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(54) **DOWNHOLE TOOL WITH INTEGRATED CIRCUIT**

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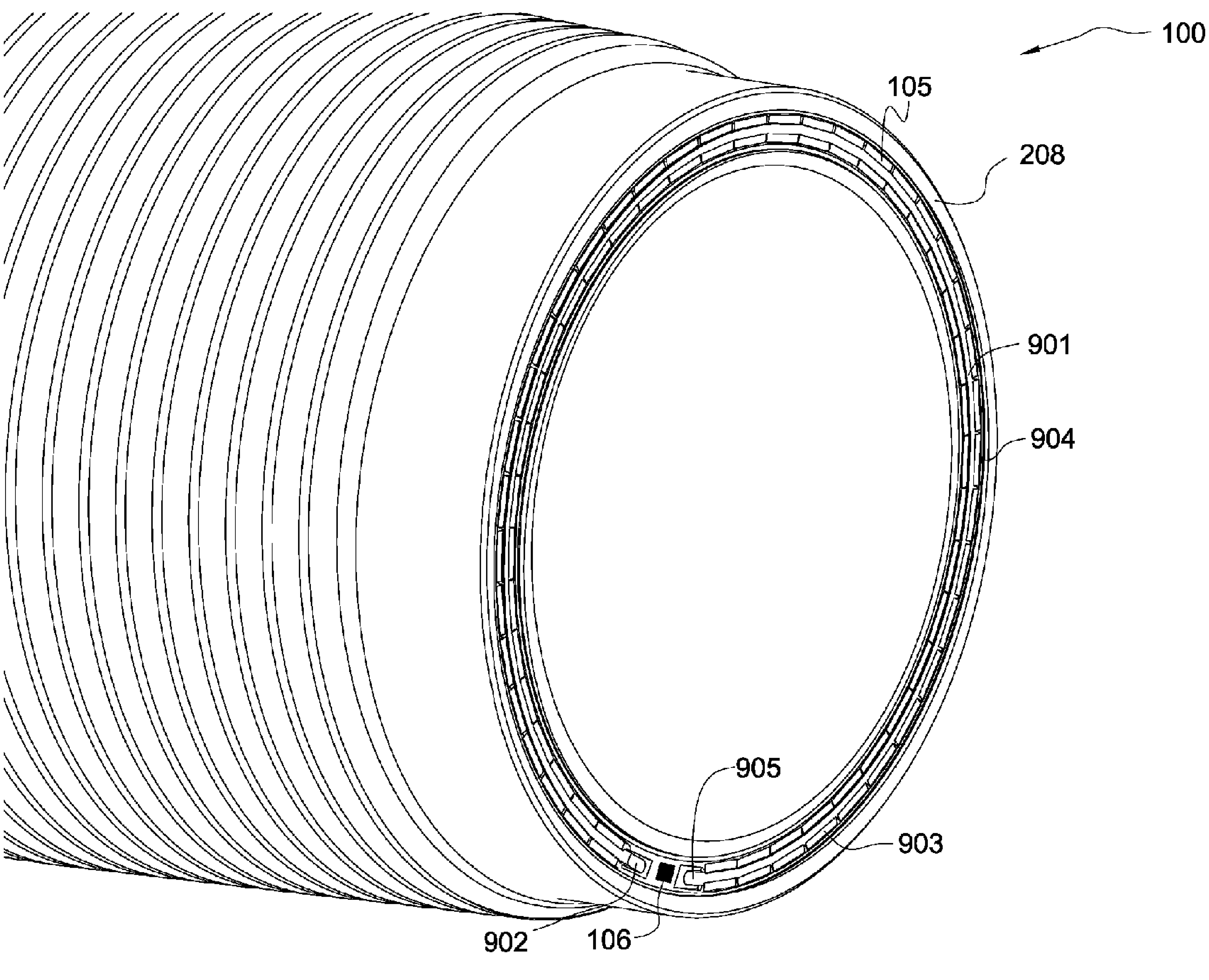
(57) **ABSTRACT**

A downhole tool has a tubular body with an end, an exterior wall, and a bore. A mating surface is formed intermediate the exterior wall and the bore in the end of the tubular body. The mating surface is adapted to couple to a second downhole tool and has an integrated circuit. In several embodiments, the integrated circuit is an RFID circuit in communication with a downhole network through an inductive coupler. A tool identification system has surface equipment with RFID interrogating circuitry connected to a protected integrated RFID circuit in a downhole tool string component through a downhole network. A method for identifying a tool in a downhole tool string includes transmitting signals between surface equipment and identification circuitry in the tool through the downhole network.



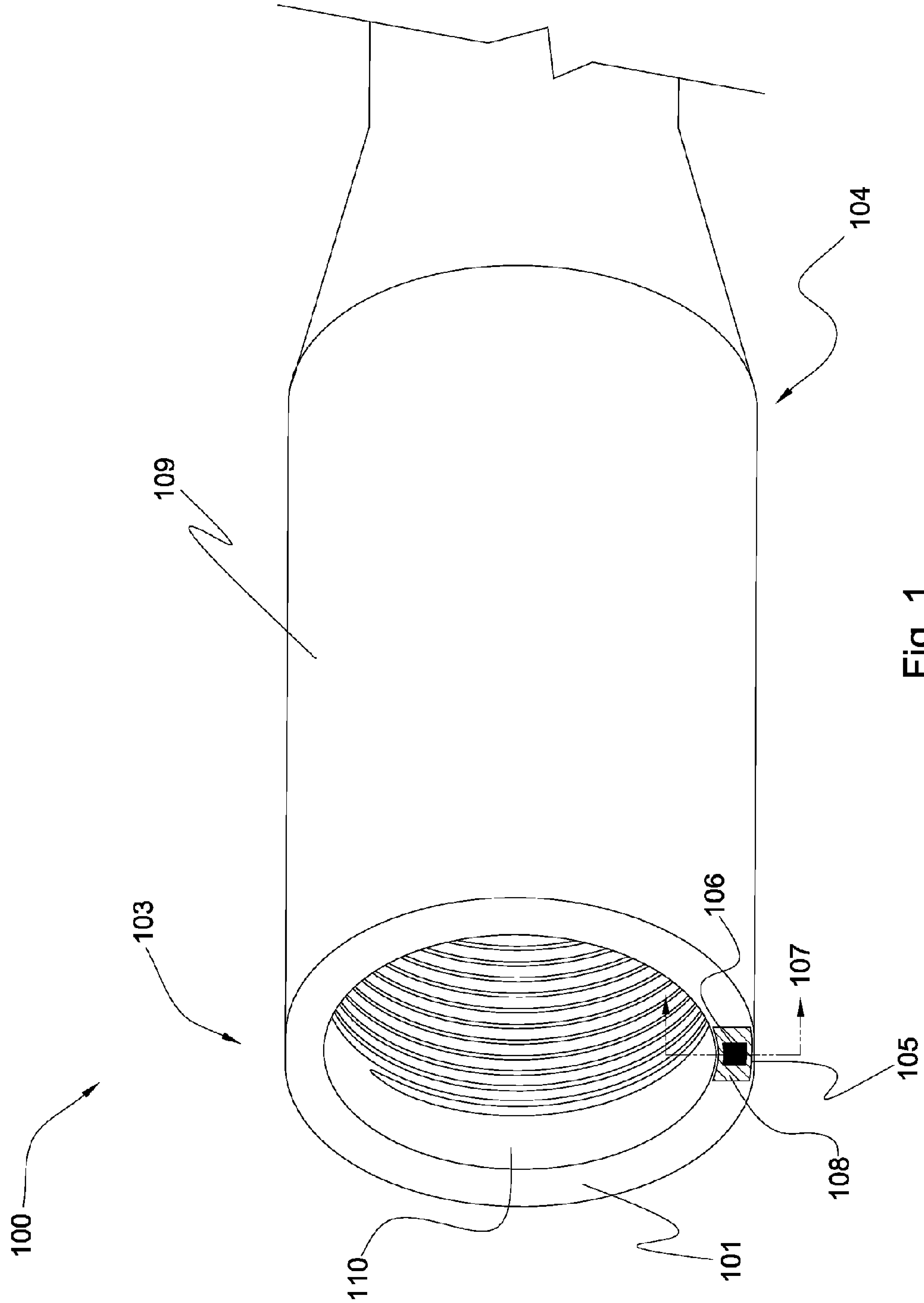


Fig. 1

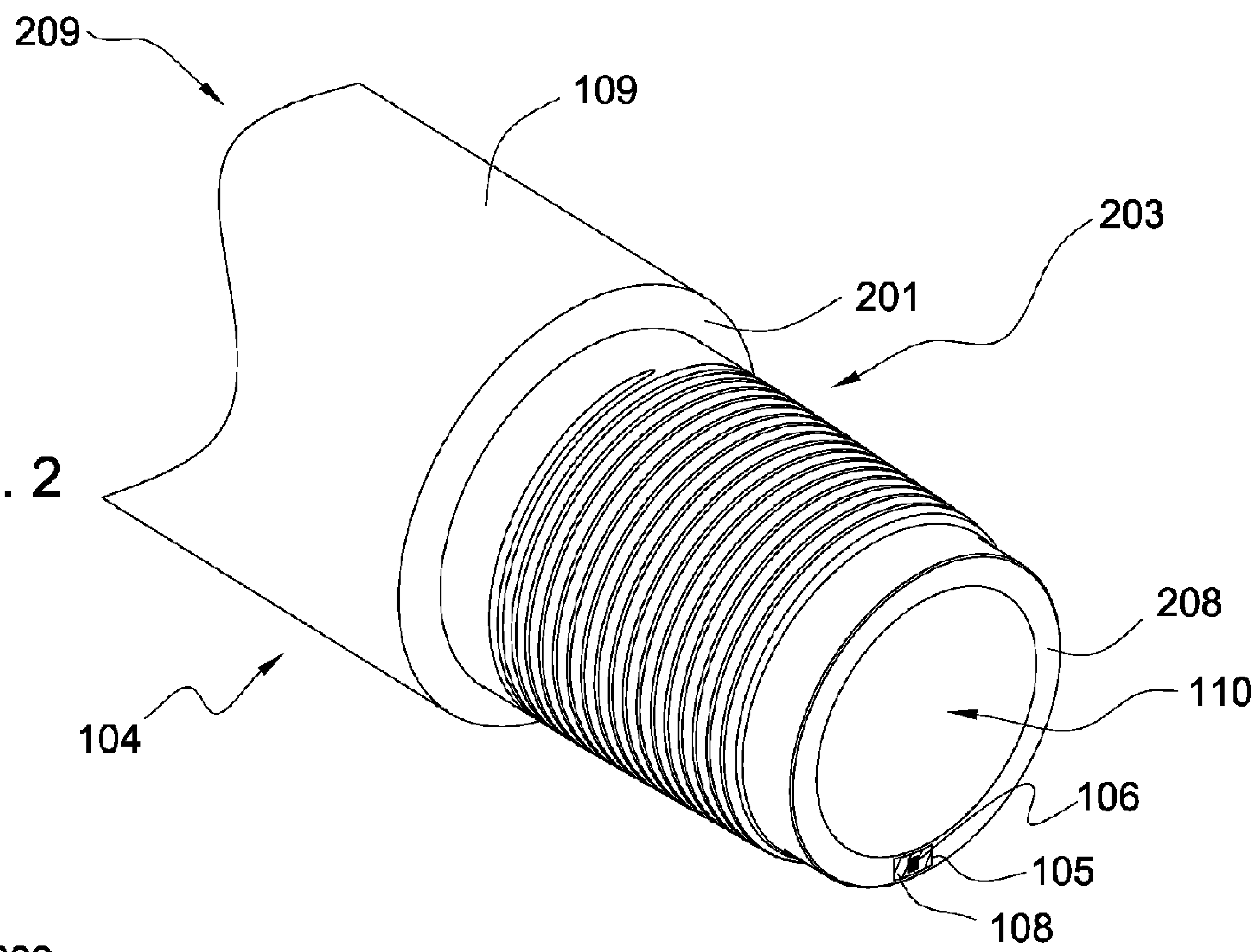
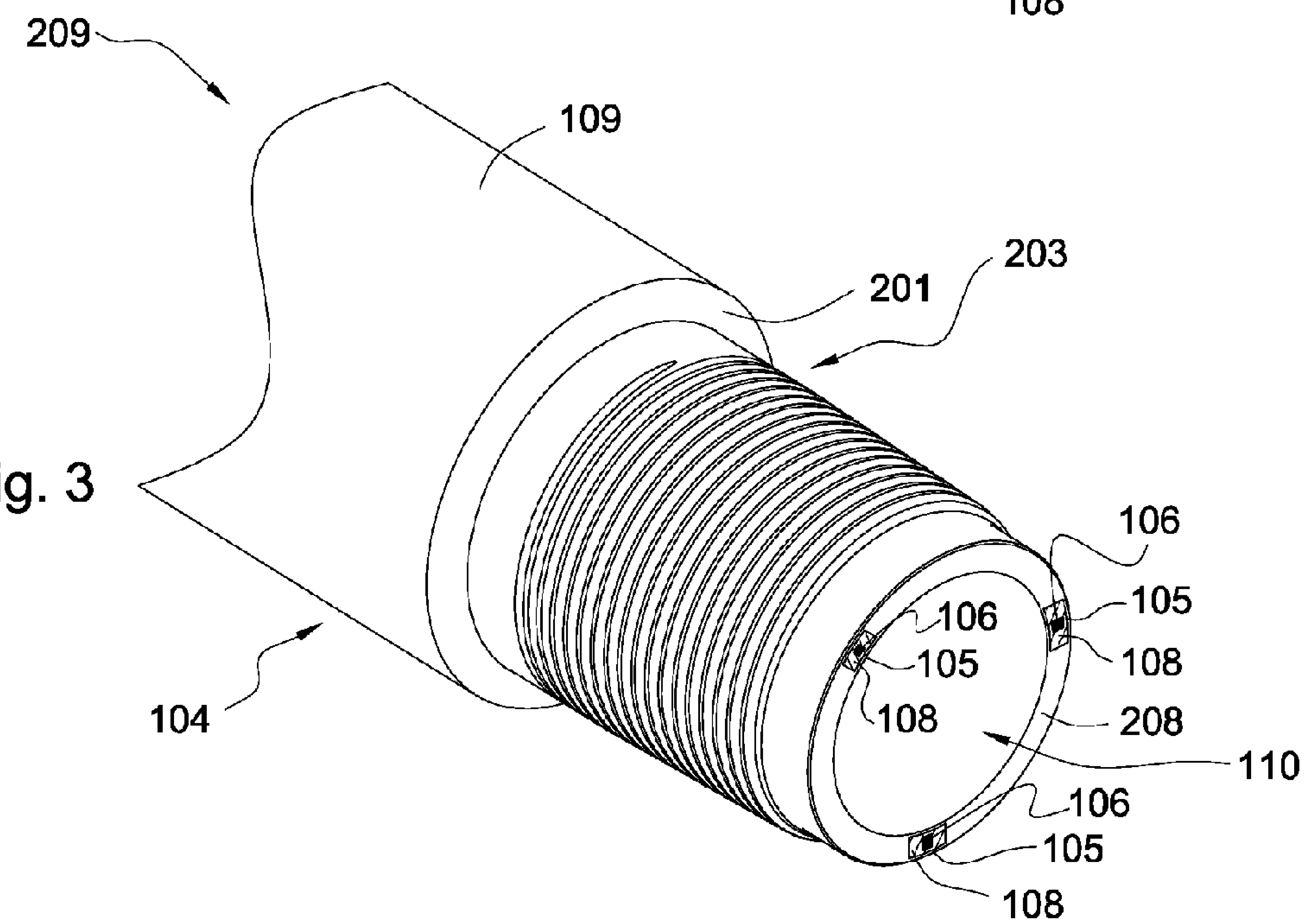

