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(71) Applicant: **CORNING OPTICAL COMMUNICATIONS LLC** [US/US]; 800 17th Street NW, Hickory, North Carolina 28601 (US).

(72) Inventors: **ISENHOUR, Micah Colen**; 1008 Park Circle, Lincolnton, North Carolina 28092 (US). **LUTHER, James Phillip**; 2471 Rolling Ridge Drive, Hickory, North Carolina 28602 (US). **WATKINS, Percil**; 234 8th Street NE, Conover, North Carolina 28613 (US).

(74) Agent: **CARROLL, Michael E., Jr.**; Corning Optical Communications LLP, Intellectual Property Department SP-TI-03-1, Corning, New York 14831 (US).

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(54) Title: OPTICAL PLUG HAVING A REMOVABLE AND REPLACEABLE NOSEPIECE AND A COMPLIMENTARY RECEPTACLE

(57) Abstract: Disclosed are optical plugs and optical connectors for making optical connections. The optical plugs and optical connectors disclosed have a nosepiece that is easily removed and replaced for allowing access to the optical interface for cleaning and the nosepiece may also protect the optical interface when installed. The nosepiece may be a single component or an assembly as desired. The devices disclosed may be hybrid devices providing both optical and electrical connectivity or they may solely have optical connectivity if desired.

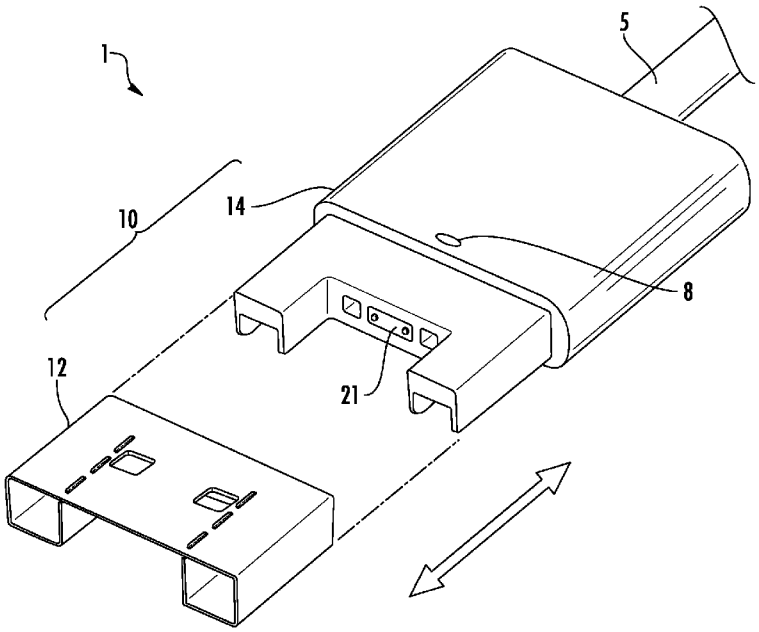


FIG. 1

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OPTICAL PLUG HAVING A REMOVABLE AND REPLACEABLE NOSEPIECE AND A COMPLIMENTARY RECEPTACLE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority of U.S. Provisional Application Serial No. 61/823,985 filed on May 16, 2013 the content of which is relied upon and incorporated herein by reference in its entirety.

FIELD

[0002] The disclosure is directed to optical connections for use in electronic devices. More specifically, the disclosure is directed to optical connectors such as optical plug connectors having a removable and replaceable nosepiece for allowing access to the optical interface for cleaning.

BACKGROUND

[0003] As electronic devices move toward operation at faster data rates the electrical interfaces on these devices along with the electrical transmission cables will reach their bandwidth capacity limitations. Additionally, the electronic devices are trending to smaller and thinner footprints. Optical fibers have displaced copper-based connectivity in much of the traditional long-haul and metro telecommunication networks for numerous reasons such as large bandwidth capacity, dielectric characteristics and the like. As consumers require more bandwidth for consumer electronic devices such as smart phones, laptops, tablets and the like optical fibers and optical ports for optical signal transmission are being considered for replacing the conventional copper-based connectivity for these applications. However, there are significant challenges for providing optical connectivity in consumer devices compared with copper-based connectivity. By way of example, devices such as smart phones, laptops and tablets are exposed to rough handling and harsh environments and the consumer will expect optical connectivity to handle these demanding conditions. Further, these types of devices will require a large number of mating/unmating cycles during their lifetime. Consequently, optical connections for consumer application will need to be easy to clean and maintain by the user.

[0004] There is an unresolved need for optical connections that may be used for relatively small devices like typical consumer applications such personnel devices such as smart phones, tablets and other consumer devices that have a relatively small footprint. The concepts disclosed herein solve this unresolved need for optical connections.

SUMMARY

[0005] The disclosure is directed to an optical plug connector having an optical portion with an optical interface and a nosepiece that fits about part of the optical portion. The nosepiece is removable and replaceable from the optical portion for accessing the optical interface. The nosepiece may be a single component or an assembly as desired. In one embodiment the plug includes both optical and electrical connectivity, but may only include optical connectivity if desired.

[0006] Other embodiments are directed to an optical plug connector having an optical portion with an inner body and an optical body having an optical interface, where the inner body has a passageway for receiving the optical body. The optical plug connector also has a nosepiece that fits about part of the optical portion, wherein the nosepiece is removable and replaceable from the optical portion for accessing the optical interface. The inner housing may be a separate component or may be integrated to another component such as integrally formed with a part of the housing.

[0007] The disclosure is also directed to a complimentary receptacle for the optical plug connector. In one embodiment, an optical receptacle includes a shell and a lens body. The lens body has an optical interface with one or more optical channels, wherein the lens body attaches to the shell. The receptacle may include a circuit board assembly attached to the lens body. The circuit board assembly may include one or more active components. Additionally, the circuit board assembly may have a tether with an electrical connection for providing quick attachment of the receptacle to a circuit board of an electronic device.

[0008] Additional features and advantages will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the same as described herein, including the detailed description that follows, the claims, as well as the appended drawings.

[0009] It is to be understood that both the foregoing general description and the following detailed description present embodiments that are intended to provide an overview or framework for understanding the nature and character of the claims. The accompanying drawings are included to provide a further understanding of the disclosure, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments and together with the description serve to explain the principles and operation.

BRIEF DESCRIPTION OF THE FIGURES

[0010] **FIG. 1** is a schematic perspective view of a first explanatory optical plug connector having a removable and replaceable nosepiece for accessing an optical interface of the connector;

[0011] **FIGS. 2 and 3** are perspective views of a cable assembly having another explanatory optical plug connector with a removable nosepiece and an electronic device having a complimentary receptacle according the concepts disclosed herein;

[0012] **FIGS. 4 and 5** are perspective views of the cable assembly and receptacle of **FIGS. 2 and 3** with the receptacle removed from the electronic device;

[0013] **FIGS. 6 and 7** are top and bottom front perspective views of the optical plug connector of the cable assembly of **FIG. 2-5** having the nosepiece removed from the optical portion of the optical plug connector for providing access to the optical interface;

[0014] **FIG. 8** is an exploded bottom view of the optical plug connector of **FIGS. 2-7** showing the nosepiece and optical portion;

[0015] **FIG. 9** is an exploded top view of the optical portion of the optical plug connector of **FIG. 8**;

[0016] **FIG. 10** is a perspective view of the inner body of the optical plug connector of **FIG. 7**;

[0017] **FIG. 11** is a perspective view of the housing of the optical plug connector of **FIGS. 2-7**;

[0018] **FIG. 12** is an exploded top view of the nosepiece of the optical plug connector of **FIG. 8**;

[0019] **FIG. 13** is a perspective view of the grip of the nosepiece of the optical plug connector of **FIG. 12**;

[0020] **FIG. 14** is a view of the explanatory receptacle of **FIGS. 4 and 5** with the receptacle separated from the circuit board;

[0021] **FIG. 15** is a bottom front perspective view of the receptacle removed from the circuit board;

[0022] **FIG. 16** is a bottom rear perspective view of the receptacle removed from the circuit board;

[0023] **FIGS. 17 and 18** are a partially exploded perspective views respectively from the front and rear side of the receptacle;

[0024] **FIGS. 19 and 20** are respective top and bottom perspective views of a cable assembly having another explanatory optical plug connector with a removable nosepiece;

[0025] **FIG. 21** is a top front perspective views of the optical plug connector of the cable assembly of **FIGS. 19 and 20** having the nosepiece removed from the optical portion of the optical plug connector for providing access to the optical interface;

[0026] **FIG. 22** is an exploded bottom view of the optical plug connector of **FIGS. 19-21** showing the nosepiece and optical portion;

[0027] **FIGS. 23 and 24** are respective top and bottom perspective views of yet another explanatory optical plug connector with a removable nosepiece and a complimentary receptacle attached to a circuit board of an electronic device in an unmated condition according the concepts disclosed herein;

[0028] **FIGS. 25 and 26** are respective top and bottom perspective views of the optical plug connector and the complimentary receptacle of **FIGS. 23 and 24** in a mated condition;

[0029] **FIGS. 27 and 28** are respective top and bottom front perspective views of the optical plug connector of **FIGS. 23-26** having the nosepiece removed from the optical portion of the optical plug connector for providing access to the optical interface;

[0030] **FIG. 29** is an exploded top view of the optical plug connector of **FIGS. 23-28** showing the nosepiece and optical portion;

[0031] **FIG. 30** is an exploded top view of the optical portion of the optical plug connector of **FIG. 29**;

[0032] **FIGS. 31 and 32** are a detailed exploded view and assembled view of part of the optical portion of the optical plug connector of **FIG. 30** to show construction details;

[0033] **FIG. 33** is an exploded top view of the nosepiece of the optical plug connector of **FIG. 29**;

[0034] **FIGS. 34 and 35** are cross-sectional views of the optical plug connector taken respectively along section lines 34-34 and 35-35 of **FIGS. 23** with the nosepiece attached to the optical portion;

[0035] **FIG. 36** is a perspective view showing the electrical contacts of the optical plug connector and receptacle in a mated state with the other components removed for clarity; and

[0036] **FIG. 37** is a cross-sectional view of the force centering alignment features of **FIGS. 31 and 32** along with the optical interface.

[0037] **FIGS. 38-40** are various perspective views of the optical plug connector or the receptacle showing explanatory dimensions.

DETAILED DESCRIPTION

[0038] Reference will now be made in detail to the embodiments of the disclosure, examples of which are illustrated in the accompanying drawings. Whenever possible, like reference numbers will be used to refer to like components or parts.

[0039] The optical connections disclosed herein enable high-speed data applications for transmitting optical signals to electronic devices such as speeds of 5 Gigabits/sec or greater along with having a relatively small and compact footprints so that they are useful for use with electronic devices such as consumer devices and the like. The concepts include an optical plug connector having a removable and replaceable nosepiece and a complimentary optical receptacle that can receive the optical plug connector. The optical receptacle may be a portion of an electronic device so it can receive and transmit optical signals. A removable and replaceable nosepiece means that the nosepiece can be removed from a fully-assembled device such as an optical plug connector and replaced. By way of example, the nosepiece may be removed without disassembly of the device. Further, the concepts of the optical connections may be used in other application such as optical backplanes, switches, routers and other equipment. In order to transmit/receive optical signals, the optical plug connector or optical receptacle may include one or more optical channels for that may include one or more lenses or not as desired. By way of example, the one or more lenses of the optical plug connector such as gradient index (GRIN) lenses are used for collimating or focusing the light from the transmission channel(s) of the plug and are optically coupled to a complementary lenses of the optical receptacle such as molded lenses that direct the optical signal to an active element such as a photodiode or the like. The receive channels of the optical plug connector obtains its signals from an active element such as a laser like a vertical-cavity surface-emitting laser (VCSEL) in communication with the molded lens of the optical receptacle for transmission of the optical signals to the GRIN lens of the optical plug connector when the optical plug connector and optical receptacle are mated together. The optical plug connector and optical receptacle according to the concepts disclosed provide easy connectivity with a footprint that is advantageous for use with electronic devices having thin and compact profiles. Further, the concepts provide a simple optical plug assembly that provides access to an optical interface for easy cleaning for applications that are expected to experience large number of mating/unmating cycles such as consumer electronic applications.

[0040] **FIG. 1** is a schematic perspective view of a portion of a cable assembly **1** having a first explanatory optical plug connector **10** (hereinafter “plug”) with a nosepiece **12** that fits

about part of an optical portion **14** and is removable and replaceable from the optical portion **14** of the optical plug connector **10**. The plug **10** is attached to cable **5**, thereby forming cable assembly **1**. The cable assembly may use any suitable cable **5** attached to the plug. Although, the cable **5** and plug **10** are shown having a straight through alignment for simplicity, the plug may have any suitable angle with respect to the cable such as 45, 60 or 90 degrees, but still other angles are possible. The nosepiece **10** is removable and replaceable from the optical portion **14** of plug **10** as represented by the line with the arrows for accessing an optical interface **21** of the optical portion **14**. Consequently, nosepiece **10** may be removed so that the user may have access to inspect, wipe and/or clean the optical interface **21** of the plug **10** as desired, which is advantageous for applications that anticipate a relatively large number of mating/unmating cycles or environments that may be exposed to dirt and debris such as consumer devices. The plug may form a portion of the optical connection that cooperates with an optical receptacle that is a portion of an electronic device such as a tablet, smart phone, display or the like having a complimentary mating geometry. Further, the plug may include a locking feature **8** for securing the nosepiece to the optical portion for inhibiting unintended removal of the nosepiece from the optical portion. The locking feature may be a passive locking feature such as a friction fit and/or protrusion or it may be an active locking feature such as a lever or slide for securing the nosepiece **12** to the optical portion **14**. Although, the nosepiece shown in this embodiment is a single component, the concepts may be used with nosepieces arranged as an assembly.

[0041] The concepts of the plug disclosed herein may also be used with hybrid connections having both optical and electrical connections as desired. In other words, both the plug and receptacle have a complimentary optical and electrical interface. By way of example, **FIGS. 2 and 3** are perspective views of a cable assembly **1'** having another explanatory optical plug connector **100** (hereinafter "plug") with a nosepiece **110** that fits about part of an optical portion **114** and is removable and replaceable from an optical portion **114** of the plug **100** as represented in **FIGS. 6 and 7.** Plug **100** is useful for mating with a complimentary optical receptacle **200** (hereinafter "receptacle") of an electronic device **2**. Plug **100** is attached to cable **5** that also optionally includes one or more optical fibers **3** and electrical conductors **4**, thereby forming cable assembly **1'** that may transmit power and/or electrical signals. In this embodiment, the nosepiece **110** is an assembly as discussed herein and as best illustrated in **FIGS. 8 and 10**.

[0042] **FIG. 3** shows electronic device **2** having receptacle **200** that includes a lens body **210** having an optical interface **221** with one or more optical channels (not numbered). As

shown, the lens body **210** includes at least one alignment feature **223** adjacent to the optical interface **221**. Receptacle **200** may also optionally include one or more electrical contacts **230** for transmitting electrical signals or power as desired. In this explanatory embodiment, lens body **210** includes alignment features **223** configured as guide pin bores in the lens body **210** for receiving respective guide pins of the plug for aligning respective optical channels; but other alignment features are possible using the concepts disclosed. For instance, alignment features could be one or more magnetic elements such as magnets and/or ferrous materials or other suitable structure as desired. Alignment features could also be protrusions on the receptacle such as castellations or such for aligning the plug to the receptacle; additionally, features such as the shell and/or electrical interface may also be used for providing course alignment with fine alignment for the optical channels provided by other features.

[0043] **FIGS. 4 and 5** are close-up perspective views showing a portion of the cable assembly **1'** with plug **100** aligned with receptacle **200** before being mated. As shown, receptacle **200** is attached to a portion of a circuit board **285**, which is removed from the electronic device **2** for illustration purposes. During mating, the plug **100** is oriented with the receptacle **200** so that the nosepiece **110** of plug **100** may be inserted into shell **250** of receptacle **200**, thereby allowing optical and electrical connectivity. In other words, the optical interface **121** of the plug **100** is aligned with the optical interface **221** of the receptacle **200** and electrical connections are made between one or more nosepiece electrical contacts **102** of the plug **100** and the one or more electrical contacts **230** of the receptacle **200**.

[0044] **FIGS. 6 and 7** depict a portion of cable assembly **1'** with top and bottom front perspective views of plug **100** having the nosepiece **110** removed from the optical portion **114** of plug **10** for providing access to the optical interface **121**. As represented by the line with the arrows, the nosepiece **110** fits about part of the optical portion **114** and is removable and replaceable from the optical portion **114**. As shown, the nosepiece **110** may optionally include grip **108** that cooperates with a housing **160** of the optical portion **114**. In this embodiment, grip **108** includes one or more extensions **108a** that extend rearward from the nosepiece **110** and cooperate with the one or more respective recesses **166** of housing **160**. Extensions **108a** aid in guiding the nosepiece to fit about the optical portion **114** of plug **100**. Further, extensions **108a** may include a first extension and a second extension have different size/shapes such as different widths that cooperate with different size/shapes such as different widths of first and second recesses **166**. Consequently, the plug **100** may be configured so that the nosepiece **110** only fits onto the optical portion **114** in the correct orientation (i.e.,

one orientation for assembly). The outer surface of a grip **108** may also include a textured surface (not numbered) such as ribs, depression or the like so the user can easily and reliably grab the nosepiece **110** to remove and replace the same from the optical portion **114**.

[0045] As shown, nosepiece **110** includes one or more nosepiece electrical contacts **102** that are in electrical contact with the electrical contacts **230** on the receptacle **230** when plug **100** is mated to receptacle **200**. However, the nosepiece **110** and the optical portion **114** of plug **100** include separate electrical contacts that are electrically disconnected when the nosepiece **110** is removed from optical portion **114** of plug **100**. Specifically, nosepiece **110** includes one or more nosepiece electrical contacts **102** for being electrical connected to the one or more optical portion electrical contacts **150** when the nosepiece **114** is attached to the optical portion **114** of plug **110**. Thus, the electrical connection from the electrical conductors **4** of cable **5** is continued to the optical portion electrical contacts **150** and then to the nosepiece electrical contacts **102** when the nosepiece **110** is attached to the optical portion **114**. In this embodiment, the nosepiece electrical contacts **102** and the optical portion electrical contacts **150** are wiping electrical contacts, but any other suitable electrical contacts are possible such as pin and socket electrical contacts. As depicted, the one or more nosepiece electrical contacts **102** are housed in one or more respective lobes **106a** of a shell **106** at a front end of the nosepiece **110**. In this embodiment, lobes **106a** are arranged as first and second lobes disposed on opposite sides of a pocket **106b** of shell **106**.

[0046] **FIG. 8** is an exploded bottom view of plug **100** showing details of nosepiece **110** and optical portion **114**. **FIG. 9** depicts an exploded top view of the optical portion **110** of plug **100** and **FIG. 12** is an exploded top view of the nosepiece **110** of plug **100**. With continuing reference to **FIGS 8 and 9**, optical portion **114** of plug **100** includes optical interface **121** as a portion of optical body **120**, an inner body **130**, a retainer **140**, one or more optical portion electrical contacts **150**, and a housing **160**. Optical interface **121** may have the optical fibers presented at the interface or include one or more lenses **122** presented at the interface as desired for creating the one or more optical channels of the plug **100**. Plugs and receptacles may have any suitable number of optical channels arranged in any desired pattern such as a linear or round array of optical channels. In this plug embodiment, the optical channels are arranged in a 2-by-2 array. Optical body **120** also includes one or more alignment features **123** for registering (i.e., aligning) the optical channels of the optical interface **121** of plug **100** with the complimentary optical channels of receptacle **200**. In this embodiment, alignment features **123** are guide pins that are integrally formed (i.e., molded) with optical body **120** and cooperate with alignment features **223** of receptacle **200** when

mated together. The alignment features **123** may have other configurations such as being non-round or discrete components as desired. For instance, the alignment features **123** may include one or more magnets such as correlated magnetics having a prearranged pattern of poles (magnetic north and magnetic south regions) for cooperating with a complimentary correlated magnet on the receptacle.

[0047] The one or more lenses **122** may be integrally formed in the optical interface **121** or arranged as one or more discrete lenses as desired. For instance, optical body **120** may be formed from an optically transmissive material with lenses integrally formed at the optical interface **121** with bores in optical body **120** leading to the respective lenses so that optical fibers may be received therein. Alternatively, the optical fiber bores **120b** of optical body **120** may extend to the front side of the optical body **120** for receiving the one or more lenses **122** therein. By way of example, the discrete lenses may be configured as gradient index (GRIN) lenses that fit into the respective bores of the optical body. Additionally, an index-matching gel may be used between the ends of the respective optical fibers inserted into the optical body **120** and the one or more lenses for aiding optical performance by bridging any gap between the components.

[0048] **FIG. 10** is a perspective view of the inner body **130** of plug **100**. Inner body **130** includes a passageway **131** that extends from a front end **135** to a rear end **137** and is sized for receiving a portion of optical body **120**. The optical interface **121** which is a portion of optical body **120** is received in the passageway **131** of inner body **130**. The optical interface **121** is accessible at the front end of the inner body **130** when the optical portion **114** is assembled so that when the nosepiece **110** is removed from the optical portion **114** the user has access to the optical interface **121**. Optical body **120** may include a stepped portion (not numbered) for limiting the forward travel of the optical body **120** into the passageway **131**. After the optical body **120** is inserted into the inner body **130** it any suitable manner. For instance, optical body **120** may be secured by a snap-fit such as resilient members formed either the optical body or the inner body **130**. In this embodiment, inner body **130** includes one or more slots **132** for receiving a retainer **140** to secure the optical body **120** in passageway **131**. Retainer **140** may be any suitable component such as a clip, spring, washer, pin, etc.; however in this embodiment retainer **140** is a wave spring. Consequently, the optical body **120** is able to move within the passageway **131** of the inner body **130**. In other words, the retainer **140** biases the optical body forward and allows the optical body **120** to move a short distance to the rearward during mating as necessary.

[0049] Inner body may also include one or more surfaces **133.** As shown, surfaces **133** are disposed outward of passageway **131** and provide a support surface for optical portion electrical contacts **150**. The optical portion electrical contacts **150** may be attached to inner body **130** in any suitable manner. For instance, inner body **130** may be formed such as molded with the optical portion electrical contacts **150** attached during the molding process. Other variations include using an adhesive or snap-fitting the optical portion electrical contacts **150** to the inner body **130**. When assembled, the optical portion electrical contacts **150** are electrically connected to electrical conductors **4** of cable **5**. Inner body **130** also includes one or more mounting features **134** such as notches or openings for placing and securing it within the housing **160**.

[0050] **FIG. 11** is a close-up perspective view of the housing **160** of plug **100**. In this embodiment, housing **160** is formed from two similar pieces, namely, a first shell **160a** and a second shell **160b** that fit together. The first and second shells **160a, 160b** include respective openings **161** shaped as a half-pipe for forming a passageway into the housing **16**0 for the receiving the cable **5**. The shells **160a, 160b** also include respective cradles **162** for securing the deformed crimp band **7** and respective tabs **163** and **165** that allow the two shells **160a, 160b** to snap-fit together.

[0051] When assembled, the inner body assembly (not numbered) fits into the housing **160** so that a portion of the inner body **130** extends forward past the housing **160** as best shown in **FIG. 6**. Specifically, the optical interface **121** and a portion of the optical portion electrical contacts **150** are exposed at the front end of the optical portion **114**. Cable **5** is attached to the inner body assembly by first threading crimp band **7** (which is shown in the FIGS. in the deformed state) onto cable **5**. Then, the optical fibers **3** of cable **5** are attached to the optical body **120** and electrical conductors **4** attached to the optical portion electrical contacts **150**. The crimp band **7** can then be crimped deformed such as shown at the appropriate location on cable **5** such as represented by necked down portion **9** (which represents the shape of the cable after the crimp band 7 is secured thereto) of cable **5** for securing the optical fibers **3** and electrical conductors **4** relative to the cable jacket and inhibit pistoning of the same. If desired, a filling material such as an adhesive, silicone, a sleeve, an insert or the like may be injected or placed into the passageway of the cable for protecting the optical fibers. When assembled, the deformed crimp band **7** is placed into cradle **162** of housing **160** for providing strain relief for the cable assembly and the mounting features **134** of the inner body **130** are received by the guide features **164** of the first and second shells **160a, 160b** of housing **160**.

