



- (51) International Patent Classification:  
*H01R 13/516* (2006.01) *H01R 13/6582* (2011.01)
- (21) International Application Number:  
PCT/US2017/016794
- (22) International Filing Date:  
7 February 2017 (07.02.2017)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
15/018,463 8 February 2016 (08.02.2016) US
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- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

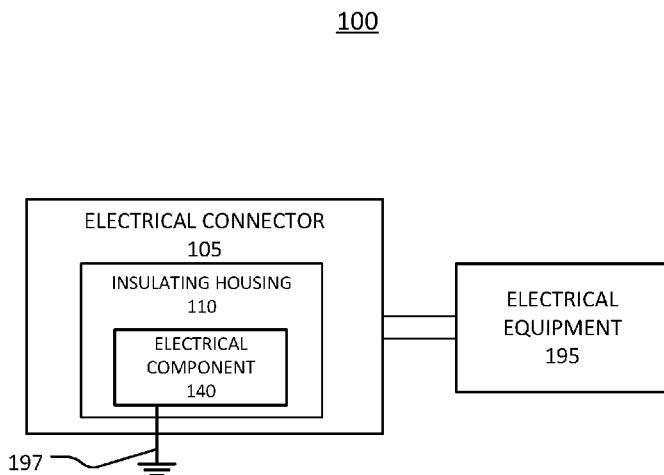
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- (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

**Published:**

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

(54) Title: ELECTRICAL CONNECTOR



(57) Abstract: An electrical connector includes an insulating housing. The insulating housing has an inner wall, a first end, and a second end. The inner wall of the insulating housing defines a cavity and a groove, the groove including a groove wall, the groove wall extending from the cavity radially into the insulating housing to a groove depth. The electrical connector also includes an electrical component in the cavity; an electrically conductive shell at an outer surface of the insulating housing; and a plug in the housing, the plug including a body and projection that radially extends from the body, the projection being received in the groove, where the groove wall applies more than 35 pounds (lbs) of force on the plug in a direction that is toward the electrical component.

FIG. 1

WO 2017/139252 A1

## ELECTRICAL CONNECTOR

### TECHNICAL FIELD

This disclosure relates to an electrical connector for a high-voltage (for example, 10  
5 kilovolts or greater) electrical system.

### BACKGROUND

An electrical connector includes an electrical component that provides a low-impedance  
10 path to ground during an over-voltage condition. The electrical connector is used to connect  
electrical transmission and distribution equipment and electrical sources within a high-voltage  
electrical system.

### SUMMARY

In one general aspect, an electrical connector includes an insulating housing. The  
15 insulating housing has an inner wall, a first end, and a second end. The inner wall of the  
insulating housing defines a cavity and a groove, the groove including a groove wall, the groove  
wall extending from the cavity radially into the insulating housing to a groove depth. The  
electrical connector also includes an electrical component in the cavity; an electrically  
conductive shell at an outer surface of the insulating housing; and a plug in the housing, the plug  
20 including a body and projection that radially extends from the body, the projection being  
received in the groove, where the groove wall applies more than 35 pounds (lbs) of force on the  
plug in a direction that is toward the electrical component.

Implementations may include one or more of the following features. The groove wall  
may apply more than 70 lbs of force on the plug in the direction. The groove wall may apply  
25 between 70 and 200 lbs of force on the plug in the direction.

The projection of the plug may have a partial cone shape. The groove wall may include a  
radially extending portion of the inner wall of the insulating housing at an end of the groove, the  
radially extending portion of the inner wall of the insulating housing makes physical contact with  
the projection of the plug and applies the force to the projection of the plug, and the direction  
30 toward the electrical component may include an axial direction.

The electrical component may include a plurality of metal oxide varistors (MOVs), the MOVs being held in direct physical contact with each other by the force. In some implementations, the electrical component lacks an additional mechanism that holds the MOVs in physical contact with each other.