209
109
203
201
208
110
106
105
108
104

Fig. 2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203
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208
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106
105
108
104

Fig. 3

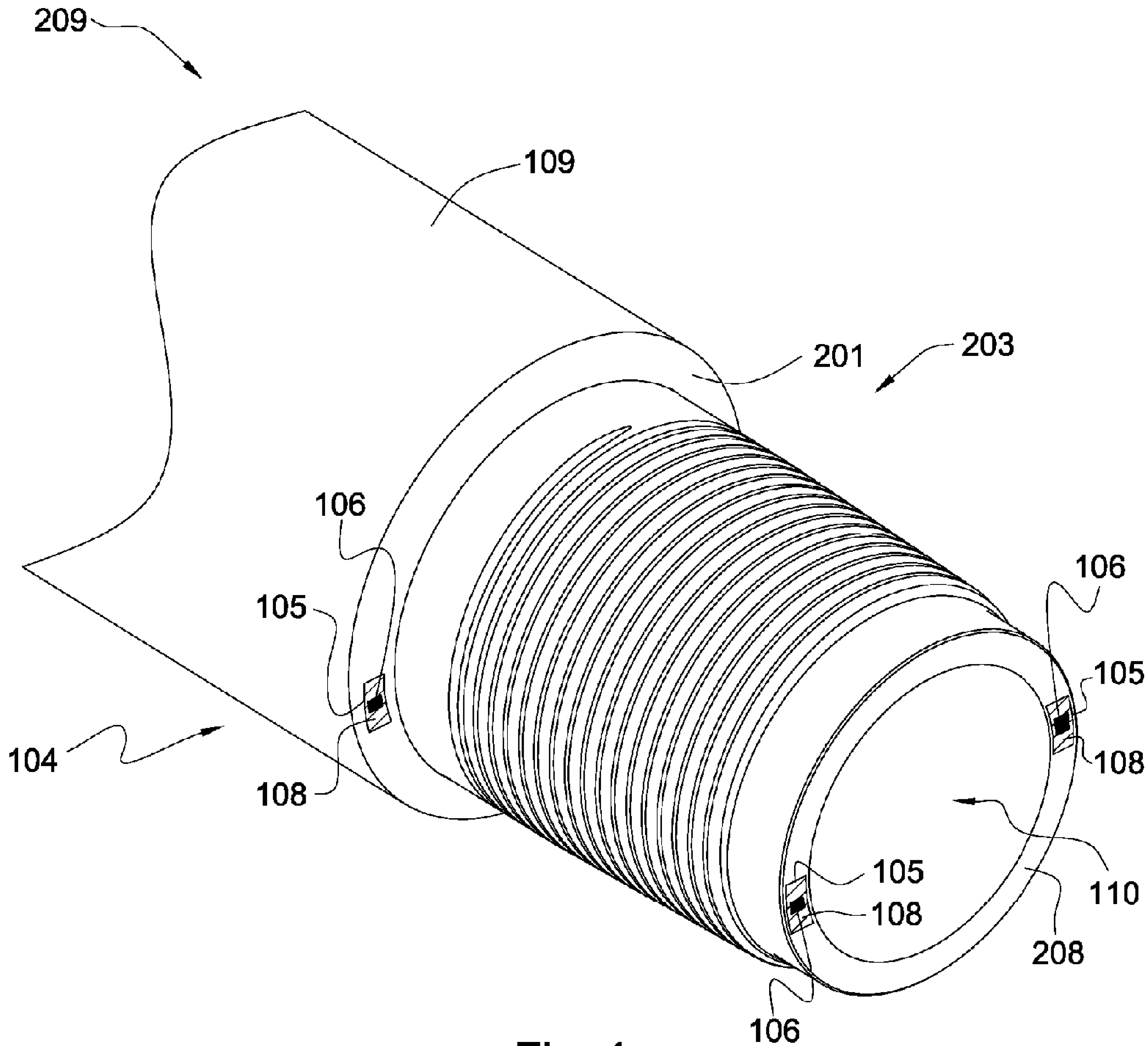

Fig. 4

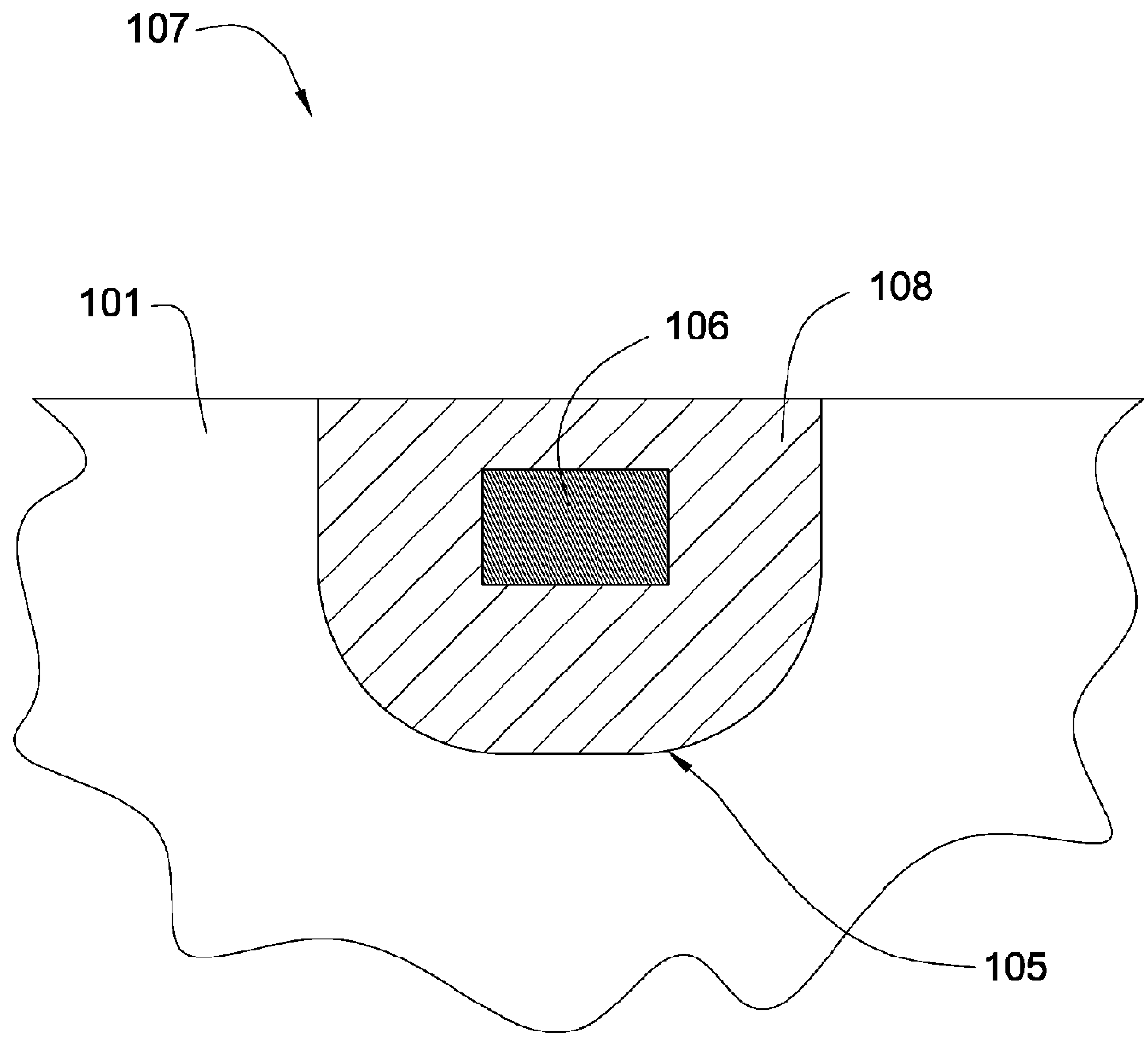

Fig. 5

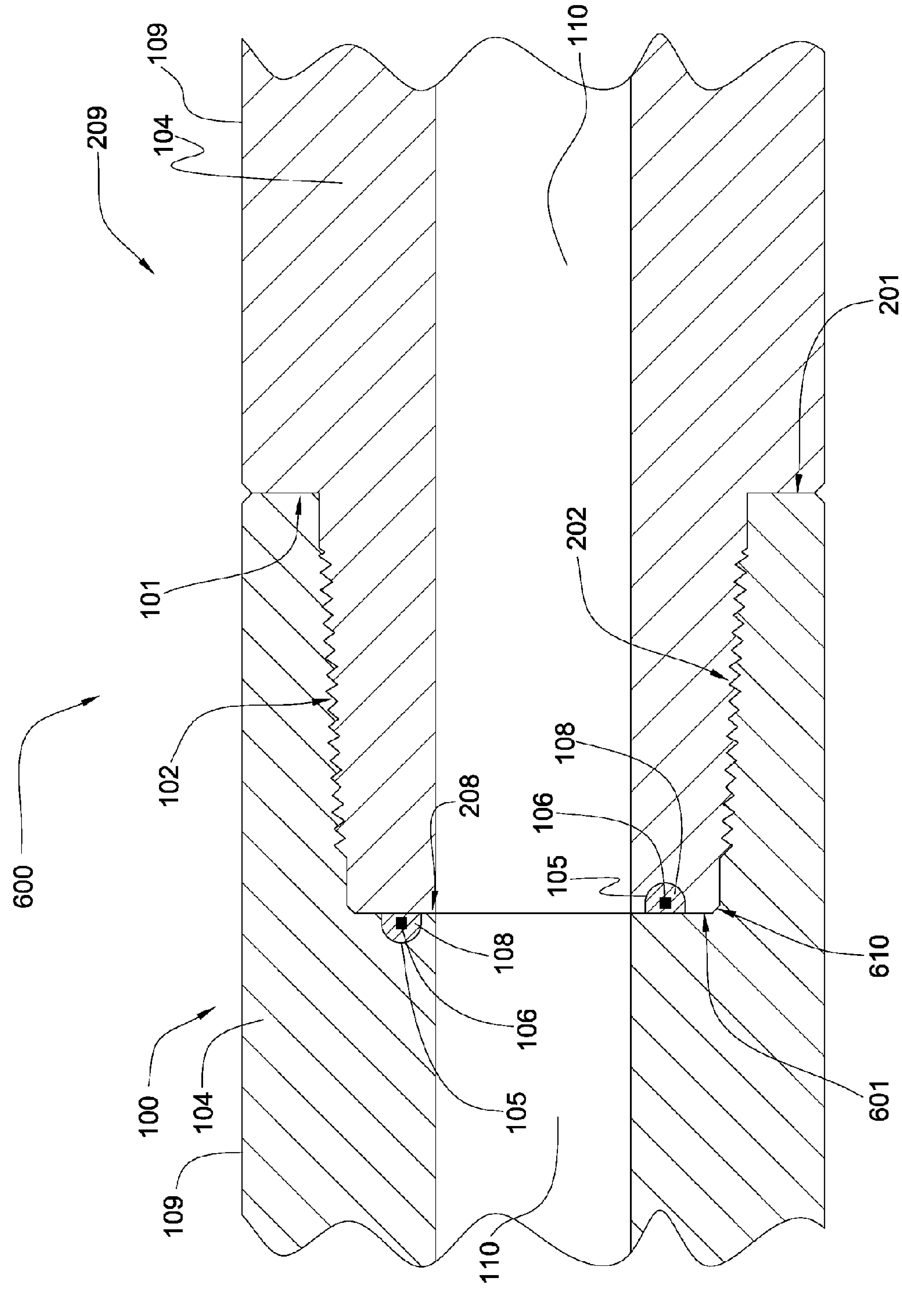
209
109
104
110
201
101
202
600
102
208
108
106
105
610
100
104
108
106
105
601
109
110