Thereafter, the first and second shells **160a, 160b** of housing **160** can be assembled about the inner body assembly.

[0052] As best depicted in **FIG. 12**, nosepiece **110** is an assembly having one or more nosepiece electrical contacts **102**, one or more rails **104**, shell **106** and grip **108**. When assembled, nosepiece electrical contacts **102** fit into respective guides **104a** of the rail **104** to form a rail assembly. The rail assembly that includes the rail and the electrical contact fit into and attach to a respective lobe **106a** of shell **106**. In this embodiment, the rails **104** are generally flush with the front end of shell **106**, but other arrangements are possible. The rail(s) **104** may be attached to the lobes **106a** of shell **106** in any suitable manner such as with tabs, protrusions, adhesive, or a friction fit. In this embodiment, the nosepiece **110** includes first and second rails **104** each having a respective nosepiece electrical contact **102** that are attached to the respective guides **104a**. As best shown in **FIG. 8**, the rails **104** have a cutout **104b** at the rear that includes a planar surface for providing access to nosepiece electrical contacts **102** so that they can electrically connect to optical portion electrical contacts **150** when the nosepiece **110** is attached to the optical portion **114**. As depicted, the lobes **106a** of shell **106** are disposed on opposite sides of a pocket **106b**. Pocket **106b** allows the shell **106** and nosepiece **110** to fit about inner body 130 when the nosepiece **110** is attached to the optical portion **114**. **FIG. 13** is a perspective view of grip **108** of the nosepiece **110** showing a passageway **108b** along with retention features **108c** disposed in the passageway. Retention features **108c** are configured as a plurality of protrusions that cooperate with complimentary retention features **106c** located on shell **106**. Retention features **106c** are configured as openings, but other methods are possible. By way of example, grip **108** may be molded about shell **106** or an adhesive may be used for securing the same, instead of a snap-fit. When assembled, a portion of shell **106** extends beyond the grip **108** so that it can engage the receptacle **200**.

[0053] **FIG. 14** is a view of the explanatory receptacle **200** with it separated from the circuit board **285** and **FIGS. 15 and 16** respectively are a bottom front and bottom rear perspective views of the receptacle **200** removed from the circuit board **285** of the electronic device. As shown, circuit board **285** includes an electrical interface **287** and one or more integrated circuits **290** for processing signals along with other components as desired for the electronic device (other structure and components on the circuit board are removed for clarity purposes). As shown in **FIGS 15 and 16**, receptacle **200** may include a receptacle circuit board assembly **240** attached to the lens body **210**. When the electronic device is assembled, the receptacle circuit board assembly **240** is electrically attached to circuit board **285** for

communicating signals between the receptacle **200** and the circuit board **285**. For instance, receptacle **200** is configured with a flexible tether having pluggable electrical attachment to circuit board **285**. Specifically, circuit board **285** includes an electrical connector **287** for cooperating with a complementary electrical connector **246** of the receptacle circuit board assembly **240** for easily making the appropriate electrical connections between the circuit board **285** and the receptacle circuit board assembly **240**. Of course, other electrical connectivity may be used with the concepts disclosed.

[0054] Receptacle circuit board assembly **240** is used for converting the optical signals to electrical signals and vice versa and may have any suitable arrangement or layout. Receptacle circuit board assembly **240** includes at least one active component **241** aligned with at least one optical channel of the optical body when properly aligned and attached to lens body **210**. As shown, receptacle circuit board assembly is attached to the lens body **210** and spaced at a suitable distance from the lenses using ledges **210a**, which provide the desired z-direction distance between the active component **241** and the lens body **210**. The receptacle circuit board assembly **240** may use a passive and/or active alignment for positioning the receptacle circuit board assembly **240** in the X-direction and Y- direction. Active component **241** is an electro-optical component used for transmitting or receiving optical signals to/from the optical channels of the lens body **210**. By way of example, active component **241** is a photodiode or other similar device for receiving optical signals or a vertical-cavity surface-emitting laser (VCSEL) for transmitting optical signals, thereby providing one or more transmit and receive channels. Additionally, receptacle circuit board assembly **240** may include further electronic components TIAs or laser drivers arranged as a first circuit portion **243** and/or a second circuit portion **245** for processing signals and other electronics such as integrated circuits (ICs) like clock and data recovery (CDR), laser drivers serializer/deserializer (SerDes), and the like on the circuit board **285**.

[0055] **FIG. 16** is a perspective bottom rear view of receptacle **200** showing the receptacle circuit board assembly **240** operably attached to the lens body **210** so that at least one active component **241** is aligned with the at least one optical channel such as lens **221a**. In this embodiment, the receptacle circuit board assembly **240** includes a circuit board **247** having electronics such as the active components **241** and other circuitry such as first circuit portion **243** mounted thereon. The active components **241** of receptacle circuit board assembly **240** aligned with the at least one optical channel of lens body **210** when attached to the lens body **210.** In this embodiment, circuit board **247** of receptacle circuit board assembly **240** is

operably attached to the ledge(s) **210a** at the rear side of the lens body **210**. In this instance, an adhesive is used for securing circuit board **247** to ledge(s) **210a**, but any suitable attachment method is possible. In this embodiment, the optical channels include respective lenses **221a** at the rear side of the optical body **210** for focusing or collimating the optical signals to/from the active components **243**. "Operably attached" means that the active components **243** of the receptacle circuit board assembly **240** are properly spaced from the optical channels of the lens body (z-direction) such as the lenses of the optical body **210** for maintaining the desired distance between the active components **243** and the optical channels and suitable aligned in the x-direction and y-direction for providing the desired level of optical coupling.

[0056] Further, receptacle circuit board assembly **240** may use a flexible substrate **244** for making electrical connections between the circuit board **247** having a first circuit portion **243** and/or a second circuit portion **245** and the circuit board **285** of the electronic device. In other words, the flexible substrate **244** allows an electrical turn so that the first and second circuit portions **243,245** of the circuit having the active components (e.g., photodiodes and VCSELs), transimpedence amplifier (TIA), and the laser drivers are electrically connected to the other integrated circuits on the circuit board **285**. In this embodiment, circuit board **247** is formed from a first portion **247a** and a second portion **247b** and sandwich part of the flexible substrate **244** between the first portion **247a** and the second portion **247b**. Specifically, the electrical connection between the electrical conductors of the flexible substrate **244** and the electrical components on circuit board **247** are made between the first and second portions **247a**, **247b** of circuit board **247**.

[0057] Splitting the electronics between the receptacle circuit board assembly **240** that is attached to the lens body **210** and other components on the circuit board **285** such as the clock and data recovery (CDR) IC and Serdes IC allow for smaller receptacle footprints and keep the specific electrical traces to/from the active components 243 such as the TIA or laser drive to short lengths such as 200 microns or less and the electrical traces may even be about 100 microns or less. Specifically, the flexible substrate **244** provides an electrical turn with flex coupling between the receptacle circuit board assembly **240** and circuit board **285**, thereby allowing relatively small form-factors for the optical connector since the CDR and Serdes IC's are relatively large and are located on another circuit portion such as the electronic device circuit board that can be orientated in different manner such as a horizontal plane where there is more space available.

[0058] Receptacle circuit board assembly **240** may also include other advantageous arrangements when having optical connectors with more than one transmit and one receive channel. For instance, the receptacle circuit board assembly **240** may use separate TIAs and/or laser drivers on the first circuit portion **243** and the second circuit portion **245** of the receptacle circuit board assembly **240** (i.e., several TIAs or laser drivers for different optical channels). By way of example, receptacle **200** has multiple optical channels arranged in a 2x2 array. Consequently, the first circuit portion **243** with the TIAs and laser drivers can now be split (i.e., multiple TIAs and laser drivers) with a dedicated TIA and laser driver placed onto each side of the plurality of optical channels that are arranged in an two-by-two array. In this embodiment, receptacle circuit board assembly **240** uses multiple TIA/laser driver arrangement (i.e., one TIA/laser driver for each side of the 2x2 array; one TIA/laser driver for the left side **243** and one TIA/laser driver for the right side **245**) for enabling a relatively small height **H** for the receptacle **200**, thereby allowing use of the optical connector in thin devices such as smart phones, tablets and the like. Further, placing electrical components such as the TIA and laser drivers relatively close to the active components such as photodiodes and VCSELs allows relatively short wire bond lengths such as 100 microns or shorter for supporting high-speed data transfer rates such as 10Gb/sec or more and even up to 20 Gb/sec and higher.

[0059] **FIGS. 17 and 18** are partially exploded perspective views from the front and rear side of the receptacle **200**, respectively. As shown, receptacle **200** includes lens body **210** having an optical interface **221** with one or more optical channels and a shell **250**. When assembled, the lens body **210** attaches to shell **250**. The lens body **210** may have an optional cover **220** attached thereto for protecting the optical interface **221**. In other words, the cover **220** may cover the lenses that form the optical channels. Cover **220** may be formed from any suitable material such as glass or a polymer. For instance, the glass cover may be made from a chemically strengthened glass. The cover **220** may further include a coating such as an anti-reflective (AR) coating or a scratch–resistant coating.

[0060] In this embodiment, lens body **210** has a portion with a U-shape, but the lens body may have other suitable shapes or configurations. As shown, the lens body **210** has one or more attachment flanges **211** for attaching it to shell **250** that generally extend from the U-shaped portion. As shown, the attachment flanges **211** may include one or more notches **211a** for allowing a friction-fit or snap-fit with one or more respective cut-outs **252** of shell **250**. Receptacle **200** also includes one or more electrical contacts **230** and lens body **210** includes one or more rails **210c** formed therein. Rails **210c** are used as a support surfaces for

the respective electrical contacts **230**. Electrical contacts **230** may be integrally molded into the lens body **210** or be configured to slide into a respective slot **213** from a rear end of the lens body **210**. As depicted, electrical contacts **230** have a generally planar surface for electrical connection to the electrical contacts **102** of the nosepiece **110**. The other end of electrical contacts **230** have a bend with a lead (not numbered) for making an electrical connection with circuit board **285**.

[0061] Other variations of the plug and/or receptacle are possible according to the concepts disclosed. By way of example, **FIGS. 19-22** depicted another cable assembly **1''** having another plug **100'** with a nosepiece **110'**. Plug **100'** is similar to plug **100** having nosepiece **110** as shown in **FIGS. 19 and 20,** except that the plug **100'** has a simplified nosepiece **110'** that does not include electrical contacts in the nosepiece. Instead, the electrical contacts **150** are extended from the optical portion **114'** of plug **100'** into the nosepiece **110'**. As best shown in **FIG. 21**, inner body **130'** of plug **100'** has a slightly different construction than inner body **130** of plug **100**. Specifically, inner body **130'** has one or more longer surfaces **133'** that extend outward on one or more rails **139** of inner body **130'** compared with surfaces **133** of inner body **130** that are shorter. Simply stated, rails **139** and associated optical portion electrical contacts **150** extend to the front end and are received in nosepiece **110'** when installed on the optical portion **114'**. Consequently, nosepiece **110'** is simplified and has fewer parts. Even though rails **139** extend outward on the outboard sides of the inner body **130** of plug **100'** access is still provided to the optical interface when the nosepiece **110'** is removed. **FIG. 22** is an exploded view of plug **100'** showing the various components. Although, nosepiece **110'** is shown with a shell **106'** and a grip **108'**, the grip may be omitted and the nosepiece may just be the shell.

[0062] Still other designs for the plug or receptacle are possible according to the concepts disclosed. By way of example, **FIGS. 23-39** are other various views of yet another explanatory plug **300** and a receptacle **400** or components thereof according to the concepts disclosed. Generally speaking, plug **300** and complimentary receptacle **400** are similar to the plug **100** and receptacle **200** and differences and distinctions of plug **300** and receptacle **400** will be discussed as appropriate.

[0063] **FIGS. 23 and 24** are respective top and bottom perspective views of plug **300** having a removable nosepiece and a complimentary receptacle **400** suitable for attach to circuit board **285** of an electronic device in an unmated state. **FIGS. 25 and 26** are respective top and bottom perspective views of the plug **300** and receptacle **400** in a mated condition. As depicted in **FIGS. 27 and 28,** plug **300** has a nosepiece **310** that fits about part

of an optical portion **314** and is removable and replaceable from the optical portion **314** of the plug **300**. Consequently, nosepiece **310** may be removed so that the user may have access to inspect, wipe and/or clean the optical interface **321** of the plug **300** as desired. Plug **300** may be attached to a suitable cable thereby forming cable assembly as discussed herein. In this embodiment, a shell **306** of plug **300** extends beyond a housing **360** for insertion into receptacle **400** and has a stepped profile with two different heights.

[0064] Specifically, shell **306** has a front portion **306a** with a first height in the y-direction and a rear portion **306b** with a second height in the y-direction, where the second height of the rear portion **306b** is greater than the first height of the front portion **306a**. On the receptacle **400**, the shell **450** only has annular construction at a forward portion as shown in **FIG. 23**. When the plug **300** and receptacle **400** are mated, the front portion **306a** of shell **306** extends into the receptacle **400** and past the annular construction at the forward portion of shell **450** and the rear portion **306b** of shell extending from the housing **360** of plug **300** is seated in the annular construction at the forward portion of shell **450** as best shown in **FIG. 25**. Consequently, the front portion **306a** of plug **300** inside the receptacle does not require as much headroom inside the electronic device since the profile is stepped down and the rear portion **306b** snuggly fits and fills the annular construction at the forward portion of shell **450** for providing a solid fit and mechanical retention. Additionally, the stepped profile of the shell **306** provides a simple orientation feature for the user to orient the plug **300** relative to the receptacle **400** during mating.

[0065] **FIG. 29** is an exploded top view of the optical plug connector **300** showing the nosepiece **310** and optical portion **314**. Optical portion **314** includes optical interface **121** as a portion of optical body **320**, a force centering element **340**, a resilient member **351**, a retainer **360**, one or more optical portion electrical contacts **350**, and a housing **380**. Optical interface **121** may have the optical fibers presented at the interface or include one or more lenses **122** presented at the interface as desired for creating the one or more optical channels of the plug **300** as discussed herein. Plug **300** has the optical channels are arranged in a linear array of eight channels, but any suitable number of channels or orientation is possible. Optical body **320** also includes one or more alignment features **123** for registering (i.e., aligning) the optical channels of the optical interface **121** of plug **300** with the complimentary optical channels of receptacle **400**. In this embodiment, alignment features **123** are guide pins that are integrally formed (i.e., molded) with optical body **320** and cooperate with alignment features **223** of receptacle **400** when mated together. The alignment features **123** may have other configurations such as being non-round or discrete components as desired.

[0066] The one or more lenses **122** may be integrally formed in the optical interface **121** or arranged as one or more discrete lenses as desired. For instance, optical body **320** may be formed from an optically transmissive material with lenses integrally formed at the optical interface **121** with bores in optical body **320** leading to the respective lenses so that optical fibers may be received therein. Alternatively, the optical fiber bores (not visible) of optical body **320** may extend to the front side of the optical body **320** for receiving the one or more lenses **122** therein. By way of example, the discrete lenses may be configured as gradient index (GRIN) lenses that fit into the respective bores of the optical body.

[0067] Plug **300** also has other components/constructions not used in the other embodiments for providing a force centering alignment of the optical interface **121** during mating. Illustratively, **FIG. 30** is an exploded top view of the optical portion **314** of plug **100** and shows the force centering alignment structure. **FIGS. 31 and 32** are a detailed exploded view and an assembled view showing the centering alignment structure removed from the optical portion **314** of plug **300**.

[0068] Housing **380** of plug **300** has a different construction than the other plug housings described. Although, housing **380** includes a first portion **380a** and a second portion **380b**, the first portion **380a** includes an inner body (not numbered) having a block-like structure having a passageway **381** that extends from a front end to a medial portion of the block-like structure and is sized for receiving a portion of optical body **320** along with force centering element **340** and resilient member **351**. In other words, the inner body of this embodiment is formed as part of (i.e. integrated with) the housing to eliminate the part count. The optical interface **121** which is a portion of optical body **320** is received in the passageway **381** and extends so it is accessible at the front of housing **380**. As shown, the optical body **320** may also include a flange (not numbered) that acts as a forward stop for optical body **320** when it is installed into the passageway **381**. In this embodiment, optical body **320** includes a pivot point **325** and is bias forward by a resilient member **351** when assembled with force centering element **340**, resilient member **351** and retainer **360** attached to the inner body (not numbered) of housing **380**.

[0069] More specifically, force centering element **340** includes a passageway **348** therethrough for receiving a rear portion **328** of optical body **320** at the front end and routing the optical fibers from the cable through the rear end. The passageway **348** is sized so that rear portion **328** of optical body **340** may pivot through a desired angular range within force centering element. Force centering element **340** also includes a pivot point configured as a saddle **345** at the front end that receives and cooperates with the pivot point **325** of optical

body **320** when assembled as best shown in **FIG. 32**. Consequently, optical body **320** may pivot within the saddle **345** during engagement with the complementary optical interface of receptacle **400**. Force centering element **340** also include a barrel **346** at the rear end for seating within the resilient member **351** as shown in **FIG. 32**.

[0070] As best shown in **FIG. 31**, retainer **360** includes a front end passage **361** that leads into a pass-through **363** that connects to cradle **369** near the rear end of the retainer **360**. Cradle **369** is used for receiving the crimp band **7** attached to the cable at the rear end. Front end passage **361** may receive resilient member **351** and may have a suitable shape. When assembled, the resilient member **351** is received in the front end passage **361** and the barrel **346** of force centering element **340** fits into the resilient member as shown in **FIG. 32**. In this embodiment, retainer **360** also includes retention features **365** for attaching/securing the force centering components within the inner body (not numbered) of the housing **360**. In this embodiment, retention features **365** are configured as resilient arms that engage and attach with the housing **380**. Specifically, the retention features **365** are received in complimentary retention features **385** on housing **380**. More specifically, the latches (not numbered) on resilient arms of the force centering element **340** are received in retention features **385** such as the windows shown in this embodiment, but other suitable retention features are possible.

[0071] **FIG. 33** is an exploded top view of the nosepiece **310** of plug **300** that is similar to nosepiece **110**. Nosepiece **310** is an assembly having one or more nosepiece electrical contacts **302**, one or more rails **304**, shell **306** and grip **308**. When assembled, nosepiece electrical contacts **102** fit into respective guides **304a** of the rail **304** to form a rail assembly. The rail assembly that includes the rail and the electrical contact fit into and attach to a respective lobe **306a** of shell **306**. In this embodiment, the rails **304** are generally flush with the front end of shell **306**, but other arrangements are possible. The rail(s) **304** may be attached to the lobes **306a** of shell **306** in any suitable manner. In this embodiment, the nosepiece **310** includes first and second rails **304** each having a respective nosepiece electrical contact **302** that are attached to the respective guides **304a**. As shown, the rails **304** have a step-up **304b** in the middle for fitting into the shell **306** having the front portion **306a** and rear portion **306b**. Nosepiece electrical contacts **302** are electrically connected to optical portion electrical contacts **351** when the nosepiece **310** is attached to the optical portion **314**. As depicted, the lobes **306a** of shell **306** are disposed on opposite sides of a pocket **306b**. Pocket **306b** allows the shell **306** and nosepiece **310** to fit about the inner body (i.e., the block-like feature) that houses optical body **320** having the optical interface **121** the when the nosepiece **310** is attached to the optical portion **314**. **FIGS. 34 and 35** are cross-sectional

views of plug **100** respectively taken along section lines 34-34 and 35-35 as shown in **FIG. 23**. **FIG. 34** depicts a cross-section near the center of the longitudinal axis and **FIG. 35** depicts a cross-section near the middle of one of the lobes **306a**. **FIG. 37** is a cross-sectional view of the force centering alignment features of plug **300** along with the optical interface **121.**

[0072] **FIG. 35** shows the nosepiece electrical contacts **302** in electrical connection with the optical portion electrical contacts **351** with the nosepiece **310** attached to the optical portion **314**. **FIG. 36** is a perspective view showing the electrical contacts of the plug and receptacle in a mated state with the other components of the plug and receptacle removed for clarity. As shown, nosepiece electrical contacts **302** act as a bridge between the optical portion electrical contacts **351** to the electrical contacts **430** of receptacle **400**.

[0073] **FIG. 38** is a front perspective view of plug **300** and **FIGS. 39 and 40** respectively are front and side perspective views of receptacle **400** showing explanatory dimensions for the plug **300** and receptacle **400**. Regarding plug **300** has a width dimension $\mathbf{X_p}$ and a total height $\mathbf{Y1_p}$ and a step-down height $\mathbf{Y2_p}$. Any suitable values may be used for plug **300**. By way of example and not limitation, plug **300** can have a width $\mathbf{X_p}$ in the range of 10-50 millimeters, the total height $\mathbf{Y1_p}$ in the range of 2-20 millimeters, and step-down height $\mathbf{Y2_p}$ in the range of 1-15 millimeters, but other dimensions are possible. Likewise, any suitable values may be used for receptacle **400**. By way of example and not limitation, receptacle **400** can have a width $\mathbf{X_R}$ in the range of 10-50 millimeters, the total height $\mathbf{Y_R}$ in the range of 2-20 millimeters, a length of the annular portion L_R in the range of 2-10 millimeters, and step-down height $\mathbf{Y1_R}$ in the range of 1-15 millimeters, but other dimensions are possible.

[0074] Although the disclosure has been illustrated and described herein with reference to embodiments and specific examples thereof, it will be readily apparent to those of ordinary skill in the art that other embodiments and examples can perform similar functions and/or achieve like results. All such equivalent embodiments and examples are within the spirit and scope of the disclosure and are intended to be covered by the appended claims. It will also be apparent to those skilled in the art that various modifications and variations can be made to the concepts disclosed without departing from the spirit and scope of the same. Thus, it is intended that the present application cover the modifications and variations provided they come within the scope of the appended claims and their equivalents.

We claim:

1. An optical plug connector, comprising:
   an optical portion having an optical interface; and
   a nosepiece that fits about part of the optical portion, wherein the nosepiece is removable and replaceable from the optical portion for accessing the optical interface.

2. The optical plug connector of claim 1, the optical portion further including an inner body and a housing.

3. The optical plug connector of claim 2, wherein the inner body is formed with the housing.

4. The optical plug connector of either one of claims 2 or 3, the optical interface being a portion of an optical body received in a passageway of the inner body.

5. The optical plug connector of claim 4, the optical body being able to move within the passageway of the inner body.

6. The optical plug connector of any one of claims 2-5, the inner body having one or more slots or windows for receiving a retainer.

7. The optical plug connector of any one of claims 1-6, the optical interface including one or more lenses.

8. The optical plug connector of claim 7, the one or more lenses being integrally formed in the optical interface or arranged as one or more discrete lenses.

9. The optical plug connector of any one of claims 1-8, the optical plug connector further including one or more magnets.

10. The optical plug connector of any one of claims 1-9, the optical portion further including one or more optical portion electrical contacts.

11. The optical plug connector of claim 10, the one or more optical portion electrical contacts being attached to the inner body.

12. The optical plug connector of any one of claims 1-11, the nosepiece being an assembly.

13. The optical plug connector of claim 12, the nosepiece including one or more nosepiece electrical contacts for being electrically connected to the one or more optical portion electrical contacts when the nosepiece is attached to the optical portion of the optical plug connector.

