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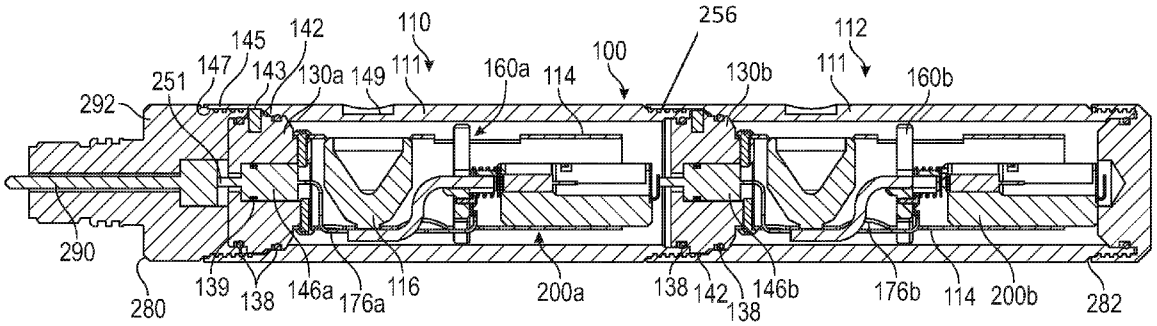

FIG. 1

(57) **Abstract:** An apparatus for selectively firing a perforating gun having a plurality of gun assemblies includes a plurality of cartridge assemblies. Each cartridge assembly is associated with a gun assembly of the plurality of gun assemblies. Each cartridge assembly includes a body having a cavity, an input contact configured to receive a signal, and a throughput contact configured to convey the signal. The perforating gun may include a carrier and at least one bulkhead.

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TITLE: **PERFORATING GUN WITH SWITCH CARTRIDGE**

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TECHNICAL FIELD

[0002] The present disclosure relates to devices and method for perforating a subterranean formation.

BACKGROUND

[0003] Hydrocarbons, such as oil and gas, are produced from cased wellbores intersecting one or more hydrocarbon reservoirs in a formation. These hydrocarbons flow into the wellbore through perforations in the cased wellbore. Perforations are usually made using a perforating gun that is generally comprised of a steel tube "carrier," a charge tube riding on the inside of the carrier, and with shaped charges positioned in the charge tube. The gun is lowered into the wellbore on electric wireline, slickline, tubing, coiled tubing, or other conveyance device until it is adjacent to the hydrocarbon producing formation. Thereafter, a surface signal actuates a firing head associated with the perforating gun, which then detonates the shaped charges. Projectiles or jets formed by the explosion of the shaped charges penetrate the casing to thereby allow formation fluids to flow through the perforations and into a production string.

[0004] In certain instances, it may be desirable to use switches to selectively fire guns in a perforating tool. The present disclosure addresses the need to house or otherwise accommodate such switches in a downhole tool.

SUMMARY

[0005] In aspects, the present disclosure provides an apparatus for use in a wellbore. The apparatus may include a first gun assembly and a second gun assembly. The first gun assembly may have: a first charge tube having a longitudinal axis defined by an axis that passes through centers of opposing ends of the charge tube; a first detonator cord disposed along the first charge tube, a first signal-conveying wire disposed along the first charge tube, a first coupler affixed to an end of the first charge tube, the first coupler including: a receptacle receiving an end of the detonator cord, and a coupler contact electrically connected to the first signal conveying wire, and a first cartridge assembly including: a body having a cavity and a cradle, an input contact positioned on the body and electrically coupled to the coupler contact, a throughput contact positioned on the body, a switch disposed in the cavity, the switch being electrically connected to the input contact and the throughput contact, and an initiating element disposed in the cradle and electrically connected to the switch, the initiating element being energetically coupled to the end of the detonator cord in the receptacle, wherein the switch and the initiating element at least partially overlap along the longitudinal axis; and a first signal transfer assembly electrically coupled to the throughput contact.

[0006] The second gun assembly may have: a second charge tube, a second detonator cord disposed along the second charge tube, a second signal-conveying wire disposed along the second charge tube, the second signal-conveying wire being electrically coupled to the first contact assembly, a second coupler affixed to an end of the second charge tube, the second coupler including: a receptacle receiving an end of the second detonator cord, and a coupler contact electrically connected to the second signal conveying wire; and a second cartridge assembly including: a body having a cavity, an input contact electrically positioned on the body and coupled to the second coupler contact, a throughput contact positioned on the body, a switch disposed in the cavity, the switch being electrically connected to at least the input contact, and an initiating element disposed in the cavity and electrically connected to the switch, the initiating element being energetically coupled to the end of the second detonator cord in the receptacle.

[0007] In aspects, the present disclosure also provides an apparatus for use with a gun assembly having charge tube with a longitudinal axis defined by an axis that passes through centers of opposing ends of the charge tube, a detonator cord disposed along the first charge tube, and a signal-conveying wire disposed along the first charge tube. The apparatus may include: a switch having an initiating element; a coupler configured to be received at an end of the first charge tube, the first coupler including: a receptacle receiving an end of the detonator cord, and a coupler contact electrically connected to the first signal conveying wire; and a cartridge assembly engagable with the first coupler, the cartridge assembly including: a body having a cavity configured to receive the switch and a cradle configured to receive the initiating element, an input contact positioned on the body, and a throughput contact positioned on the body, wherein engaging the cartridge assembly with the coupler simultaneously electrically couples the input contact to the coupler contact and energetically couples the initiating element with the end of the detonator cord, and wherein the switch and the initiating element are positioned in a parallel, side-by-side arrangement to at least partially overlap along the longitudinal axis.

[0008] In aspects, the present disclosure provides a perforating gun. The perforating gun may include a carrier and at least one bulkhead. The carrier may have at least two sections connecting to one another at a connection. There are no sealing members between the two sections at the connection. The bulkhead is disposed within the carrier and has at least one sealing member forming a seal between the bulkhead and an inner surface of the carrier.

[0009] It should be understood that certain features of the invention have been summarized rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contributions to the art may be appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will in some cases form the subject of the claims appended thereto.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] For detailed understanding of the present disclosure, references should be made to the following detailed description taken in conjunction with the accompanying drawings, in which like elements have been given like numerals and wherein:

FIG. 1 schematically illustrates a side sectional view of a perforating gun with a switch cartridge according to one embodiment of the present disclosure;

FIG. 2 isometrically illustrates the FIG. **1** embodiment without a carrier;

FIG. 3 schematically illustrates a side sectional view of portion of the FIG. **1** embodiment;

FIGS. 4A-B illustrate a coupler according to one embodiment of the present disclosure;

FIGS. 5A-B illustrate one embodiment of a cartridge assembly according to the present disclosure;

FIGS. 6A-B schematically illustrate prior art switches;

FIG. 7 illustrates a side sectional view of an interface between a bulkhead and a cartridge assembly according to one embodiment of the present disclosure;

FIG. 8 illustrates a side sectional view of an interface between a coupler and a cartridge assembly in accordance with one embodiment of the present disclosure;

FIG. 9 schematically illustrates a side sectional view of a perforating gun with a switch cartridge according to another embodiment of the present disclosure;

FIG. 10 isometrically illustrates the **FIG. 9** embodiment without a carrier;

FIG. 11A-C illustrate another coupler according to the present disclosure;

FIGS. 12A-B illustrate another embodiment of a cartridge assembly according to the present disclosure;

FIG. 13 illustrates a side sectional view of an interface between a bulkhead and the **FIGS. 12A-B** cartridge assembly according to one embodiment of the present disclosure; and

FIG. 14 illustrates a side view of another arrangement of the **FIG. 9** perforating tool according to one embodiment of the present disclosure.

DETAILED DESCRIPTION

[0011] The present disclosure relates to devices and methods for perforating a formation intersected by a wellbore. The present disclosure is susceptible to embodiments of different forms. There are shown in the drawings, and herein will be described in detail, specific embodiments of the present disclosure with the understanding that the present disclosure is to be considered an exemplification of the principles of the disclosure, and is not intended to limit the disclosure to that illustrated and described herein.

[0012] Referring to **FIG. 1**, there is shown one embodiment of a perforating tool **100** in accordance with the present disclosure. The perforating tool **100** may include a first gun assembly **110** and a second gun assembly **112**. Each gun assembly **110**, **112** includes a carrier **111** that is shaped to receive a charge tube **114**. Each gun assembly **110**, **112** also includes one or more shaped charges **116** fixed within the charge tube **114**. To enable selectively firing the gun assemblies, a select fire system may be used in which a cartridge assembly **200a** is programmed to only fire the first gun assembly **110** and a cartridge assembly **200b** is programmed to only fire the second gun assembly **112**. While two gun assemblies **110**, **112** are shown, three or more gun assemblies and associated cartridge assemblies may be used.

[0013] Generally, the perforating tool **100** is lowered into a wellbore (not shown) on electric wireline, slickline, tubing, coiled tubing, or other conveyance device (not shown) until it is adjacent to the hydrocarbon producing formation (not shown). Thereafter, a surface signals are used to actuate the gun assemblies **110**, **112**, which then detonate the associated shaped charges. Projectiles or jets formed by the explosion of the shaped charges penetrate a casing (now shown) lining a wellbore (not shown) to thereby allow formation fluids to flow through the perforations and into a production string (not shown). Illustrative arrangements according to the present disclosure for enabling select firing of the gun assemblies **110**, **112** are described below.

[0014] Referring now to **FIG. 2**, a gun assembly **110** in accordance with one embodiment of the present disclosure is shown in an isometric view. For clarity, the

carrier **111** (**FIG. 1**) is not shown. In this embodiment, the charge tube **114** may be formed as a tubular member having a first end **118,** a second end **120**, and an interior bore **122**. The charge tube **114** provides a receiving structure in which the shaped charges **116**, a bulkhead **130a**, a coupler **160a**, and the cartridge assembly **200a** (**FIG. 1**) are secured. The bulkhead **130a** may be fixed to the first end **118** with a suitable fastening element **132**, such as a screw.

[0015] The charge tube **114** may include a first opening **148** through which the shaped charge **116** may be inserted into the interior bore **122** and a second opening **150** through which the coupler **160a** may be inserted into the interior bore **122**. Depending on the configuration of the coupler **160a**, a third opening **152** (**FIG. 3**) may be present through which a portion of the coupler **160a** may project out of the charge tube **114**.

[0016] Referring to **FIGS. 1** and **3**, the bulkhead **130a** acts a structural barrier between sections of the perforating tool **100**. In embodiments, the bulkhead **130a** may be a disk-like member having an outer circumferential surface **134** (**Fig. 3**) and a passage **136** (**Fig. 3**). The bulkhead **130a** may include an alignment key **143** fixed on the outer surface **134** that is complementary to a keyway **145** (**FIG. 1**) formed along an inner surface **147** of the carrier **111**. The keyway **145** may be a slot, groove, or other similar surface depression that has a specified angular orientation relative to one or more features of the perforating gun **110**, *e.g.*, a scallop **149** or another reduced thin wall section of the carrier **111**. Thus, upon the alignment key **143** entering the keyway **145**, the shaped charge **116**, which has a fixed angular alignment relative to the alignment key **143**, can be aligned with the scallop **149**.

[0017] As shown in **FIG. 1**, the charge tube **114** is sealed between the opposing bulkheads **130a,b** inside the carrier **111**. In one arrangement, one or more seals **138** may be disposed on the outer circumferential surface **134**. The seals **138** provide an interior of the carrier **111** that is fluid-tight. The passage **136** of the bulkhead **130a** is shaped to receive an signal transfer assembly **146a**. The signal transfer assembly **146a** is configured to transmit signals across the bulkhead **130a** or other structural barriers in the perforating tool **100** (**FIG. 1**). The signal transfer assembly **146a** also has seals **139** to form a fluid-tight seal in the passage **136**. An signal transfer assembly **146b** is

configured to transmit signals across the bulkhead **130b** and is generally similar to the signal transfer assembly **146a**. The bulkhead **130b** may have the same construction as the bulkhead **130a**.

[0018] Referring to **Figs. 3** and **4 A,B**, there is shown a coupler **160a** in accordance with one embodiment of the present disclosure. The coupler **160a** provides two operative connections when engaged with the cartridge assembly **200a (FIG. 1)**. The first connection is an energetic connection between a detonator cord **174** and the cartridge assembly **200a (FIG. 1)**. As used herein, an "energetic connection" or "energetic coupling" is a connection or coupling that enables the transmission of sufficient energy, such as thermal energy, to detonate the detonator cord **174**. The second connection transfers power (*e.g.*, electrical power) and / or signals (*e.g.*, control signals), hereafter collectively "signals," from the signal transfer assembly **146a** to the cartridge assembly **200a (FIG. 1)**. The coupler **160b** provides similar operative connections for the cartridge assembly **200b (FIG. 1)**.

