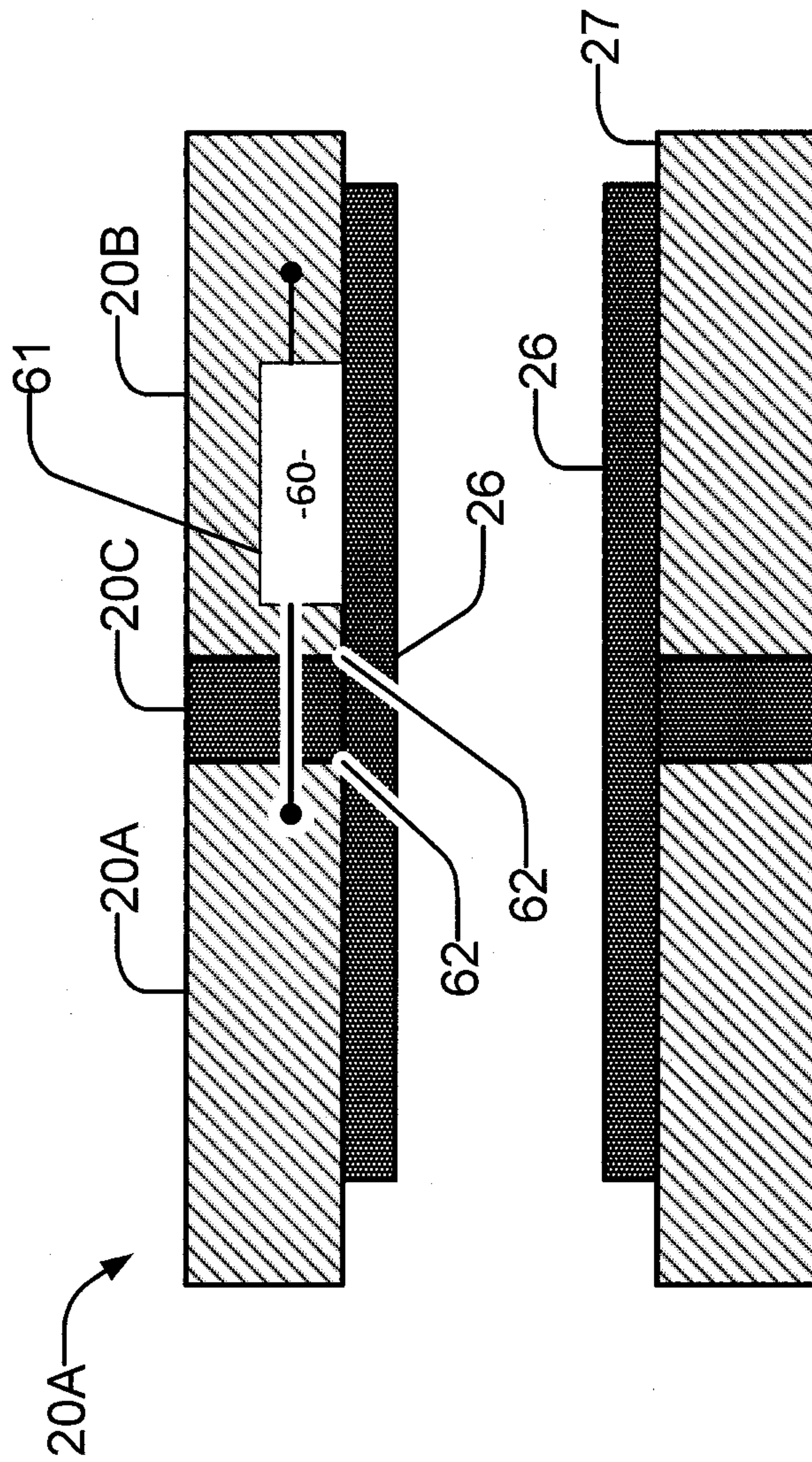


FIG. 6