Fig. 6

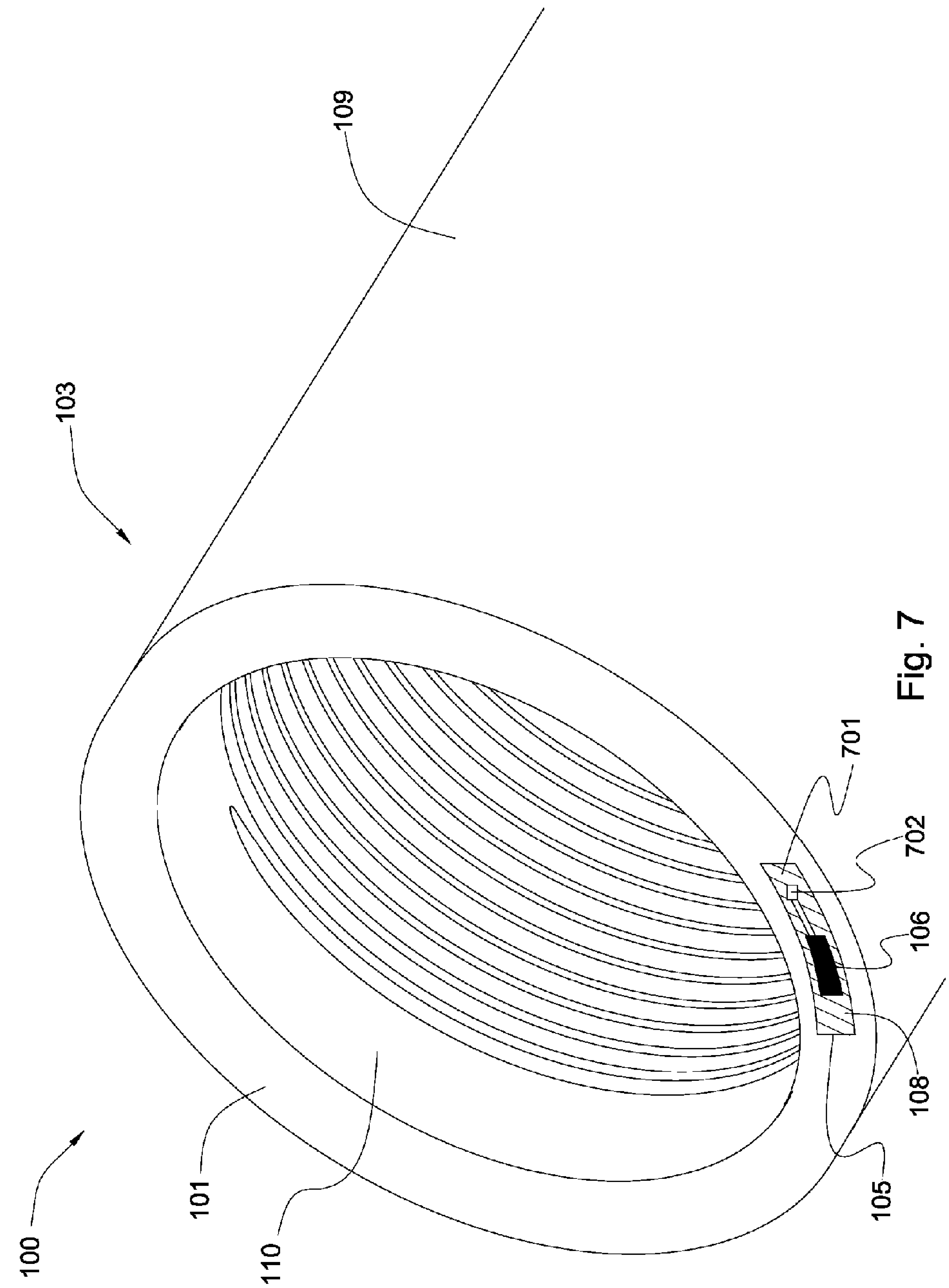

Fig. 7

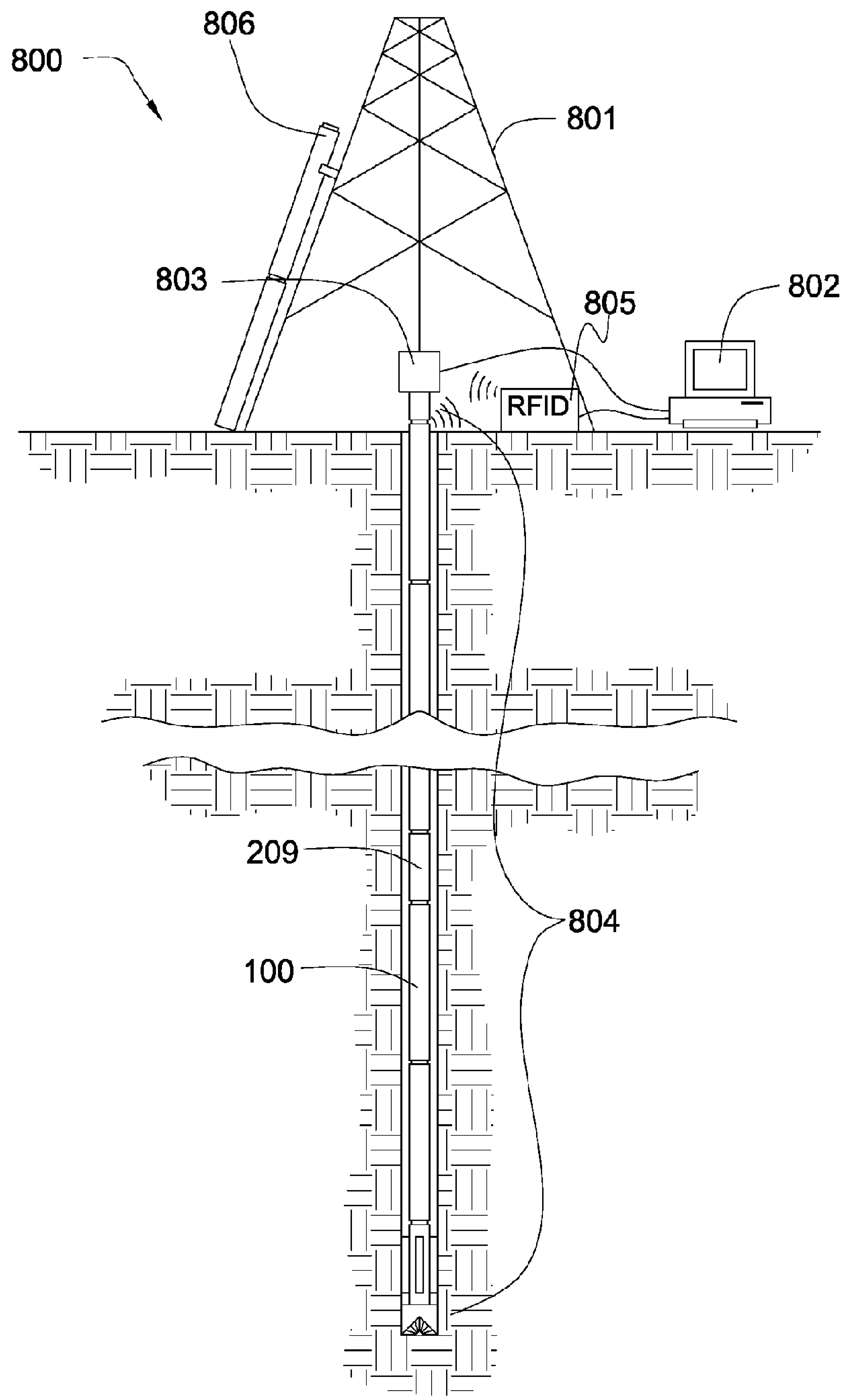

Fig. 8

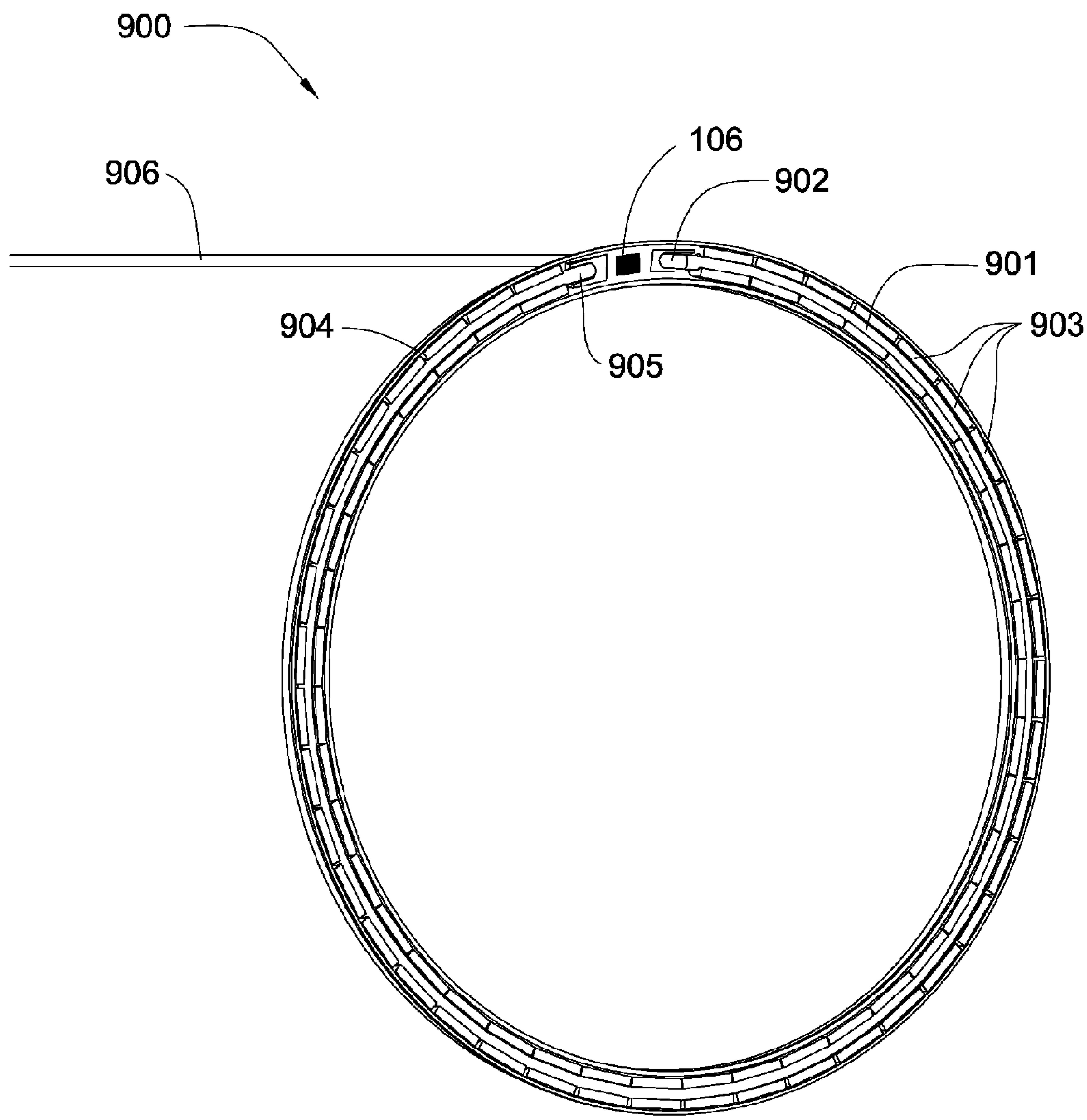

Fig. 9

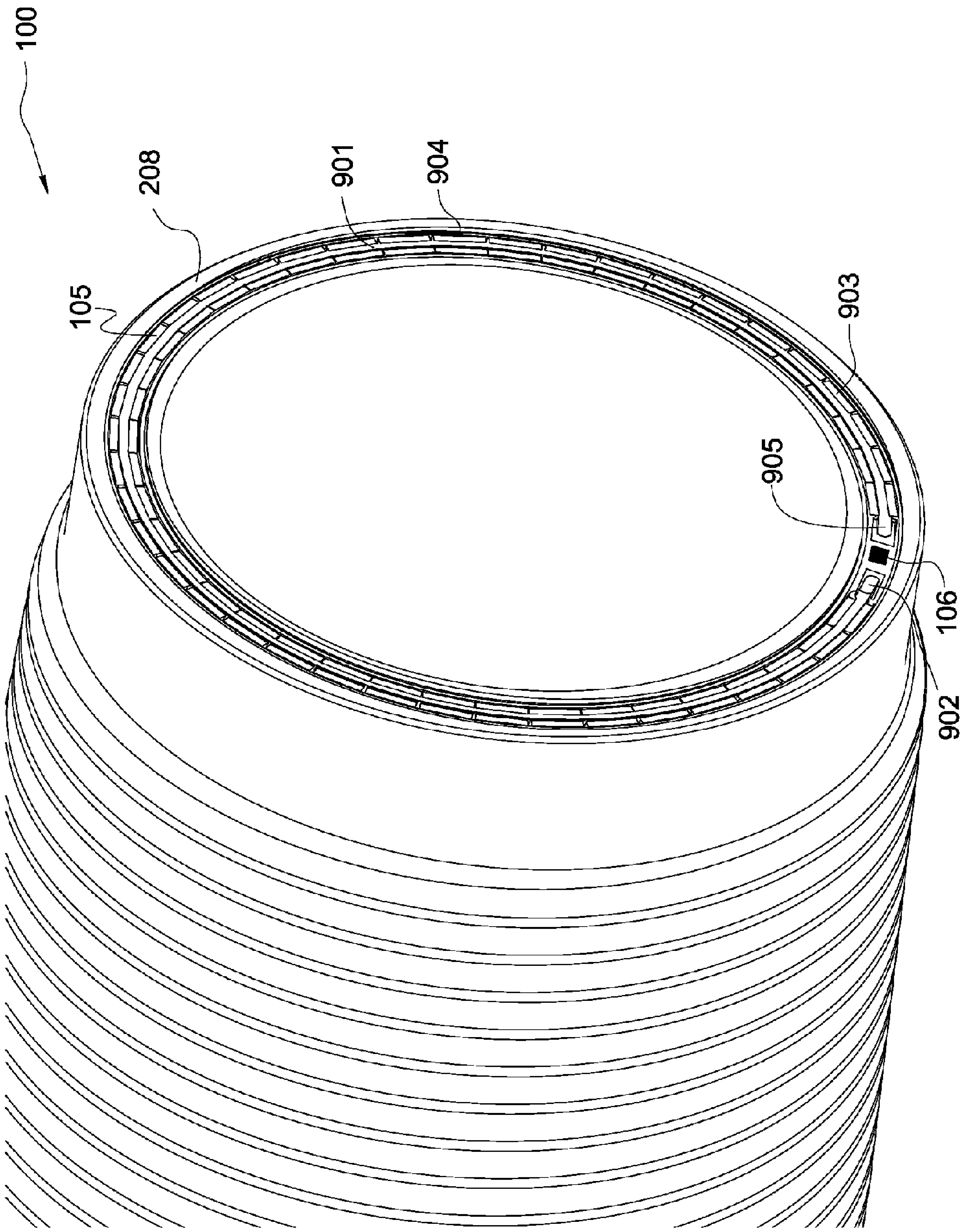