[0019] Referring to **Figs. 4A,B**, in one embodiment, the coupler **160a** may include a body **162** on which a coupler contact **167** is positioned. The coupler contact **167** may include a coupler contact surface **164** and a wiring contact **166**. As illustrated, the coupler contact surface **164** is formed on a coil spring disposed on a tubular receptacle **168** of the body **162**. However, other coupler contact surfaces **164** configured for compressive engagement, such as on leaf springs, may be used. In still other embodiments, the coupler contact surface **164** may not use a biasing feature; *i.e.*, a feature that provides a biasing force. The wiring contact **166** may be any type of fastener, hook, frame, or other member that can be affixed to the body **162** and has at least a portion that is electrically conductive. A coupler **160b** is generally of the same construction as that of the coupler **160a**.

[0020] Referring to **Figs. 5A-B**, there is schematically shown a cartridge assembly **200a** in accordance with one embodiment of the present disclosure. Cartridge assembly **200b** may use a similar configuration as cartridge assembly **200a**. As will be apparent from the discussion below, the cartridge assembly **200a** acts as a structural and electrical adaptor that enables switches of various different configurations and sizes to be used in the perforating tool **100**. Exemplary switches

180, 181 that may be operatively connected to the cartridge assembly **200a** are shown in **Figs. 6A-B**.

[0021] Referring to **FIG. 6A**, the switch **180** may be any conventionally constructed electrical device that, in response to a received signal, can output sufficient thermal energy to detonate an energetic material such as that used in the detonator cord **174 (FIG. 3)** or the booster **172 (FIG. 3)** and / or transmit, re-transmit, or otherwise convey an electrical signal. One class of switches are considered "select fire" switches because they can be programmed to initiate the firing of one perforating gun of a plurality of perforating guns or the firing of a sub-set of perforating guns of sets of perforating guns. The switch **180** may include analog and/or digital circuity configured to receive and interpret signals. Interpreting signals may be as simple as recognizing polarity or comparing a received signal with a preprogrammed code or pattern. Irrespective of the configuration, the switch **180** either initiates the firing of the associated perforating gun or passes the signal to the next switch **180** based on the received signal.

[0022] A conventional construction may include a body **182** that has an electrical input **184**, an electrical output **186**, and an initiating element **188**. The electrical input **184** may be a wire, terminal, pad, or other structure to which a wire, node, pad, or such structure can be electrically connected. The electrical output **186** may also be a similarly configured wire, terminal, a node, or a pad. The initiating element **188** applies activating energy for detonating the detonator cord **174** or booster **172** in response to an activation signal (*e.g.*, electrical energy). In some embodiments, the initiating element **188** may be metal rod or similar member that generates heat with the application of electrical energy. Wires **190**, **192** connect the initiating element **188** to the body **182** of the switch **180**. Thus, the initiating element **188** may be positioned at a location that is different from where the body **182** is positioned. The switch **180** may also include a ground wire **194**.

[0023] Referring to **FIG. 6B**, another prior art switch **181** may include a body **183** that has an electrical input **185**, an electrical output **187**, and an initiating element **189**. The electrical input **185** may be a wire, terminal, pad, or other structure to which a wire, node, pad, or such structure can be connected. The electrical output **187** may

also be a wire, terminal, a node, or a pad. The initiating element **189** applies activating energy for detonating the detonator cord **174** or booster **172** in response to an activation signal (*e.g.*, electrical energy). In some embodiments, the initiating element **189** may be metal rod or similar member that generates heat with the application of electrical energy. In this embodiment, the initiating element **189** is integral with the body **183** and, therefore, co-located with the body **183**. The switch **181** may also include a ground wire **195**.

[0024] It is emphasized that the present disclosure is not limited to any particular switch design or initiating element. To the contrary, with the benefit of the present teachings, one skilled in the art will appreciate that the devices of the present disclosure can be readily adapted to accommodate a wide variety of switches that employ different electrical and physical configurations. Also, for brevity, reference to the switch **180** is inclusive of a reference to the switch **181** (**FIG. 6B**).

[0025] Referring to **FIG. 5A-B**, the cartridge assembly **200a** includes a body **202** in which a cavity **204** is formed and an electrical assembly **206** for communicating signals to and from the switch **180** (**FIG. 6A**). The cavity **204** is sized and shaped to house the switch **180** (**FIG. 6A**). In one arrangement, the electrical assembly **206** forms electrical connections with the switch **180** (**FIG. 6A**) using a throughput contact **208** and an input contact **210**.

[0026] The input contact **210** conveys a received signal to the switch **180** (**FIG. 6A**) inside the cartridge assembly **200a**. The input contact **210** may include an external input contact **222** and a wire **224**. The external input contact **222** may be a screw or other fastening element that is fixed to a second face **226** of the body **202** and is electrically connected to the wire **224**. The external input contact **222** may be sized to present a suitable contact surface **230** for physically contacting the coupler contact surface **164** (**FIG. 3**). The wire **224** has an end **228** that leads to the cavity **204**. The end **228** may be electrically connected to the electrical input **184** (**FIG. 6A**) of the switch **180** (**FIG. 6**).

[0027] The throughput contact **208** conveys the signal received by the cartridge assembly **200a** to another cartridge assembly, here cartridge **200b**. The signal may be the same as or similar to the received signal or a new signal. The throughput contact

208 may include a external throughput contact **212**, an eyelet **214**, and a wire **216**. The external throughput contact **212**, may be a disk or plate that is fixed using the eyelet **214**, or other suitable device, to a first face **218** of the body **202**. The eyelet **214** may be a screw or other fastening element that is also fixed to the first face **218** and is electrically connected to the external throughput contact **212** and the wire **216**. The wire **216** has an end **220** that terminates within or near the cavity **204**. The end **220** may be electrically connected to the electrical output **186 (FIG. 6A)** of the switch **180 (FIG. 6)**. In certain embodiments, the external throughput contact **212** may be formed as a compressive element that acts as a biasing member; *e.g.*, a spring. In such embodiments, the external throughput contact **212** applies a compressive force to the cartridge **200**. Thus, the compressive force applied by the external throughput contact **212** and / or the coupler contact surface **164 (FIG. 3)** may be used to ensure that the cartridge assembly **200** compressively engages the coupler **160**. This compressive engagement ensures that signals and activation energy (*e.g.*, thermal energy) can be transferred between the cartridge assembly **200** and the coupler **160**

[0028] In embodiments, the cartridge assembly **200** may also include an electrical grounding assembly **240** for grounding the switch **180 (FIG. 6)**. The grounding assembly **240** may include a contact element **242** positioned in the cavity **204**, an external ground contact **244**, and a wire **245** electrically connecting the contact element **242** to the external ground contact **244**. The external ground contact **244** may be electrically connected to a biasing member **246** that is in contact with an inner surface of the charge tube **114 (FIG. 2)**. In one arrangement, the cartridge assembly **200** may use a metal bow spring as the biasing member **246**.

[0029] Referring to **Figs. 2** and **5A-B**, in embodiments, the cartridge assembly **200a** may be secured in the charge tube **114** with a mechanical interlocking mechanism. For example, the second end **120** of the charge tube **114** may include a "J" slot **250** that is shaped and dimensioned to be complementary to a post **252** that projects out of the body **202**.

[0030] It should be appreciated that the switch **180 (FIG. 6A)** may be pre-installed in the cartridge assembly **200a** prior to assembly of the perforating tool **100**. This pre-installation may include making electrical connections between the electrical

input **184** and electrical output **186** (**FIG. 6A**) of the switch **180** (**FIG. 6A**) and the wires **224**, **220** (**FIG. 5B**), respectively, of the cartridge assembly **200a** (**FIG. 5B**). Conventionally, making such electrical connections may require twisting of wires, soldering, etc. Advantageously, in embodiments of the present disclosure, such activity is done beforehand between the switch **180** (**FIG. 6A**) and the cartridge assembly **200a**. Later installation simply requires sliding or otherwise positioning the cartridge assembly **200a** inside the perforating tool **100** to engage the coupler **160** and form the electrical connections. Here, the engagement occurs by positioning the cartridge assembly **200a** into a side-by-side relative relationship. These electrical connections may be formed by electrically conductive surfaces that are in physical contact, and possibly in compressive contact, or sufficiently close as to allow the transmission of electrical signals. Moreover, the energetic connection that enables the transfer of thermal energy may also be formed by the same installation action.

[0031] The gun assembly **112** also includes similar features, *e.g.*, a cartridge assembly **200b**, a bulkhead **130b**, a coupler **160b**, etc. and uses the same construction as gun assembly **110**, although in other embodiments a different construction may be used.

[0032] An exemplary use of the perforating tool **110** be described with reference to **FIGS. 1- 8**.

[0033] Referring to **FIG. 1**, the perforating gun **100** has an uphole end **280** and a downhole end **282**. The uphole end **280** connects to a conveyance device such as a wireline (not shown), which extends to a surface location. The downhole end **282** points a well bottom (not shown). While two gun assemblies **110**, **112** are shown between the ends **280**, **282**, three or more gun assemblies, each with one or more shaped charges **116**, may be present. In one exemplary mode of operation, the perforating gun closest to the downhole end **282**, here perforating gun **112**, is fired first. Thereafter, the next most adjacent perforating gun uphole of the fired perforating gun, here perforating gun **110**, is fired. To facilitate sequential "bottom up" firing of the perforating tool **100**, multiple firing signals may be sent. For instance, a first firing signal may be sent to fire the perforating gun **112** and a second firing signal may be sent to fire the perforating gun **110**. As further described below, the cartridge assembly

200a is programmed to pass the first firing signal to the cartridge **200b**. The cartridge **200b** is programmed to fire the perforating gun **112** upon receiving the first firing signal. The cartridge **200a** is programmed to fire the perforating gun **110** upon receiving the second firing signal. If more than two gun assemblies are present, then three or more cartridge assemblies and associated firing signals may be needed.

[0034] Referring to **FIG. 1**, to initiate firing, the first firing signal may be transmitted from a surface location to the perforating gun **100** by a signal conducting carrier **290**. A signal receiving interface for receiving the first firing signal is provided in an end cap **292**. The end cap **292** may be a disk-like closure member attached to the uphole end **280** of the perforating tool **100**. The signal transfer assembly **146a** includes a signal conducting tip **251** on one end and a connection with a wire **176a** at the other end. The wire **176a** is in signal communication with the cartridge assembly **200a** via the coupler **160a**. Therefore, when the tip **251** electrically engages the signal conducting carrier **290**, a signal conducting circuit is formed across the bulkhead **130a** such that the first firing signal can be communicated from the signal conducting carrier **290** to the coupler **160a**.

[0035] The signal transfer from the signal transfer assembly **146a** to the coupler **160a** is illustrated in **FIG. 8**. In one arrangement, a signal conducting circuit is formed by the wire **176a** and a coupler contact **167**. The wire **176a** and the coupler contact **167**, which includes the wiring contact **166** and the coupler contact surface **164**, are all formed of an electrically conductive material, such as a metal, and are electrically connected to one another using suitable known electrical connections. In this arrangement, the body **162** is made of an electrically non-conductive material, *e.g.*, a non-metal such as a plastic. The first firing signal travels via the wire **176a** to the wiring contact **166** and then to the coupler contact surface **164**. The electrical connection between the coupler contact surface **164** and the external input contact **222** of the input contact **210** transfers the first firing signal to the input contact **210** of the cartridge **200a**.

[0036] Referring to **Figs. 5A,B**, the first firing signal travels from the external input contact **222** via the wire **224** to the electrical input **184** (**FIG. 6A**) of the switch **180** (**FIG. 6A**). Because the switch **180** (**Fig. 6A**) is programmed to fire the gun

assembly **110** (**FIG. 1**) only after receiving the second firing signal, the switch **180** (**FIG. 6A**) passes the first firing signal to the throughput contact **208** via the electrical connection to the wire **216**. The first firing signal travels via the wire **216** to the eyelet **214** and the external throughput contact **212**.

[0037] **FIG. 7** illustrates the signal transmission interface and signal transfer from the external throughput contact **212** of the cartridge assembly **200a** to contact assembly **146b** in the bulkhead **130b**. The contact assembly **146b** includes a signal conducting tip **251** on one end and a connection with a wire **176b** at the other end. The wire **176b** is in signal communication with the cartridge assembly **200b** via a coupler **160b** (**FIG. 1**). Therefore, when the tip **251** contacts the external throughput contact **212** of the cartridge assembly **200a**, a signal conducting circuit is formed across the bulkhead **130b** such that the first firing signal can be communicated from the cartridge assembly **200a** of the perforating gun **110**, via the coupler **160b**, to the cartridge assembly **200b** of the perforating gun **112** (**Fig. 1**).