5           The cavity may include a first cavity portion that extends along a first direction, and a second cavity portion that extends along a second direction, and the first cavity portion and the second cavity portion may be fluidly sealed from each other. The electrical connector also may include an electrical contact that is electrically connected to the electrical component. The electrical contact may be configured to connect to a high-power electrical system. The electrical  
10           contact may extend into the second cavity portion and toward the second end of the insulating housing, and the electrical component may be in the first cavity portion.

In some implementations, a semiconductive insert is in the cavity between the first cavity portion and the second cavity portion, and the semiconductive insert fluidly seals the first cavity portion from the second cavity portion.

15           The insulating housing of the electrical connector may have a thickness in a direction that extends radially from the electrical component, and a ratio of the thickness of the insulating housing to the diameter of the electrical component may be at least 0.4. The ratio of the thickness of the insulating housing to the diameter of the electrical component may be at least  
20           0.5. The ratio of the thickness of the insulating housing to the diameter of the electrical component may be between 0.5 and 0.7.

The insulating housing of the electrical connector may have a thickness in a direction that extends radially from the cavity, and a ratio of the thickness of the insulating housing to the groove depth may be less than 3. In some implementations, the ratio of the thickness of the insulating housing to the groove depth is 2.3-2.6.

25           The insulating housing may define a plurality of grooves, each groove including a groove wall that extends radially from the cavity into the insulating housing, and a projection of a plug may be received in each groove.

In some implementations, the electrical connector also includes an electrically conductive connection between the plug and the electrically conductive shell.

30           In another general aspect, a method of assembling an electrical connector includes

providing an insulating housing, the insulating housing including a material that expands under applied force and contracts when the applied force is removed, the insulating housing defining a cavity that is open at least at one end of the housing and a groove radially extending from the cavity into the insulating housing; inserting an electrical component into the cavity; inserting a  
5 plug into the open end of the insulating housing, the plug including a projection having a first width and a second width, the first width being larger than a diameter of the cavity and larger than the second width; and applying a force to the insulating housing to place the projection of the plug in the groove, the force being in a first direction that is parallel to a longitudinal axis of the cavity and toward the first opening, and the force expanding the insulating housing in the  
10 first direction; removing the applied force to allow the insulating housing to contract in a second direction that is away from the first opening such that a radially extending portion of the groove exerts force on the plug in the second direction to hold the electrical component in the cavity, where the radially extending portion of the groove exerts between 35 and 200 pounds (lbs) of force on the plug in the second direction.

15 Implementations may include one or more of the following features. The insulating housing may be placed inside an electrically conductive shell; and the plug may be electrically connected to the electrically conductive shell through an electrically conductive connection.

In another general aspect, an electrical connector includes an insulating housing including an inner wall, a first end, and a second end, the inner wall of the insulating housing having a  
20 thickness and defining a cavity and a groove, the groove including a groove wall extending from the cavity radially to a groove depth; an electrical component in the cavity; an electrically conductive shell at an outer surface of the insulating housing; and a plug in the housing, the plug including a body and projection that radially extends from the body, the projection being received in the groove, where the thickness of the insulating housing is at least 1.3 centimeters,  
25 and the ratio of the insulating housing to a radius of the electrical component is at least 0.4.

Implementations may include one or more of the following features. The thickness of the insulating housing may be at least 1.9 centimeters. A ratio of the thickness of the insulating housing to a diameter of the electrical component may be greater than 0.5. A ratio of the thickness of the insulating housing to a diameter of the electrical component may be greater than  
30 0.55.

The electrical component in the cavity may include a plurality of MOVs, and the groove wall may apply a force to the plug in an axial direction, the force holding the MOVs in physical contact with each other.