14. The optical plug connector of either one of claims 12 or 13, the nosepiece including a shell and one or more rails.

15. The optical plug connector of any one of claims 1-14, the optical portion further including a cover.

16. The optical plug connector of any one of claims 1-15 being a portion of a cable assembly.

17. An optical plug connector, comprising:

an optical portion having an inner body and an optical body having an optical interface, the inner body having a passageway for receiving the optical body; and

a nosepiece that fits about part of the optical portion, wherein the nosepiece is removable and replaceable from the optical portion for accessing the optical interface.

18. The optical plug connector of claim 17, the optical portion further including a housing.

19. The optical plug connector of claim 18, the inner body being formed with the housing.

20. The optical plug connector of any one of claims 17-19, further including a force centering element having a pivot point.

21. The optical plug connector of claim 17, the optical body being able to move within the passageway of the inner body.

22. The optical plug connector of any one of claims 17-21, the inner body having one or more slots or windows for receiving a retainer.

23. The optical plug connector of any one of claims 17-22, the optical interface including one or more lenses.

24. The optical plug connector of claim 23, the one or more lenses being integrally formed in the optical interface or arranged as one or more discrete lenses.

25. The optical plug connector of any one of claims 17-24, the optical plug connector further including one or more magnets.

26. The optical plug connector of any one of claims 17-25, the optical portion further including one or more optical portion electrical contacts.

27. The optical plug connector of claim 26, the one or more optical portion electrical contacts being attached to the inner body.

28. The optical plug connector of any one of claims 17-27, the nosepiece being an assembly.

29. The optical plug connector of claim 28, the nosepiece further including one or more nosepiece electrical contacts for being electrically connected to the one or more optical portion electrical contacts when the nosepiece is attached to the optical portion of the optical plug connector.

30. The optical plug connector of either one of claims 28 or 29, the nosepiece including a shell and one or more rails.

31. The optical plug connector of any one of claims 17-30, the optical portion further including a cover.

32. The optical plug connector of any one of claims 17-31 being a portion of a cable assembly.

33. An optical receptacle, comprising:

a shell;

a lens body having an optical interface with one or more optical channels, wherein the lens body attaches to the shell.

34. The optical receptacle of claim 33, the lens body having one or more attachment flanges for securing the lens body to the shell.

35. The optical receptacle of either one of claims 33 or 34, further including a receptacle circuit board assembly attached to the lens body.

36. The optical receptacle of claim 35, the receptacle circuit board assembly further including one or more active components.

37. The optical receptacle of any one of claims 33-36, wherein the lens body has a portion with a U-shape.

38. The optical receptacle of any one of claims 33-37, further including a cover.

39. The optical receptacle of any one of claims 33-38, the lens body including one or more rails formed therein.

40. The optical receptacle of claim 39, the lens body including one or more electrical contacts on the one or more rails.

41. The optical receptacle of any one of claims 33-40, the lens body having at least one alignment feature adjacent to the optical interface.

42. The optical receptacle of any one of claims 33-41, the shell having an open side.

43. The optical receptacle of any one of claims 33-42 being attached to a circuit board.

44. The optical receptacle of any one of claims 33-43 being a portion of an electronic device.

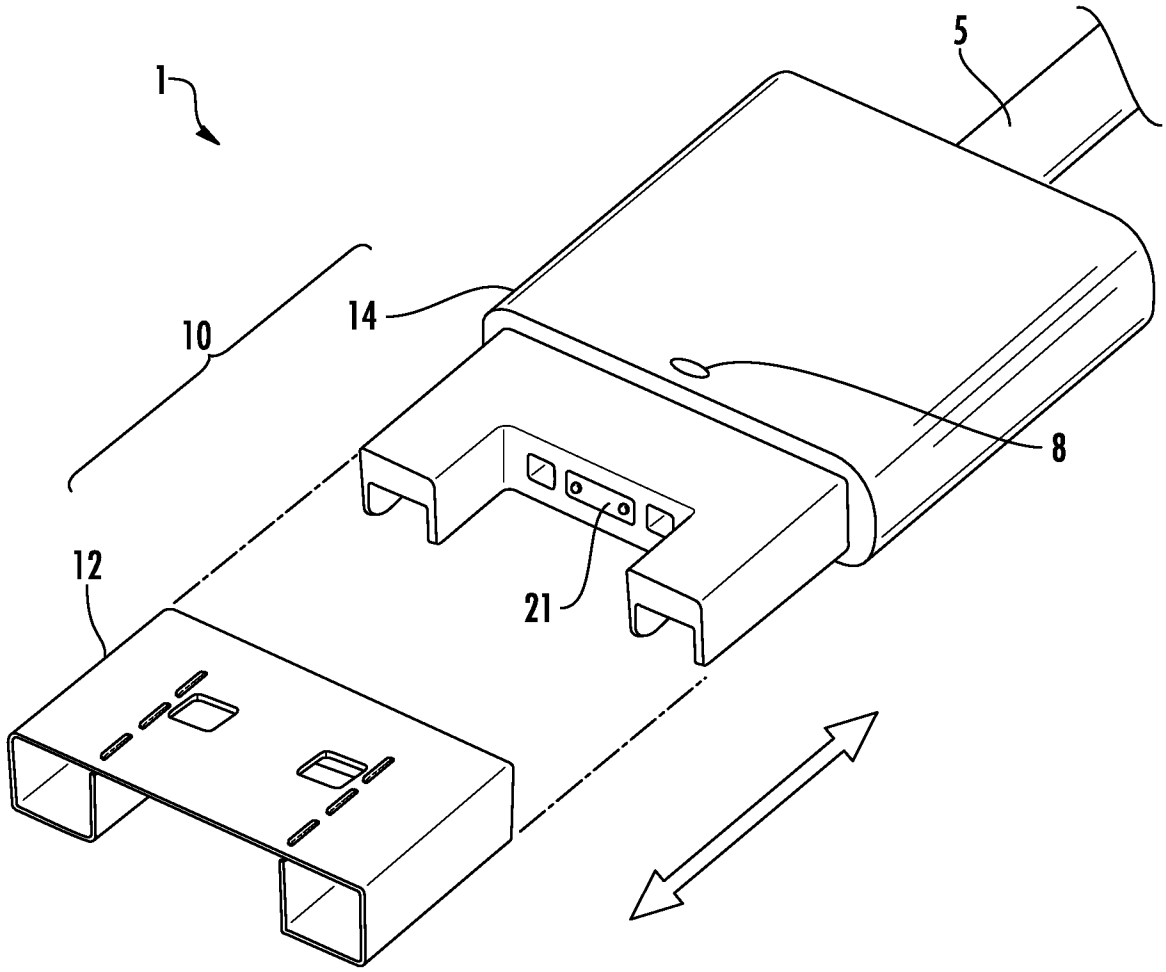


FIG. 1

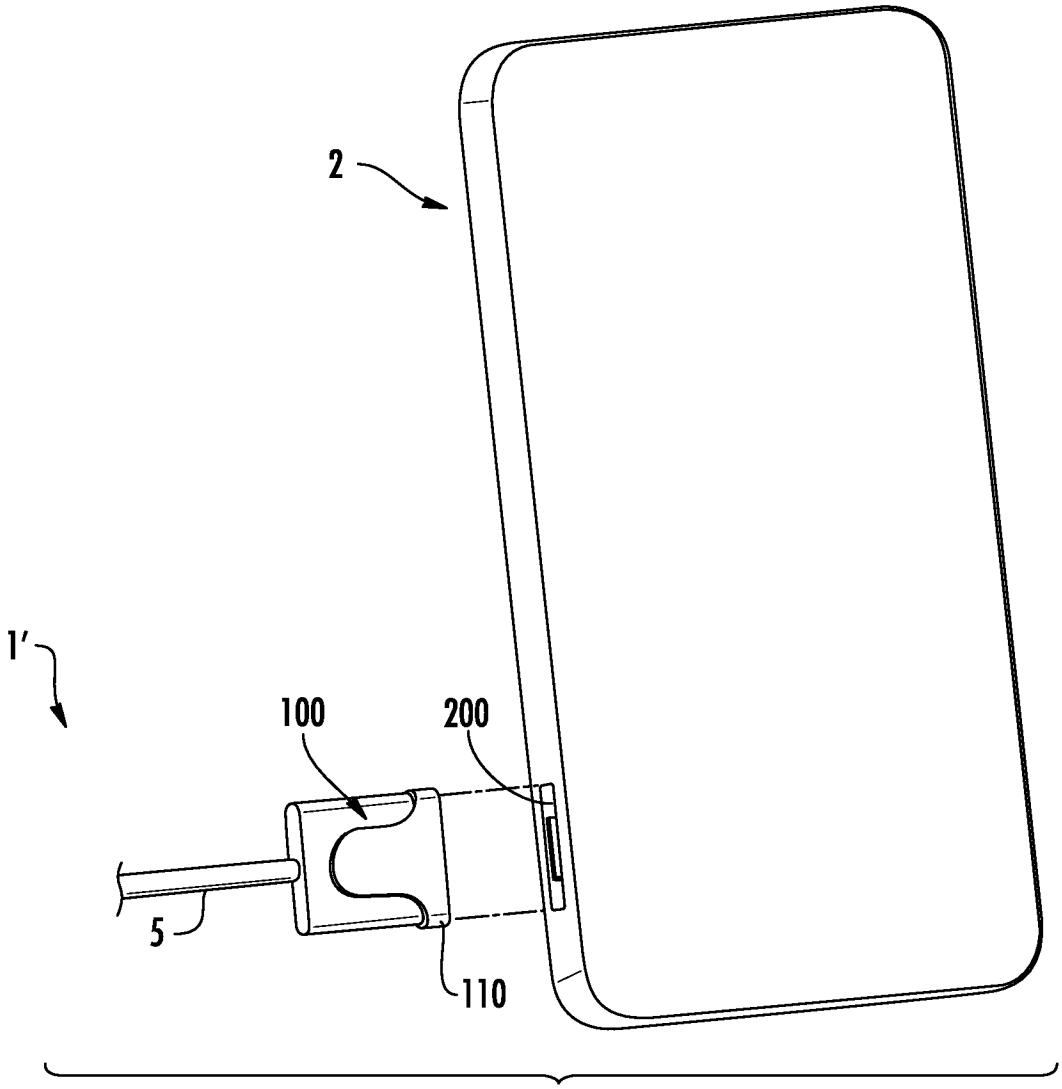


FIG. 2

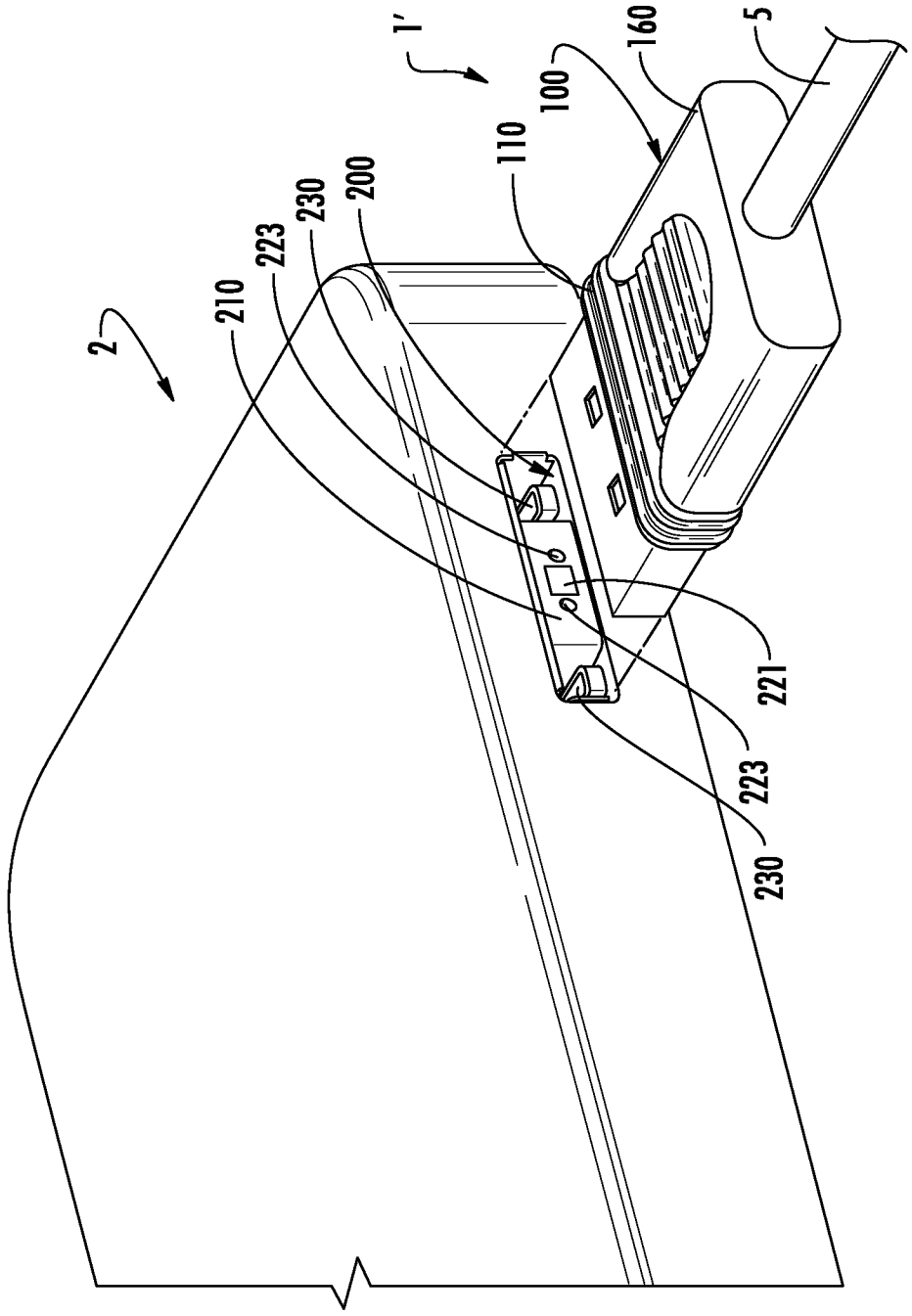


FIG. 3

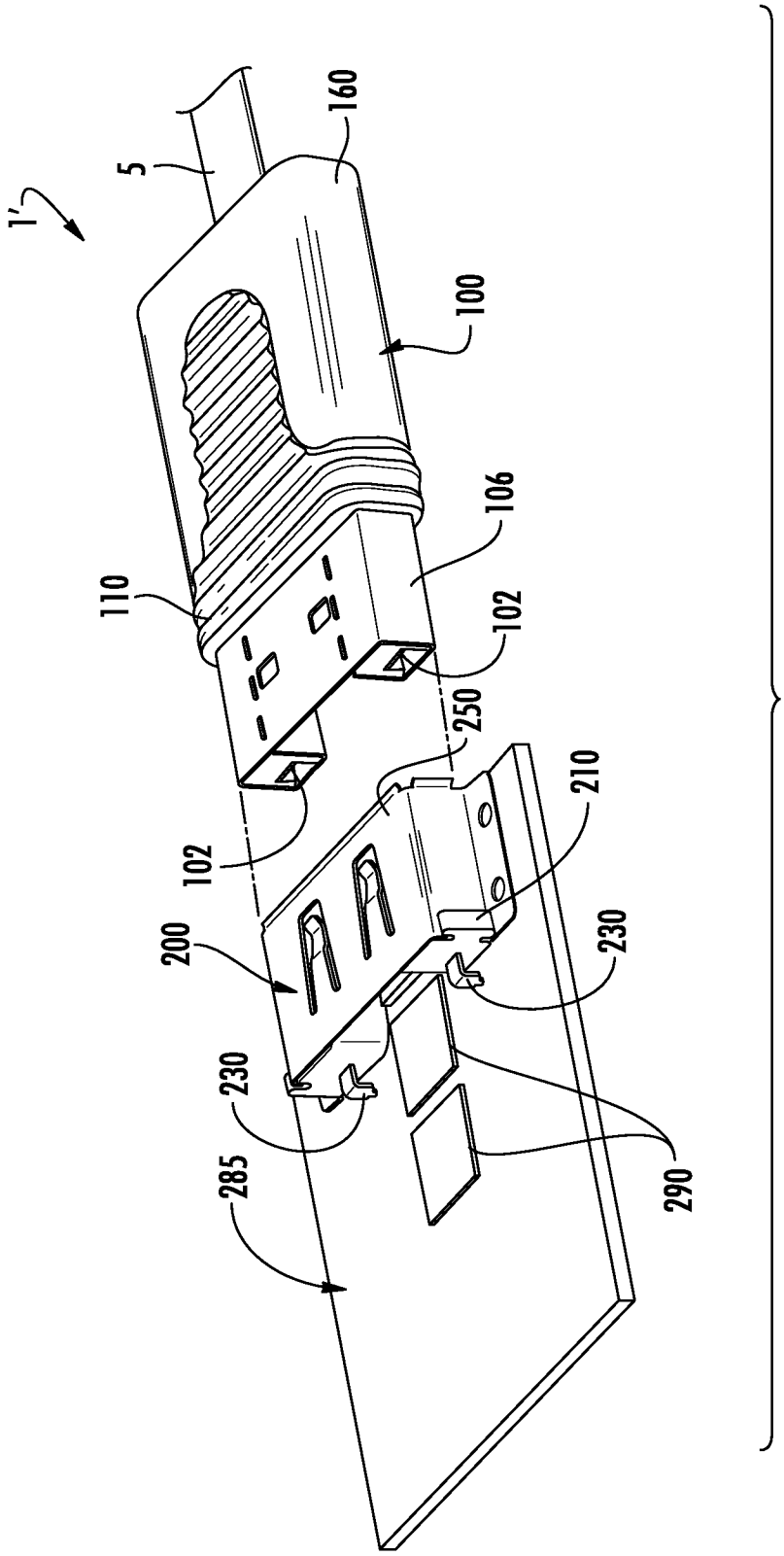


FIG. 4

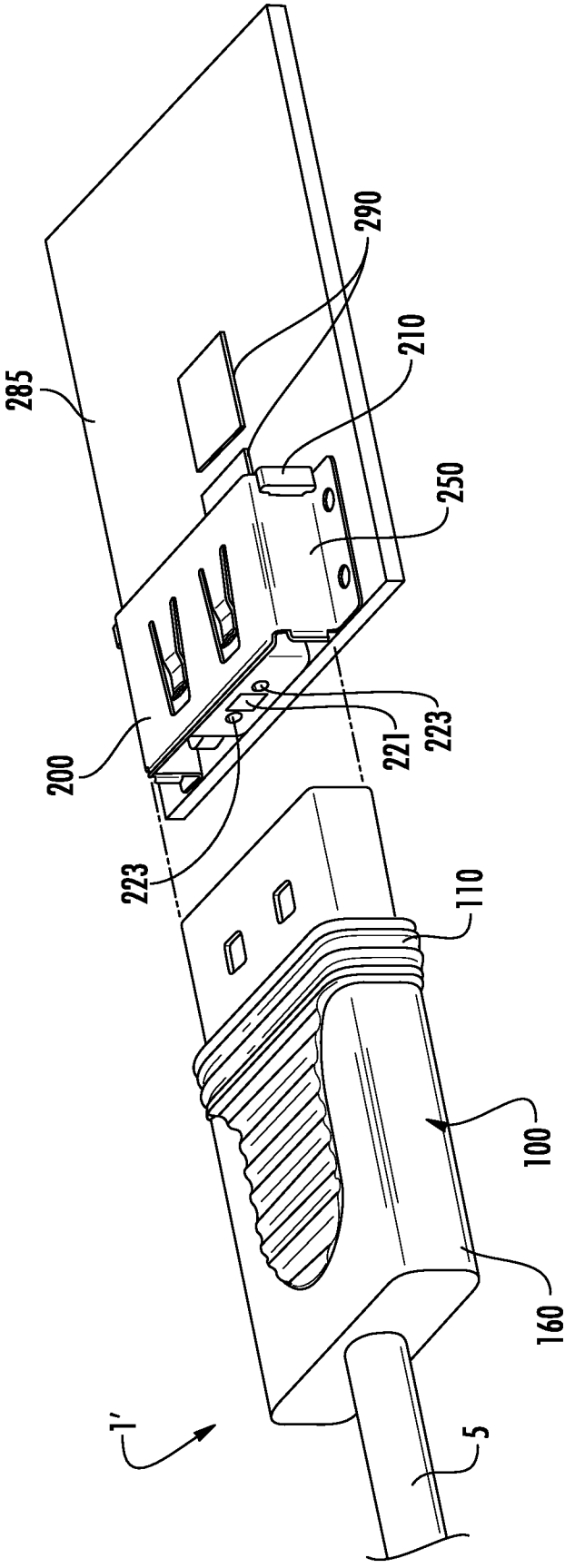


FIG. 5

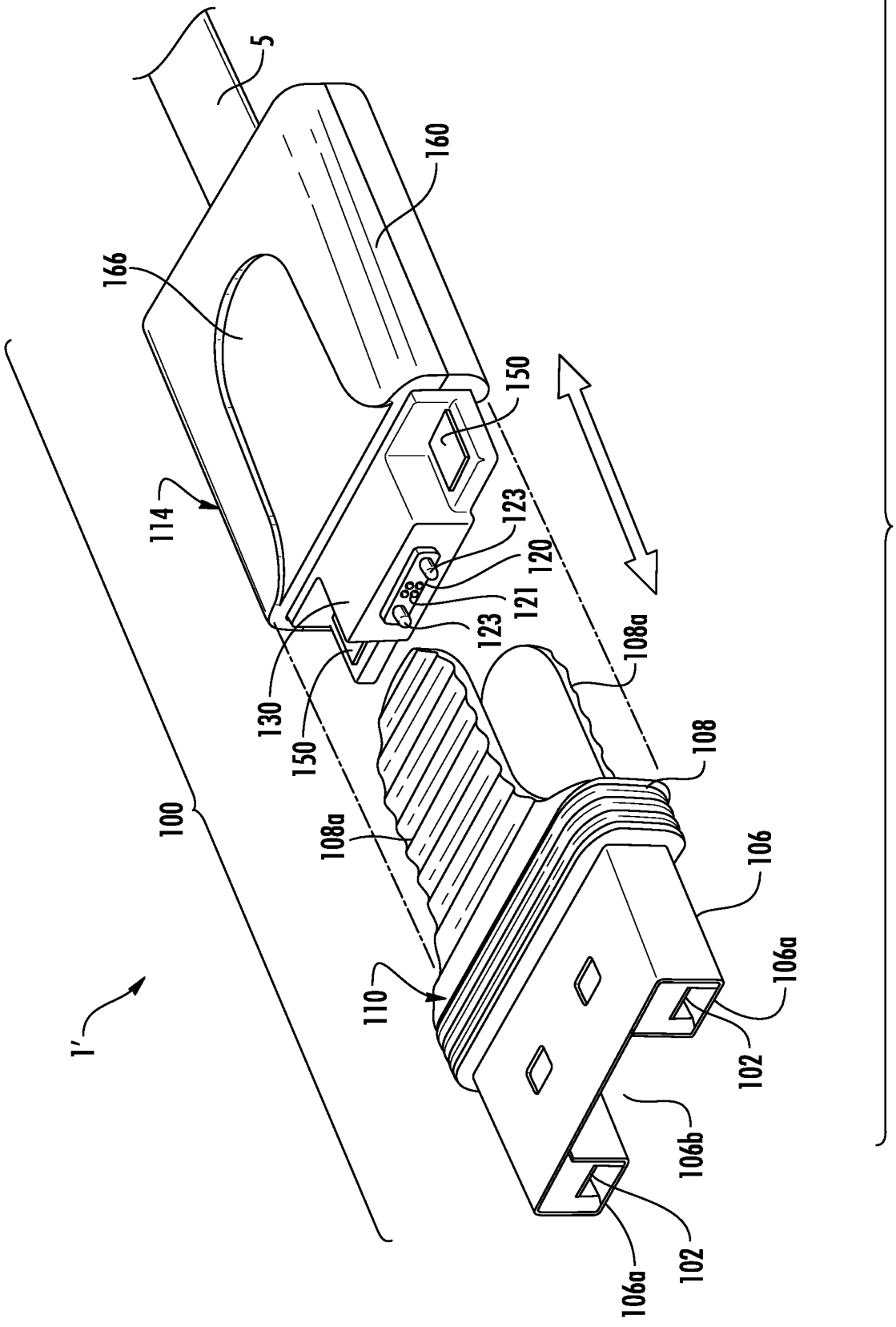

1'
100
5
160
166
114
150
123
120
121
123
130
150
108a
108
108a
106
106a
110
102
106b
102
106a