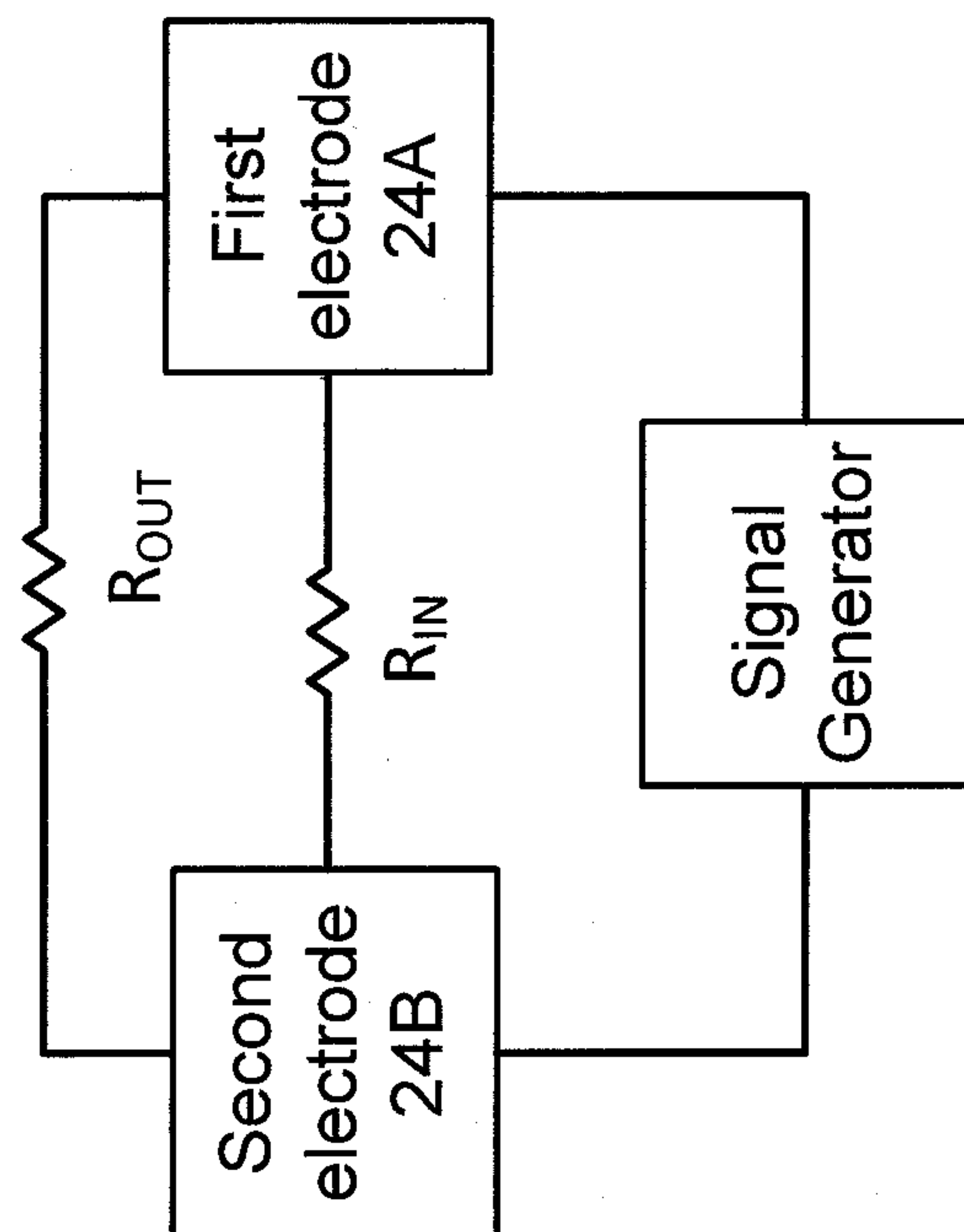


FIG. 4

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