In another general aspect, an electrical connector includes an insulating housing including  
5 an inner wall and an outer surface, the insulating housing having a thickness between the inner wall and the outer surface, the inner wall of the insulating housing defining a cavity, the insulating housing including a material being associated with a resting state and being configured to elongate in a longitudinal direction relative to the resting state; an electrical component in the cavity, the electrical component having a diameter in a direction that is perpendicular to the  
10 longitudinal direction; an electrical conductor configured to connect to a high-voltage electrical system; an electrically conductive shell at the outer surface of the insulating housing, the electrically conductive shell being configured to connect to ground; a connection junction electrically connected to the electrical component and to the electrical conductor, the insulating housing being between the connection junction and the electrically conductive shell; and an  
15 electrically conductive plug in the housing, the plug being electrically connected to the electrical component and being configured to connect to ground, where a portion of the housing is elongated at least 10% more than the resting state, and a ratio of the thickness of the housing to the diameter of the electrical component is greater than 0.4.

Implementations may include one or more of the following features. The plug may apply  
20 a force that is greater than 35 lbs on the electrical component, the applied force being toward the semiconductive insert.

The electrical component includes a plurality of MOVs, the MOVs being held in direct physical contact with each other by the force, and the electrical component may lack an additional mechanism that holds the MOVs to each other.

25 The ratio of the thickness of the housing to the diameter of the electrical component may be greater than 0.5. The ratio of the thickness of the housing to the diameter of the electrical component may be between 0.55 and 0.65.

Implementations of any of the described techniques above may include an apparatus, a system, an electrical connector, a device for protecting a power system, and/or a method. The  
30 details of one or more implementations are set forth in the accompanying drawings and the

description below. Other features will be apparent from the description and drawings, and from the claims.

#### DRAWING DESCRIPTION

FIG. 1 is a block diagram of an example electrical system that includes an electrical  
5 connector.

FIG. 2A is a side cross-sectional block diagram of an example insulating housing for an electrical connector.

FIG. 2B is a side cross-sectional block diagram of an example electrical connector that includes the insulating housing of FIG. 2A.

10 FIG. 2C is a side cross-sectional block diagram of an example plug for the electrical connector of FIG. 2B.

FIG. 2D is a block diagram of a contact assembly for the electrical connector of FIG. 2B.

FIG. 2E is a side cross-sectional block diagram of an example electrical connector that includes the insulating housing of FIG. 2A.

15 FIG. 3A is a side cross-sectional block diagram of another example electrical connector.

FIG. 3B is a side cross-sectional block diagram of an example plug for the electrical connector of FIG. 3A.

FIG. 4 is a side cross-sectional block diagram of another example insulating housing for an electrical connector.

20 FIG. 5 is a side cross-sectional block diagram of another example electrical connector.

FIG. 6 is a flow chart of an example process for assembling an electrical connector.

#### DETAILED DESCRIPTION

Referring to FIG. 1, a block diagram of an example electrical system 100 is shown. The  
25 system 100 includes an electrical connector 105, which is connected between electrical equipment 195 and ground 197. The electrical connector 105 protects the electrical equipment 195 from electrical voltage surges. The electrical equipment 195 may be, for example, a transformer, a power source, or an electrical system that includes a collection of such devices. The electrical connector 105 may be used in a high-power electrical system, for example, a  
30 system that operates at greater than 10 kilovolts (kV) or between 12 and 36 kV.

The electrical connector 105 includes an insulating housing 110 and an electrical component 140 in the insulating housing 110. The electrical component 140 has a high impedance under normal operating conditions. As the voltage across the electrical component 140 increases, the impedance of the electrical component 140 decreases. At voltages above a breakdown voltage associated with the material of the electrical component 140, the impedance of the electrical component 140 is negligible and the electrical component 140 forms a low impedance current path from the electrical equipment 195 to ground 197. The electrical component 140 is selected such that when the voltage across the electrical component 140 increases beyond the maximum safe voltage for the electrical equipment 195 (such as during an over-voltage condition), the electrical component 140 provides a low impedance current path to ground 197 to conduct excess current away from the electrical equipment 195.

As discussed below, the insulating housing 110 is configured to apply a longitudinally compressive force to the electrical component 140 such that the electrical component 140 works properly and as expected without using additional compression mechanisms such as wraps, adhesives or bonding agents, or springs. Additionally, the insulating housing 110 has a thickness that helps the electrical connector 105 maintain its shape during use.