FIG. 6

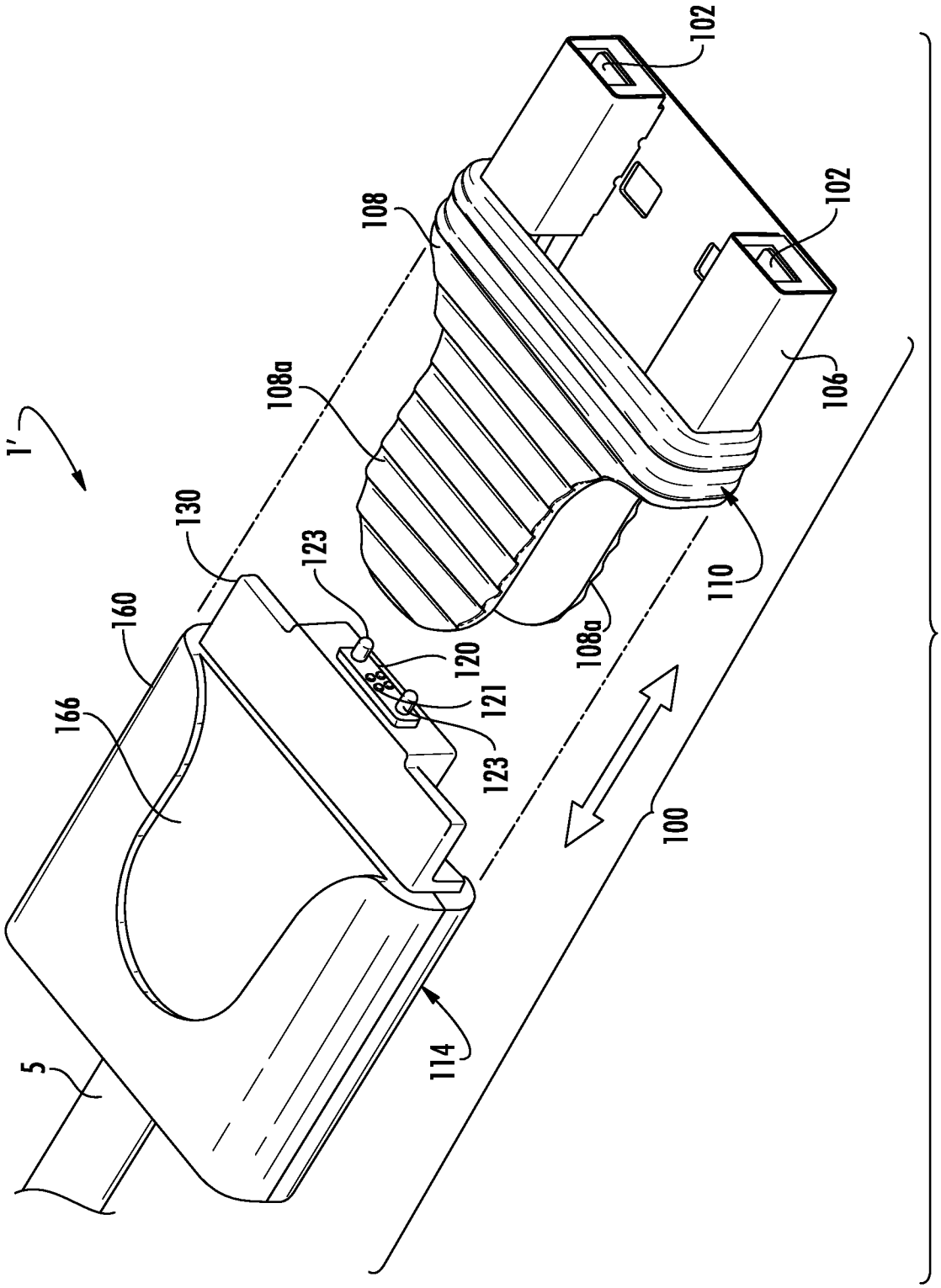

1'
5
160
166
130
108a
108
102
102
106
123
120
121
123
110
108a
114
100

FIG. 7

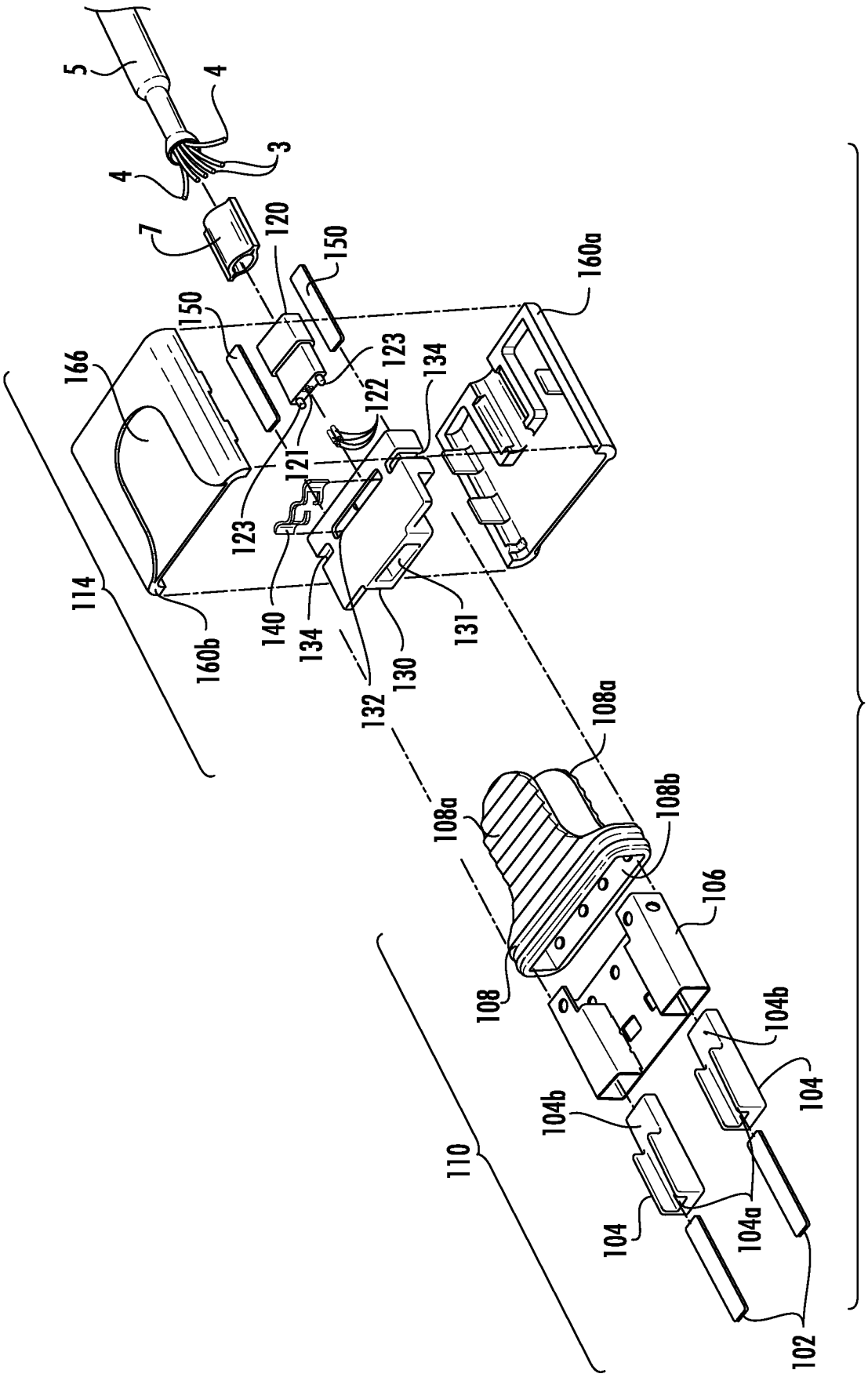

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160b
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104a
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102

FIG. 8

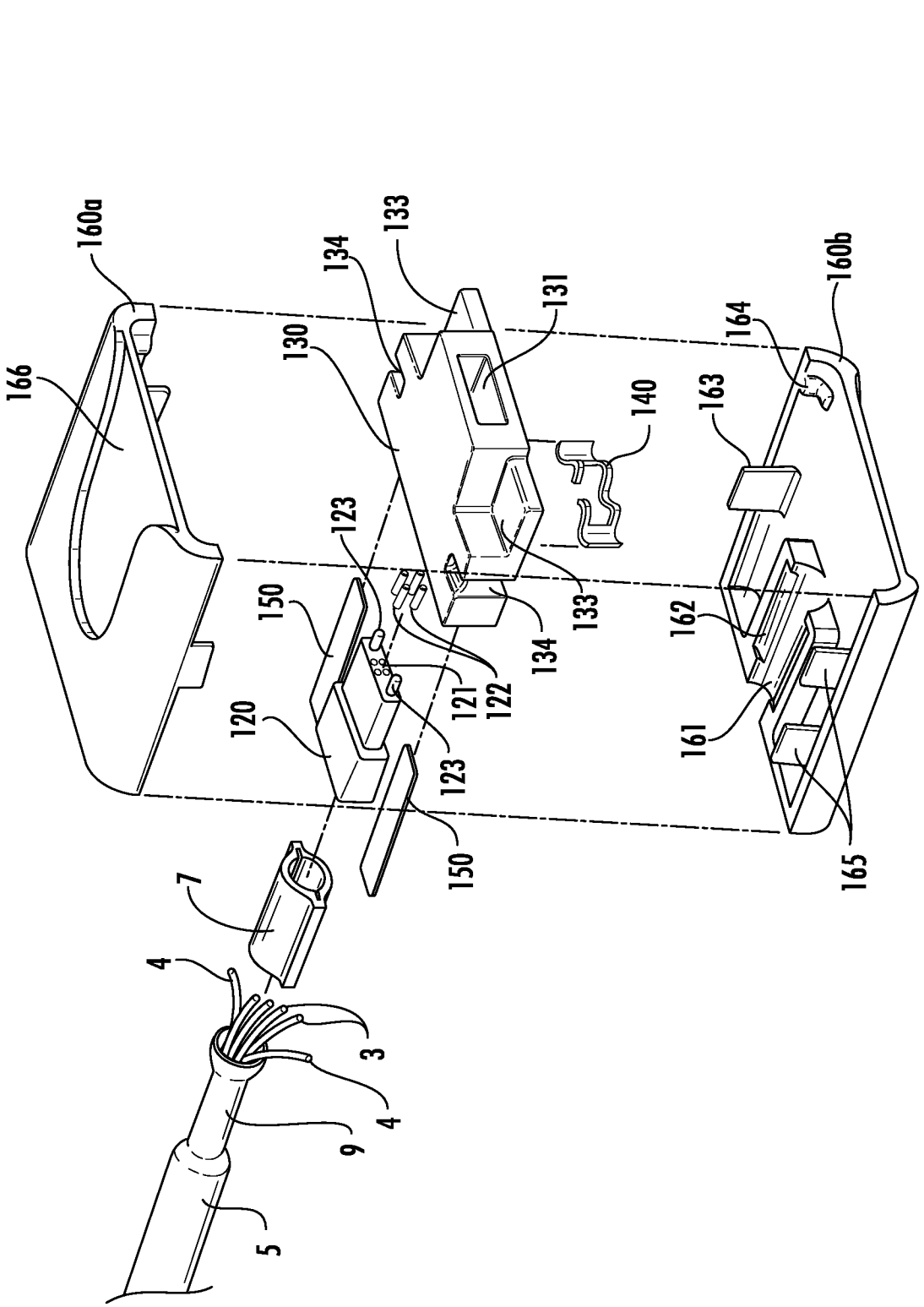

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FIG. 9

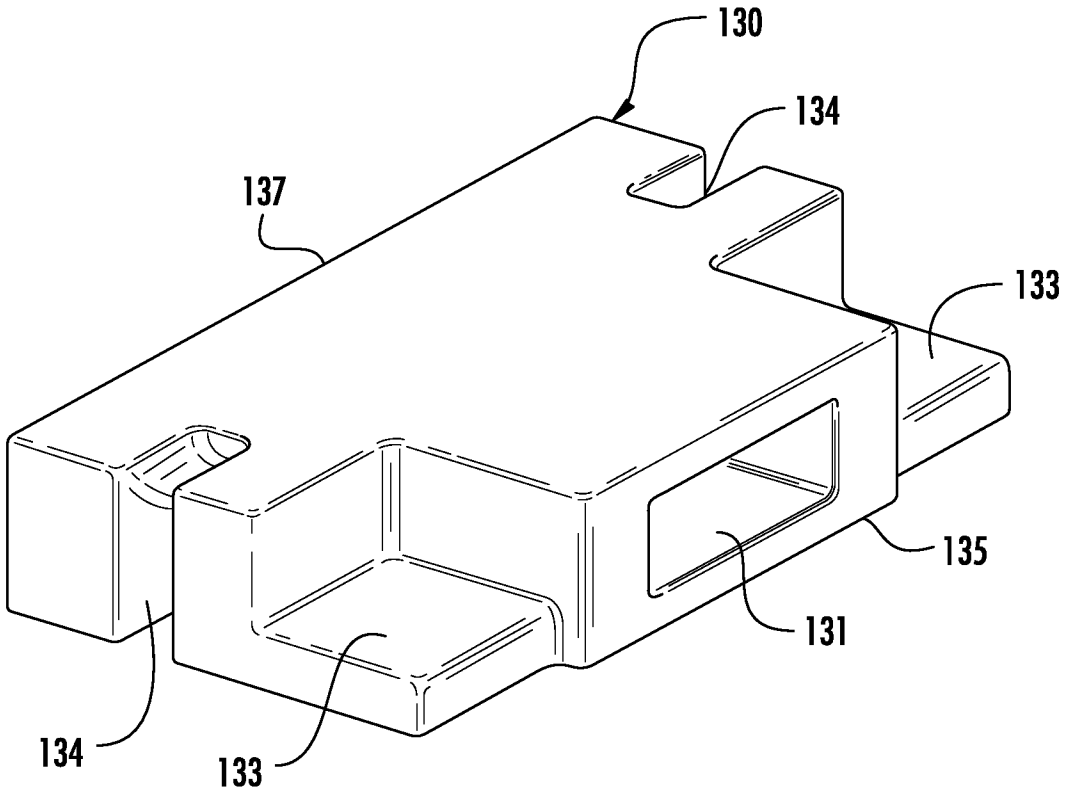


FIG. 10

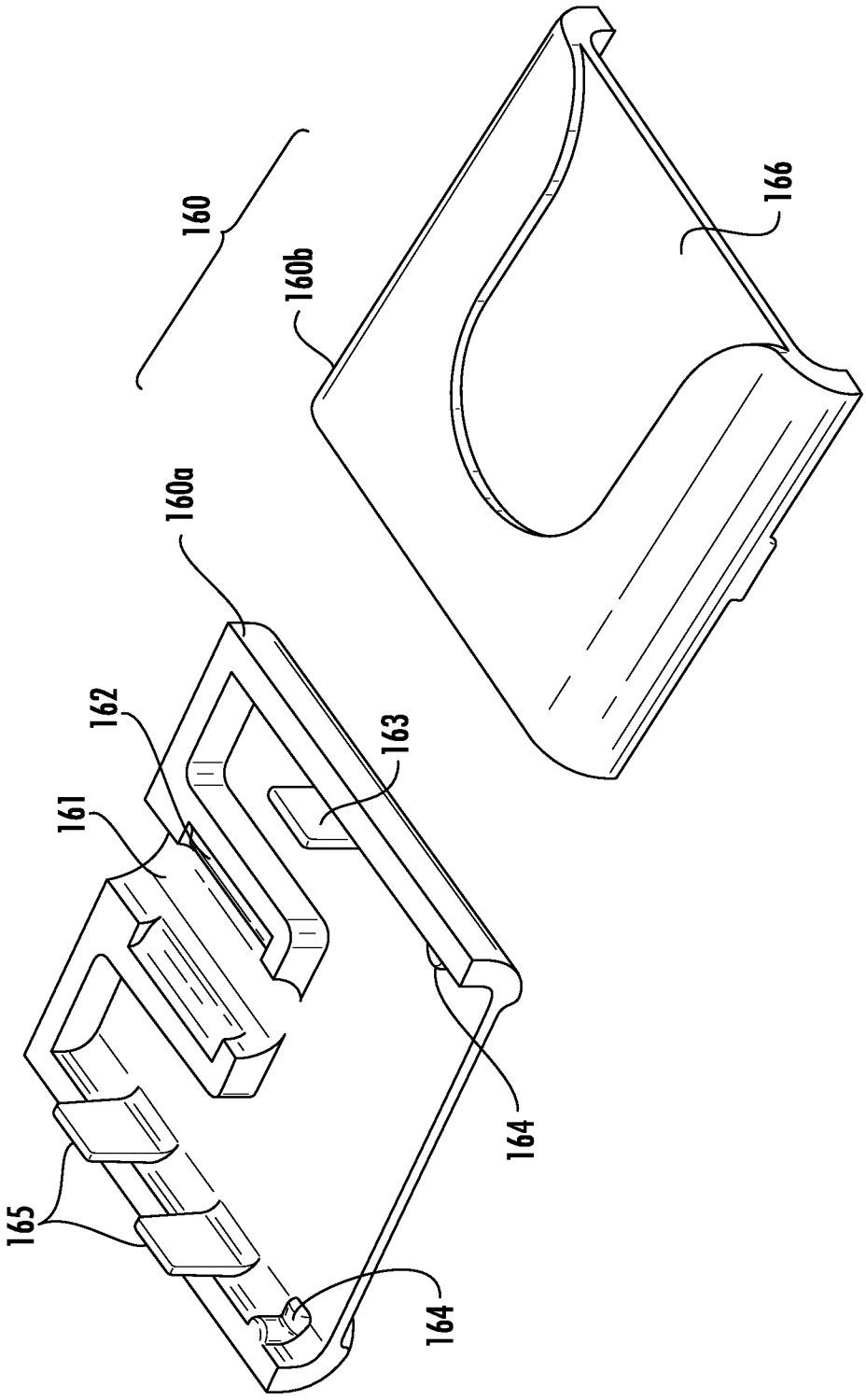


FIG. 11

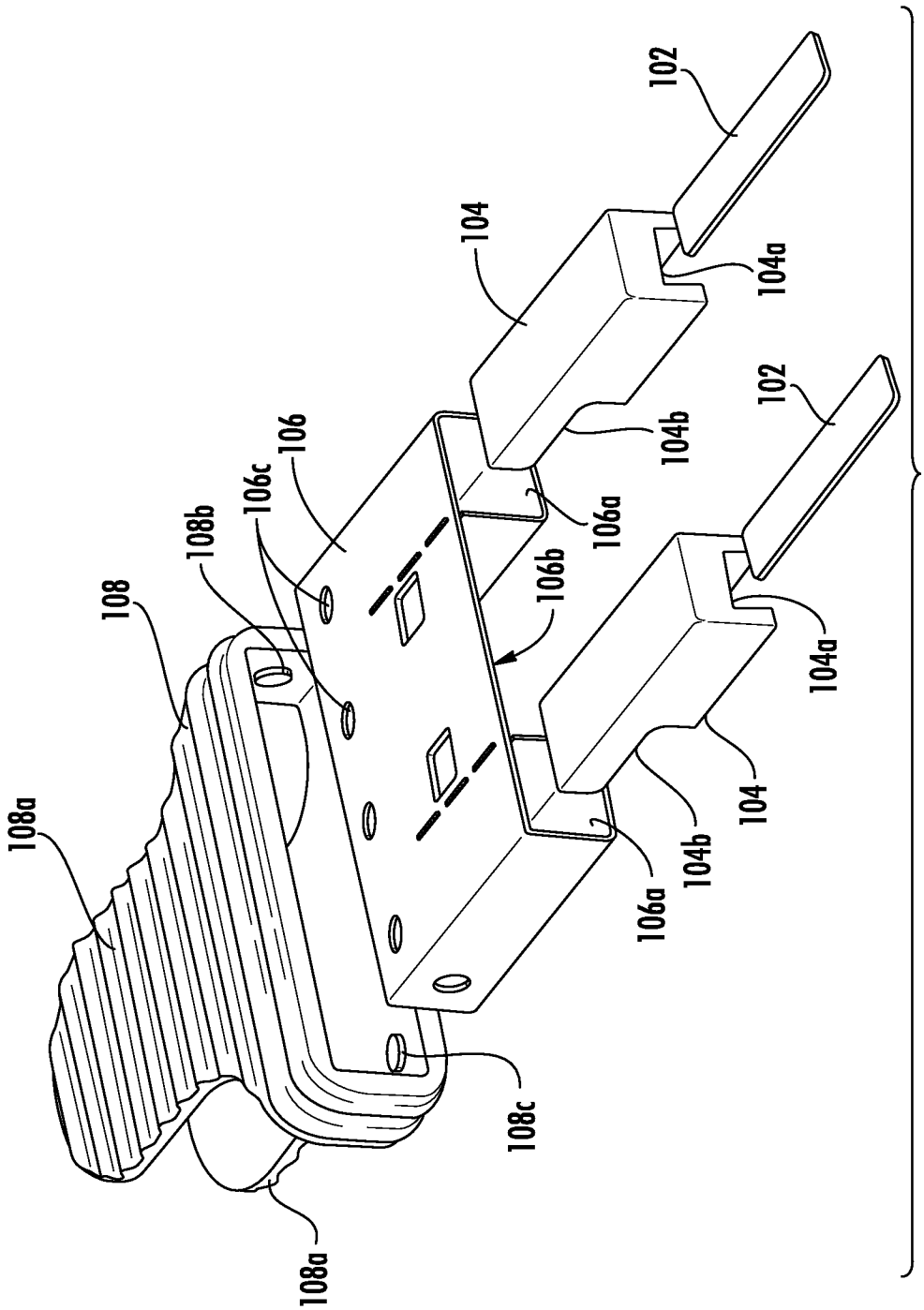

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108c
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FIG. 12