[0038] The electrical connection between the contact assembly **146b** in the bulkhead **130b** and the coupler **160b** and the electrical connection between the coupler **160b** and the cartridge assembly **200b** is similar to that already described in connection with **FIGS. 8** and 7, respectively. The first firing signal travels through these electrical connections to the input contact **210** of the cartridge assembly **200b**.

[0039] Referring to **Figs. 5A,B**, the first firing signal is received at the external input contact **222** and transmitted by the wire **224** to the electrical input **184** (**FIG. 6A**) of the switch **180** (**FIG. 6A**). Because switch **180** (**Fig 6A**) is programmed to recognize that the first firing signal is for firing the perforating gun **112**, the switch **180** initiates the firing of the perforating gun **112**.

[0040] Referring to **FIG. 3**, the firing of the perforating gun **112** is performed by using a detonation-transfer type energetic connection between the cartridge assembly **200b** (**FIG. 1**) and the coupler **160b**, which is the same as coupler **160a** shown in this Figure. In one arrangement, the coupler **160a** has a receptacle **168** in which is formed a bore **170** for receiving an optional booster charge **172** and an end of a detonator cord **174**. The detonator cord **174** is energetically connected to the shaped charge **116**. Upon receiving sufficient thermal energy from the cartridge assembly

200b (**FIG. 1**), as described below, the booster charge **172** detonates, which detonates the detonator cord **174**. The detonation train then detonates the shaped charge **116**. It should be understood that the booster charge **172** is optional and may be omitted in embodiments wherein the detonator cord **174** can be directly detonated.

[0041] **FIG. 8** illustrates the energetic connection between the cartridge assembly **200a** and the coupler **160**a. A similar energetic connection is present between the cartridge assembly **200b** and the coupler **160b**. Referring to **FIGS. 8** and **6A,** the switch **180** may include an initiating element **188**. The initiating element **188** applies activating energy for detonating the detonator cord **174** or the booster **172** in response to an activation signal (*e.g.*, electrical energy). In some embodiments, the initiating element **188** may be formed of a metal that is resistant to electrical flow and generates heat when electrical current is applied. The initiating element **188** may act directly on and detonate the detonator cord **174**. In other embodiments, the initiating element **188** may act on the booster charge **172** disposed in the receptacle **170** and positioned immediately adjacent to the initiating element **188**. When fully assembled, the booster charge **172** may be in physical contact with or spatially separated from the initiating element **188**. Nevertheless, the booster charge **172** is sufficiently close enough to be detonated by the thermal energy emitted by the initiating element **188**. The booster charge **172** and / or the detonator cord **174** may be formed of energetic materials include, but are not limited to, RDX (cyclotrimethylenetrinitramine or hexahydro-**1**,**3**,**5**-trinitro-**1**,**3**,**5**-triazine), HMX (cyclotetramethylenetetranitramine or **1**,**3**,**5**,7-tetranitro-**1**,**3**,**5**,7-tetraazacyclooctane), TATB (triaminotrinitrobenzene), HNS (hexanitrostilbene), and other similar materials that are formulated to generate a high order output *(i.e.*, thermal energy and shock waves). Detonation of the booster charge **172** thereafter detonates the detonator cord **174**, which carries the detonation to one or more shaped charges **116** of the perforating gun **112**.

[0042] To fire the perforating gun **110**, the second firing signal is transmitted via the signal conducting carrier **290** to the perforating tool **100**. The second firing signal is communicated to the cartridge **200a** in a manner previously described. In this instance, however, the switch **180** (**FIG. 6A**) recognizes that the second firing signal is an instruction to firing the perforating gun **110**. Thus, instead of passing on the

signal, the switch **180** (**FIG. 6**A) initiates the firing of the perforating gun **110** in a manner previously described.

[0043] Referring to **Figs. 1** and 7, embodiments of the present disclosure form fluid-tight seals between the bulkhead **130a,b** and an inner surface **140** defining an inner bore of the carrier **111**. Referring to **FIG. 7,** two carriers, carriers **111a** and **111b**, are shown connected at a threaded connection **252**. It should be noted that, in this embodiment, at the threaded connection **252**, there are no sealing elements forming a seal between the surface of carrier **111a** and carrier **111b**. That is, there is only metal-to-metal contact between the carriers **111a,b** and there are no interposed members, such as o-rings, that forms seals between the contacting surfaces of the carriers **111a,b**. Additionally, may be metal-to-metal contact between the carriers **111a,b** and the bulkheads **130a,b**. Instead, the sealing elements **138** only form seals between the bulkhead **130a**,**b** and the inner surface **140**. A similar sealing arrangement is present at the uphole end **280** adjacent to the end cap **292**. In other embodiments one or more seals (not shown) may be at the threaded connection **252**.

[0044] Additionally, embodiments of the present disclosure isolate a perforating gun interior from the shockwaves from the firing of an adjacent perforating gun. Referring to **FIG. 7**, the bulkhead **130** may be formed with sufficient axial thickness and of a material sufficiently strong to prevent the pressure waves and shock from one perforating gun from affecting an adjacent gun. In one arrangement, the bulkhead may have a first of seals **138a** forming a seal with a first carrier **111a** and a second set of seals **138b** forming a seal with a second carrier **111b**. The bulkhead **130** may be fixed between a first interior torque shoulder **254a** of the first carrier **111a** and a second interior torque shoulder **254b** of the second carrier **111b**. Thus, when the carriers **111a,b** are threaded together at a threaded connection **256**, the bulkhead **130** is compressed between the torque shoulders **254a,b**. In some embodiments, the toque shoulder **254a,b** may be formed on other locations of the carriers **111a,b**. As noted previously, seals **139** form a fluid barrier between the contact assemblies **146a,b** and the bulkheads **130a,b** respectively.

[0045] Referring to **FIG. 9**, there is shown another embodiment of a perforating tool **100** in accordance with the present disclosure. The perforating tool

100 may include a first gun assembly **110** and a second gun assembly **112**. Each gun assembly **110**, **112** includes a carrier **111** that is shaped to receive a charge tube **114**. Each gun assembly **110**, **112** also includes one or more shaped charges **116** fixed within the charge tube **114**. To enable selectively firing the gun assemblies **110**, **112**, a select fire system may be used in which a cartridge assembly **300a** is programmed to only fire the first gun assembly **110** and a cartridge assembly **300b** is programmed to only fire the second gun assembly **112**. Illustrative arrangements according to the present disclosure for enabling such select firing are described below.

[0046] Referring now to **FIG. 10**, the gun assembly **110** in accordance with one embodiment of the present disclosure is shown in an isometric view. For clarity, the carrier **111 (FIG. 9)** is not shown. In this embodiment, the charge tube **114** may be formed as a tubular member having a first end **118,** a second end **120**, and an interior bore **122**. The charge tube **114** provides a receiving structure to which the shaped charges **116**, a bulkhead **130a**, and a coupler **400a** are secured. The bulkhead **130a** may be fixed to the first end **118** with a suitable fastening element **132**, such as a screw.

[0047] The charge tube **114** may include a first opening **148** through which the shaped charge **116** may be inserted into the interior bore **122** and a second opening **151** through which a detonator cord **174** may be inserted into the interior bore **122**. The charge tube **114** also includes one or more slots **462** for receiving the coupler **400a**.

[0048] The coupler **400a** provides a bay into which the cartridge assembly **300a (FIG. 9)** can be inserted during assembly of the perforating tool **100 (FIG. 9)**. Upon insertion, the cartridge assembly **300a (FIG. 9)** becomes operatively engaged with the coupler **400a**: *i.e.*, physically connected to the structure of the perforating tool **100 (FIG. 9)**, electrically coupled into the signal communication wiring of the perforating tool **100 (FIG. 9)**, and energetically coupled to the ballistic assembly, which include the detonator cord **174** and optional booster charge (not shown). As further described below, the use of sliding surfaces and biased connections enable the structural, electrical connections, and energetic connections to be made principally during insertion and with minimal additional handling. **FIG. 11A** is a sectional isometric view of the cartridge assembly **300a** positioned within the coupler **400a**.

FIG. 11B is an isometric view of the coupler **400a**. **FIG. 11C** is an end view of the coupler **400a**.

[0049] Referring to **FIGS. 11A-C**, in one embodiment, the coupler **400a** may include a hollow body **402** having a tubular receptacle **404** that communicates with an interior **406** and a coupler contact **408**.

[0050] Referring to **FIG. 11C,** the tubular receptacle **404** extends from the body **402** and includes a bore **410**. The bore **410** is sized and shaped to receive an end **412** of the detonator cord **174 (FIG. 10)** and optionally a booster charge **414**. The coupler contact **408** includes a coupler contact surface **416** and a wiring contact **420**. The coupler contact surface **416** may be formed on a body, such as, plate, a rod, tube, fastener, or other electrically conductive member that is exposed to the interior **406**. The wiring contact **420** may be an eyelet, fastener, hook, frame, or other member that is exposed to an exterior of the body **402** and has at least a portion that is electrically conductive. The wiring contact **420** is electrically connected to a signal conducting carrier, such as a wire **176**. Referring to **FIGS. 11B** and **C**, wings **422** formed on an external surface of the body **402** may be sized and shaped to be closely received into complementary slots **462 (FIG. 10)** formed at the end **120 (FIG. 10)** of the charge tube **114**. The coupler **400b** is generally of the same construction as that of the coupler **400a**.

[0051] Referring to **FIGS. 12A-B**, there is schematically shown a cartridge assembly **300a** in accordance with one embodiment of the present disclosure that is housed at least partially within the interior **406** of the coupler **400**a **(FIG. 11 B** and **C)**. Cartridge assembly **300b** may use a similar configuration as cartridge assembly **300a**. **FIG. 12**A is a top view of the cartridge assembly **300**a that omits an upper section so that the interior may be visible. **FIG. 12**B is an isometric view of the cartridge assembly **300**a.

[0052] As will be apparent from the discussion below, the cartridge assembly **300a** acts as a structural and electrical adaptor that enables switches of various different configurations and sizes to be used in the perforating tool **100 (FIG. 9)**. Exemplary switches **180, 181** that may be operatively connected to the cartridge assembly **300a** have already been described in connection with **FIGS. 6A-B**.

[0053] In one embodiment, the cartridge assembly **300a** includes a body **302** in which a cavity **304** is formed and electrical contact assemblies for communicating signals to and from the switch **180** (**FIG. 6A**). The body **302** is sized to be received into the interior **406** of the coupler **400**a (**FIG. 11B** and **C**). The cavity **304** is sized and shaped to house the switch **180** (**FIG. 6A**). In one arrangement, the electrical assemblies include a throughput contact **308** and an input contact **310** to form electrical connections with the switch **180** (**FIG. 6A**).

[0054] The input contact **310** conveys a received signal to the switch **180** (**FIG. 6A**) inside the cartridge assembly **300a**. The input contact **310** may include a resilient external input contact **322** that projects from an exterior wall **326** of the body **302**. The external input contact **322** may be sized to present a contact surface that is biased away from the body **302**. The biasing allows the external input contact **322** to compressively and physically contact the coupler contact surface **416** (**FIG. 11A**). The input contact **310** may have an end **328** positioned within the cavity **304** and that is suitable to electrically connect with the electrical input **184** (**FIG. 6A**) of the switch **180** (**FIG. 6**). The input contact **310** may be a spring, plate, pad, or other conductive element. In one embodiment, the input contact **310** is formed as continuous thin electrically conductive plate. In other embodiments, the input contact **310** may be formed of two or more elements.

[0055] **FIG. 11A** illustrates the signal transmission interface and signal transfer via the input contact **310** of the cartridge assembly **300a**. A signal communication path is formed when the external input contact **322** of the cartridge assembly **300a** (**FIG. 12**A) electrically couples to the coupler contact surface **416** of the coupler **400a**, which is in electrical communication with the wiring contact **420**. Therefore, when the electrical contact surface **322** of the cartridge **200a** (**FIG. 12A**) contacts the coupler contact surface **416**, a signal conducting circuit is formed between the wire **176** and the switch **180** (**FIG. 6A**) inside the cartridge assembly **300a** (**FIG. 12A**).

[0056] The throughput contact **308** conveys the signal received by the cartridge assembly **300a** to another cartridge assembly, here the cartridge assembly **300b** (**FIG. 9**). The signal may be the same as or similar to the received signal or a new signal.

The throughput contact **308** may include an external throughput contact **332** and an end **334**. The external throughput contact **332** may be sized to present a contact surface that is biased away from the body **302** to compressively and physically contact the conductive tip **251** (**FIG. 13**) as described later. The end **334** terminates within or near the cavity **304** and may be electrically connected to the electrical output **186** (**FIG. 6A**) of the switch **180** (**FIG. 6**). In one embodiment, the throughput contact **308** is formed as continuous thin electrically conductive plate. In other embodiments, the throughput contact **308** may be formed of two or more elements.