Referring to FIG. 2A, a side cross-sectional block diagram of an example insulating housing 210 is shown. FIG. 2B is a side cross-sectional block diagram of an example electrical connector 205 that includes the insulating housing 210. The insulating housing 210 has a first end 206, a second end 208, an outer surface 211, and an inner wall 231. The inner wall 231 defines a groove 220 and a cavity 230.

The groove 220 is a notch, depression, hole, opening, or other space defined by the inner wall 231 of the insulating housing 210. The groove 220 is open to the cavity 230 and extends radially away from the cavity 230 into the insulating housing 210 to a groove depth 222. A portion of the inner wall 231 forms a groove wall 224 that extends radially to the groove depth 222. The cavity 230 includes a first portion 236, which extends along a direction 201, and a second portion 237, which extends along a direction 202. In the example of FIGS. 2A and 2B, the directions 201 and 202 are perpendicular to each other. However, in other implementations, the directions 201 and 202 may be non-perpendicular to each other.

The insulating housing 210 has a thickness 212. In the example of FIG. 2A, the thickness 212 is the distance between the inner wall 231 of the cavity 230 and the outer surface 211 of the

insulating housing 210 along the direction 202. As shown in FIG. 2A, the thickness 212 is at a portion of the insulating housing 210 that does not include the groove 220. The cavity 230 has a diameter 232 in the direction 202.

Referring also to FIGS. 2B-2D, an electrical component 240 is received in the first  
5 portion 236 of the cavity 230. The electrical component 240 has an outer diameter 243. The outer diameter 243 is similar to the diameter 232 of the cavity 230, with the diameter 232 of the cavity 230 being slightly smaller than the outer diameter 243 of the electrical component 240. Due to this configuration, the insulating housing 210 applies a radially compressive force, which is directed radially inward from the inner wall 231, on the electrical component 240. This  
10 radially compressive force results in an interference fit between the electrical component 240 and the inner wall 231 of the insulating housing 210. The interference fit helps to hold the electrical component 240 in the insulating housing 210. Additionally, the interference fit may eliminate air that could otherwise be in a space between the electrical component 240 and the inner wall 231.

Further, as discussed in greater detail below, the thickness 212 is relatively large, and the  
15 ratio of the thickness 212 to the diameter 243 of the electrical component 240 is also relatively large (for example, 0.4 or greater). The relatively large thickness 212 and ratio results in a larger radially compressive force being applied to the electrical component 240, as well as a greater longitudinal force being applied to the electrical component 240, than is possible with a thinner housing. The relatively thick housing and high ratio of the thickness 212 to the diameter 243 of  
20 the electrical component 240 also helps the electrical connector 205 maintain shape during use, including during over-voltage conditions.

The electrical component 240 is electrically connected through a contact assembly 260 to an electrical conductor 270, which extends along the direction 202 in the second portion 237 of the cavity. The electrical conductor 270 is used to connect the electrical connector 205 to an  
25 electrical system, such as the electrical equipment 195 of FIG. 1. The electrical system to which the electrical connector 205 is connected is a high-voltage electrical system that operates at, for example, 10 kV or more.

In the example of FIG. 2B, the electrical component 240 is a plurality of metal oxide varistors (MOV) blocks 240a-240f. Each of the MOV blocks 240a-240f have an impedance  
30 close to zero when the voltage across the MOV block exceeds the breakdown voltage of the material from which the MOV block is formed. To ensure that the MOV blocks 240a-240f are

held in contact with each other so that the electrical component 240 conducts current from the electrical conductor 270 to ground 297 during an over-voltage condition, a force F is applied to the electrical component 240 in the direction 201. As discussed below, the force F arises from a cooperation between a plug 250 (FIG. 2C) and the insulating housing 210.