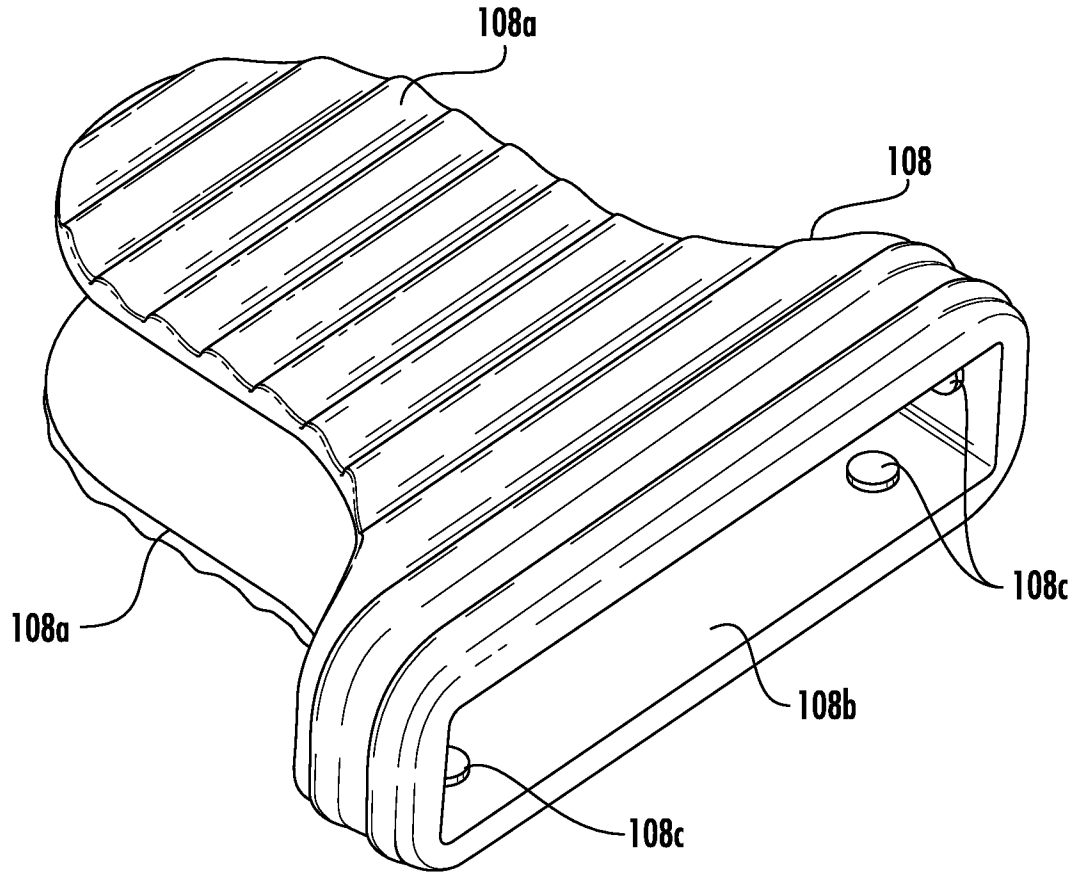


FIG. 13

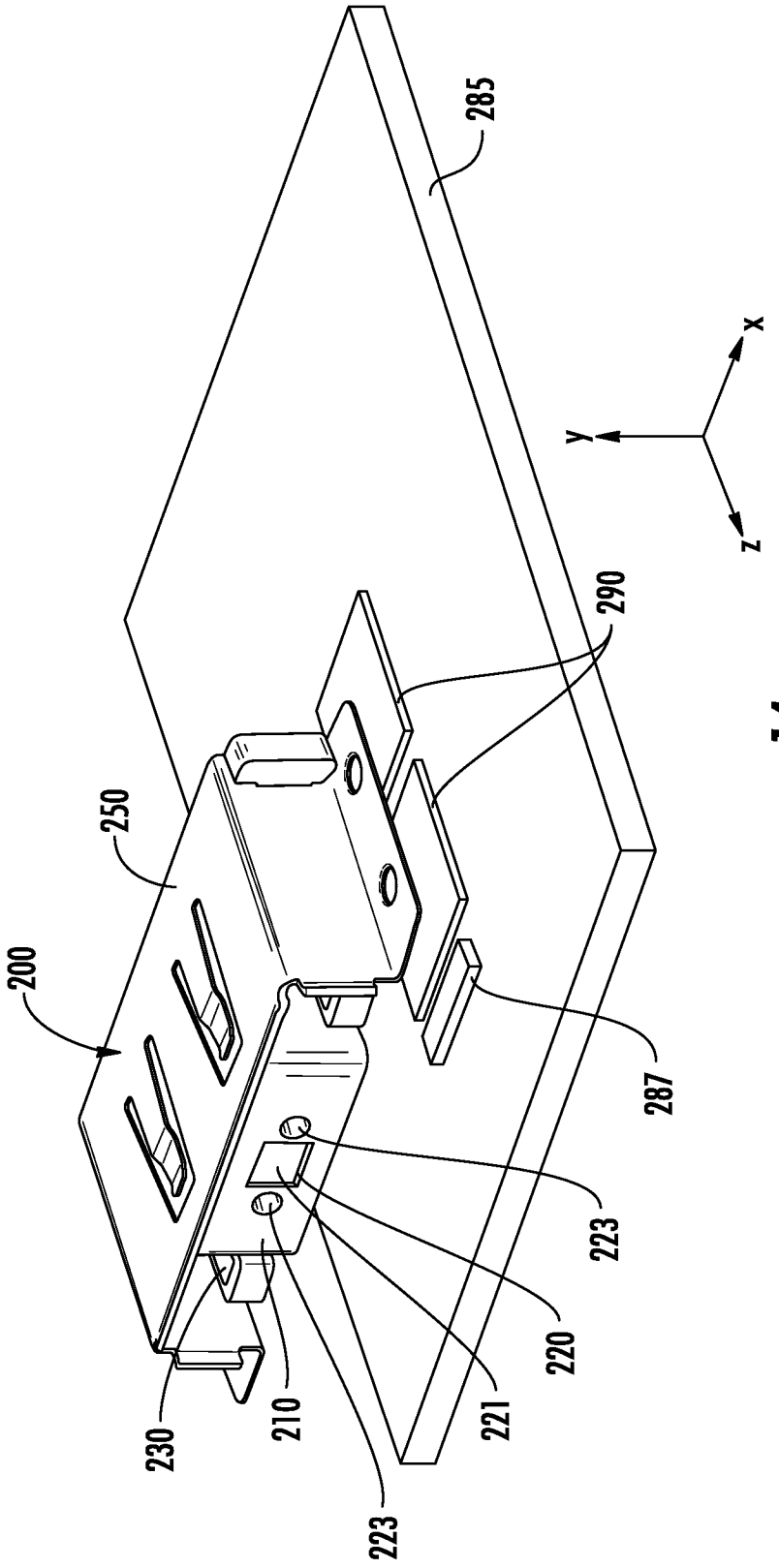


FIG. 14

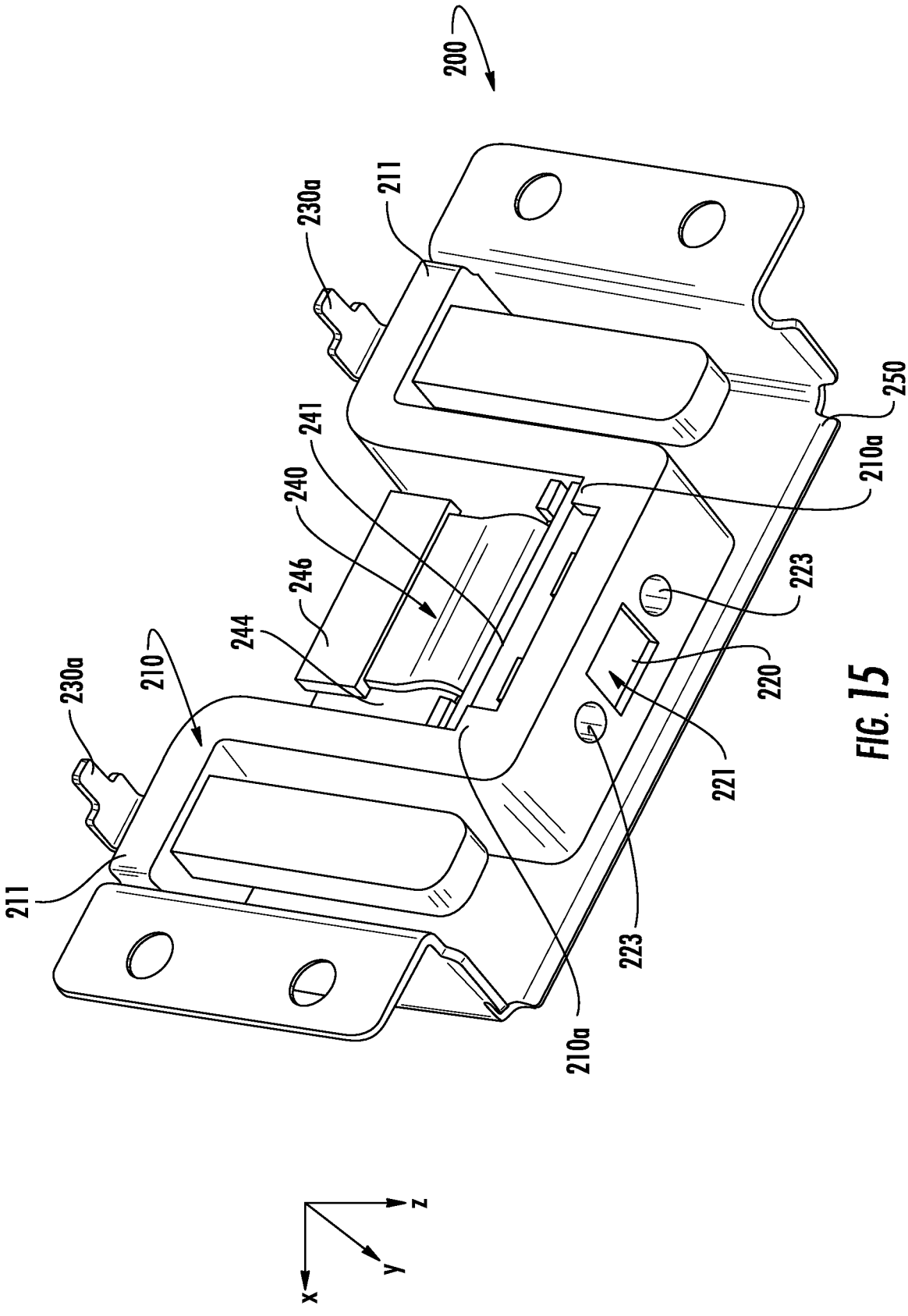

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FIG. 15

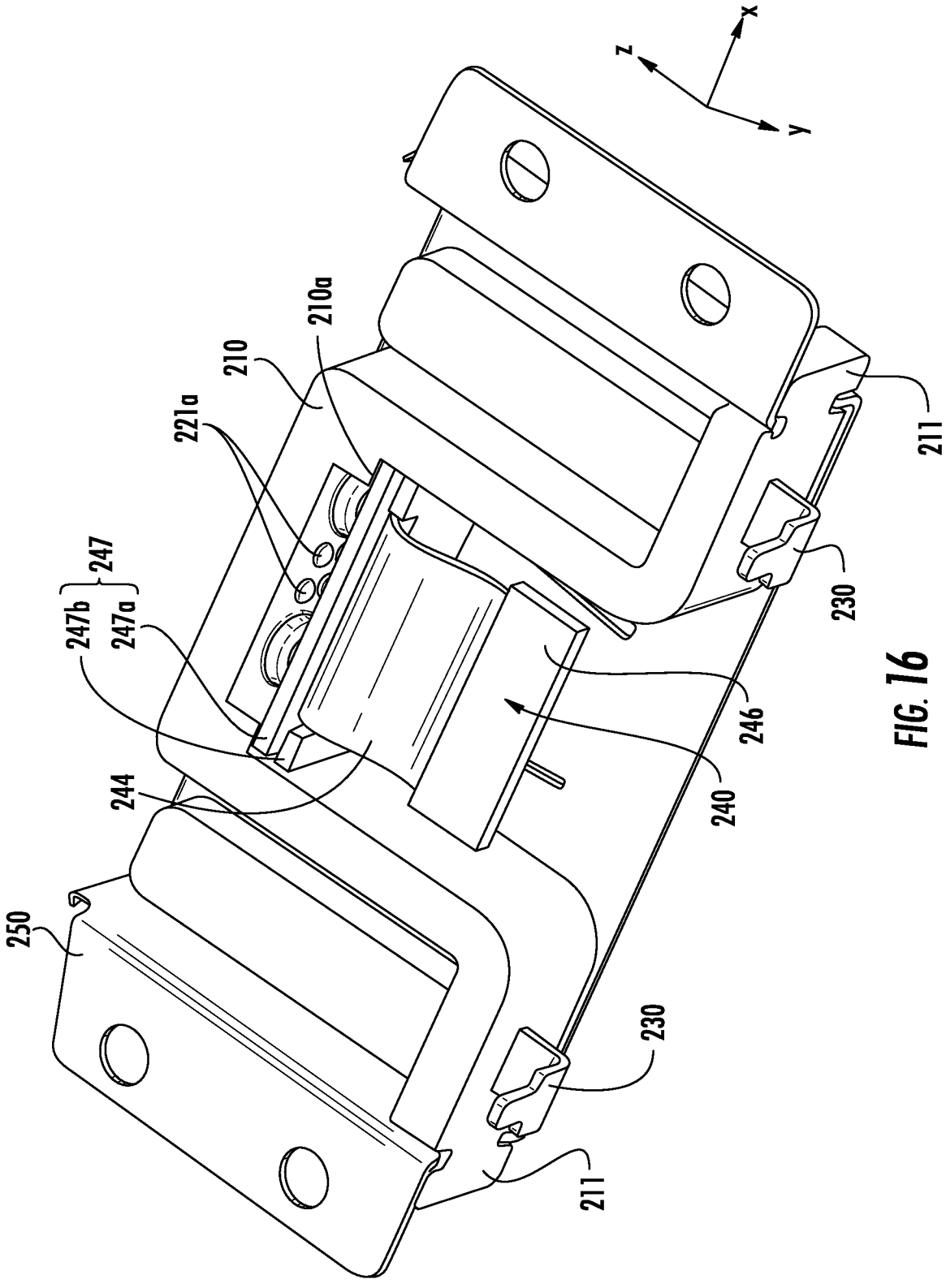


FIG. 16

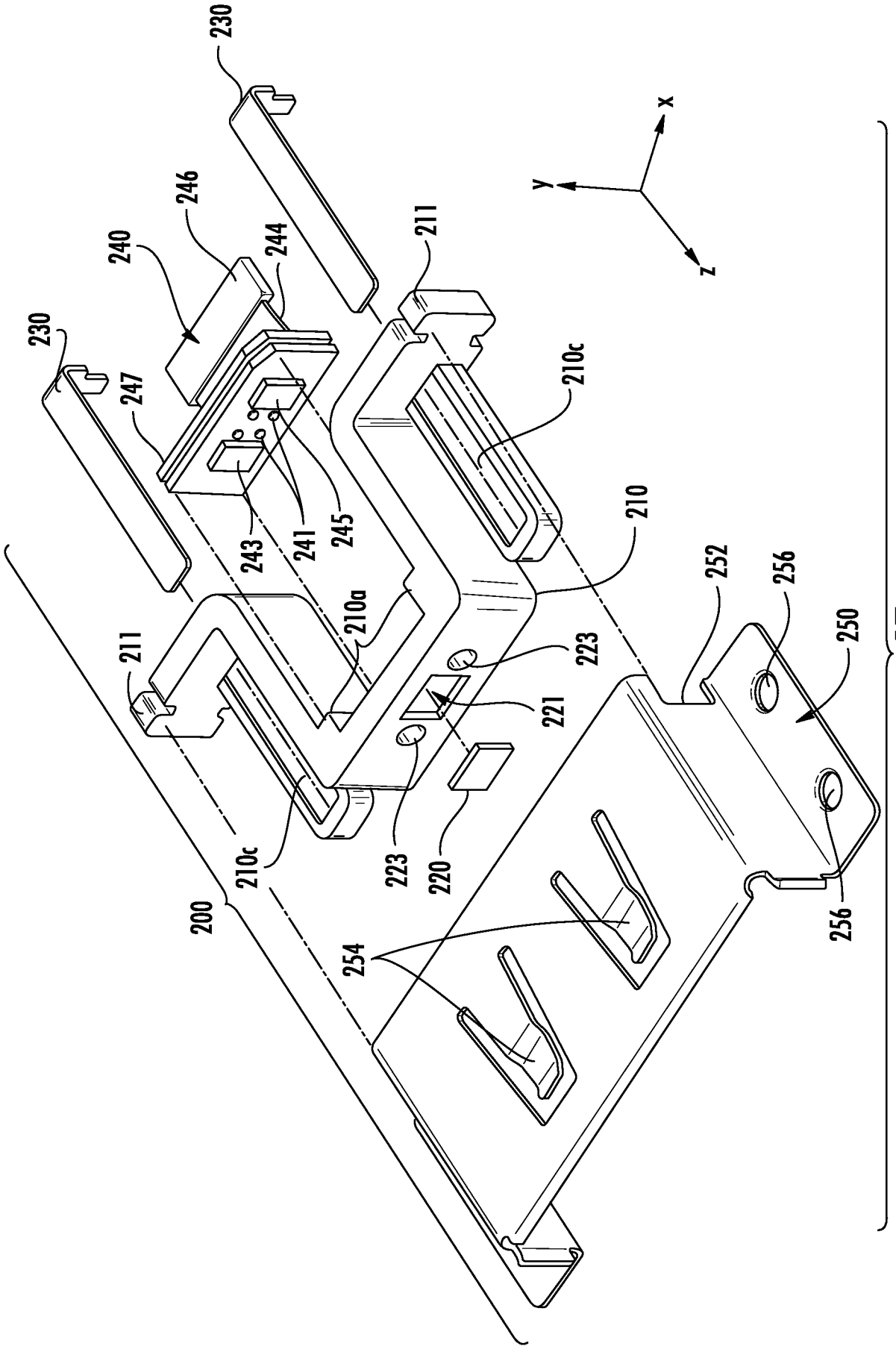

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FIG. 17

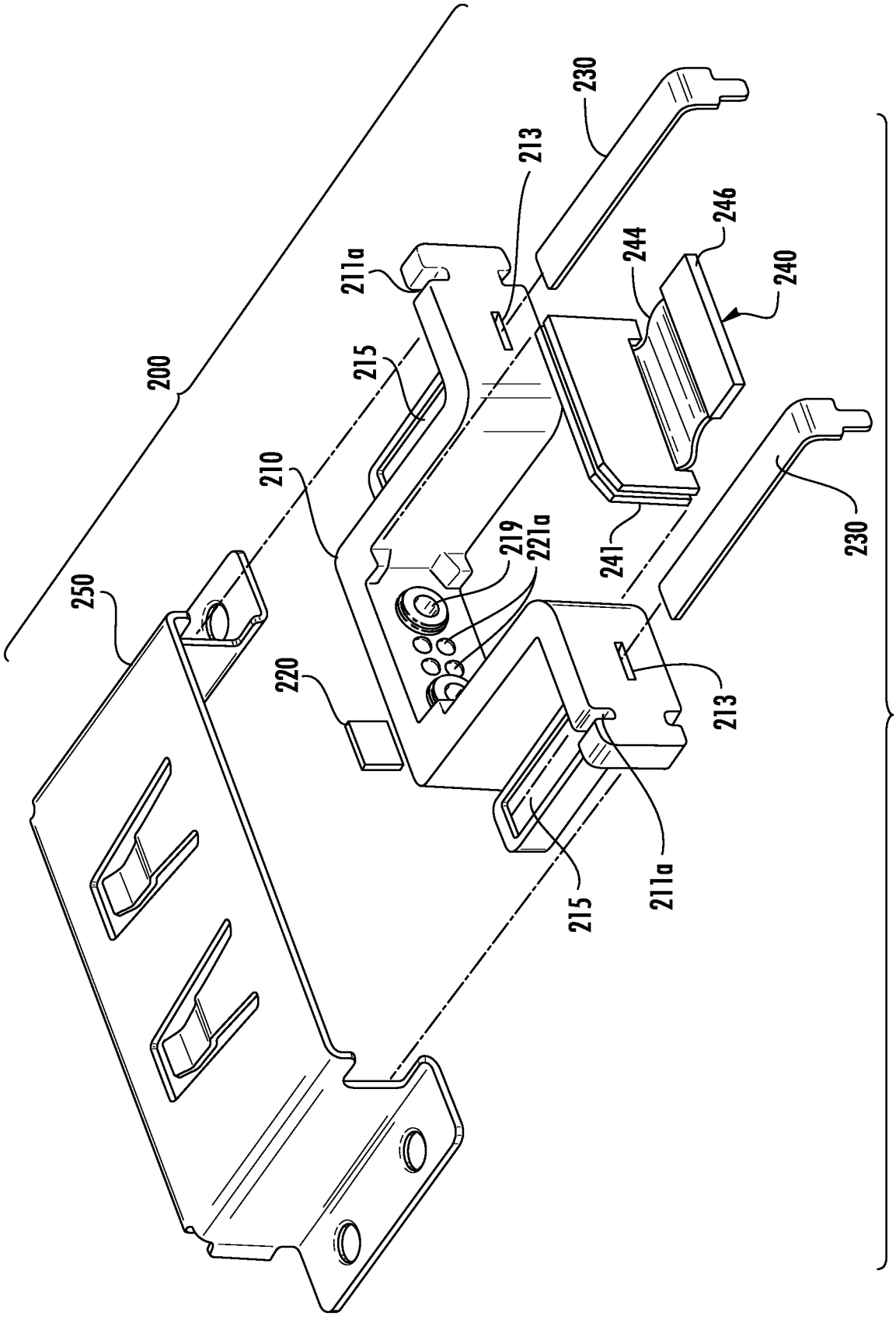


FIG. 18

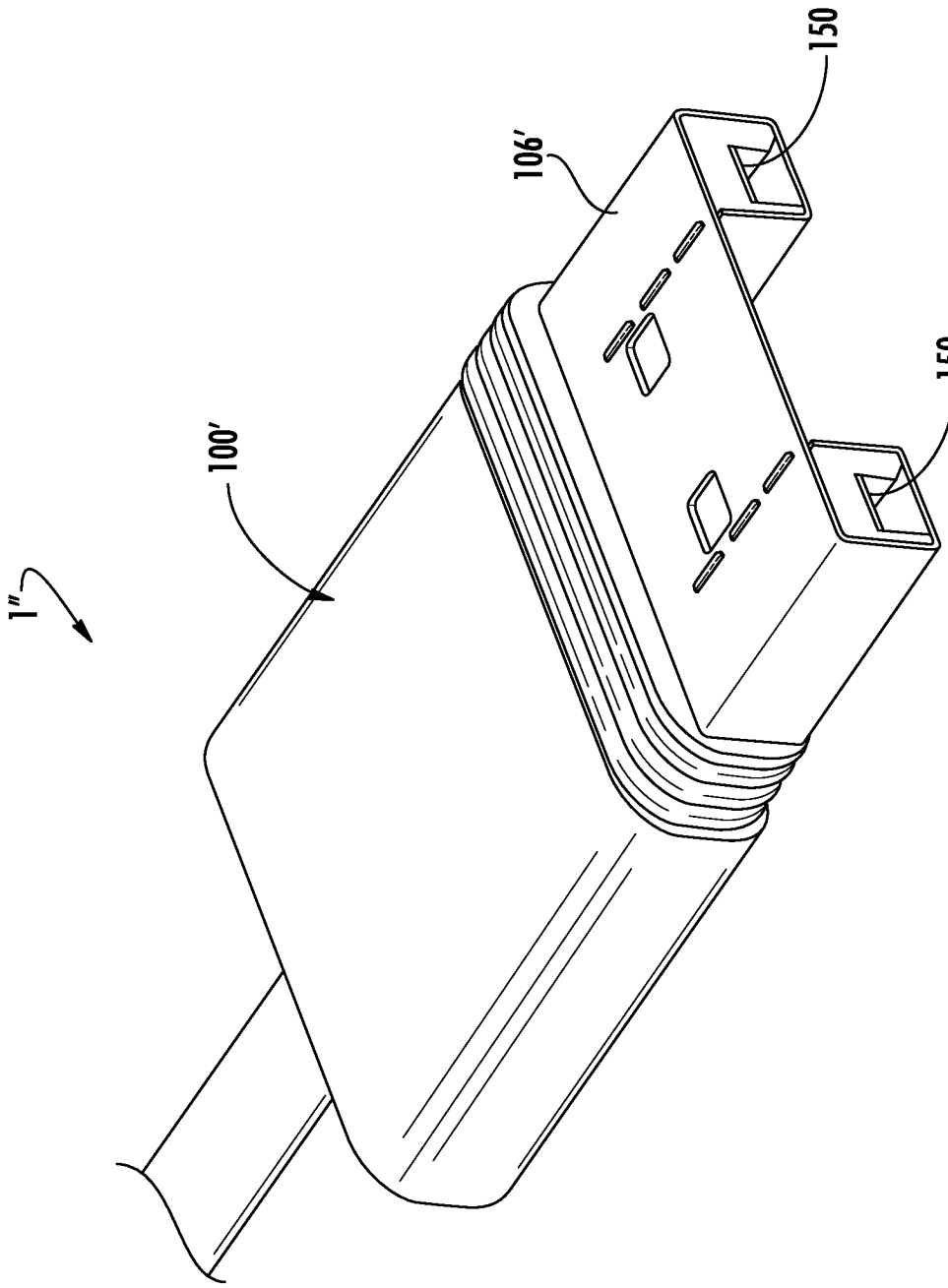


FIG. 19

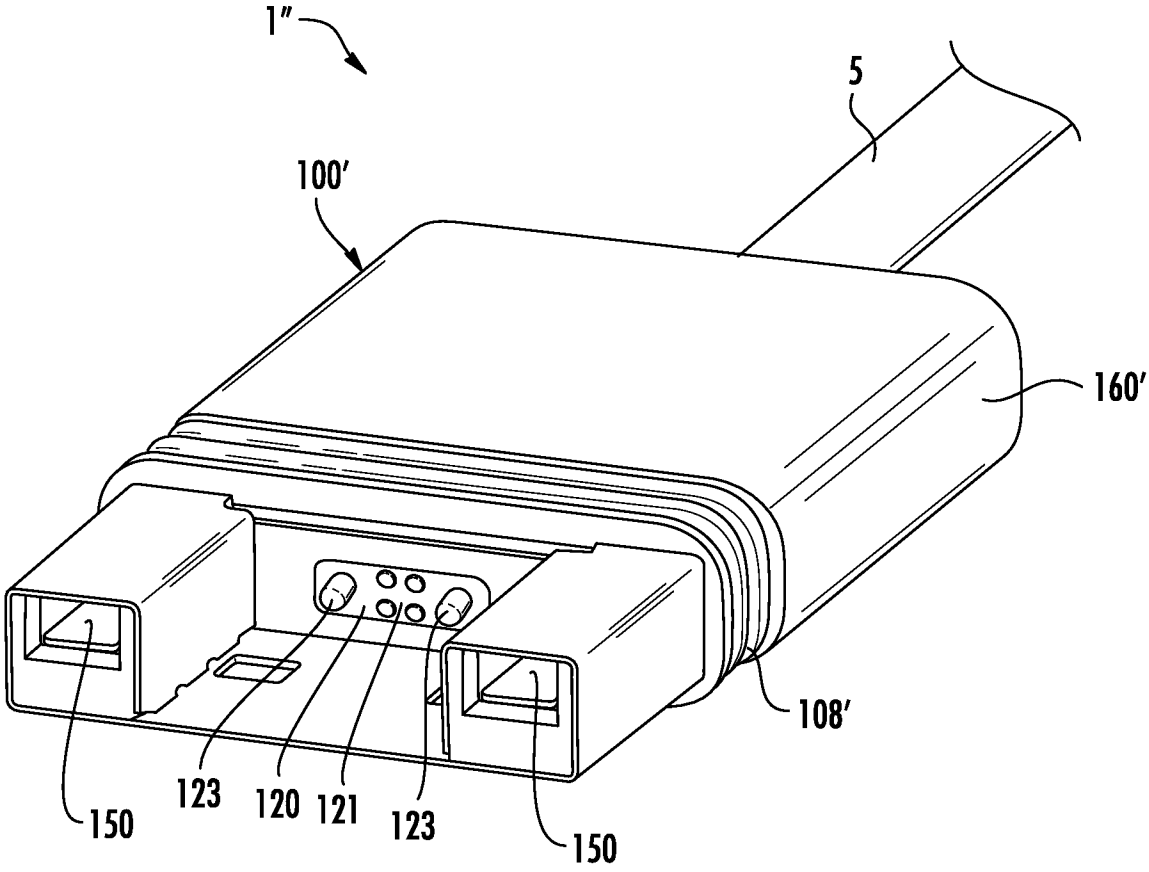


FIG. 20

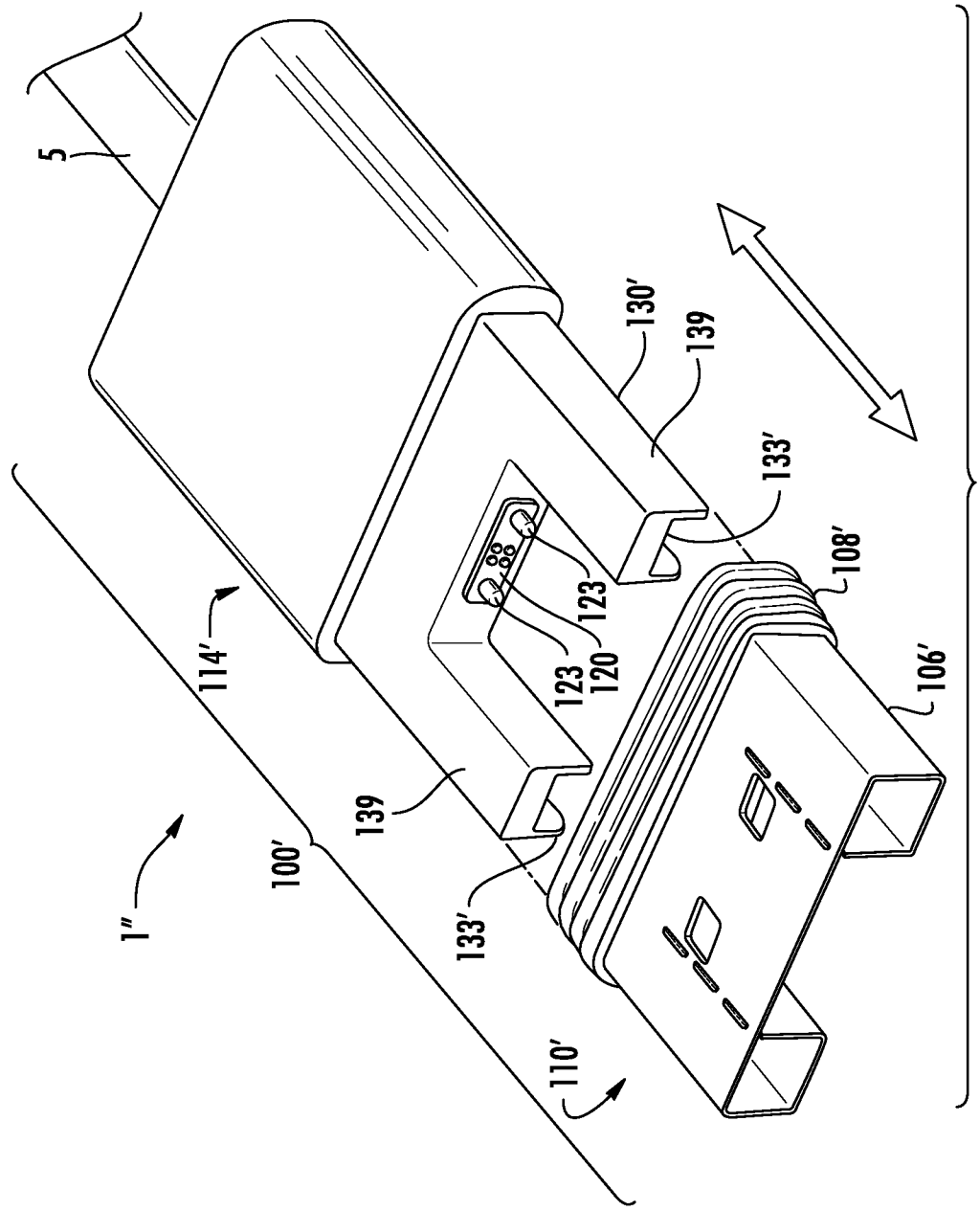


FIG. 21

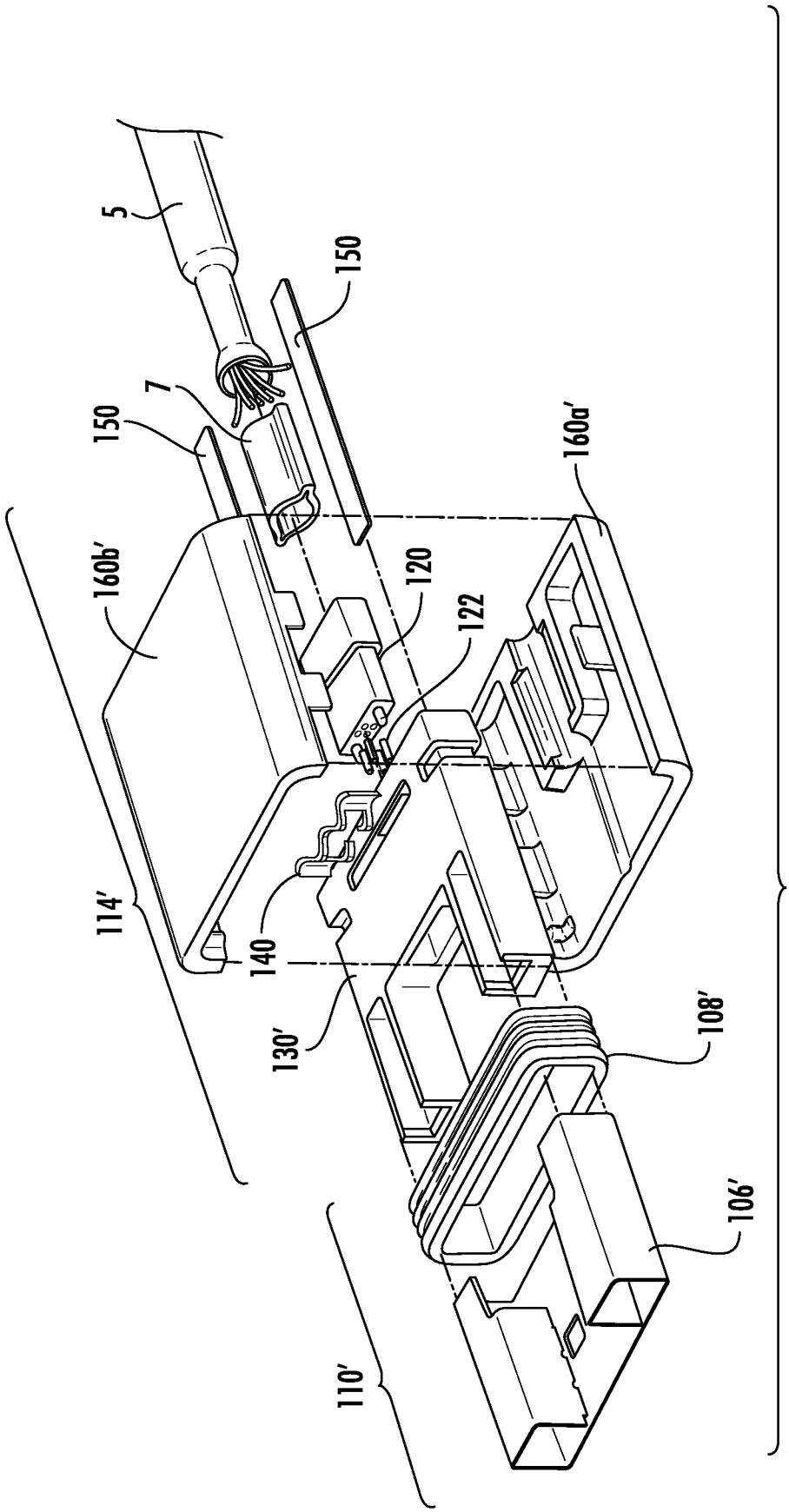


FIG. 22

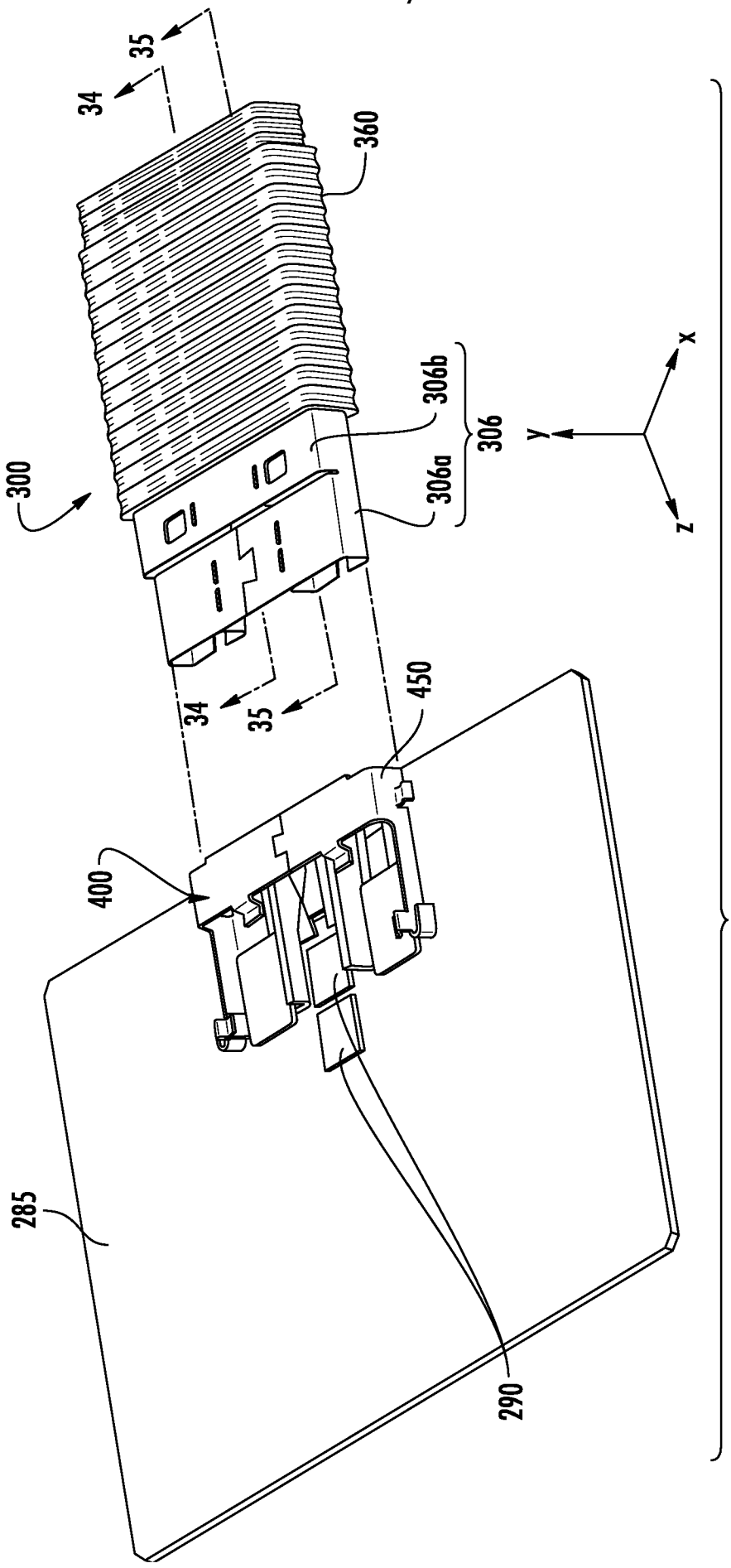


FIG. 23

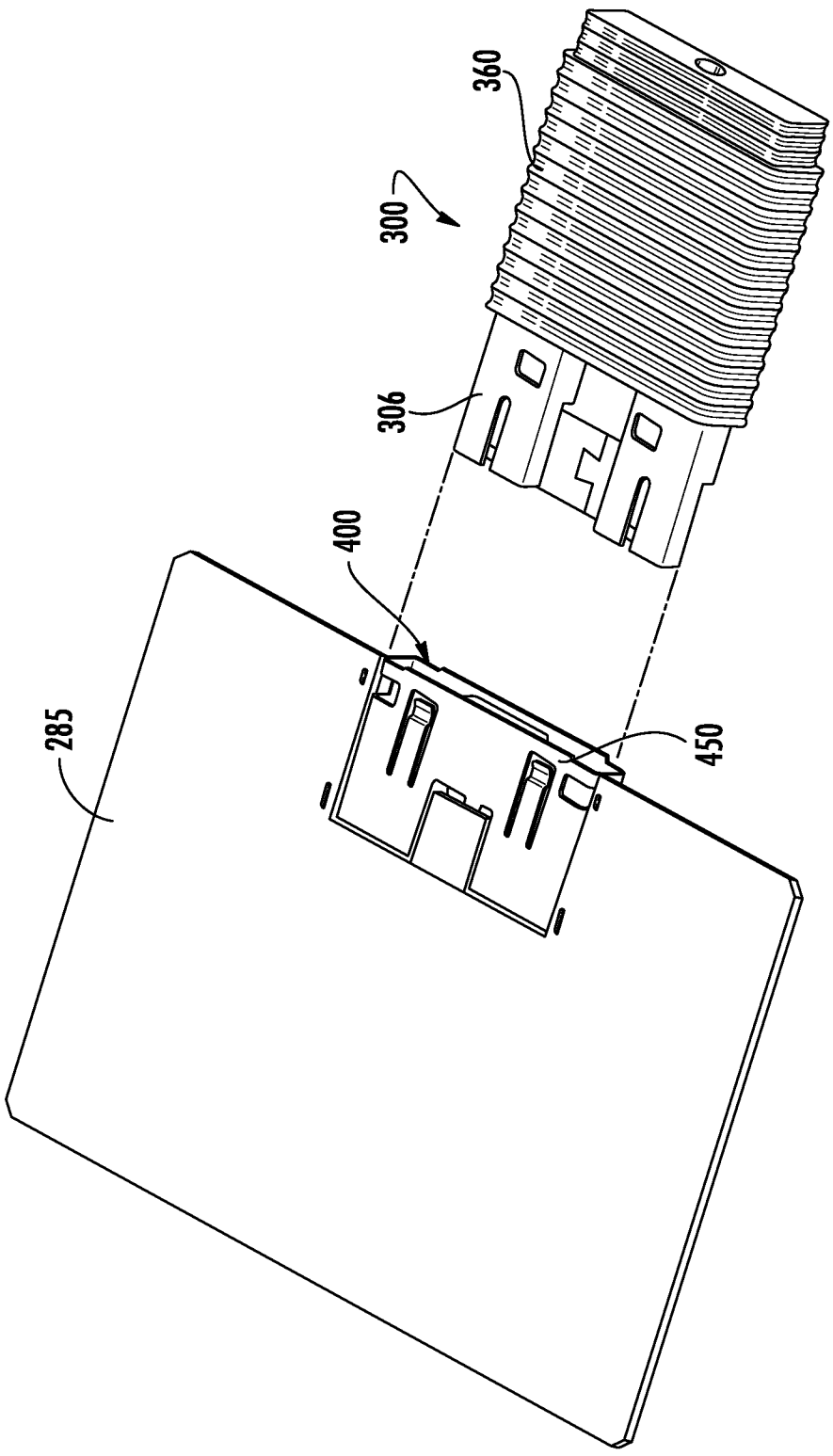


FIG. 24

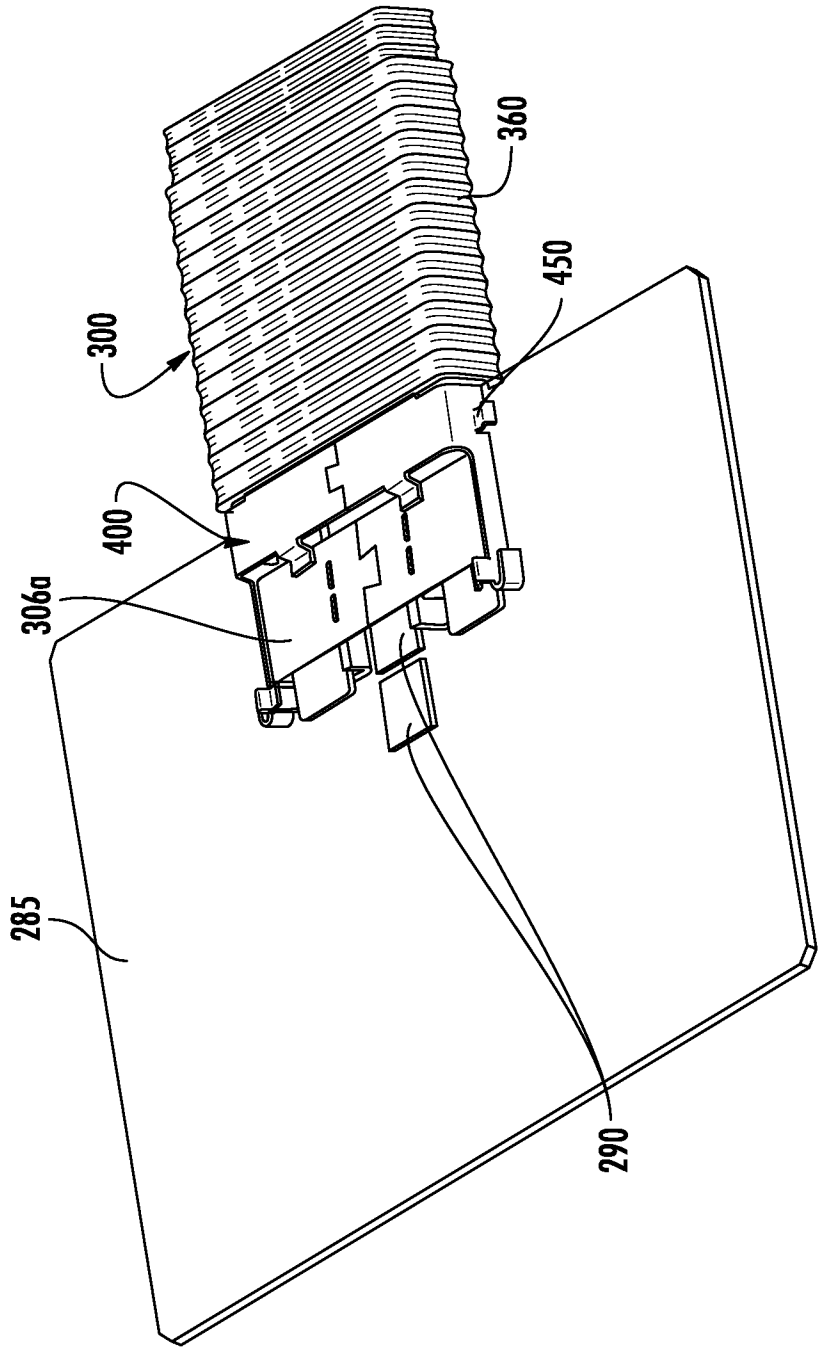


FIG. 25

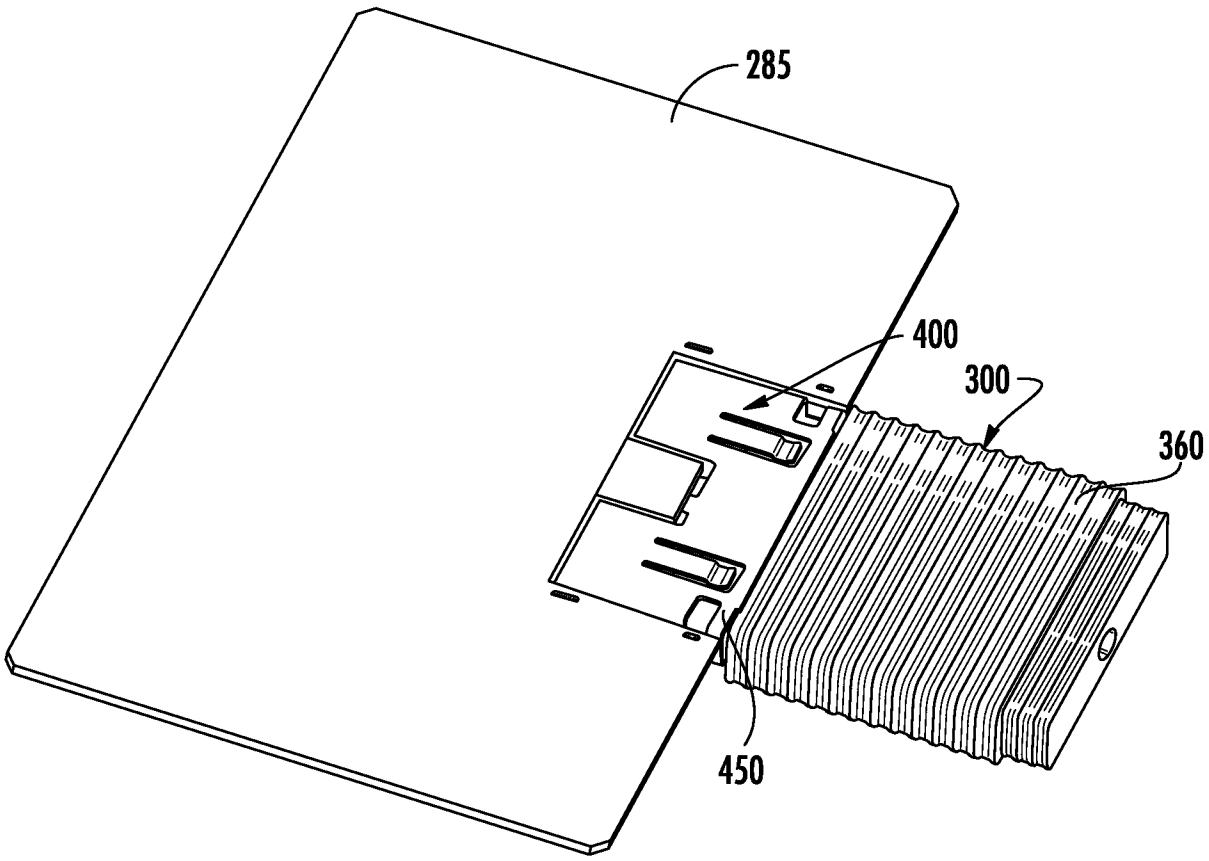


FIG. 26

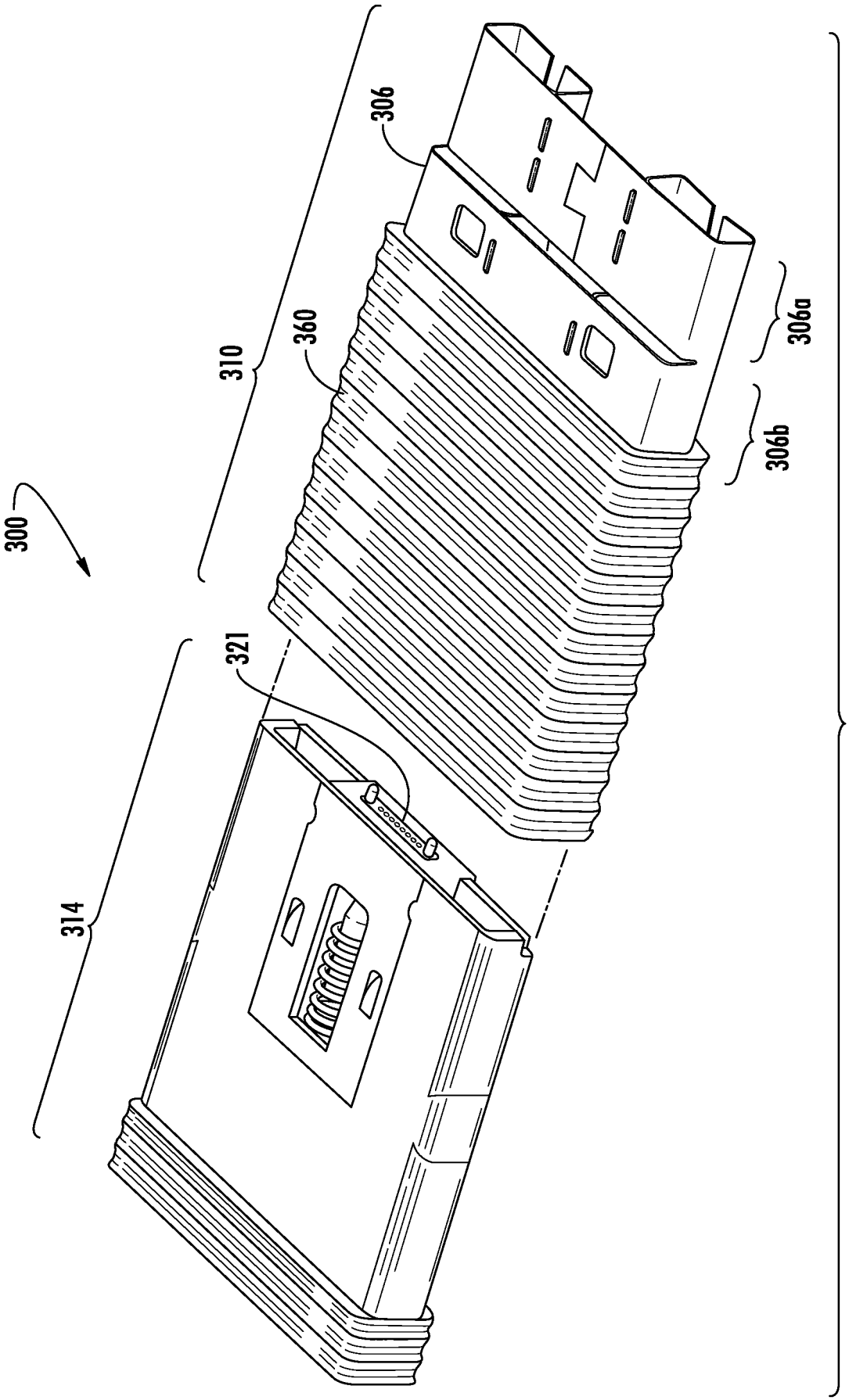