[0057] In embodiments, the cartridge assembly **300** may also include a grounding contact **340** for electrically grounding the switch **180** (**FIG. 6**). The grounding contact **340** may include an end **342** positioned in the cavity **304** and an external ground contact **344**. The external ground contact **344** may be in electrical contact with an inner surface of the charge tube **114** or bulkhead **130b** (**FIG. 2**). The end **342** terminates within or near the cavity **304** and may be electrically connected to the ground wire **194** (**FIG. 6A**) of the switch **180** (**FIG. 6**). In one embodiment, the grounding member **340** is formed as continuous thin electrically conductive plate. In other embodiments, the grounding member **340** may be formed of two or more elements.

[0058] The cartridge assembly **300a** further includes a cradle **350** for receiving the initiating element **188** (**FIG. 6A**)). Referring to **FIGS. 11 A** and **12A**, the cradle **350** is sized and shaped to position the initiating element **188** (**FIG.11A**) sufficiently close to detonate the detonating cord end **412** and / or booster **414** in the tubular receptacle **404** in a manner already previously described; *i.e.*, form an energetic connection. The cradle **350** may communicate with the cavity **304** using suitable openings (not shown) that can accommodate hardware and wiring.

[0059] Referring to **FIG. 11A, 12A** and **FIG. 6A**, it should be noted that the cradle **350** and the cavity **304** are oriented to position the switch **180** and the initiating element **188** in a parallel, or side-by-side, relative alignment. That is, the switch **180** and the initiation element **188** at least partially overlap along a longitudinal axis of the perforating tool **100** (**FIG. 9**), the longitudinal axis being an axis that passes through centers of the ends **118**, **120** of the charge tube **114** (**FIG. 9**). In some embodiments,

the switch **180** and the initiation element **188** may have different radial offsets or distances from the longitudinal axis. In further embodiments, an annular space relative to the longitudinal axis may separate the switch **180** and the initiation element **188**. Consequently, when inserted into the perforating tool **100** (**FIG. 9**), the switch **180** and the initiation element **188** also at least partially overlap along a longitudinal axis of the perforating tool **100** (**FIG. 9**). As should be appreciated, the parallel, side-by-side arrangement occupies less total axial distance along the longitudinal axis than a serial, end-to-end arrangement. Additionally, in certain embodiments, the longitudinal axis may intersect the initiation element **188**. That is, the initiation element **188** may centrally positioned at or concentric with the longitudinal axis and the switch **180** may be radially offset from the initiation element **188** and the longitudinal axis. Also, as best seen in **FIG. 12B**, a lid **360** may be used to enclose the switch **180** (**FIG. 6**) within the cavity **304**.

[0060] **FIG. 13** illustrates the signal transmission interface and signal transfer via the throughput contact **308** of the cartridge assembly **300a**. A signal communication path is formed when the external throughput contact **332** of the cartridge assembly **300a** electrically couples to the contact assembly **146b** in the bulkhead **130b**. As described previously, the contact assembly **146b** includes a signal conducting tip **251** on one end and a connection with a wire **176b** at the other end. The wire **176b** is in signal communication with the cartridge assembly **300b** (**FIG. 9**). Therefore, when the tip **251** contacts the external throughput contact **332** of the cartridge assembly **300a**, a signal conducting circuit is formed across the bulkhead **130b** such that the first firing signal can be communicated from the cartridge assembly **300a** of the perforating gun **110** to the cartridge assembly **300b** of the perforating gun **112** (**FIG. 9**).

[0061] Like embodiments previously described, it should be appreciated that the switch **180** (**FIG. 6A**) may be pre-installed in the cartridge assembly **300a** prior to assembly of the perforating tool **100** (**FIG. 9**). This pre-installation may include making electrical connections between the electrical input **184**, electrical output **186**, and ground **194** (**FIG. 6A**) of the switch **180** (**FIG. 6A**) and the ends **328**, **334**, **342**, respectively, (**FIG. 12A**). The electrical connections may be made by known

techniques such as soldering, splicing, etc. Later installation simply requires sliding the cartridge assemblies **300a,b (FIG. 9)** inside the couplers **400a,b (FIG. 10)**, respectively, of the perforating tool **100 (FIG. 9)** to form the electrical connections.

[0062] Referring to **FIG. 9**, the gun assembly **112** also includes features similar to those described in connection with the gun assembly **110**, *e.g.*, a cartridge assembly **300b**, a bulkhead **130b**, a coupler **400b**, etc. and uses the same construction as gun assembly **110**, although in other embodiments a different construction may be used.

[0063] Referring to **FIGS. 9** and **10**, in one illustrative mode of assembly, two or more perforating guns, *e.g.*, guns **110**, **112**, may be assembled with wiring **176a,b** and the components required to form a ballistic train (e.g., detonating cord **174**, shaped charges **116**, etc) but without the cartridge assembly **300**a, which contains the addressable switch **180** and initiating element **188 (FIG. 6**A). The wiring **176** winds around an outer surface **361** of the charge tube **114** and connects to the external contact member **408 (FIG. 11**A) which is positioned on wing **422**a. While not visible in **FIG. 10**, it should be appreciated that the external contact member **408** is positioned external to the charge tube **114** such that an electrical connection with the wiring **176** can be readily made.

[0064] Thereafter, the perforating guns **110**, **112** may be shipped to a rig site. At the rig site, the cartridge assembly **300**a is inserted into the coupler **400**a and the cartridge assembly **300**b engages the coupler **400b** upon being inserted into the coupler **400**b. It should be noted that the engagement is accomplished without removing or disassembling the charge tube assembly. A similar procedure is used if three or more perforating guns are present. Thereafter, the gun assemblies may be connected sequentially.

[0065] It should be noted that the assembly at the rig site forms electrical and energetic connections at the same time that perforating gun **100** is assembled. For example, sliding the cartridge assembly **300**a into the coupler **400**a physically and electrically couples the coupler contact surface **416** with the external input contact **322**. The external input contact **322** may be a spring-like biased body that can compress into a biased engagement with the coupler contact surface **416**. Sliding the cartridge

assembly **300**a into the coupler **400**a also physically positions the initiating assembly **188** (**FIG. 11A**) close enough to the detonator cord end **412** (**FIG. 11A**) or booster **414** (**FIG. 11A**) to form an energetic connection therebetween. Also, installing the bulkhead **130**b onto the end **118** of the charge tube **114** physically and electrically couples the resilient external throughput contact **332** and the conductive tip **251** as well as the contact **340** and a surface of the charge tube **114** or the bulkhead **130b**. The external throughput contact **332** may also be a spring-like biased body that can compresses into a biased engagement with the conductive tip **251**. Likewise, the contact **340** may be a spring-like biased body that can compresses into a biased engagement with the bulkhead **130b** or charge tube **114**.

[0066] The operation of the **FIGS. 9-13** embodiments is generally similar to the perforating guns and assemblies previously described. Referring to **FIG. 9**, in one exemplary mode of operation, the perforating gun closest to the downhole end **282**, here perforating gun **112**, is fired first. Thereafter, the next most adjacent perforating gun uphole of the fired perforating gun, here perforating gun **110**, is fired. To facilitate sequential "bottom up" firing of the perforating tool **100**, multiple firing signals may be sent. For instance, a first firing signal may be sent to fire the perforating gun **112** and a second firing signal may be sent to fire the perforating gun **110**. As further described below, the cartridge assembly **300a** is programmed to pass the first firing signal to the cartridge **300b**. The cartridge **300b** is programmed to fire the perforating gun **112** upon receiving the first firing signal. The cartridge **300a** is programmed to fire the perforating gun **110** upon receiving the second firing signal. If more than two gun assemblies are present, then three or more cartridge assemblies, couplers, and associated firing signals may be needed. However, as described in with **FIG. 14** later, the signal direction can be reversed by transmitting the firing signal to throughput contacts **308** and passing firing signals through the input contacts **310**. That is, the cartridges **300a,b** are bi-directional.

[0067] To initiate firing, the first firing signal may be transmitted from a surface location to the perforating gun **100** by a signal conducting carrier **290**. A signal receiving interface for receiving the first firing signal is provided in the end cap **292**. The signal transfer assembly **146a** includes a signal conducting tip **251** on one end and

a connection with a wire **176a** at the other end. The wire **176a** is in signal communication with the cartridge assembly **300a** via the coupler contact **408** (**FIG. 11**A). Therefore, when the tip **251** electrically engages the signal conducting carrier **290**, a signal conducting circuit is formed across the bulkhead **130a** such that the first firing signal can be communicated from the signal conducting carrier **290** via wire **176a** to the coupler contact **408** and then to the switch **180** (**FIG. 6**A) inside the cartridge assembly **300a** (**FIG. 12A**).

[0068] Referring to **FIG. 11A**, the first firing signal travels from the coupler contact **408** to the electrical input **184** (**FIG. 6A**) of the switch **180** (**FIG. 6A**). Because the switch **180** (**FIG. 6A**) is programmed to fire the gun assembly **110** (**FIG. 1**) only after receiving the second firing signal, the switch **180** (**FIG. 6A**) passes the first firing signal to the throughput contact **308** (**FIG. 12**a). Referring to **FIG. 13**, the first firing signal travels via the external throughput contact **332** of the throughput contact **308** and the signal conducting tip **251** to the wire **176b**. Thereafter, the first firing signal travels via the wire **176b** to the cartridge assembly **300b**. Because switch **180** (**Fig 6A**) in cartridge assembly **300b** is programmed to recognize that the first firing signal is for firing the perforating gun **112**, the switch **180** (**FIG. 6**A) initiates the firing of the perforating gun **112**.

[0069] To fire the perforating gun **110**, the second firing signal is transmitted via the signal conducting carrier **290** to the perforating tool **100**. The second firing signal is communicated to the cartridge **300a** in a manner previously described. In this instance, however, the switch **180** (**FIG. 6A**) recognizes that the second firing signal is an instruction to firing the perforating gun **110**. Thus, instead of passing on the signal, the switch **180** (**FIG. 6A**) initiates the firing of the perforating gun **110** in a manner previously described.

[0070] Referring to **FIG. 14**, there is shown another embodiment of a perforating tool **100** in accordance with the present disclosure. The perforating tool **100** may include a first gun assembly **110** and a second gun assembly **112**, which include features previously discussed such as associated bulkheads **130a,b,** respectively. To initiate firing, the first firing signal may be transmitted from a surface location to the perforating gun **100** by a signal conducting carrier **290**. To enable

selectively firing the gun assemblies **110**, **112**, a select fire system may be used in which a cartridge assembly **300a** is programmed to only fire the first gun assembly **110** and a cartridge assembly **300b** is programmed to only fire the second gun assembly **112**. The cartridge assembly **300a** has an associated coupler **400a**. The cartridge assembly 300b has an associated coupler **400b**.

[0071] In the **FIG. 14** arrangements, the firing signals are conveyed in an opposite direction through the cartridge assemblies **300a,b** as compared to the **FIG. 9** arrangement. That is, the firing signals are conveyed by the signal conducting carrier **290** to the throughput contact **308a**. Depending on the firing signal, the firing signal either fires the gun assembly **110** or passes the firing signal via the input contact **310a** to the gun assembly **112**. Thus, the throughput contact **308a** can receive a signal to fire switch **180** inside cartridge **300A** or can pass the firing signal to input contact **310a** to the switch **180 (FIG. 6A)** inside the cartridge assembly **300b**.

[0072] As used in this disclosure, the terms "aligned" means co-linear or concentric. Thus, axes that are aligned are concentric. Axes that are misaligned or eccentric are separated by a predetermined distance. As used in this disclosure, terms such as "substantially," "about," and "approximately" refer to the standard engineering tolerances that one skilled in the art of well tools would readily understand.

[0073] As used herein, an "electrical connection" or "electrical engagement" is a connection wherein electrical signals are conveyed between two or more objects. Physical contact between the two bodies may or may not be present.

[0074] It is also reiterated that devices according to the present disclosure may be used in conjunction with the switch **180**, the switch **181** or any other switch configuration, whether or not addressable.

[0075] The foregoing description is directed to particular embodiments of the present invention for the purpose of illustration and explanation. It will be apparent, however, to one skilled in the art that many modifications and changes to the embodiment set forth above are possible without departing from the scope of the invention. It is intended that the following claims be interpreted to embrace all such modifications and changes.