5           The configuration of the insulating housing 210 and the plug 250 allows the force F to be sufficiently large such that the MOV blocks 240a-240f are compressed in the direction 201 and held in contact with each other and with the contact assembly 260 without any additional compression mechanisms. For example, the ratio of the thickness 212 to the groove depth 222 enables the groove wall 224 and the projection 254 to cooperate to provide a force on MOV  
10 blocks 240a-240f of the electrical component 240 in the direction 201 that is sufficiently strong to hold the MOV blocks 240a-240f in contact without additional compression mechanisms (for example, springs, adhesives, and/or a fiberglass wrap). Thus, the electrical connector 205 may contain fewer parts than a typical electrical connector making the electrical connector 205 less expensive to manufacture and less prone to failure.

15           The plug 250 includes a body 252 and a projection 254, which extends radially from the body 252. The plug 250 is made of a material that conducts electricity. For example, the plug 250 may be made of a metallic material, such as brass. The projection 254 is received in the groove 220 and a portion of the projection 254 contacts the groove wall 224. The insulating housing 210 is made from a non-conductive material that is capable of expanding and  
20 contracting along the direction 201. When the projection 254 is in the groove 220, the contraction of the insulating housing 210 in the direction 201 causes the groove wall 224 to apply force to the projection 254 in the direction 201. The force on the projection 254 results in the body 252 also applying force to the electrical component 240 in the direction 201.

          To apply the force to the electrical component 240 in the direction 201, the insulating  
25 housing 210 is elongated in the direction 203, and the plug 250 is inserted into the insulating housing 210 by stretching the housing 210 in the direction 203 and over the projection 254 of the plug 250. After the force is removed, the insulating housing 210 contracts in the direction 201, and the projection 254 becomes seated in the groove 220. However, the positioning of the groove 220 is such that even after the housing 210 contracts in the direction 201 and the  
30 projection 254 is seated in the groove, the housing 210 remains elongated as compared to the original, resting state of the insulating housing 210 (a state prior to any elongating force being

applied in the direction 203). Because the portion 216 remains somewhat elongated, the portion 216 also continues to experience an opposing compressive effect, resulting in the groove wall 224 applying the force F to the projection 254 in the direction 201. The force F on the projection 254 is such that the electrical component 240 operates properly without additional longitudinal  
5 compression mechanisms. The force F may be, for example, 35 pounds (155 Newtons) or greater.

To ensure that the force F is sufficiently large, a portion of the housing between the contact assembly 260 and the groove wall 224 (labeled as 216) may be elongated by, for example, 25% more than the resting state of this portion of the housing. In other words, the  
10 portion 216 of the housing remains elongated by 25% than its original, resting state after the electrical connector 205 is assembled and while the electrical connector 205 is in use. In other examples, the portion 216 may be elongated between 10% and 30% more than the resting state during use.

The relatively large groove depth 222 and the relatively large thickness 212 of the  
15 housing 210 allow the housing 210 to be stretched in the direction 203 and to remain sufficiently elongated after the electrical connector 205 is assembled. Having a relatively large groove depth 222 corresponds to having a large groove wall 224, thus providing a larger surface area to hold the projection 254. As compared to a design with a smaller groove depth, or no groove that extends radially outward from the cavity 230 and into the housing 210, the groove depth 222 of  
20 the electrical connector 205 results in a configuration in which the plug 250 remains in the groove 220 without falling out as the housing 210 contracts in the direction 201. Additionally, the thickness 212 of the housing 210 is relatively large such that the groove depth 222 does not extend so far into the housing 210 that the presence of the groove 220 would negatively impact the integrity (for example, the shape and/or rigidity) of the housing 210.