FIG. 27

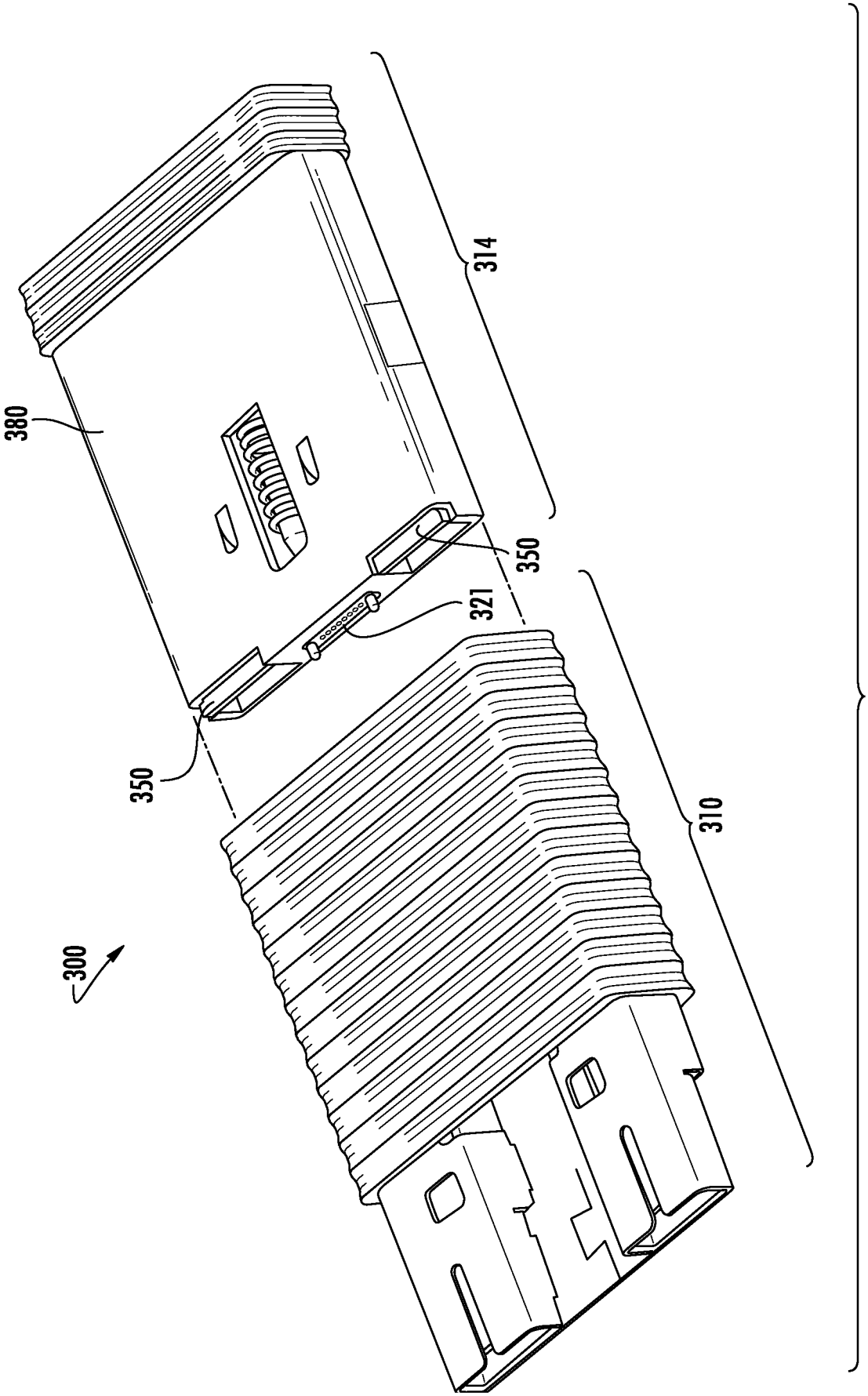


FIG. 28

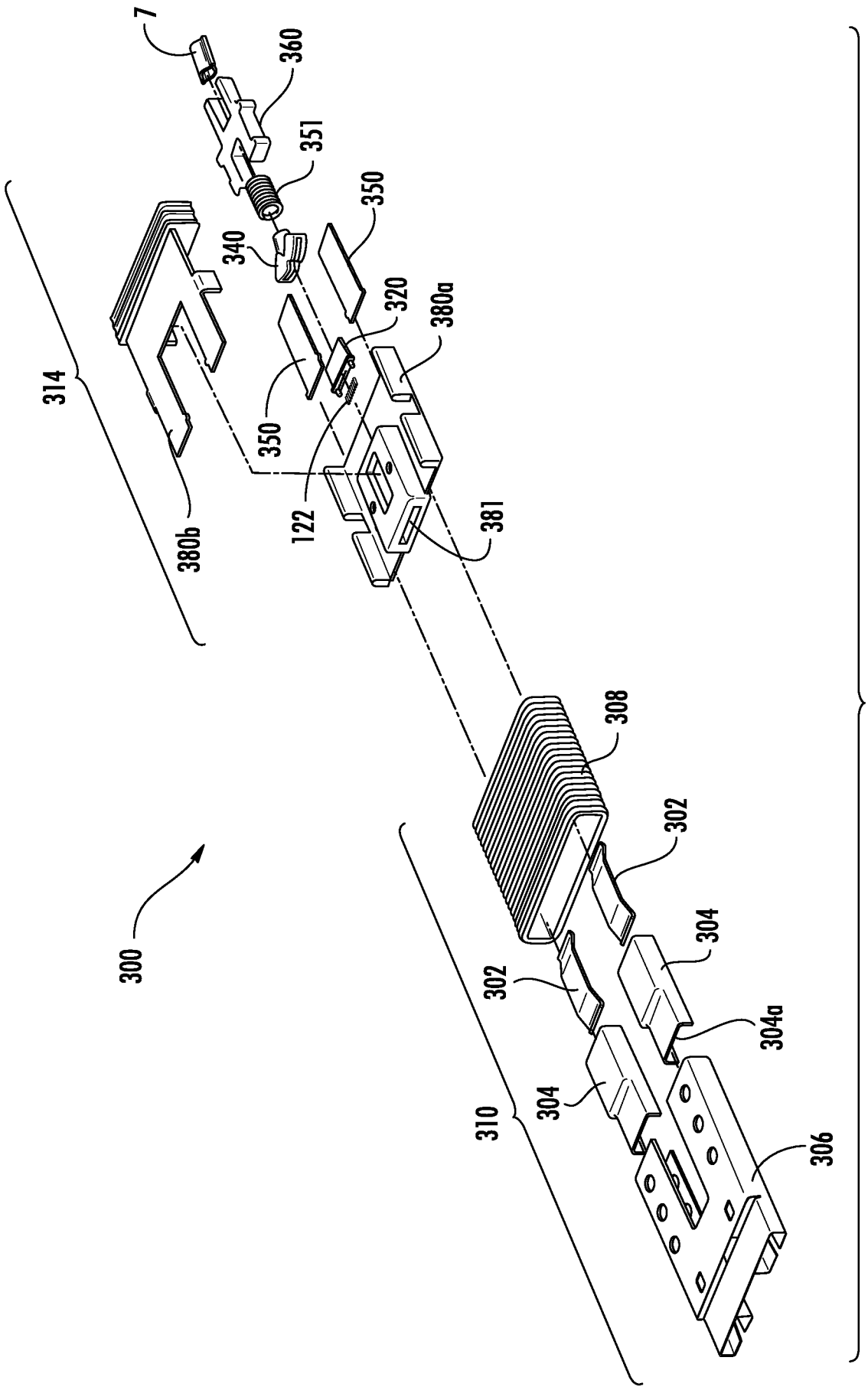

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FIG. 29

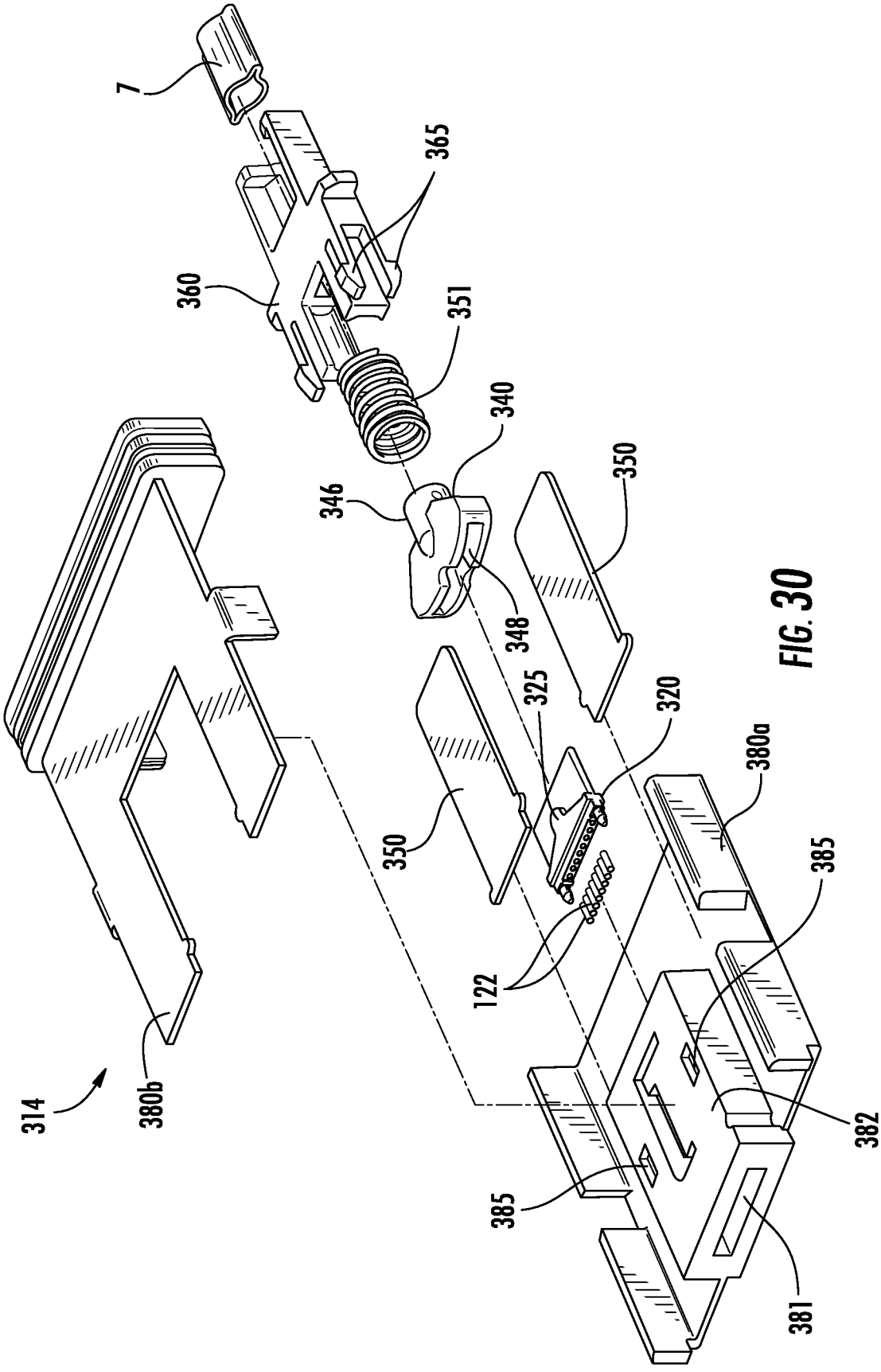

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FIG. 30

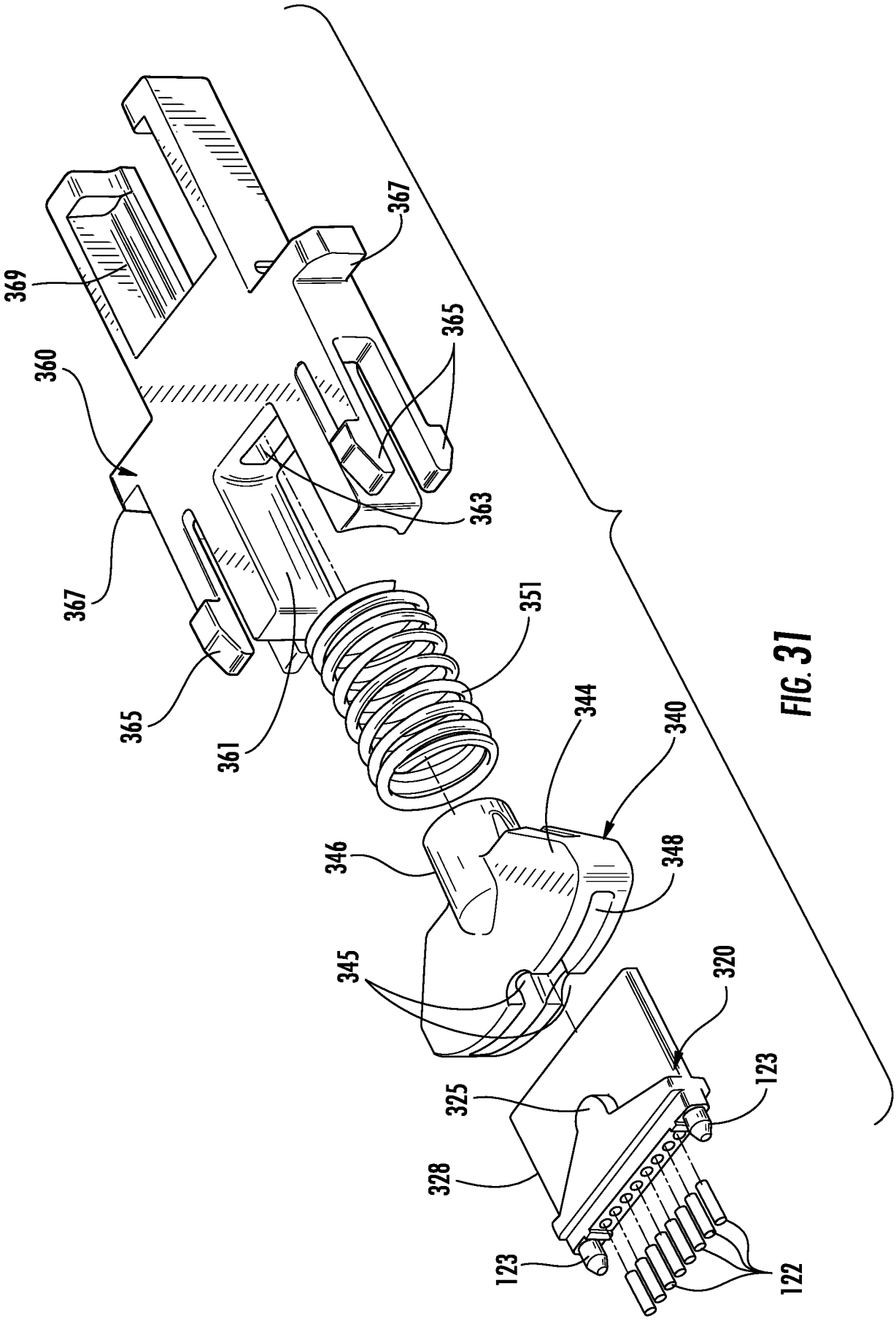

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FIG. 31

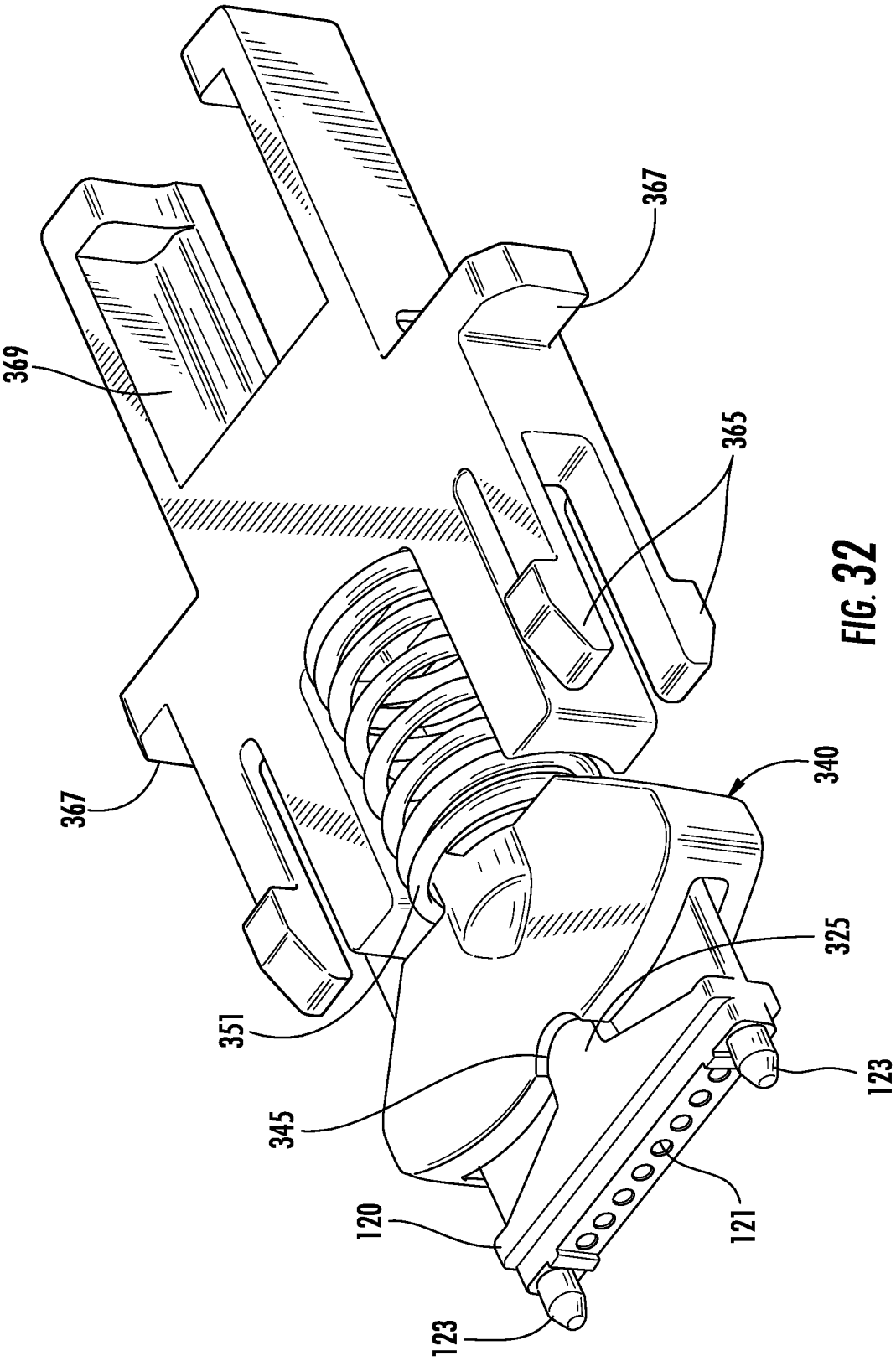


FIG. 32

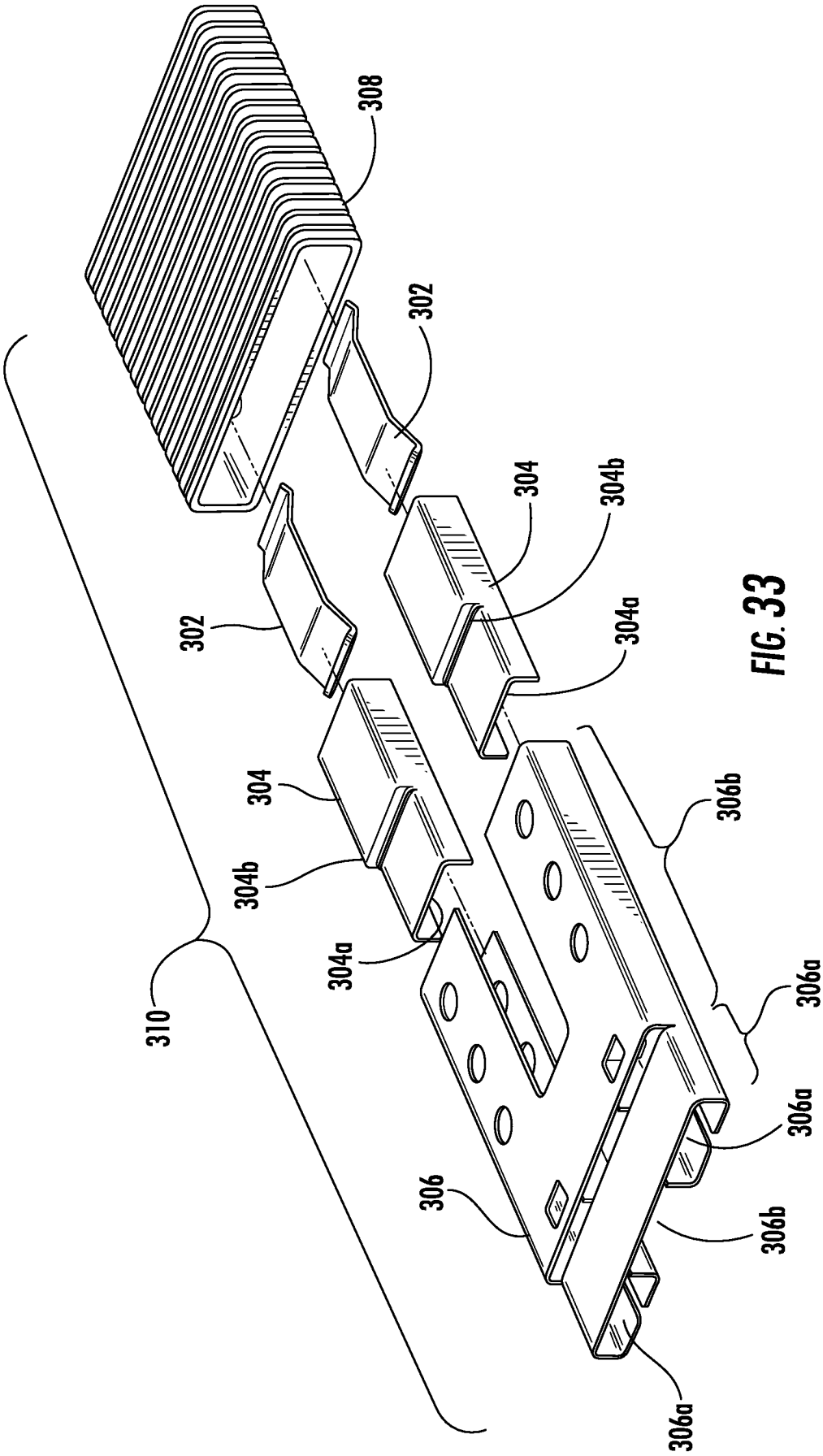

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FIG. 33

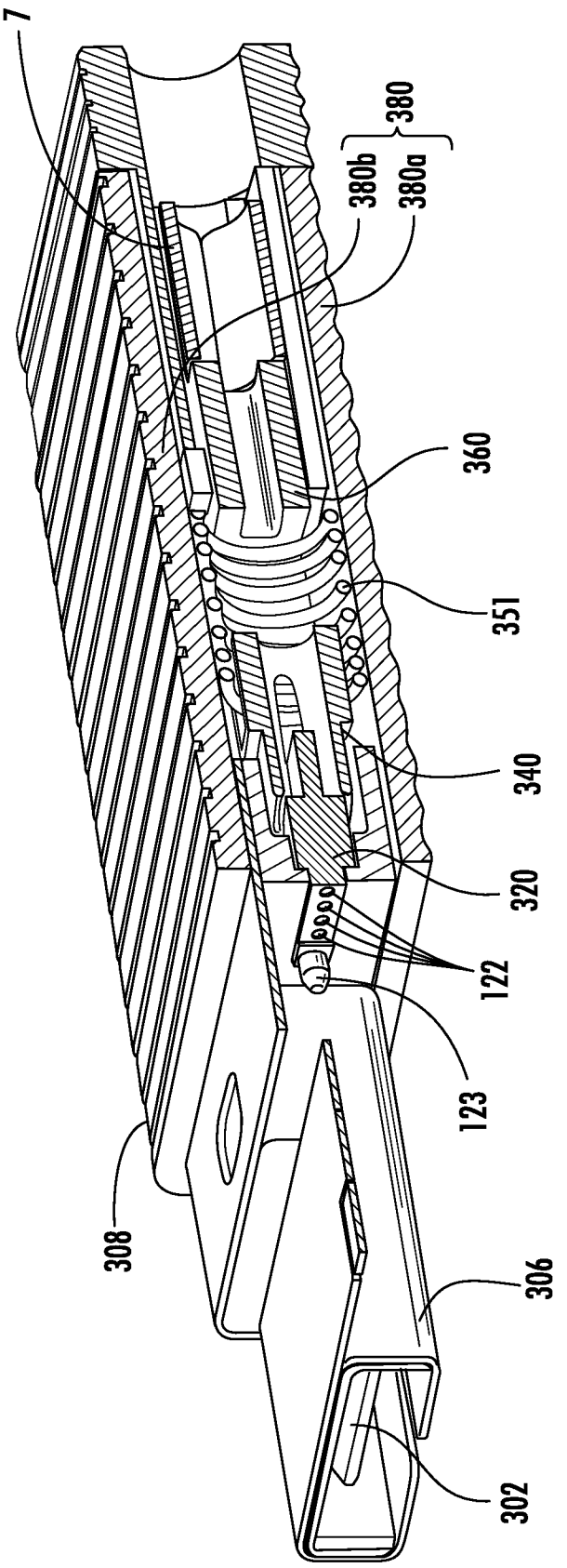


FIG. 34

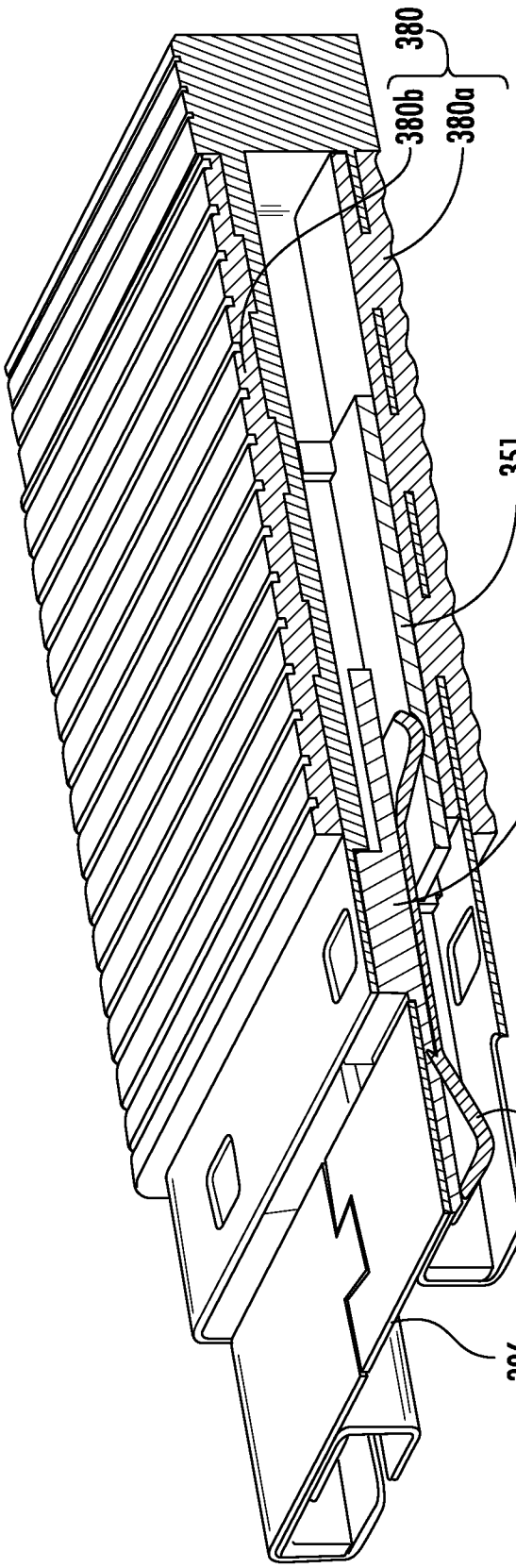


FIG. 35

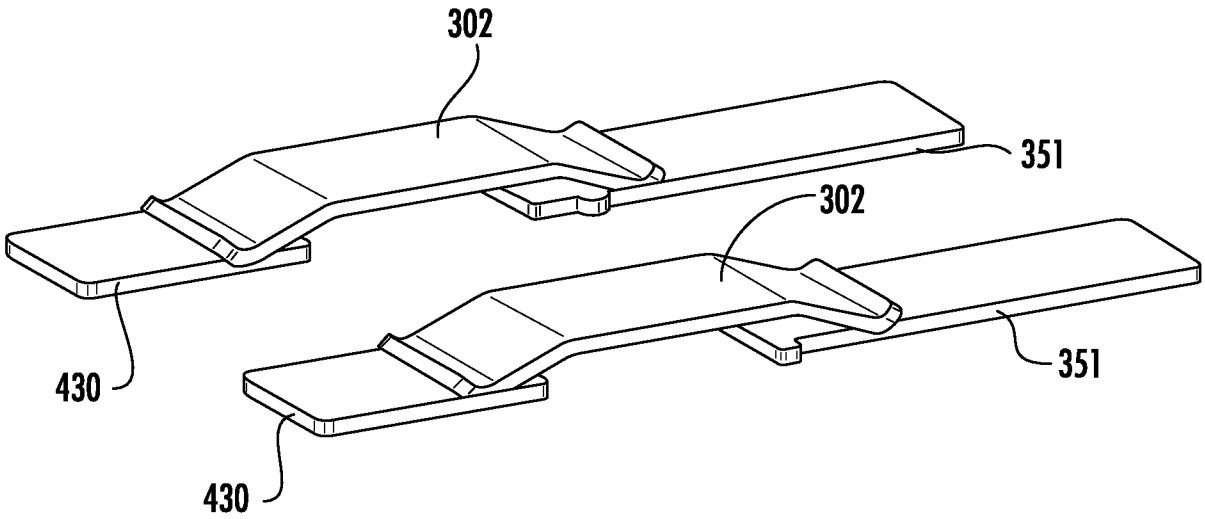


FIG. 36

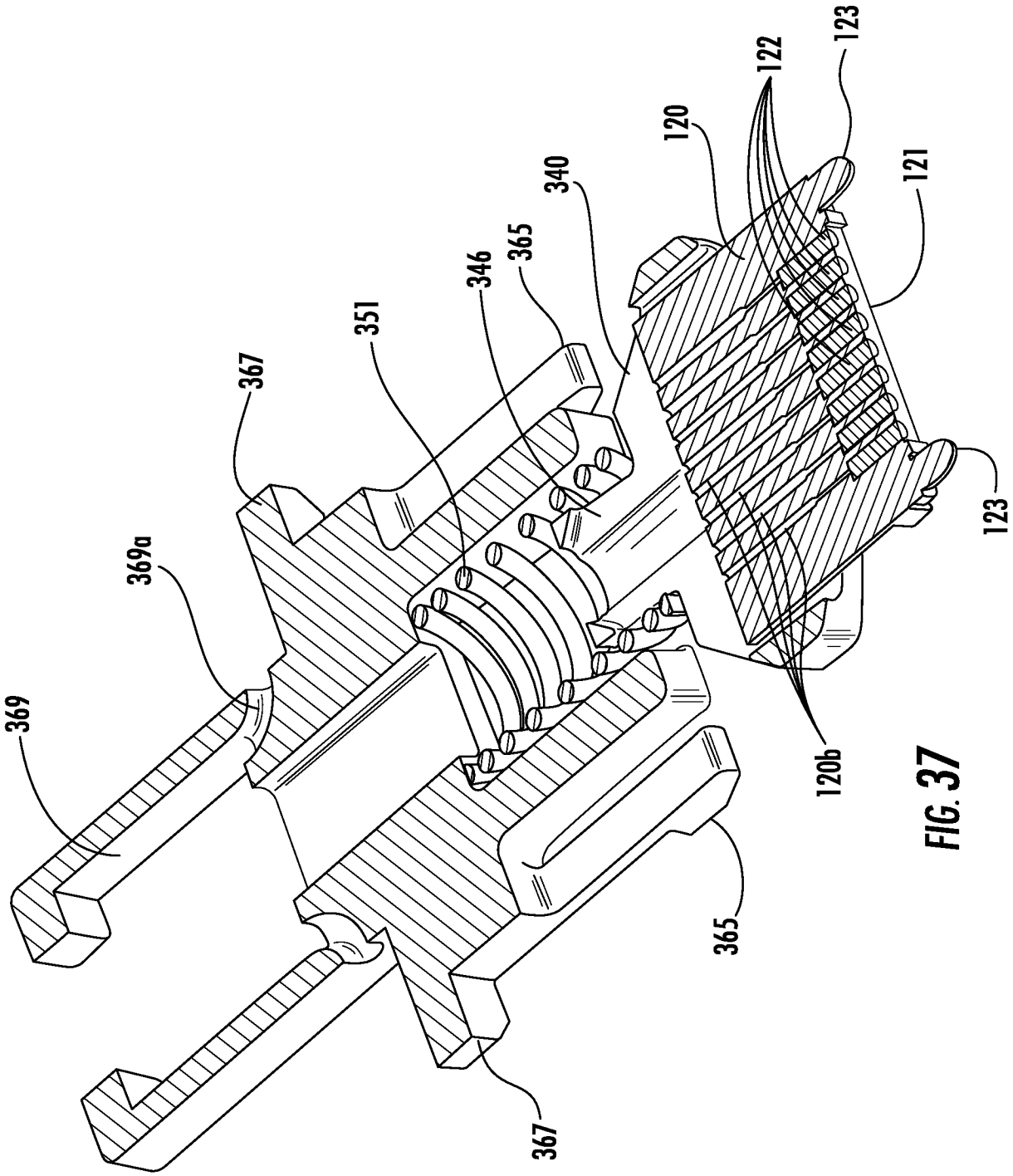


FIG. 37

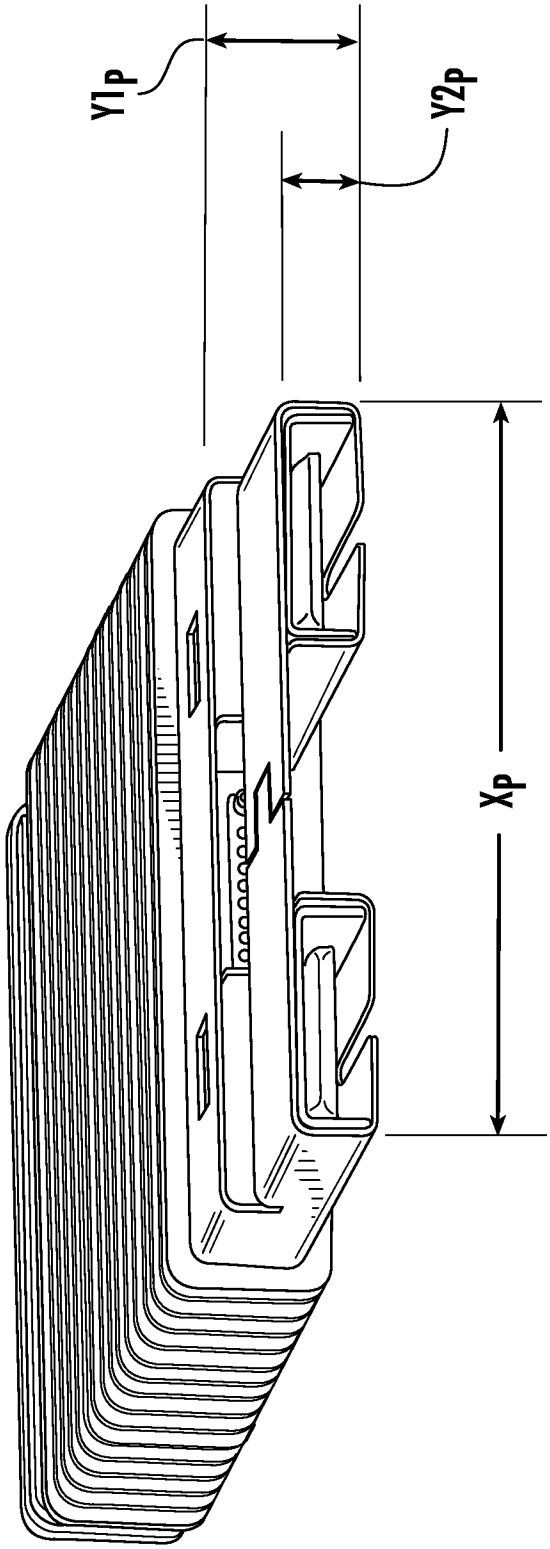


FIG. 38

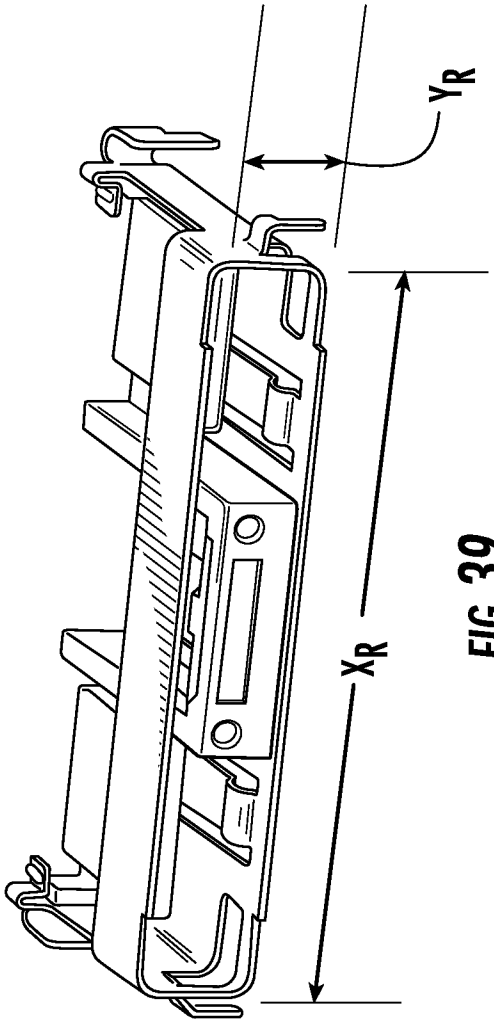