THE CLAIMS

What is claimed is:

1. An apparatus for use in a wellbore, comprising:

a first gun assembly having:

- a first charge tube having a longitudinal axis defined by an axis that passes through centers of opposing ends of the charge tube;
- a first detonator cord disposed along the first charge tube,
- a first signal-conveying wire disposed along the first charge tube,
- a first coupler affixed to an end of the first charge tube, the first coupler including:
    - a receptacle receiving an end of the detonator cord, and
    - a coupler contact electrically connected to the first signal conveying wire, and
- a first cartridge assembly including:
    - a body having a cavity and a cradle,
    - an input contact positioned on the body and electrically coupled to the coupler contact,
    - a throughput contact positioned on the body,
    - a switch disposed in the cavity, the switch being electrically connected to the input contact and the throughput contact, and
    - an initiating element disposed in the cradle and electrically connected to the switch, the initiating element being energetically coupled to the end of the detonator cord in the receptacle, wherein the switch and the initiating element at least partially overlap along the longitudinal axis; and
- a first signal transfer assembly electrically coupled to the throughput contact; and

a second gun assembly having:

- a second charge tube,
- a second detonator cord disposed along the second charge tube,

- a second signal-conveying wire disposed along the second charge tube, the second signal-conveying wire being electrically coupled to the first contact assembly,
- a second coupler affixed to an end of the second charge tube, the second coupler including:
    - a receptacle receiving an end of the second detonator cord, and
    - a coupler contact electrically connected to the second signal conveying wire; and
- a second cartridge assembly including:
    - a body having a cavity,
    - an input contact electrically positioned on the body and coupled to the second coupler contact,
    - a throughput contact positioned on the body,
    - a switch disposed in the cavity, the switch being electrically connected to at least the input contact, and
    - an initiating element disposed in the cavity and electrically connected to the switch, the initiating element being energetically coupled to the end of the second detonator cord in the receptacle.

2. The apparatus of claim 1, wherein the switch of the second cartridge is also connected to the throughput contact of the second cartridge, and wherein the second gun includes a second signal transfer assembly electrically coupled to the throughput contact of the second cartridge assembly, and further comprising:

a third gun assembly having:

- a third charge tube,
- a third detonator cord disposed along the third charge tube,
- a third signal-conveying wire disposed along the third charge tube, the third signal-conveying wire being electrically coupled to the second contact assembly,
- a third coupler affixed to an end of the third charge tube, the third coupler including:

- a receptacle receiving an end of the third detonator cord, and
- a coupler contact electrically connected to the third signal conveying wire; and

- a third cartridge assembly including:
  - a body having a cavity and a cradle,
  - an input contact electrically positioned on the body and coupled to the third coupler contact,
  - a throughput contact positioned on the body,
  - a switch disposed in the cavity, the switch being electrically connected to at least the input contact, and
  - an initiating element disposed in the cradle and electrically connected to the switch, the initiating element being energetically coupled to the end of the third detonator cord in the receptacle.

3. An apparatus for use with a gun assembly having charge tube with a longitudinal axis defined by an axis that passes through centers of opposing ends of the charge tube, a detonator cord disposed along the first charge tube, and a signal-conveying wire disposed along the first charge tube, the apparatus comprising:

- a switch having an initiating element;
- a coupler configured to be received at an end of the first charge tube, the first coupler including:
  - a receptacle receiving an end of the detonator cord, and
  - a coupler contact electrically connected to the first signal conveying wire; and
- a cartridge assembly engagable with the first coupler, the cartridge assembly including:
  - a body having a cavity configured to receive the switch and a cradle configured to receive the initiating element,
  - an input contact positioned on the body, and
  - a throughput contact positioned on the body,

wherein engaging the cartridge assembly with the coupler simultaneously electrically couples the input contact to the coupler contact and energetically couples the initiating element with the end of the detonator cord, and

wherein the switch and the initiating element are positioned in a parallel, side-by-side arrangement to at least partially overlap along the longitudinal axis.

4. The apparatus of claim 3, wherein the initiation element is intersected by the longitudinal axis and the switch is radially offset from the longitudinal axis.

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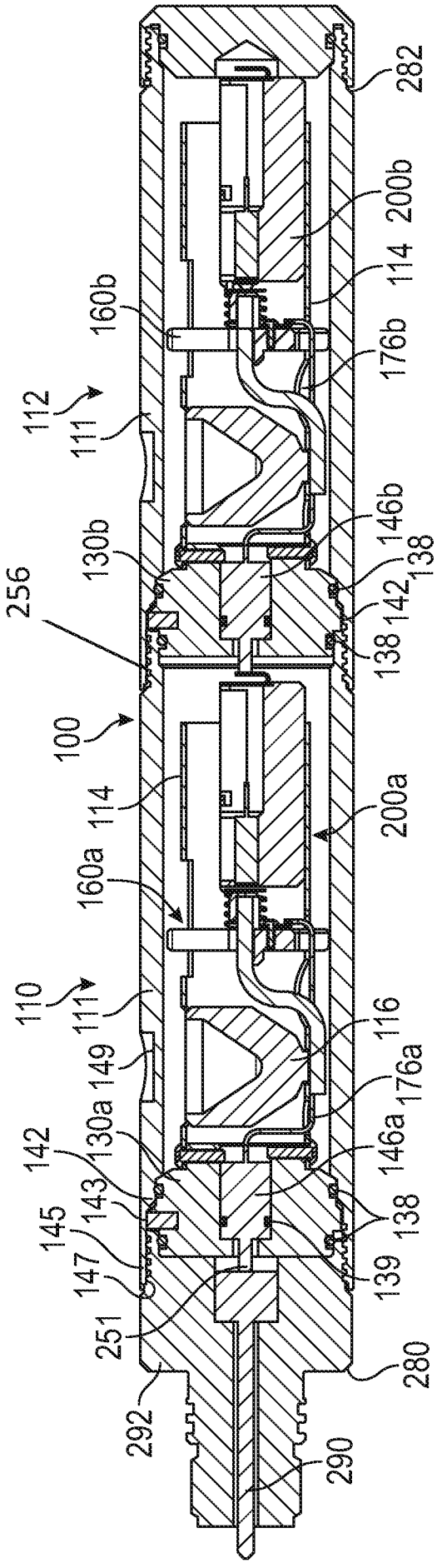

FIG. 1

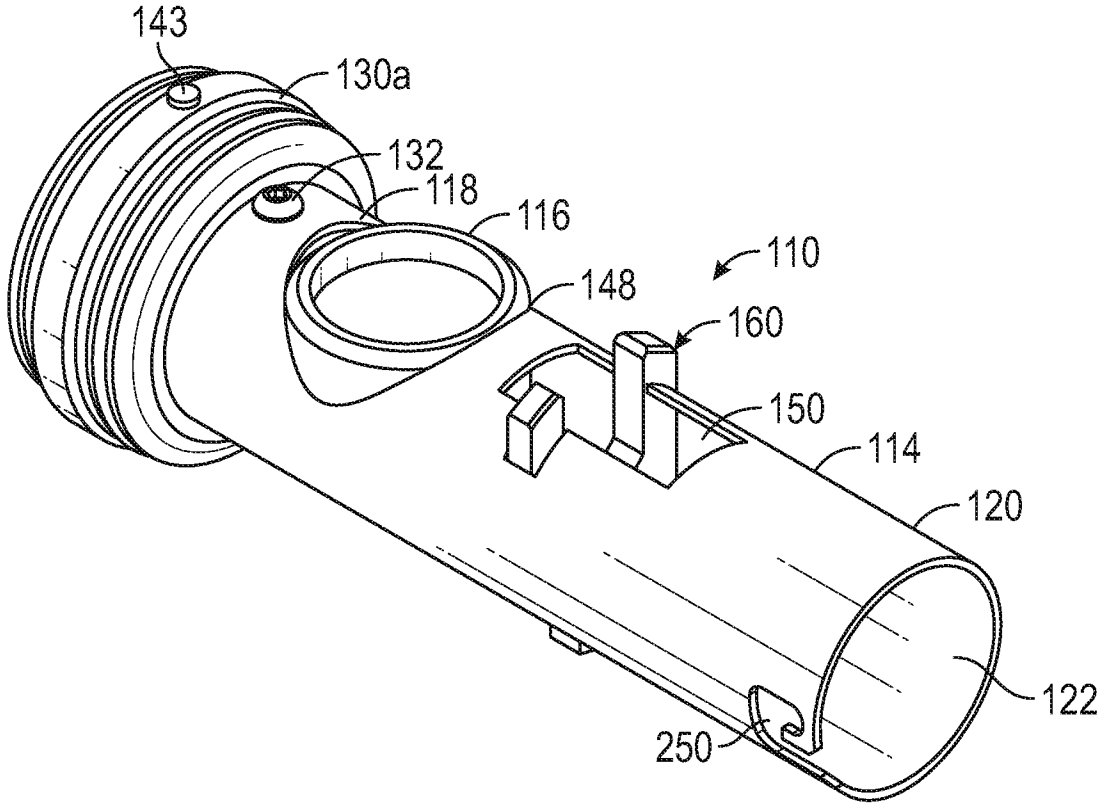
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FIG. 2

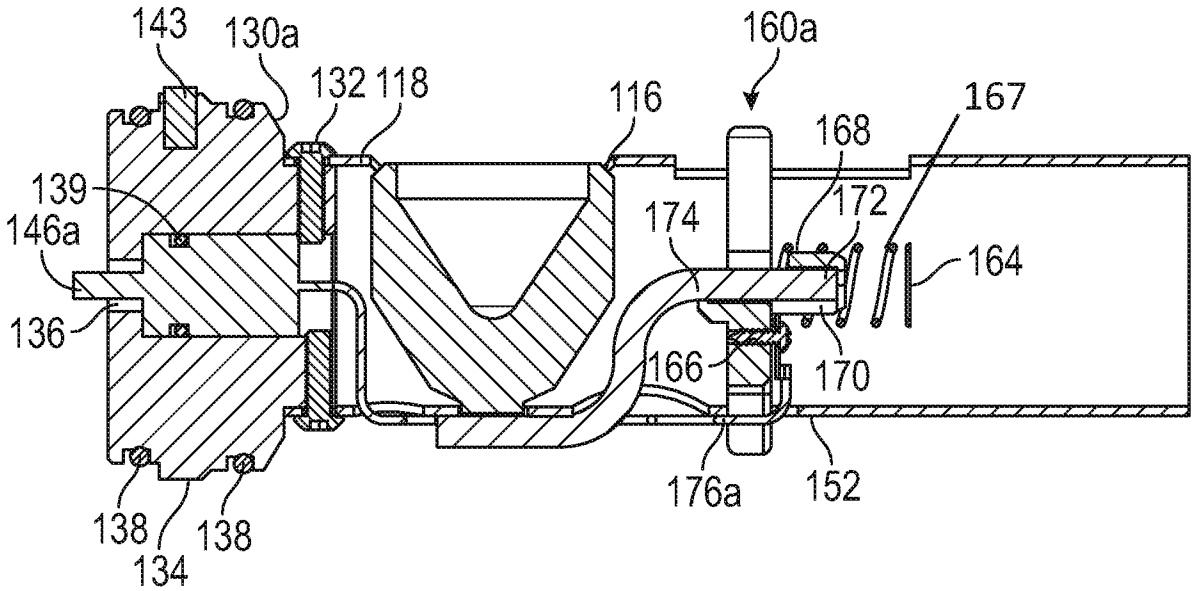
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FIG. 3

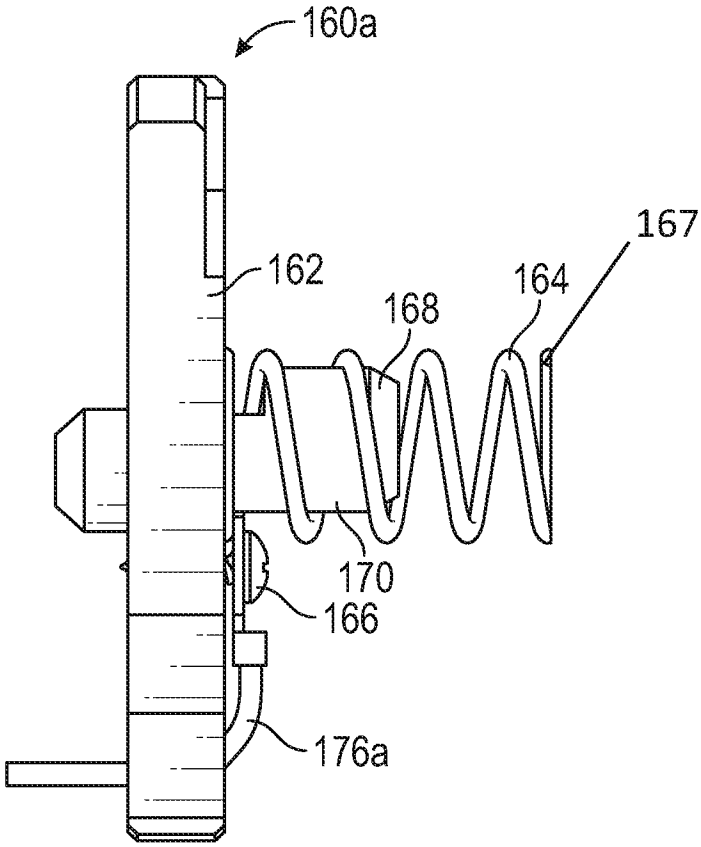
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FIG. 4A