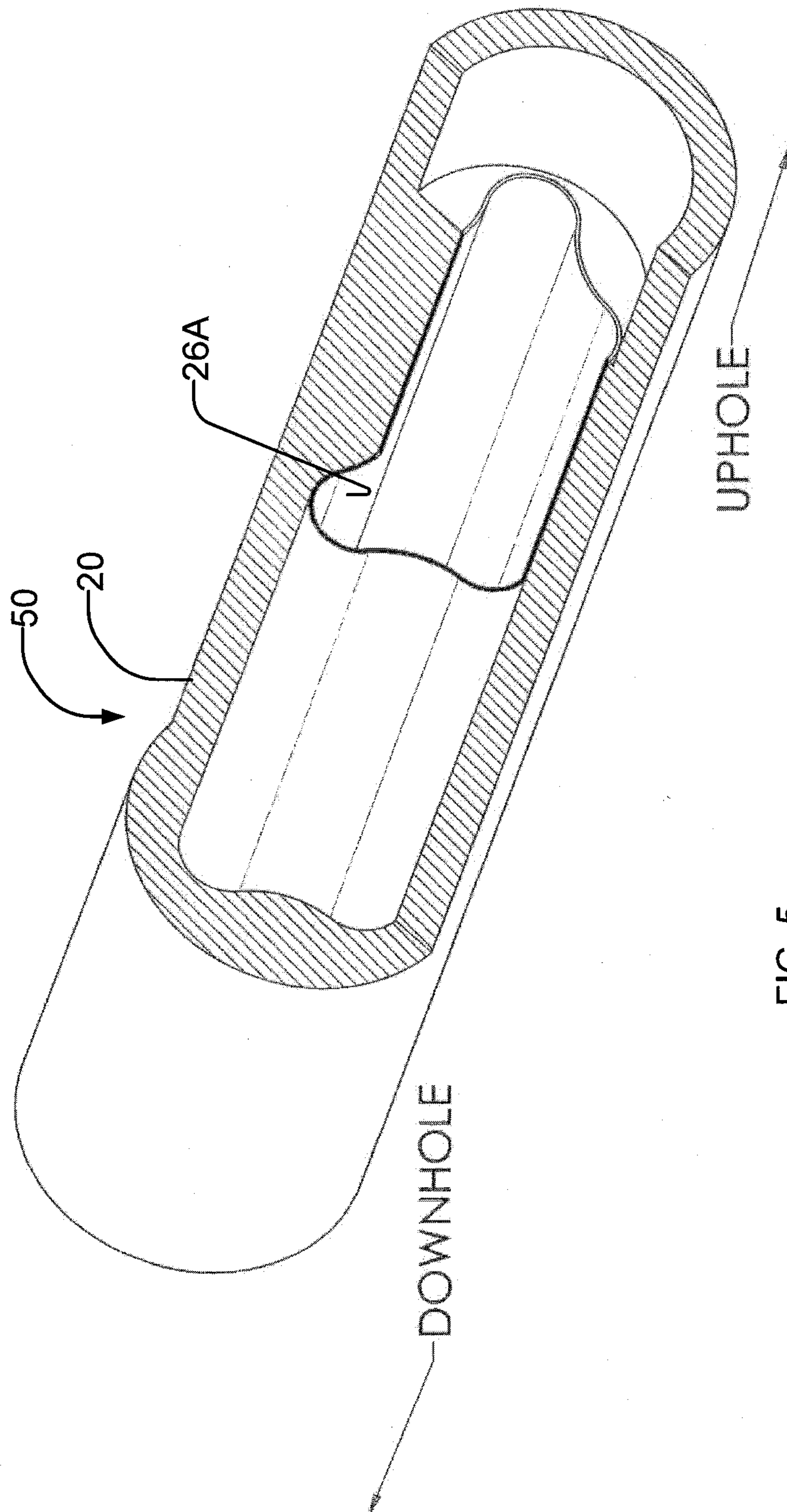