FIG. 39

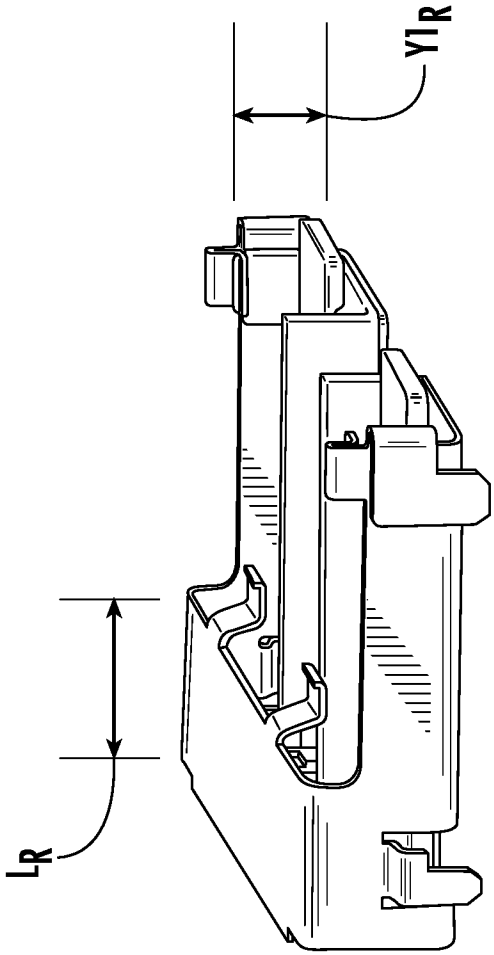


FIG. 40

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/037956

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B6/42 G02B6/32 G02B6/38
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)
G02B

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 016 968 A (HAMMOND RODNEY W [US] ET AL) 21 May 1991 (1991-05-21)	1-4, 6-12, 14-19, 22-28, 30,31
Y	column 3, lines 20-28; figure 2 column 4, lines 60-65 column 6, lines 60-68	5,21
Y	US 2011/229090 A1 (ISENHOUR MICAH C [US] ET AL) 22 September 2011 (2011-09-22) paragraph [0031]; figure 5	5,21
X	US 2012/114289 A1 (DEMERITT JEFFERY ALAN [US] ET AL) 10 May 2012 (2012-05-10) paragraph [0043]; figures 9,10A,10B	33-44

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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

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

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

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

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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
29 August 2014	10/09/2014

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	Verdrager, Véronique

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Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/037956

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 339 876 A1 (AMP INC [US] WHITAKER CORP [US]) 2 November 1989 (1989-11-02) figure 3	1,17,33
A	US 2012/195556 A1 (WANG TAK K [US] ET AL WANG TAK KUI [US] ET AL) 2 August 2012 (2012-08-02) figures 1A,2A	1,17,33

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2014/037956

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