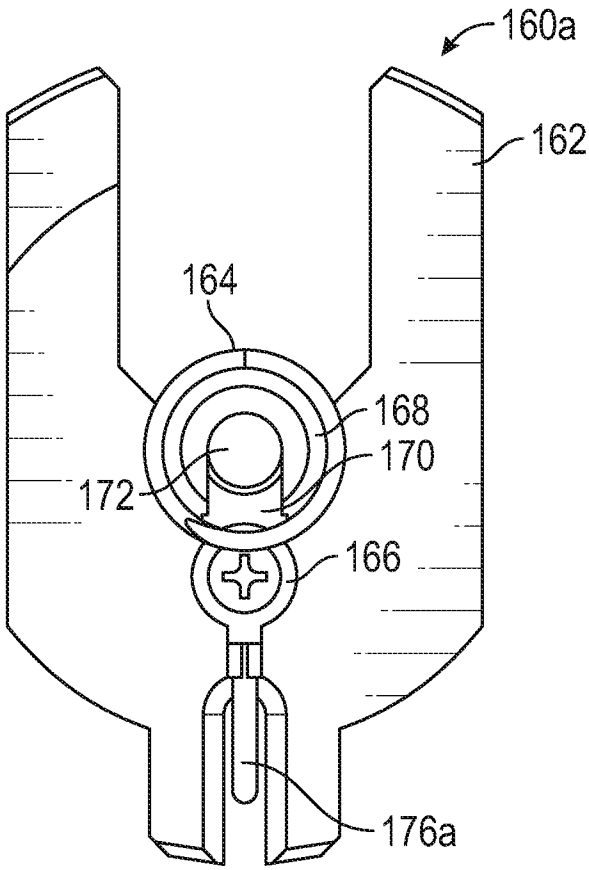
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FIG. 4B

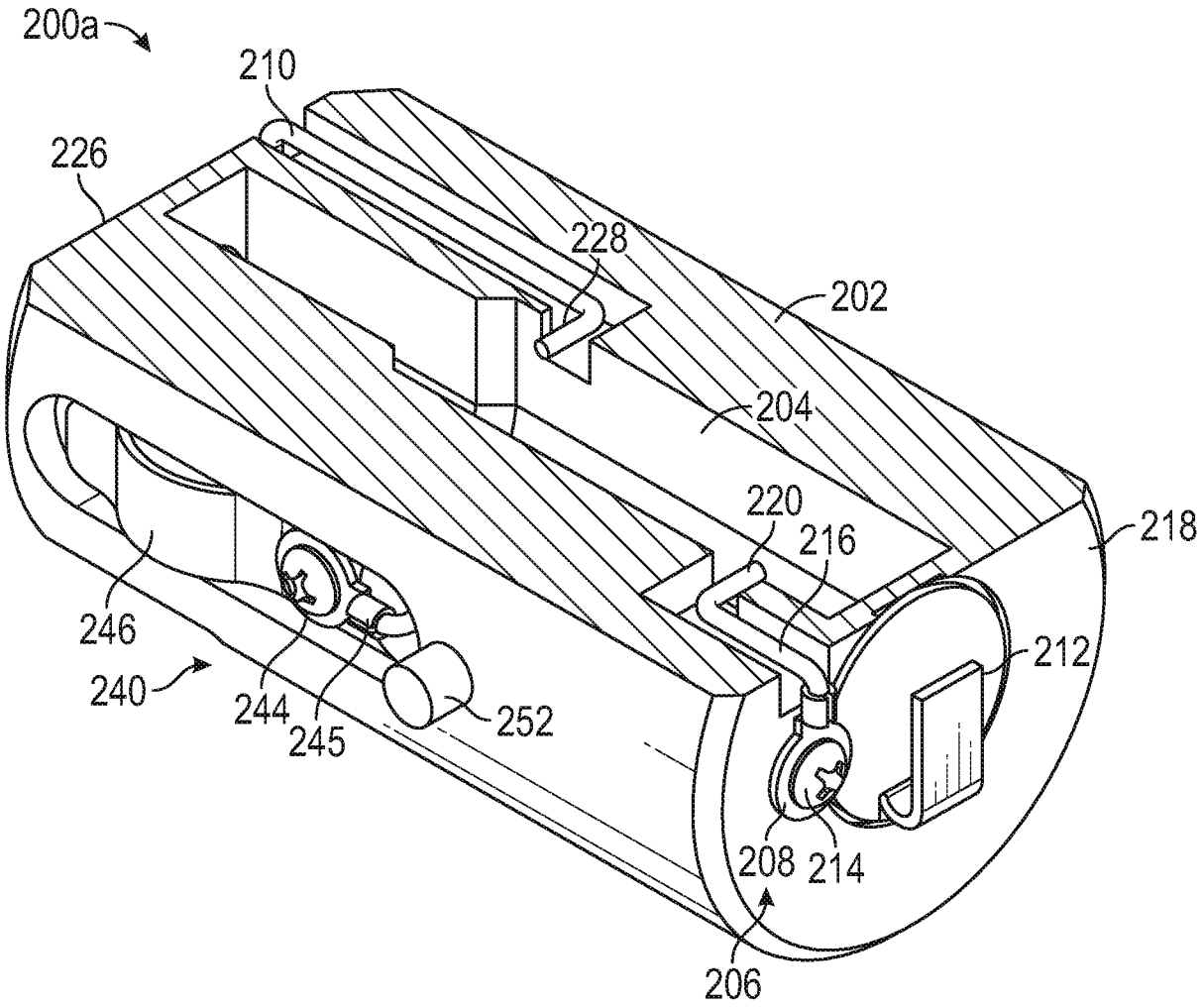
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FIG. 5A

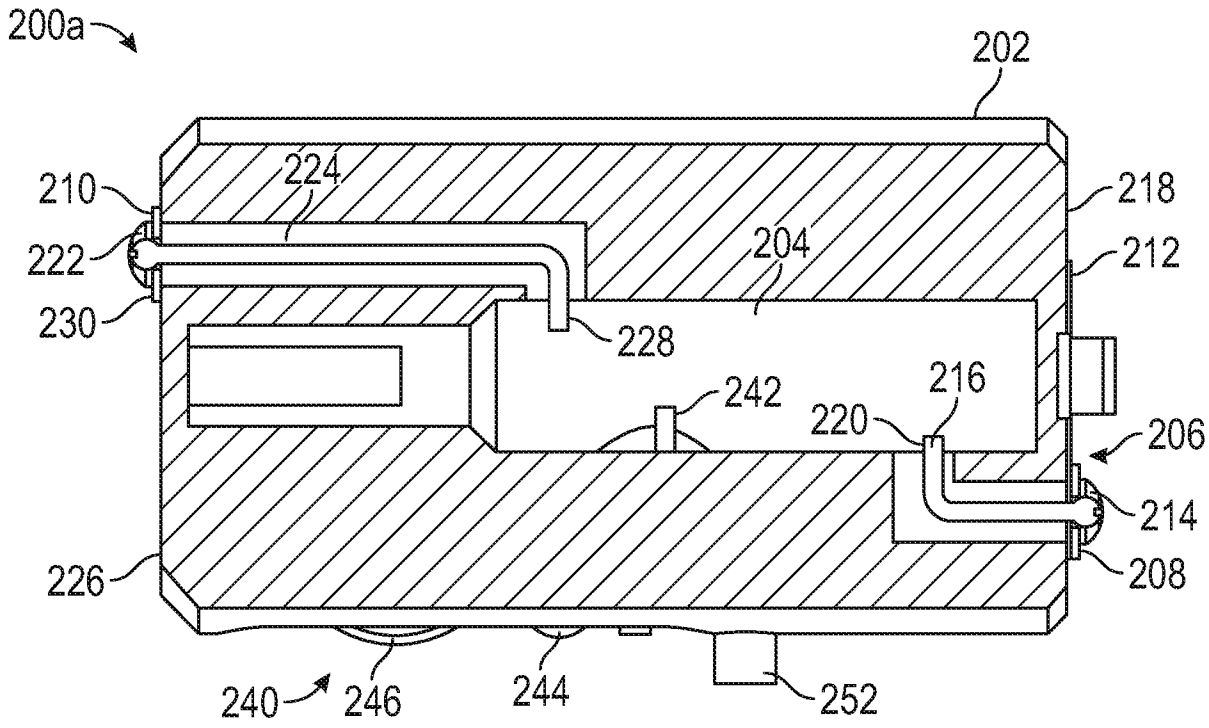
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FIG. 5B