Fig. 10

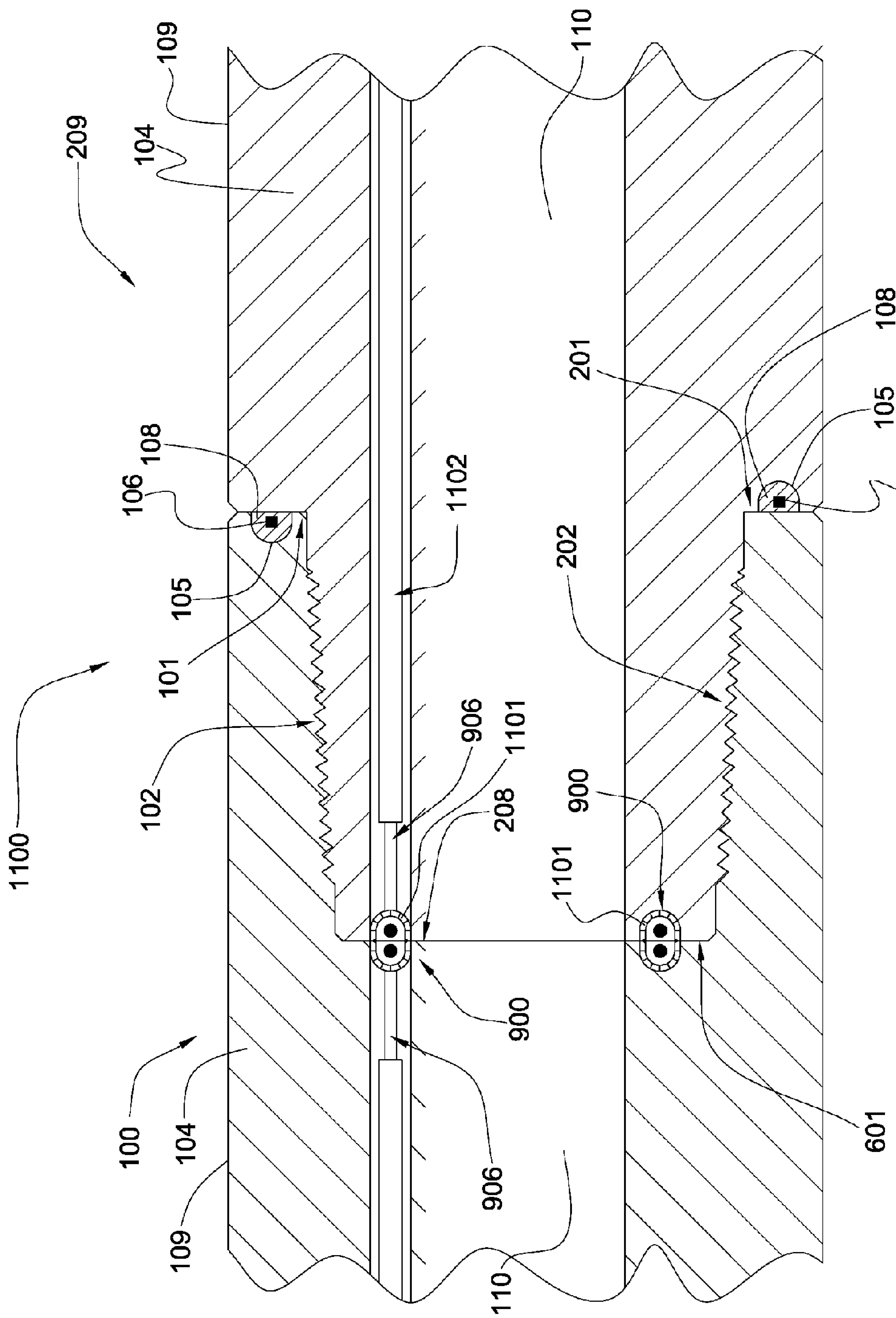
109
110
209
104
201
108
105
106
108
106
1102
105
202
101
1100
102
906
1101
208
900
1101
900
100
104
906
601
109
110