FIG. 5

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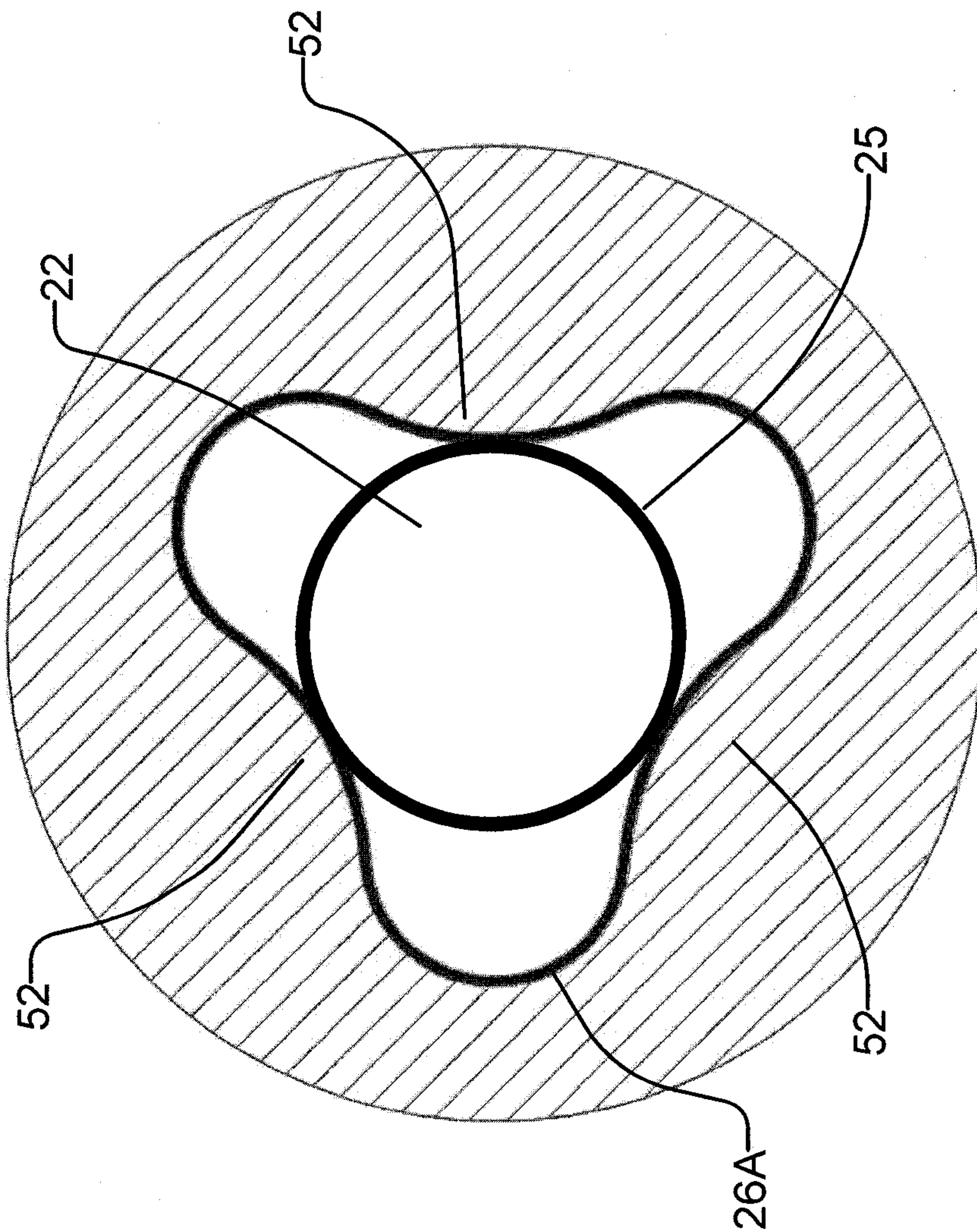


FIG. 5A

20

DOWNHOLE

20B

22

26

20C

20A

UPHOLE

20D

21

24B

23B

23

25

23C

23A

24A

21