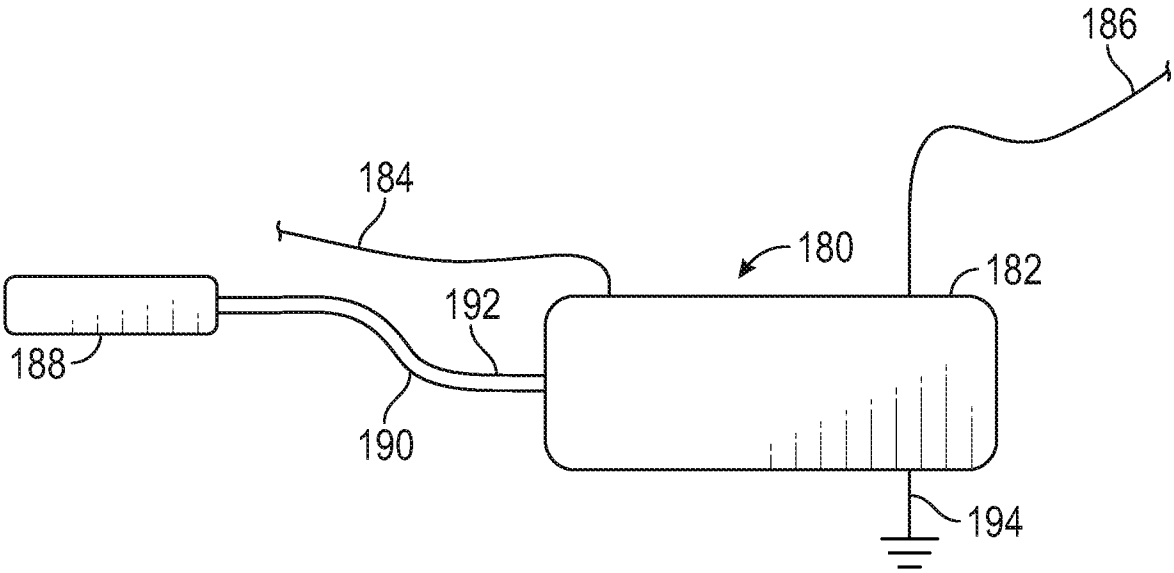


FIG. 6A

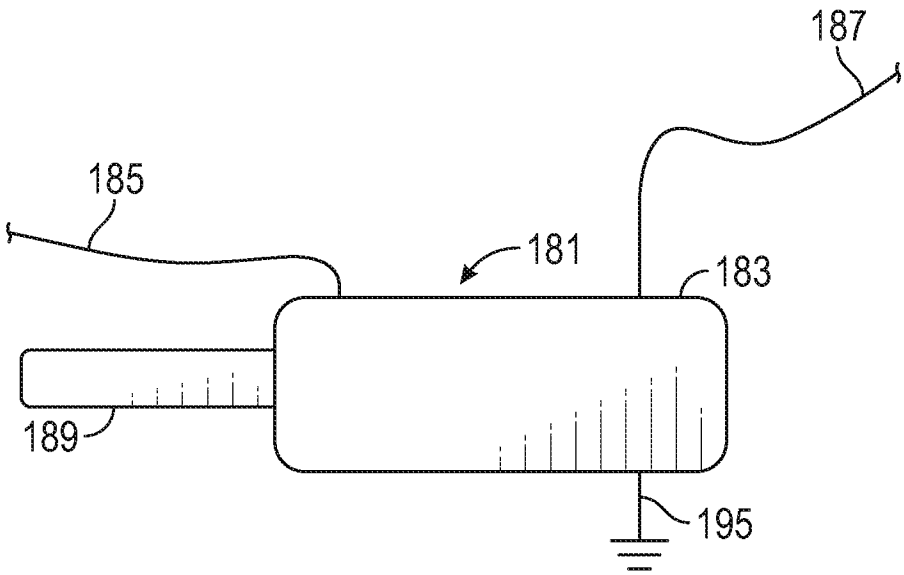
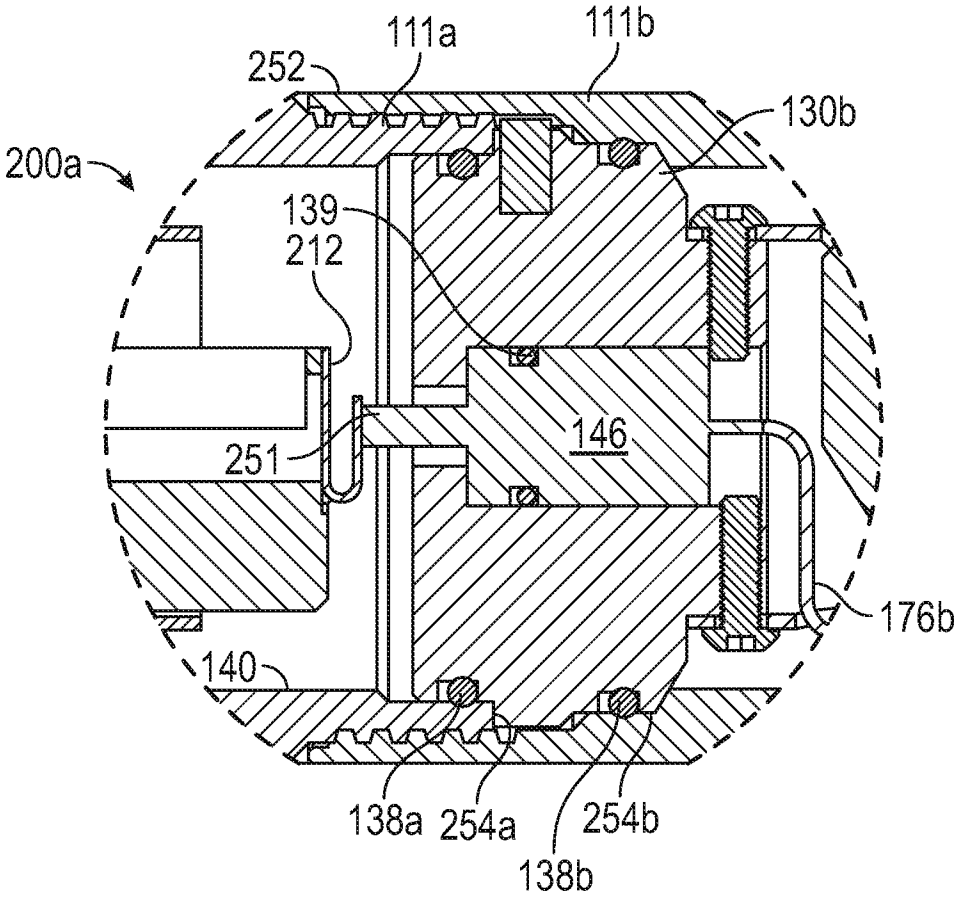


FIG. 6B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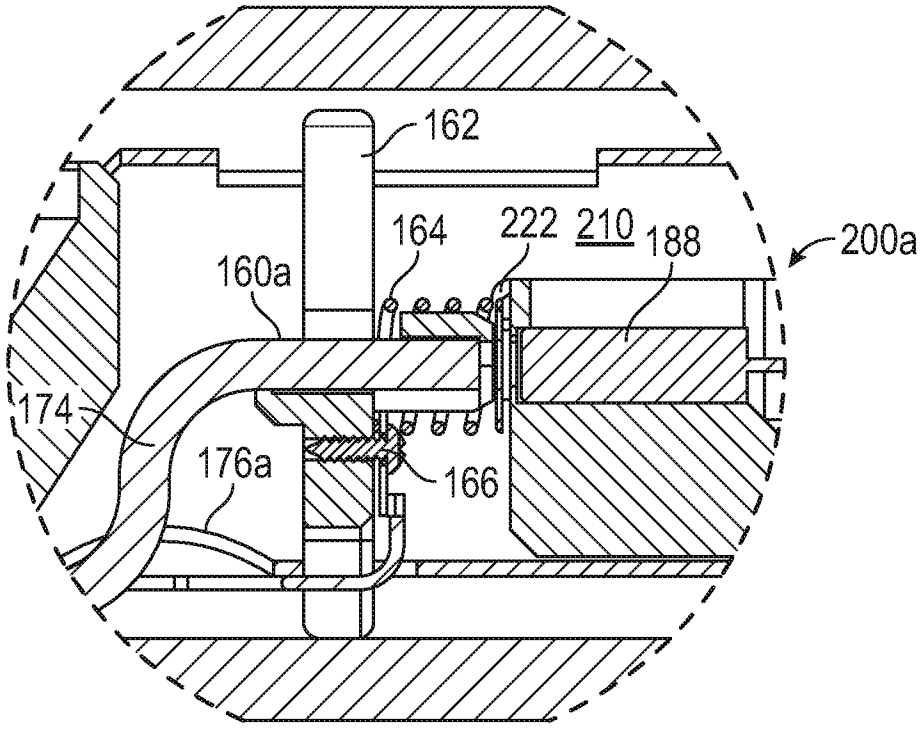
251
176b
140
138a
254a
254b
138b

FIG. 7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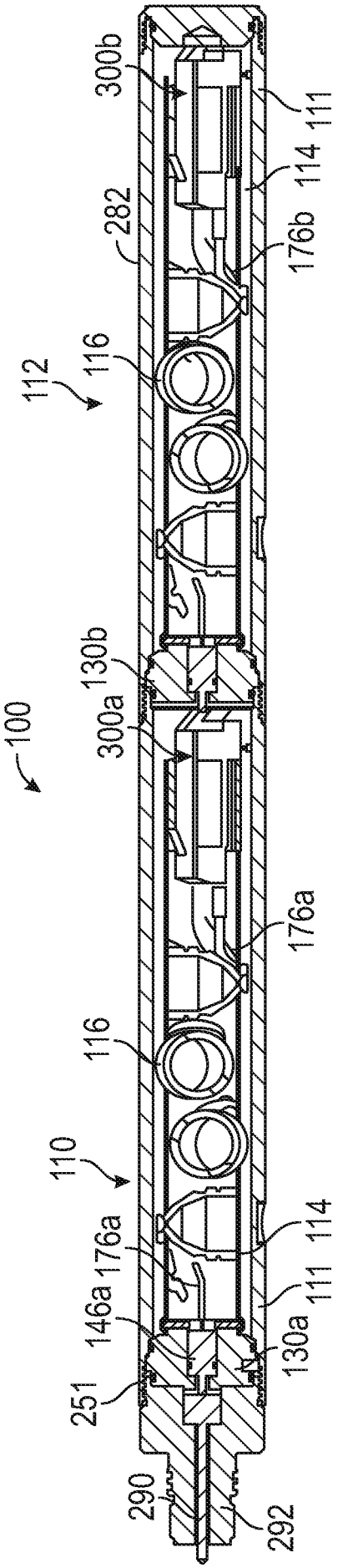
176a
166

FIG. 8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176a
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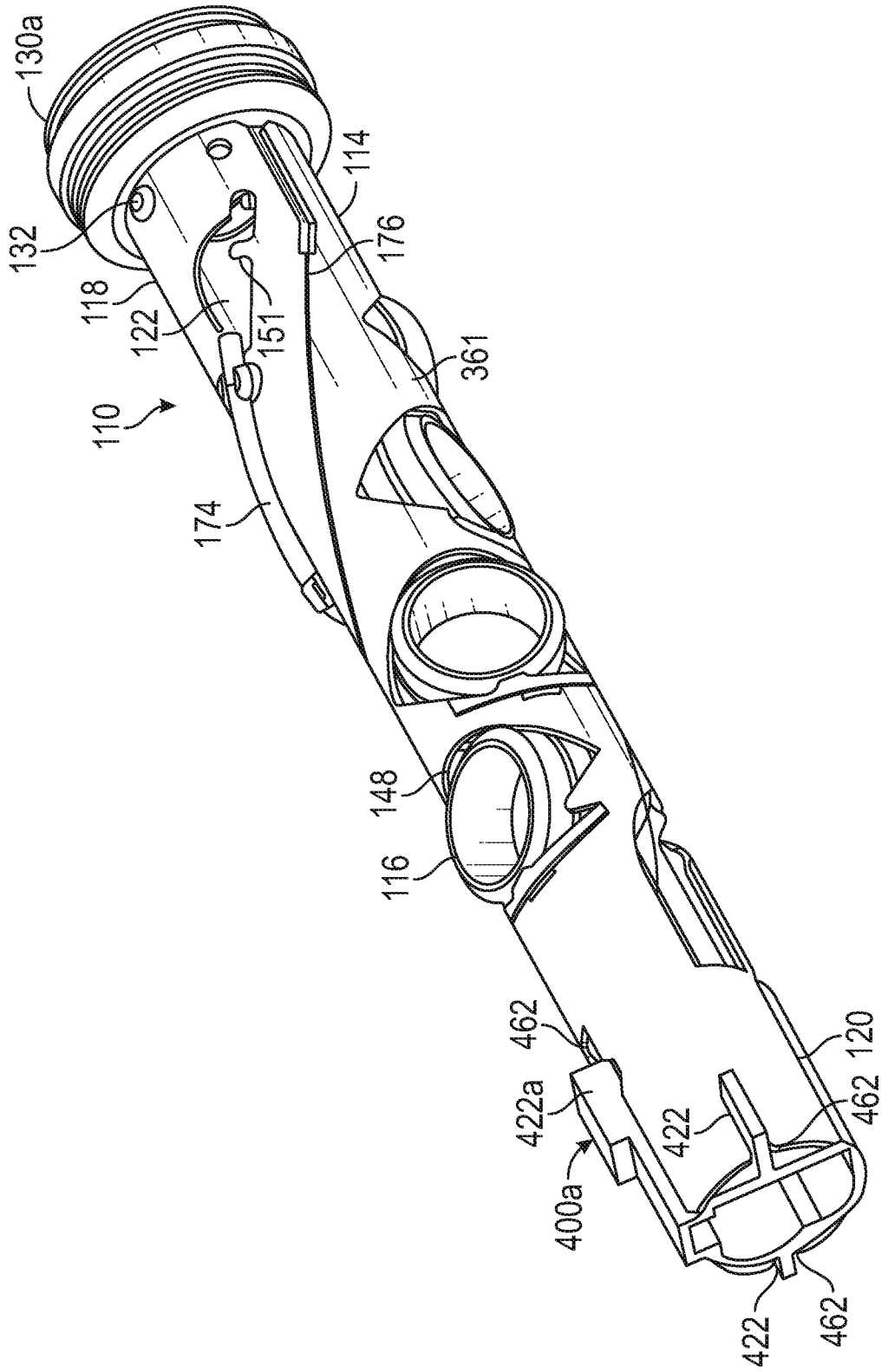
290
292
300a
300b