Fig. 11

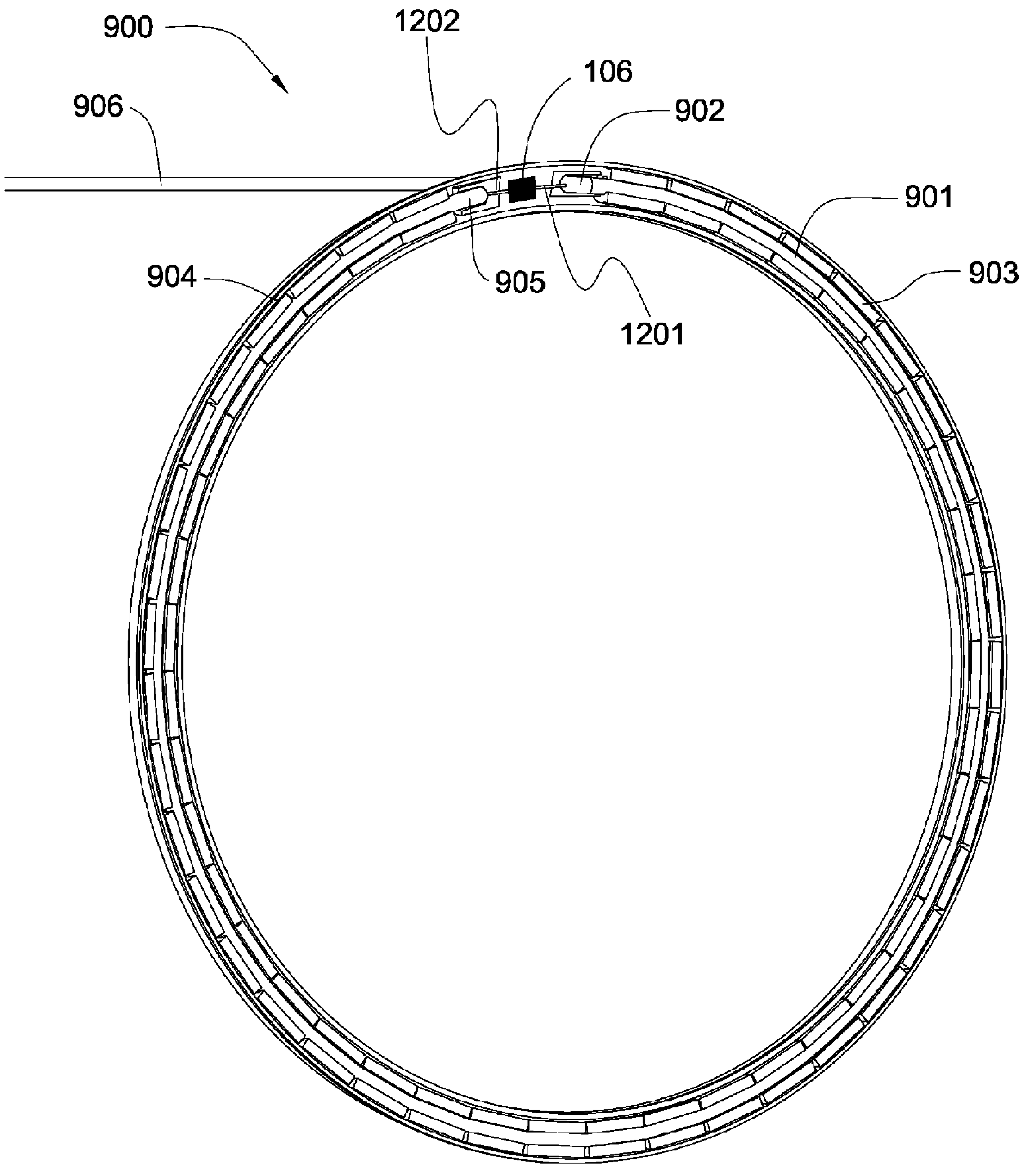

Fig. 12

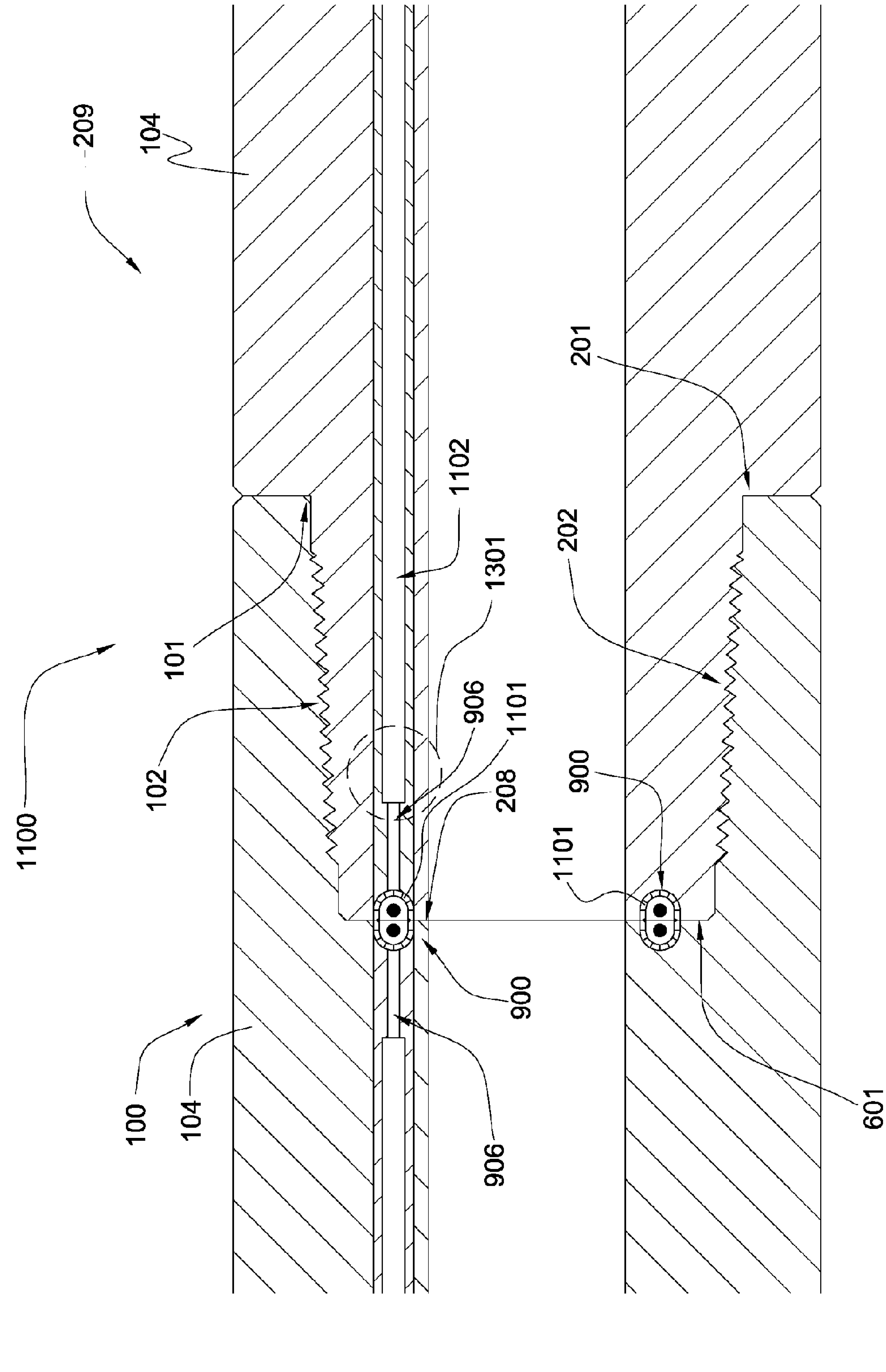
209
104
1100
101
102
1102
1301
906
1101
208
201
202
900
1101
100
104
900
906
601

Fig. 13

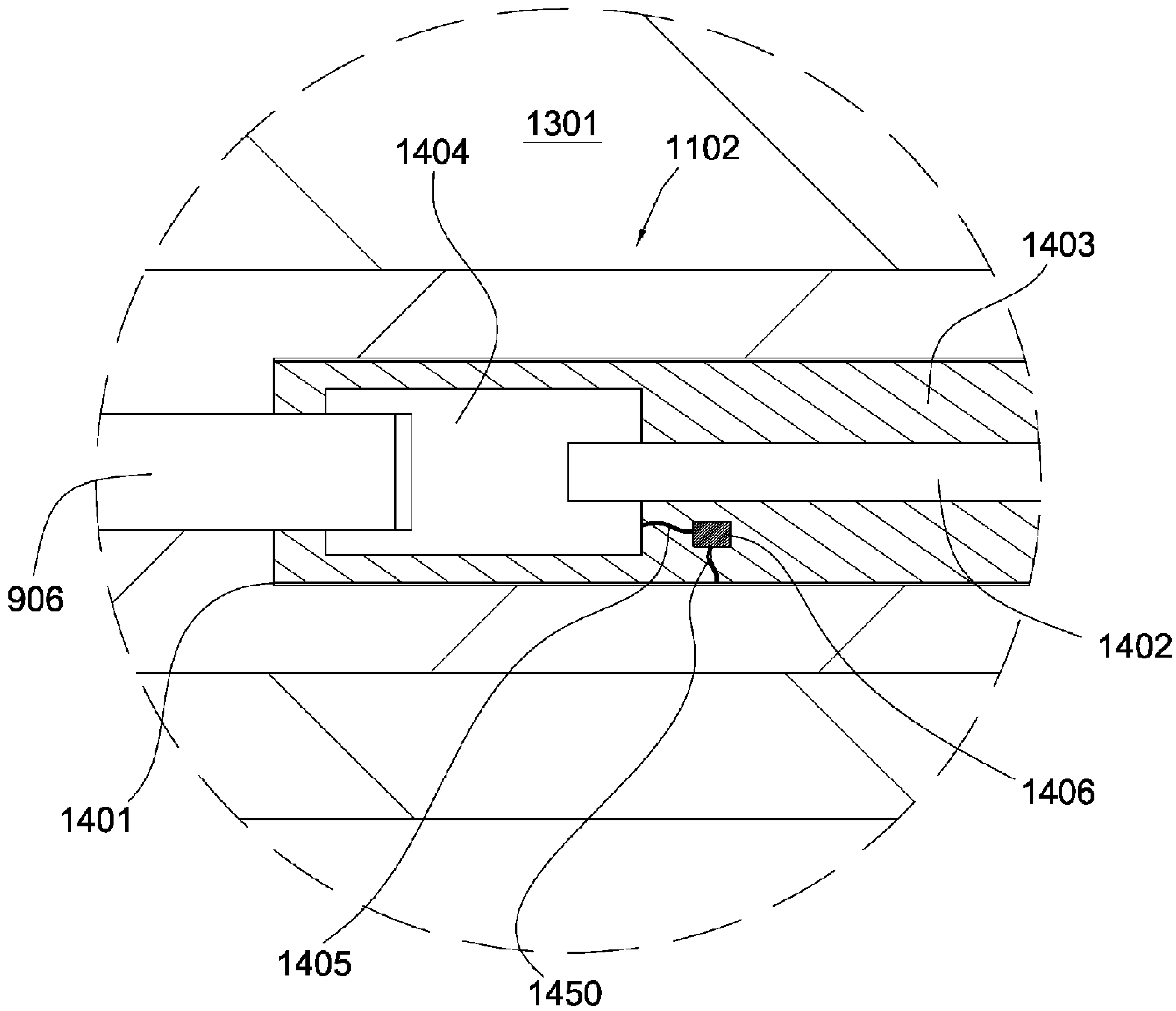

Fig. 14

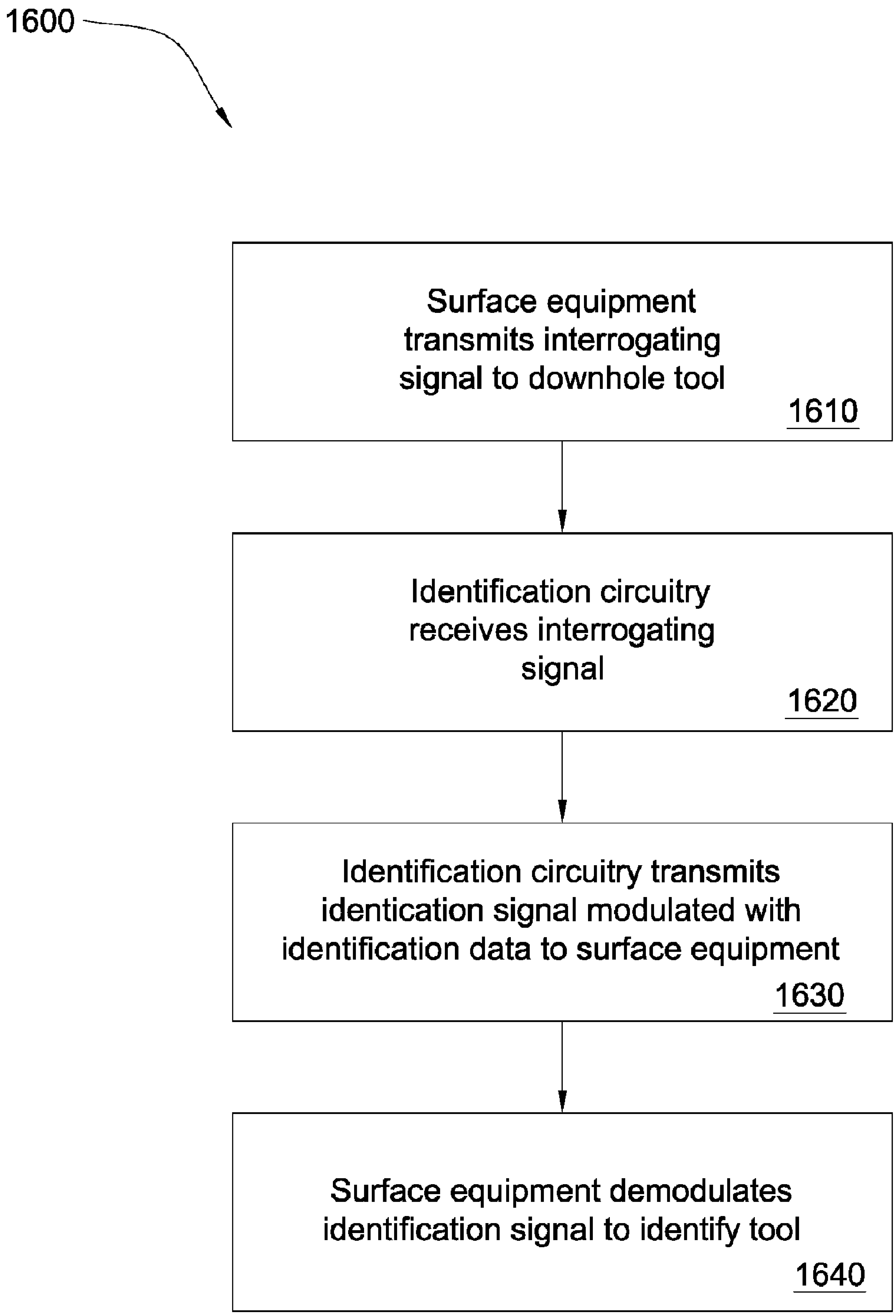
1600
Surface equipment transmits interrogating signal to downhole tool
1610
Identification circuitry receives interrogating signal
1620
Identification circuitry transmits identication signal modulated with identification data to surface equipment
1630
Surface equipment demodulates identification signal to identify tool
1640