To enable the insulating housing 210 and the plug 250 to apply a sufficient amount of  
25 force to the electrical component 240, the groove depth 222 and the thickness 212 are relatively large, and the ratio of the housing thickness 212 to the groove depth 222 is also relatively large. For example, the ratio of the housing thickness 212 to the groove depth 222 may be 2.6 to 3.2. The groove depth 222 may be, for example, 0.7-0.8 centimeters (cm). The insulating housing  
30 thickness 212 may be, for example, at least 1.3 cm. In some implementations, the thickness 212 is between 1.3 and 2 cm. In other implementations, the thickness is between 1.95 and 2 cm, and

may be, for example, 1.96 cm. The ratio of the thickness 212 of the housing 210 to the outer diameter 243 of the electrical component 240 may be, for example, between 0.5 and 0.7, between 0.58 and 0.60, or 0.59. These configurations allow the groove wall 224 to apply, for example, 35 pounds (lbs), 50 lbs or more, 70 to 200 lbs, 100 to 200 lbs, or more than 200 lbs of force on the projection 254 along the direction 201.

Additionally, the relatively large thickness 212 of the insulating housing 210 results in an insulating housing 210 that is more rigid and sturdy than a housing with a smaller thickness. The thickness 212 of the housing 210 allows the electrical connector 205 to retain its shape (with portions of the housing 210 extending along the directions 201 and 202) during use, including during over-voltage conditions during which the electrical component 240 provides a low-impedance current path. When the electrical component 240 forms a low-impedance current path, large currents (for example, currents on the order of 10,000 Amperes) pass through the electrical component 240, and plasma and hot gasses may form in the first portion 236 of the cavity 230. The plasma and hot gasses may escape from the end 206. Because the electrical connector 205 retains its shape during use, plasma and hot gasses that escape from the end 206 are directed primarily along the direction 203 (which is opposite to the direction 201). In this way, the direction of escaping plasma and hot gasses is known and fairly predictable as compared to an electrical connector that experiences substantial flexing or shape changes in which portions of the electrical connector intended to extend along different directions may instead extend along the same direction during use.

In the example of FIGS. 2A and 2B, the thickness 212 is measured from the inner wall 231 to the outer surface 211 in the direction 202. However, the insulating housing 210 also may be made relatively thick in other regions of the insulating housing 210. For example, the thickness of the insulating housing 210 from the inner wall 231 to the outer surface 211 in a radial direction at a region 214, which is a region of the housing 210 where a portion of the housing 210 that extends in the direction 201 and a portion of the housing 210 that extends in the direction 202 meet, also may have a thickness of 1.3 cm or greater.

As discussed above, the electrical conductor 270 and the electrical component 240 are electrically connected to each other by the contact assembly 260. FIG. 2D is a block diagram of the contact assembly 260. The contact assembly 260 includes a semiconductive insert 262, which substantially surrounds or partially surrounds a connection junction 266. The electrical

conductor 270 and the electrical component 240 are mounted in and are physically connected at the junction 266, which may be made out of a metallic material such as, for example, brass. The semiconductive insert 262 may be a faraday cage, and the semiconductive insert 262 may be made of the same material as the conductive shell 213. The components of the contact assembly 5 260, such as the connection junction 266, may be at the high operating voltages (for example, 12-36 kV) of the electrical equipment to which the electrical conductor 270 is connected. Because the insulating housing 210 does not conduct electricity, the insulating housing 210 forms an electrically insulating barrier between the high voltage components in the contact assembly 260 and the conductive shell 213.

10 In some implementations, the contact assembly 260 also fluidly seals the first portion 236 of the cavity 230 from the second portion 237 of the cavity 230. In these implementations, plasma and hot gasses that may form in the first portion 236 cannot flow into the second portion 237. To seal the first portion 236 from the second portion 237, the semiconductive insert 262 and the junction 266 are connected to each other or joined to each other such that fluid cannot 15 flow through the connection. The semiconductive insert 262 and the junction 266 may be connected to each other by, for example, an adhesive bond that is directly between the junction 266 and the semiconductive insert 262. In other examples, an O-ring seal may be placed on the electrical conductor 270 to fluidly seal the first portion 236 of the cavity 230 from the second portion 237 of the cavity 230.