FIG. 9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462

FIG. 10

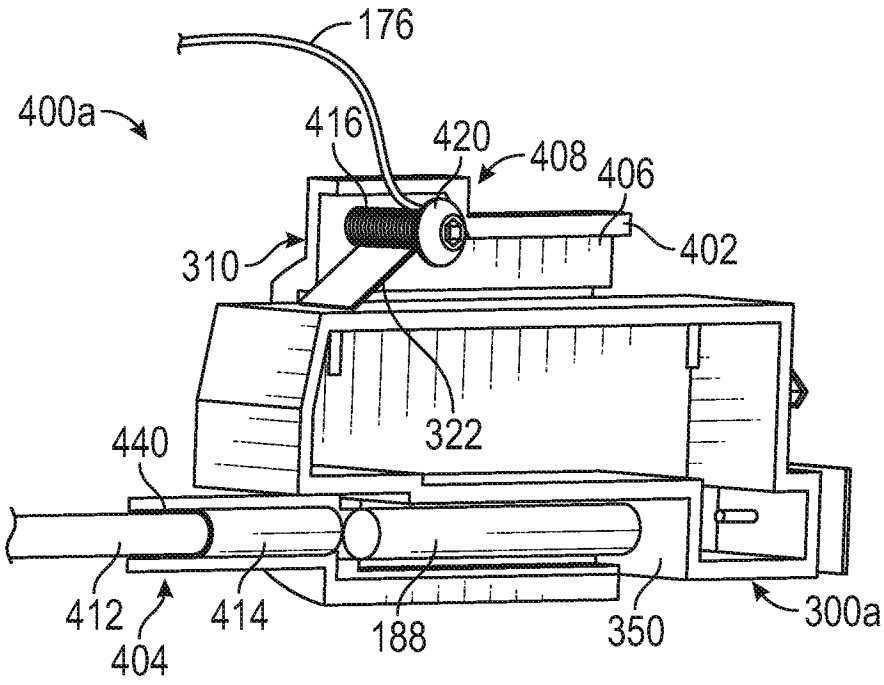

FIG. 11A

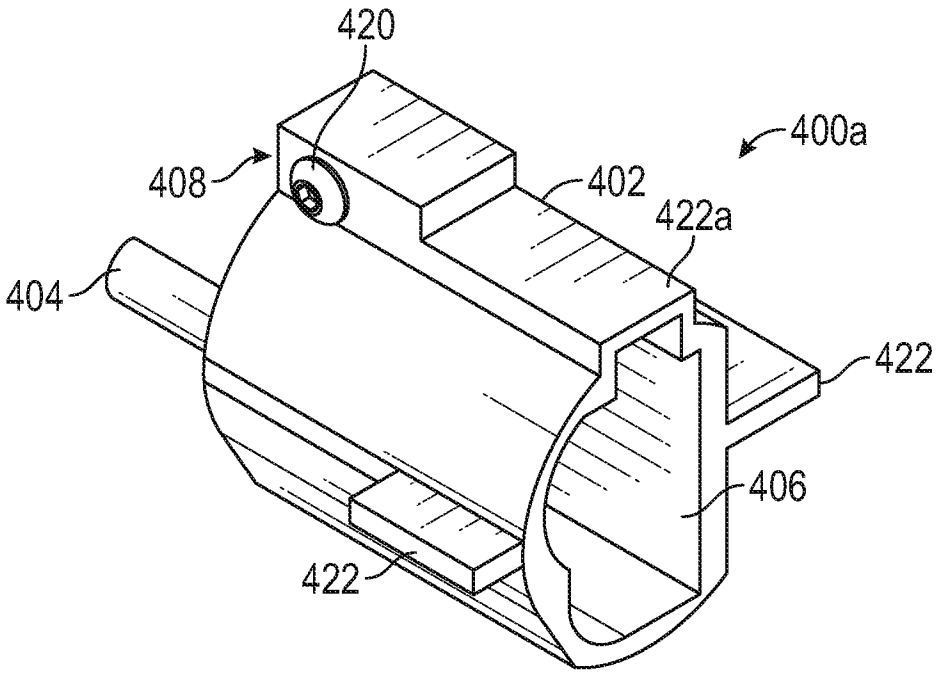

FIG. 11B

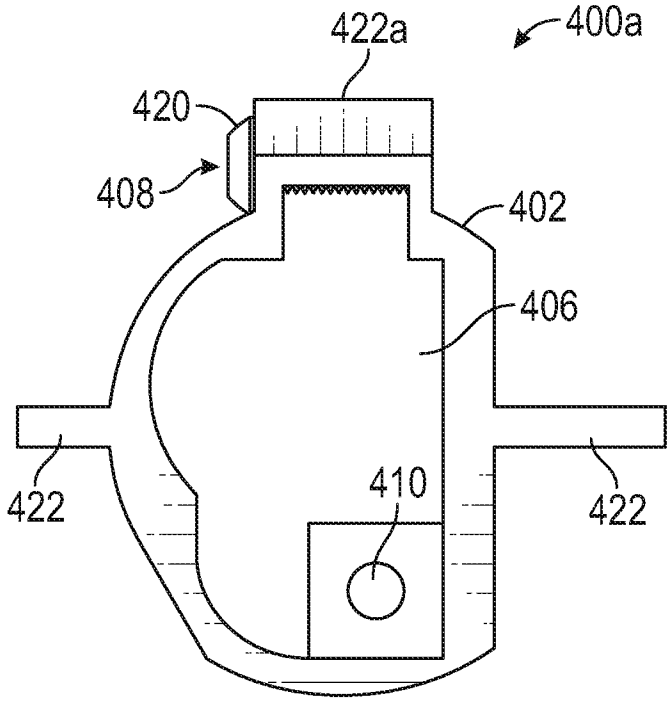

FIG. 11C

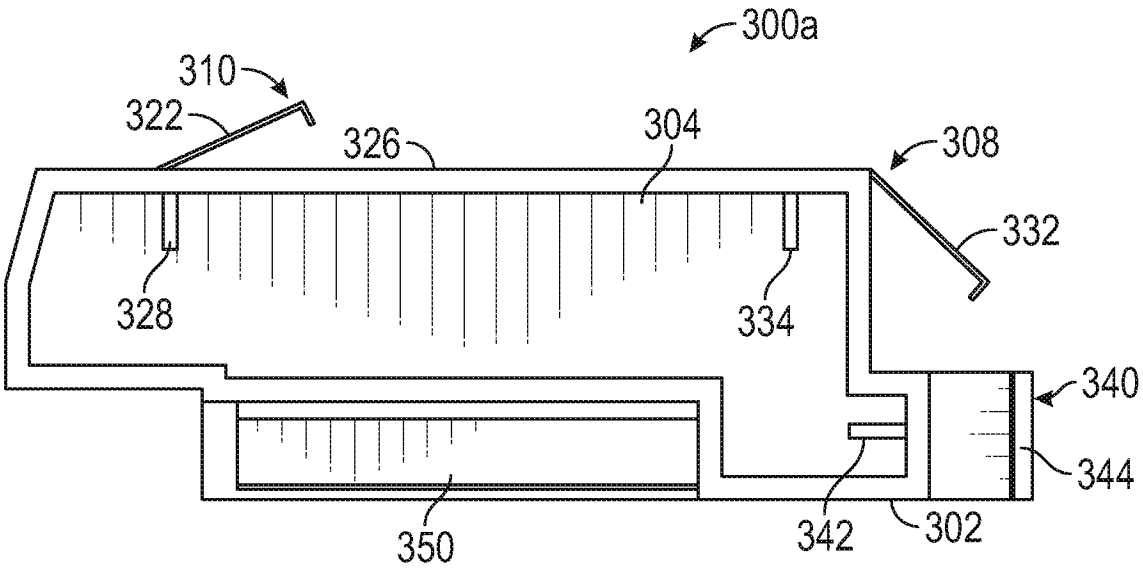

FIG. 12A

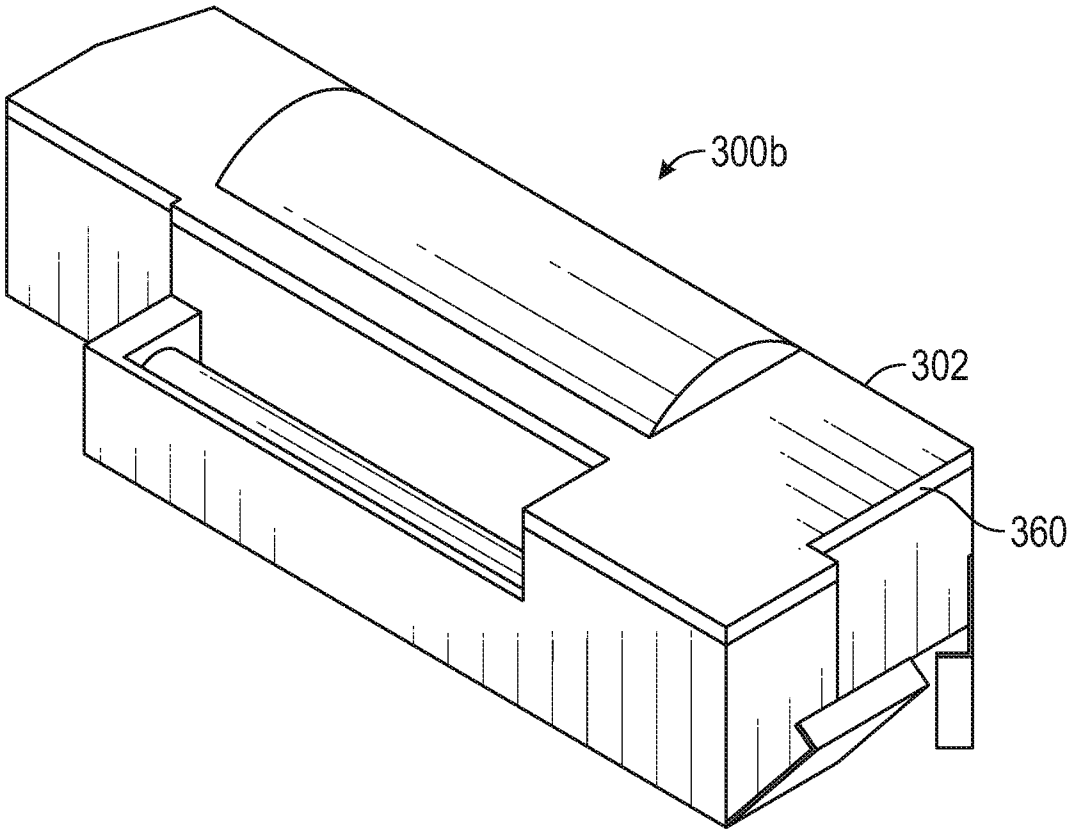

FIG. 12B

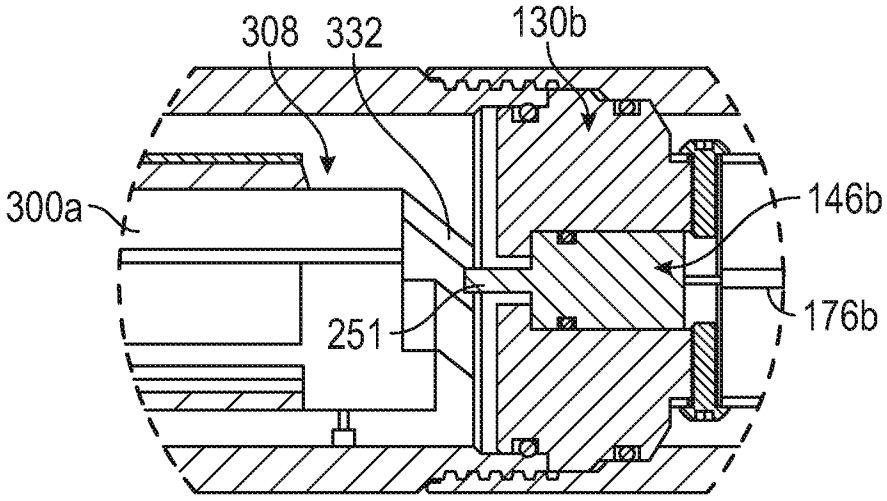

FIG. 13

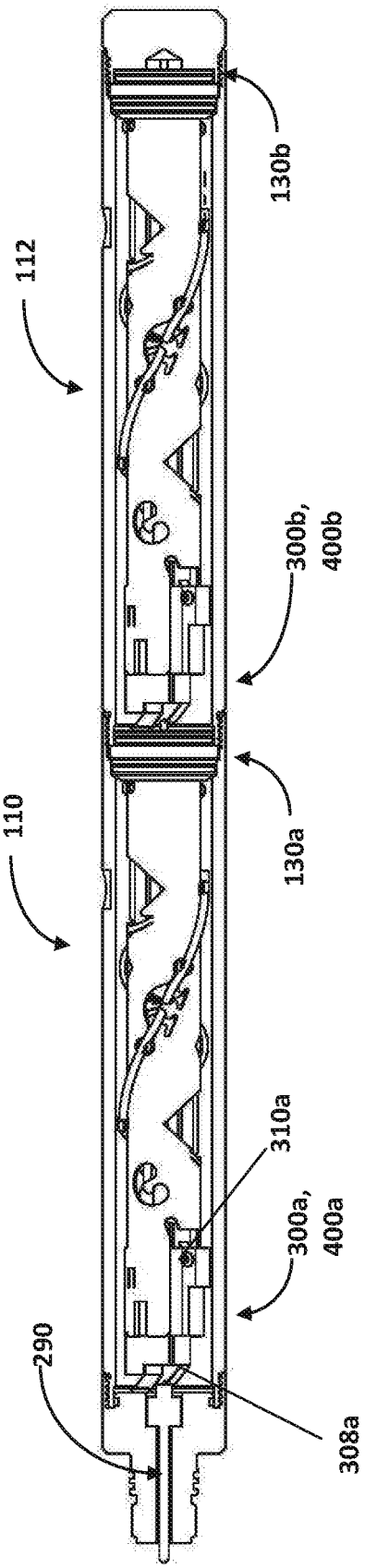

FIG. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/068118

A. CLASSIFICATION OF SUBJECT MATTER
INV. E21B43/1185
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
E21B

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2016/245056 A1 (HARDESTY JOHN T [US] ET AL) 25 August 2016 (2016-08-25) paragraphs [0052], [0083] - [0086]; figures 1, 5-7, 13-14	1-4
A	US 2015/000509 A1 (CURRENT PETER J [US] ET AL) 1 January 2015 (2015-01-01) paragraphs [0030] - [0035], [0060] - [0063]; figures 1-4	1-4
A	US 2018/087352 A1 (GREENWAY GRAEME ALASTAIR [US] ET AL) 29 March 2018 (2018-03-29) paragraphs [0030] - [0031]; figures 1-6	1-4

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 March 2020	09/04/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Brassart, P

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2019/068118

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		US 2016245054 A1	25-08-2016
		US 2016245056 A1	25-08-2016
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		WO 2015020738 A2	12-02-2015
US 2018087352 A1	29-03-2018	NONE	