Fig. 15

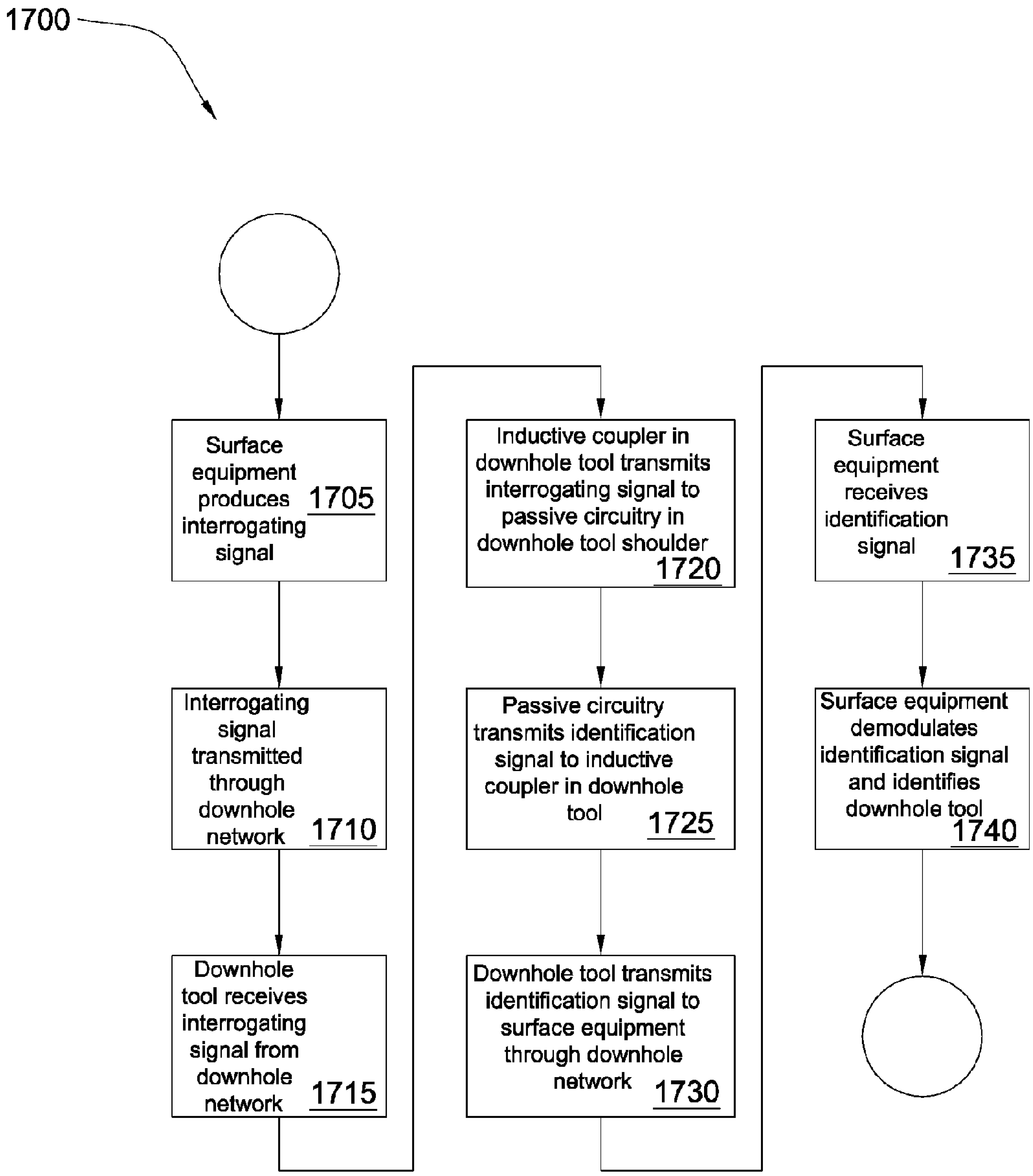
1700
Surface equipment produces interrogating signal 1705
Interrogating signal transmitted through downhole network 1710
Downhole tool receives interrogating signal from downhole network 1715
Inductive coupler in downhole tool transmits interrogating signal to passive circuitry in downhole tool shoulder 1720
Passive circuitry transmits identification signal to inductive coupler in downhole tool 1725
Downhole tool transmits identification signal to surface equipment through downhole network 1730
Surface equipment receives identification signal 1735
Surface equipment demodulates identification signal and identifies downhole tool 1740

Fig. 16

DOWNHOLE TOOL WITH INTEGRATED CIRCUIT

BACKGROUND OF THE INVENTION

[0001] The present invention relates to the field of downhole drilling. More specifically, it relates to downhole tools in a tool string with protected integrated circuits.

[0002] Due to high costs associated with drilling for hydrocarbons and extracting them from underground formations, efficiency in drilling operations is desirable to keep overall expenses down. Electronic equipment may be useful in drilling operations to accomplish many tasks, such as providing identification information about specific downhole components to surface equipment, performing downhole measurements, collecting downhole data, actuating tools, and other tasks.

[0003] Notwithstanding its utility in the drilling process, downhole has proven to be a rather hostile environment for electronic equipment. Temperatures downhole may reach excesses of 200° C. Shock and vibration along a tool string may knock circuitry out of place or damage it. A drilling mud with a high pH is often circulated through a tool string and returned to the surface. The drilling mud and other downhole fluids may also have a detrimental effect on electronic equipment downhole exposed to it.

[0004] In the art, a first group of attempts to protect downhole electronics comprises an apparatus with electronic circuitry in a sonde that is lowered into a borehole by a cable periodically throughout the drilling process. The sonde provides protection from downhole conditions to the electronic circuitry placed inside. Examples of this type of protection (among others) may be found in U.S. Pat. No. 3,973,131 to Malone, et al. and U.S. Pat. No. 2,991,364 to Goodman, which are herein incorporated by reference.

[0005] A second group comprises adapting downhole tools to accommodate and protect the electronic circuitry. In this manner the electronic circuitry may remain downhole during drilling operations. For example, U.S. Pat. No. 6,759, 968 discloses the placement of an RFID device in an O-ring that fills a gap in a joint of two ends of pipe or well-casing. U.S. Pat. No. 4,884,071 to Howard discloses a downhole tool with Hall Effect coupling circuitry located between an outer sleeve and an inner sleeve that form a sealed cavity.

BRIEF SUMMARY OF THE INVENTION

[0006] A downhole tool comprises a tubular body having threaded ends, an exterior wall, and a bore. At least one of the ends typically comprises a mating surface formed intermediate the exterior wall and the bore. The mating surface may be a primary mating surface or a secondary mating surface, and is adapted to receive a radio frequency identification (RFID) or other integrated circuit. The mating surface may have a groove, or other recess formed upon it, and the integrated circuit may be disposed within the recess. The downhole tool may comprise several integrated circuits disposed within the mating surface. In such a case, the mating surface may comprise a plurality of recesses with integrated circuits disposed within them, or a plurality of integrated circuits may be disposed within a single recess. The end may also comprise a plurality of shoulders having grooves and a plurality of integrated circuits disposed within the recesses.

[0007] The integrated circuit may be encapsulated in a protective material that substantially conforms to the dimensions of the recess and secures the integrated circuit in addition to protecting it from potentially damaging downhole conditions. The integrated circuit may be a passive circuit or an active circuit. For active circuits, a power source may also be disposed within the recess and deliver electrical power to the integrated circuit. In embodiments where the integrated circuit comprises RFID circuitry, the circuitry may be configured to store and transmit an identification signal.

[0008] The downhole tool may also have an inductive coupler disposed within the recess. The inductive coupler may be in electromagnetic communication with both a downhole network and the integrated circuit, allowing the integrated circuit to communicate with devices in the downhole network. An RFID integrated circuit in electromagnetic communication with the inductive coupler may therefore be in communication with surface equipment through the downhole network. The RFID circuit may comprise a direct electrical connection to the inductive coupler, especially when the inductive coupler acts as an external antenna for the RFID circuit. The inductive coupler may comprise an electrically conducting coil lying in a magnetically conductive, electrically insulating trough.

[0009] A tool identification system comprises surface equipment with RFID interrogating circuitry and a downhole tool with an integrated RFID circuit. The RFID interrogating circuitry and the integrated RFID circuit in the downhole tool string component are in electromagnetic communication with each other through a downhole network.

[0010] A method for identifying a downhole tool in a downhole tool string comprises the steps of transmitting an interrogating signal from surface equipment to the downhole tool and receiving the interrogating signal in RFID or other identification circuitry disposed within a mating surface of the downhole tool. The interrogating signal may be transmitted to the downhole tool through a downhole network integrated into the tool string.

[0011] The method further comprises the steps of transmitting an identification signal modulated with identification data from the identification circuitry to the surface equipment through the downhole network and demodulating the identification data from the identification signal to identify the downhole tool. The identification data may be a serial number comparable to information in a database, and the interrogation signal may be transmitted at about 13.56 MHz.

[0012] It should be understood that for the purposes of this specification the term "integrated circuit" refers to a plurality of electronic components and their connections produced in or on a small piece of material. Examples of integrated circuits include (but are not limited to) circuits produced on semiconductor substrates, printed circuit boards, circuits produced on paper or paper-like substrates, and the like.

[0013] It should also be understood that for the purposes of this specification the term "protected" refers to a state of being substantially secure from and able to function in spite of potential adverse operating conditions.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. **1** is a perspective view of a box end of a downhole tool with an integrated circuit in a primary mating surface

[0015] FIG. **2** is a perspective view of a pin end of a downhole tool with an integrated circuit in a secondary mating surface.

[0016] FIG. **3** is a perspective view of a pin end of a downhole tool with a plurality of integrated circuits in a secondary mating surface.

[0017] FIG. **4** is a perspective view of a pin end of a downhole tool with integrated circuits in both a primary and a secondary mating surface.

[0018] FIG. **5** is a cross-sectional view along line **107** of FIG. **1**.

[0019] FIG. **6** is a cross-sectional view of a tool joint.

[0020] FIG. **7** is a perspective view of a box end of a downhole tool with an integrated circuit and a power supply in a primary mating surface.

[0021] FIG. **8** depicts one embodiment of a downhole network.

[0022] FIG. **9** is a perspective view of an inductive coupler and an integrated circuit consistent with the present invention.

[0023] FIG. **10** is a perspective view of a pin end of a downhole tool with the inductive coupler and integrated circuit of FIG. **9** disposed within a groove.

[0024] FIG. **11** is a cross-sectional view of a tool joint with inductive couplers in the secondary mating surfaces of the downhole tools and integrated circuits in the primary mating surfaces of the downhole tools.

[0025] FIG. **12** is a perspective view of another embodiment of an inductive coupler and an integrated circuit consistent with the present invention.

[0026] FIG. **13** is a cross-sectional view of tool joint with inductive couplers in the secondary mating surfaces of the downhole tools.

[0027] FIG. **14** is a detailed view of FIG. **13**.

[0028] FIG. **15** is a flowchart illustrating a method for identifying a tool in a downhole tool string.

[0029] FIG. **16** is a flowchart illustrating a more detailed method for identifying a tool in a downhole tool string.

DETAILED DESCRIPTION OF THE INVENTION AND THE PREFERRED EMBODIMENT

[0030] Referring to FIG. **1**, a portion of a downhole tool **100** according to the present invention is shown. The downhole tool **100** comprises a tubular body **104** that may allow the passage of drilling fluids under pressure through the downhole tool **100**. The tubular body **100** has a threaded box end **103**, an exterior wall **109** and a bore **110**. The box end **103** may be designed to couple to a pin end **203** of another downhole tool **209** (see FIG. **6**). The threaded box end **103** may be adapted to create a secure joint between two downhole tools **100**, **209** (see FIG. **2**).