20 The electrical connector 205 also includes a conductive shell 213, which surrounds the insulating housing 210. The conductive shell 213 is electrically conductive and may be made of, for example, a conductive elastomeric material. For example, the conductive shell 213 may be rubber material that includes an electrically conductive component, such as ethylene propylene diene monomer (EPDM) loaded with carbon. The conductive shell 213 may be made of any 25 material that conducts electricity.

In some implementations, an end 256 of the plug 250 is electrically connected to the conductive shell 213 through a conductive connection 280. The conductive connection 280 may be, for example, a metallic wire. In the example of FIG. 2B, the conductive shell 213 is connected to ground 297 through a wire 281. The wire 281 may be, for example, a braided 30 copper wire capable of conducting large amounts of current (for example, 10,000 Amperes or more). Thus, the plug 250 is connected to ground 297 through the conductive connection 280

and the wire 281. In an over-voltage condition, current is conducted through the electrical component 240 and the plug 250 to ground 297 through the conductive connection 280 and the wire 281. In other implementations, the conductive connection 280 may connect directly to ground 297 without being connected to the conductive shell 213, with the conductive shell 213  
5 being connected to ground 297 separately.

In some implementations, the conductive connection 280 is formed from the conductive shell 213. FIG. 2E, which is a block diagram of another example electrical connector 205E, shows an example of such an implementation. The electrical connector 205E is the same as the electrical connector 205 except that, in the electrical connector 205, the conductive shell 213  
10 extends along the end 206 of the insulating housing and makes physical contact with the plug 250. Because the conductive shell 213 and the plug 250 are electrically conductive, the physical connection between the conductive shell 213 and the plug 250 forms the conductive connection 280. Thus, in these implementations, the conductive connection 280 is the conductive shell 213 itself, and the wire 281 connects the plug 250 to ground 297. The electrical component 240 is  
15 connected to ground 297 through the plug 250 and the wire 281. The plug 250 and the wire 281 are metallic and can carry large currents (such as 10 kA and greater). In implementations in which the conductive shell 213 is made from a conductive rubber, the plug 250 and the wire 281 can carry larger amounts of current than the conductive shell 213 without burning or otherwise degrading, and connecting the plug 250 directly to ground 297 through the wire 281 may result  
20 in safer and/or more efficient operation.

Regardless of the configuration of the conductive connection 280 and the wire 281, the conductive shell 213 is connected to ground 297, removing or reducing the risk of electrical shock to an operator.

In the example of FIGS. 2A and 2B, the groove 220 has a rectangular shaped cross-section in a plane defined by the directions 201 and 202. However, in other implementations, the groove may have a different configuration.  
25

Referring to FIG. 3A, a side cross-sectional block diagram of another example electrical connector 305 is shown. The electrical connector 305 includes an insulating housing 310, which is surrounded by a conductive shell 311. The insulating housing 310 has an inner wall 331 that  
30 defines a cavity 330 and a groove 320. The electrical component 240 (shown as the blocks 240a-240f) is in a first portion 336 of the cavity 330, and the electrical conductor 270 is in a second

portion 337 of the cavity 330. The electrical conductor 270 and the electrical component 240 are electrically connected by the contact assembly 260. The MOV blocks 240a-240f are held in contact by a force F, which acts along a direction 301. The force F is provided by the interaction of a plug 350 and the groove 320 of the insulating housing 310.

5           The insulating housing 310 is similar to the insulating housing 210 except for the shape of the groove 320. As discussed below, the configuration of the plug 350 and the groove 320 may allow the plug 350 to be more easily inserted into the cavity 330. Similar to the insulating housing 210, the insulating housing 310 and the plug 350 interact to provide a force that is sufficient to hold the MOV blocks 240a-240f in physical contact with each other and against the  
10           contact assembly 260 without using other compression mechanisms.

          The groove 320 has a first groove end 326 and a second groove end 328. Of the first groove end 326 and the second groove end 328, the first groove end 326 is closer to a first end 306 of the insulating housing 310. The groove 320 extends radially into the insulating housing 310, with the first groove end 326 extending to a groove depth 322. The portion of the groove  
15           320 between the second groove end 328 and the first groove end 326 extends radially into the insulating housing to a depth that is less than the groove depth 322.