[0031] The box end **103** of the downhole tool **100** comprises a primary mating surface **101**, which in the shown embodiment is a primary shoulder. The primary mating surface **101** is intermediate the exterior wall **109** and the bore **110**. The primary mating surface **101** is adapted to couple to a primary mating surface **208** in a second downhole tool **209** (see FIG. **6**). The primary mating surface **101** comprises a recess **105** in which an integrated circuit **106** is disposed. In the embodiment shown, the recess **105** is somewhat rectangular with dimensions proportionate to the physical dimensions of the integrated circuit **106**. In other embodiments, the recess **105** may be an annular groove or have a shape disproportionate to the dimensions of the integrated circuit **106**.

[0032] The integrated circuit **106** may be a radio frequency identification (RFID) circuit. Preferably, the integrated circuit **106** is a passive device powered by a received electromagnetic signal. In other words, an interrogation signal received by the integrated circuit **106** may provide the energy necessary to power the circuit **106**. This particular characteristic may be desirable as it may eliminate the need of providing and periodically replacing a power supply for each integrated circuit.

[0033] An integrated circuit **106** comprising RFID circuitry may be desirable for various applications—for instance, the circuitry may store identification information such as a serial number that it may provide to an RFID query device (e.g. a hand-held wand, a fixed RFID interrogator, etc.) upon receiving an interrogating signal.

[0034] The integrated circuit **106** may be encapsulated in a protective material **108**. The protective material **108** may conform to the dimensions of the recess **105**. The protective material **108** may be a permanent potting material such as a hard epoxy material. In other embodiments, the protective material **108** may be a less permanent potting material such as rubber, foam, and the like. The protective material **108** may guard the integrated circuit **106** from downhole fluids such as drilling mud and oil. When the threaded box end **103** of the downhole tool **100** in this embodiment is coupled to the threaded pin end **203** of another downhole tool **209** (see FIG. **6**) in a tool string, the primary mating surface **101** may substantially contact the primary mating surface **201** of the pin end **203** and form an effective mechanical seal, thus providing additional protection to the integrated circuit **106** from the downhole environment.

[0035] View **107** is a cross-sectional view of the integrated circuit **106** and the recess **105** and is depicted in FIG. **5**.

[0036] Referring now to FIG. **2**, a downhole tool **209** with an integrated circuit **106** is shown. In this embodiment, the downhole tool **209** comprises a threaded pin end **203**. The threaded pin end **203** may comprise a primary mating surface **201** and a secondary mating surface **208**, both mating surfaces **201**, **208** being intermediate the exterior wall **109** and the bore **110**. The integrated circuit **106** may be disposed within a recess **105** in the secondary mating surface **208**. The pin end **203** may be designed to couple to the box end **103** of a separate downhole tool **100** through mating threads **202**. When this occurs, the secondary mating surface **208** of the pin end **203** may make contact with a secondary mating surface **601** (depicted in FIG. **6**) of the box end **103** and form an effective mechanical seal, providing additional protection to the integrated circuit **106**.

[0037] Referring now to FIG. **3**, it may be beneficial to have a plurality of integrated circuits **106** in a downhole tool. For example, if the integrated circuits **106** are passive RFID devices, they may emit an identification signal modulated with identification data such as a serial number to a receiver. However, due to their passive nature, a plurality of RFID devices configured to emit similar responses may provide a signal that is more easily detected by a receiver than that provided by a single RFID device. A plurality of recesses **105** may be circumferentially distributed along the secondary mating surface **208** to hold the plurality of integrated circuits **106**. In this manner, reception by a short-range RFID receiver may be facilitated for a rotating tool string in which a single integrated circuit **106** is constantly varying its position with respect to a fixed surface receiver.

[0038] Referring now to FIG. **4**, a downhole tool **209** may comprise recesses **105** in both the primary mating surface **201** and the secondary mating surface **208**. The recesses **105** may comprise integrated circuits **106** with various specific applications. Due to the physical characteristics of the integrated circuits **106** and/or nature of these applications, it may be more advantageous for an integrated circuit **106** to be located at a specific spot in the downhole tool **209** than in other locations. For instance, an integrated circuit **106** may be large enough that the recess **105** in which it is disposed affects the structural characteristics of the downhole tool. In cases where several such integrated circuits **106** are used in the downhole tool **209**, it may be beneficial to distribute the integrated circuits **106** between the primary mating surface **201** and the secondary mating surface **208** in order to minimize the affect on the structural characteristics in the downhole tool **209**.

[0039] FIG. **5** is a cross-sectional view **107** of the integrated circuit **106** disposed within the recess **105** of the shoulder **101** shown in FIG. **1**. In this particular embodiment, the integrated circuit **106** is encapsulated in a protective material **108**. The protective material **108** may serve a variety of purposes. For example, the protective material **108** may form a chemical bond with the material of the recess **105** and the integrated circuit **106**, serving to fix the integrated circuit **106** in its position relative to the recess **105**. The protective material **108** may also serve as a protection against drilling mud and other downhole fluids such as oil and/or water that may have an adverse effect on the integrated circuit **106**.

[0040] In the embodiment shown, the protective material **108** conforms to the dimensions of the recess **105** in order to provide additional structural security in the downhole tool **100** and protection from shocks and jolts to the integrated circuit **106**. The protective material **108** may comprise any of a variety of materials including (but not limited to) epoxies; synthetic plastics; glues; clays; rubbers, foams, potting compounds; Teflon®, PEEK® and similar compounds; ceramics; and the like. For embodiments in which the integrated circuit **106** comprises RFID circuitry and other applications, the protective material **108** may be magnetically conductive in order to facilitate the transmission of electromagnetic communication to and from the integrated circuit **106**. In some embodiments, it may also be desirable for the protective material **108** to be electrically insulating and/or high-temperature resistant.

[0041] The protective material **108** may permanently encapsulate the integrated circuit **106**. Alternatively, the integrated circuit **106** may be pre-coated with a material such as silicon, an RTV (room temperature vulcanizing) rubber agent, a non-permanent conformal coating material, or other material before encapsulation by the protective material **108** to facilitate its extraction from the protective material **108** at a later time.

[0042] Referring now to FIG. **6**, a cross-sectional view of a tool joint **600** comprising the junction of a first downhole tool **100** comprising a threaded box end **103** and a second downhole tool **209** comprising a threaded pin end **203** is shown. The first downhole tool **100** may be joined to the second downhole tool **209** through mated threads **102**, **202**. The tool joint **600** may comprise the primary mating surface **101** and the secondary mating surface **601** of the first tool **100** being in respective mechanical contact with the primary mating surface **201** and the secondary mating surface **208** of the second tool **209**, respectively. Specifically, the contact between secondary mating surfaces **601**, **208** may provide a mechanical seal that protects one or more integrated circuits **106** disposed in recesses **105** therein from fluids, debris and other adverse environmental conditions. The protective material **108** encapsulating the integrated circuits **106** may be substantially flush with the surface of the secondary mating surface **601**, **208** in which they are disposed to create an optimal sealing surface on the secondary mating surfaces **601**, **208**.

[0043] In some embodiments of the invention, measures may be taken to relieve pressure in the recess **105** if drilling mud, lubricants, and other downhole fluids become trapped within the recess **105** as the tool joint **600** is being made up. This high pressure may damage the integrated circuit **106** or displace it from the recess **105**. One means of relieving downhole pressure in the recess **105** is disclosed in U.S. patent application Ser. No. 10/710,586, filed Jul. 22, 2004 in the name of Hall, et. al. (hereafter referred to as the '586 application) which is herein incorporated by reference for all that it discloses. The means described in the '586 application comprises a pressure equalization passageway that permits fluids under pressure in the mating threads **202**, **102** of the tool joint **600** to flow between interior and exterior regions of tubular bodies **104** of the downhole tools **100**, **209**.

[0044] Referring now to FIG. **7**, a downhole tool **100** may comprise an integrated circuit **106** with active circuitry disposed within a recess **105** in a primary mating surface **101**. Active circuitry requires a power source **701** in order to function properly. In addition to the integrated circuit **106**, the recess **105** may comprise such a power source **701** in electrical communication with the integrated circuit **106** through a system of one or more electrical conductors **702**. The power source **701** may be a battery. The active circuitry may be active RFID circuitry capable of receiving interrogating signals and transmitting identification information at greater distances than are possible with purely passive circuitry. The integrated circuit **106**, power source **701**, and electrical conductor(s) **702** may all be encapsulated in a protective material **108**.

[0045] Referring now to FIG. **8**, the present invention may be implemented in a downhole network **800**. The downhole network **800** may comprise a tool string **804** suspended by a derrick **801**. The tool string **804** may comprise a plurality of downhole tools **100**, **209** of varying sizes connected by mating ends **103**, **203**. Each downhole tool **100**, **209** may be in communication with the rest of the downhole network **800** through a system of inductive couplers.

[**0046**] One preferred system of inductive couplers for downhole data transmission is disclosed in U.S. Pat. No. 6,670,880 (hereafter referred to as the '880 patent) to Hall, et. al, which is herein incorporated by reference for all that it discloses. Other means of downhole data communication may be incorporated in the downhole network such as the systems disclosed in U.S. Pat. Nos. 6,688,396 and 6,641,434 to Floerke and Boyle, respectively; which are also herein incorporated by reference for all that they disclose.

[**0047**] A data swivel **803** located at the top of the tool string **804** may provide a communicatory interface between the rotating tool string **804** and stationary surface equipment **802**. In this manner data may be transmitted from the surface equipment **802** through the data swivel **803** and throughout the tool string **804**. Alternatively a wireless communication interface may be used between the tool string **804** and the surface equipment **802**. In the embodiment shown, an RFID transmitter/receiver apparatus **805** is located at the surface and may query RFID circuitry in downhole tools **100**, **209** as they are added to or removed from the tool string **804**. In this way, an accurate record of which specific tools make up the tool string **804** at any time may be maintained. Also, if a communications problem were traced to a specific downhole tool **100**, **209** in the tool string **804**, identification information received by the RFID transmitter/receiver apparatus **805** may be used in a database to access specific information about the faulty tool downhole **100**, **209** and help resolve the problem. The RFID transmitter/receiver apparatus **805** may be in communication with the surface equipment **802** or may be an independent entity.

[**0048**] In other embodiments, the surface equipment **802** may not need the RFID transmitter/receiver **805** to communicate with the circuitry disposed within the downhole tools **100**, **209**. The surface equipment **802** may be equipped to send a query directly through wired downhole tools **100**, **209** in the network **800** to RFID circuitry as will be discussed in more detail in the description of FIG. **16**. In other embodiments still, downhole tools **806** that are not connected to the network **800** may be queried by an RFID query device such as a wand (not shown) and relay identification information stored in the RFID circuitry.

[**0049**] Referring now to FIG. **9**, an inductive coupler **900** designed to be disposed in the recess **105** of a downhole tool shoulder is depicted. In this embodiment the recess **105** is an annular groove designed to house both the inductive coupler **900** and the integrated circuit **106** (shown in FIG. **10**). The inductive coupler **900** is substantially similar to the inductive coupler disclosed in the '880 patent with the addition of an integrated circuit **106**. The inductive coupler **900** comprises an electrically conducting coil **901** lying in a magnetically conductive electrically insulating trough **1101** (see FIG. **11**). The electrically conducting coil **901** is shown as a single-turn coil of an electrically conducting material such as a metal wire; however, in other embodiments the electrically conducting coil **901** comprises multiple turns. The magnetically conductive electrically insulating trough may comprise a plurality of U-shaped fragments **903** arranged to form a trough around the electrically conducting coil **901**. A preferred magnetically conductive electrically insulating material is ferrite, although several materials such as nickel or iron based compounds, mixtures, and alloys; mu-metals; molypermalloys; and metal powder suspended in an electrically-insulating material may also be used. A data signal may be transmitted from an electrical conductor **906** to a first point **902** of the electrically conducting coil **901** from which it flows through the electrically conducting coil **901** to a second point **905** which is preferably connected to ground.

[**0050**] When a first inductive coupler **900** is mated to a second similar inductive coupler **900**, magnetic flux passes from the first magnetically conductive electrically insulating trough to the second magnetically conductive electrically insulating trough according to the data signal in the first electrically conducting coil **901** and induces a similar data signal in the second electrically conducting coil **901**.

[**0051**] The inductive coupler **900** comprises an integrated circuit **106** which is preferably an RFID circuit. The integrated circuit **106** may comprise an active RFID tag, a passive RFID tag, low-frequency RFID circuitry, high-frequency RFID circuitry, ultra-high frequency RFID circuitry, and combinations thereof. The integrated circuit **106** may be located in a gap between the first point **902** and the second point **905** of the electrically conducting coil **901**. The integrated circuit **106**, electrically conducting coil **901**, and U-shaped fragments **903** may be encapsulated within a protective material **108** as disclosed in the description of FIG. **5**. The inductive coupler **900** may further comprise a housing **904** configured to fit into the recess **105** of the downhole tool shoulder.

[**0052**] The integrated circuit **106** may be in electromagnetic communication with the electrically conducting coil **901** due to their close proximity to each other. The electrically conducting coil **901** may act as a very short-range radio antenna and transmit a signal that may be detected by RFID circuitry in the integrated circuit **106**. Likewise, an identification signal transmitted by the RFID circuitry in the integrated circuit **106** may be detected by the electrically conducting coil **901** and transmitted throughout a downhole network **800**. In this manner, surface equipment **802** and other network devices may communicate with the integrated circuit **106**. Signals received from the integrated circuit **106** in the electrically conducting coil **901** of the inductive coupler **900** may require amplification by repeaters (not shown) situated along the downhole network **800**.

[**0053**] Referring now to FIG. **10**, a downhole tool **100** is shown with the inductive coupler **900** of FIG. **9** disposed in a recess **105** of a secondary mating surface **208**. In this embodiment, the recess **105** is an annular groove. The inductive coupler **900** may be configured to mate with a second inductive coupler in a secondary mating surface **601** of a box end **103**.

[**0054**] Referring now to FIG. **11**, a cross-sectional view of a tool joint **1100** comprising the junction of a first downhole tool **100** and a second downhole tool **209** is shown. Each tool **100**, **209** comprises both an inductive coupler **900** in a secondary mating surface **601**, **208** and an integrated circuit **106** disposed within the recess **105** of a primary mating surface **101**, **201**. Both inductive couplers **900** may be in close enough proximity to transfer data and/or power across the tool joint **1100**. Both inductive couplers **900** may be lying in magnetically conductive, electrically insulating troughs **1101**. Data or power signals may be transmitted from an inductive coupler **900** in one end of a downhole tool

100, 209 to an inductive coupler 900 in another end by means of the electrical conductor 906 in the inductive coupler 900. This electrical conductor 906 may be electrically connected to an inner conductor of a coaxial cable 1102.

[0055] Mechanical seals created by the junction of primary mating surfaces 101, 201 and secondary mating surfaces 601, 208 may protect both the inductive couplers 900 and the integrated circuits 106 from downhole conditions.

[0056] Referring now to FIG. 12, another embodiment of an inductive coupler 900 according to the invention may comprise an integrated circuit 106 in direct electrical contact with the electrically conducting coil 901 through electrical conductor 1201. The integrated circuit 106 may further be in electrical communication with ground through electrical conductor 1202. The integrated circuit 106 may comprise passive RFID circuitry that requires a connection to an external antenna in order to receive and transmit RF signals. The electrically conducting coil 901 may function as that antenna.

[0057] Through the downhole network 800, the RFID transmitter/receiver 805 of the surface equipment 802 may be in electromagnetic communication with the integrated circuit 106.

[0058] Referring now to FIGS. 13 and 14, a cross-sectional view of another embodiment of a tool joint 1100 is shown. Tools 100, 209 may be connected to the downhole network 800 through inductive couplers 900 and coaxial cable 1102. As is shown in FIG. 8, the downhole network 800 may comprise surface equipment 802 comprising an RFID transmitter/receiver 805 configured with RFID interrogating circuitry.

[0059] Tool 209 may comprise an integrated RFID circuit 1406. FIG. 14 shows a detailed view 1301 of FIG. 13. The coaxial cable 1102 may comprise an outer conductor 1401 and an inner conductor 1402 separated by a dielectric 1403. The inner conductor 1402 may be in electrical communication with the electrical conductor 906 of the inductive coupler 900 through connector 1404. The outer conductor 1401 may be in electrical communication with ground. In some embodiments, the outer conductor 1401 may also be in electrical communication with the tubular body 104 of the downhole tool 100 thus setting its potential at ground and providing access to a node with a ground potential for the inductive coupler 900.

[0060] Still referring to FIG. 14, protected RFID integrated circuit 1406 is shown comprising a first electrical connection 1405 to electrical conductor 906 of the inductive coupler 900 (See FIG. 9) through connector 1404. Integrated circuit 1406 may also comprise a second electrical connection 1450 to ground through the outer conductor 1404. In other embodiments, the RFID integrated circuit 1406 may be located between the coaxial cable 1102 and the inductive coupler 900. These locations may be particularly advantageous in providing a substantially protected environment from downhole operating conditions. In any location, the RFID integrated circuit 1406 may comprise connections 1405 to ground and inductive coupler 900. In this manner, the integrated RFID circuit 1406 may utilize the inductive coupler 900 as an external antenna (see description of FIGS. 13, 15).

[0061] Through the downhole network 800, the RFID transmitter/receiver 805 of the surface equipment 802 may be in electromagnetic communication with the RFID integrated circuit 1406.

[0062] In other embodiments of the invention, a direct electrical contact coupler or a hybrid inductive/electrical coupler such as is disclosed in U.S. Pat. No. 6,641,434 to Boyle, et al may be substituted for the inductive coupler 900. Also U.S. Patent Publication No. 20050074988 discloses a direct connect system compatible with the present invention and is herein incorporated by reference for all that it discloses.

[0063] Referring now to FIG. 15, a method 1600 for identifying a downhole tool 100 in a tool string 804 is depicted. The method 1600 comprises the steps of transmitting 1610 an interrogating signal from surface equipment 802 to the downhole tool 100 and receiving 1620 the interrogating signal in identification circuitry disposed within a shoulder of the downhole tool 100. The interrogating signal may be an electromagnetic signal transmitted through a downhole network 800 and the identification circuitry may be an integrated circuit 106. The identification circuitry may further comprise RFID circuitry.

[0064] The RFID interrogation signals may be transmitted at first frequency while network data is transmitted at second frequency. In selected embodiments, a first series of RFIDs may respond to interrogation signals on a first frequency, while a second series of RFIDs may respond to interrogation signals on a second frequency. For example, it may be desirable to identify all of the downhole tools comprising network nodes. An interrogation signal may be sent on a frequency specific for those tools comprising network nodes and other RFIDs in communication with the downhole network will not respond.

[0065] The method 1600 further comprises the steps of transmitting 1630 an identification signal modulated with identification data from the identification circuitry to the surface equipment 802 and demodulating 1640 the identification data from the identification signal to identify the downhole tool 100. The identification data may be a serial number.

[0066] Referring now to FIG. 16, a more detailed method 1700 for identifying a downhole tool 100 in a tool string 804 is illustrated. The method 1700 comprises the steps of surface equipment 802 producing 1705 an interrogating signal and the interrogating signal being transmitted 1710 through a downhole network 800. The interrogating signal may be an electromagnetic signal at a predetermined frequency and amplitude for a predetermined amount of time. The parameters of frequency, amplitude, and signal length may be predetermined according to characteristics of one or more passive integrated circuits 106 in one or more downhole tools 100. The downhole network 800 may comprise a downhole data transmission system such as that of the previously referenced '880 patent.

[0067] The method 1700 further comprises the downhole tool 100 receiving 1715 the interrogating signal from the downhole network 800 and transmitting 1720 the interrogating signal from an inductive coupler 900 to passive circuitry in a shoulder of the downhole tool 100. The passive circuitry is preferably an integrated circuit 106 that comprises RFID capabilities. The downhole tool **100** may receive **1715** the interrogating signal in the inductive coupler **900**. The inductive coupler **900** may communicate wirelessly with the passive circuitry through an internal antenna in the passive circuitry. In other embodiments, the inductive coupler **900** may act as an external antenna for the passive circuitry and communicate with it through direct electrical communication. The passive circuitry may then transmit **1725** an identification signal to the inductive coupler **900** in the downhole tool **100**. The identification signal may comprise identification information such as a serial number modulated on a sinusoidal electromagnetic signal.

[0068] The method further comprises the downhole tool **100** transmitting **1730** the identification signal to the surface equipment **802** through the downhole network **800**. The surface equipment **802** may receive **1735** the identification signal from the downhole network **800** and demodulate **1740** the identification signal to retrieve the identification information and identify the downhole tool **100**. The identification information on the identification signal may then permit the surface equipment **802** to access a database or other form of records to obtain information about the downhole tool **100**.

[0069] Whereas the present invention has been described in particular relation to the drawings attached hereto, it should be understood that other and further modifications apart from those shown or suggested herein, may be made within the scope and spirit of the present invention.

What is claimed is:

1. A downhole tool comprising:

a tubular body having an end, an exterior wall, and a bore; and

a mating surface formed intermediate the exterior wall and the bore in the end of the tubular body;

wherein the mating surface is adapted to receive an integrated circuit and to couple to a second downhole tool.

2. The downhole tool of claim 1, wherein the integrated circuit is disposed within a recess formed in the mating surface.

3. The downhole tool of claim 2, wherein the recess is a groove.

4. The downhole tool of claim 2, wherein the mating surface is a shoulder.

5. The downhole tool of claim 2, comprising a plurality of mating surfaces having recesses in the end of the tubular body and a plurality of integrated circuits disposed within the recesses.

6. The downhole tool of claim 2, wherein the integrated circuit is encapsulated in a protective material.

7. The downhole tool of claim 6, wherein the protective material substantially conforms to the dimensions of the recess.

8. The downhole tool of claim 1, wherein the mating surface is adapted to receive a plurality of integrated circuits.

9. The downhole tool of claim 1, further comprising a power source for the integrated circuit.

10. The downhole tool of claim 1, wherein the integrated circuit comprises passive circuitry.

11. The downhole tool of claim 1, wherein the integrated circuit comprises radio frequency identification (RFID) circuitry.

12. A downhole tool comprising:

a tubular body comprising an end having a shoulder;

an inductive coupler disposed within a groove in the shoulder; and

an integrated radio frequency identification (RFID) circuit also disposed within the groove;

wherein the inductive coupler and the integrated circuit are in electromagnetic communication.

13. The downhole tool of claim 12, wherein the downhole tool is in communication with a downhole network through the inductive coupler.

14. The downhole tool of claim 12, further comprising a direct electrical connection between the integrated circuit and the inductive coupler.

15. The downhole tool of claim 14, wherein the inductive coupler acts as an external antenna for the RFID circuit.

16. The downhole tool of claim 12, wherein the integrated circuit is in communication with surface equipment through the inductive coupler.

17. The downhole tool of claim 12, wherein the inductive coupler and the integrated circuit are encapsulated in a protective material.

18. The downhole tool of claim 12, wherein the inductive coupler comprises an electrically conducting coil lying in a magnetically conductive electrically insulating trough.

19. The downhole tool of claim 12, wherein the RFID circuitry is selected from the group consisting of active RFID tags, passive RFID tags, low-frequency RFID circuitry, high-frequency RFID circuitry, ultra-high frequency RFID circuitry, and combinations thereof.

20. A tool identification system comprising:

surface equipment comprising radio frequency identification (RFID) interrogating circuitry;

a downhole tool comprising a protected integrated RFID circuit;

wherein the RFID interrogating circuitry and the protected integrated RFID circuit are in electromagnetic communication through a downhole network.

21. The tool identification system of claim 20, wherein the protected integrated RFID circuit comprises a first electrical connection to a data coupler in the downhole tool and a second electrical connection to ground.

22. The tool identification system of claim 21, wherein the data coupler is selected from the group consisting of inductive couplers, direct electrical couplers, and combinations thereof.

23. The tool identification system of claim 21, wherein the protected integrated RFID circuit is disposed between the data coupler and a data transmission cable.

24. The tool identification system of claim 22, wherein the first electrical connection is in electrical communication with an inner conductor of the data transmission cable.

25. The tool identification system of claim 21, wherein the second electrical connection is in electrical communication with an outer conductor of a data transmission cable.

26. A method for identifying a downhole tool in a tool string comprising:

transmitting an interrogating signal from surface equipment to the downhole tool through a downhole network;

receiving the interrogating signal in identification circuitry disposed within a shoulder of the downhole tool;

transmitting an identification signal modulated with identification data from the identification circuitry to the surface equipment through the downhole network;

demodulating the identification data from the identification signal to identify the downhole tool.

27. The method of claim 25, wherein the identification circuitry comprises RFID circuitry.

28. The method of claim 25, wherein the interrogating signal is transmitted at a frequency of about 13.56 MHz.

29. The method of claim 25, further comprising the step of comparing the identification data with a database record.

30. The method of claim 25, wherein the identification data is a serial number.

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