          FIG. 3B is a side block diagram of the plug 350. The plug 350 includes a body 352 and a projection 354, which extends radially from the body 352. The projection 354 has a partial cone shape. The projection 354 has a first width 355 at a first end 356 and a second width 357 at a  
20           second end 358. The first width 355 is smaller than the second width 357, and the projection 354 has a trapezoidal shaped cross-section.

          The groove 320 is shaped to receive the projection 354. As discussed above, at the first groove end 326, the groove 320 extends into the insulating housing 310 radially to the groove depth 322. Because the first end 356 of the projection 354 has a smaller width than the second  
25           end 358 of the projection 354, the plug 350 may be more easily inserted into the cavity 330 and the groove 320.

          When the projection 354 is in the groove 320, a groove wall 324, which is the portion of the inner wall 231 that is at the first groove end 326, makes contact with the second end 358 of the projection 354. The groove wall 324 applies a force in the direction 301 to the second end  
30           358 of the projection 354 when the insulating housing 310 contracts in the direction 301. This force also results in the first end 356 of the projection 354 applying a force to the electrical

component 240 in the direction 301. The insulating housing 310 has a thickness 312, which may be, for example, greater than 1.3 cm, greater than 1.9 cm, or between 1.95 and 2 cm. Similar to the example discussed in FIGS. 2A and 2B, the relatively large thickness 312 and the groove depth 322 allow a cooperation between the groove 320 and the plug 350 that results in the application of 50 lbs or more of force on the plug 350 in the direction 301. Thus, the electrical component 240 is compressed in the axial direction by the interaction of the insulating housing 310 and the plug 350.

Referring to FIG. 4, a side cross-sectional block diagram of another example an insulating housing 410, which may be used as in the electrical connectors 105 (FIG. 1), 205 (FIG. 2A), or 305 (FIG. 3A) instead of the insulating housings 110, 210, and 310, respectively. The insulating housing has a thickness 412 and an inner wall 431. The thickness 412 may be, for example, greater than 1.3 cm, greater than 1.9 cm, or between 1.95 and 2 cm. The inner wall 431 defines a cavity 430, which has a first portion 436 that extends in a direction 301 and a second portion 437 that extends in a direction 302.

The insulating housing 410 is similar to the insulating housings 210 (FIGS. 2A and 2B) and 310 (FIG. 3), except that the inner wall 431 of the insulating housing 410 defines a plurality of grooves 420 that extend into the insulating housing 410. Each of the grooves 420 has a groove wall 424 that extends into the insulating housing 410 to a groove depth 422. The plurality of grooves 420 may all have the same shape and size cross-section in a plane defined by the directions 301 and 302, or the grooves 420 may have different shapes and cross-sections.

When the insulating housing 410 is assembled into an electrical connector, each of the plurality of grooves 420 receives a plug (such as the plug 350 of FIG. 3B), and an electrical component (such as the electrical component 240) is held in the first portion 436 of the cavity 430 by a force generated by the cooperation of the plugs and the grooves 420. The amount of force applied to the electrical component 240 may be increased by using a configuration with multiple plugs and grooves.

The electrical connectors 205, 205E, and 305 are shown as an elbow connectors with an opening and a bushing for connection to a high-power electrical system at one end (for example, the end 208 of the electrical connector 205). However, groove configurations and housing thicknesses such as discussed with respect to electrical connectors 205, 205E, and 305 may be

used with other forms of electrical connectors. For example, such a housing and groove may be used in a T-body electrical connector.

Referring to FIG. 5, a side cross-sectional block diagram of another example electrical connector 505 is shown. The electrical connector 505 is similar to the electrical connector 205, except the electrical connector 505 is a T-body electrical connector. A T-body electrical connector may include a portion with two openings, and another portion that extends perpendicularly and includes a surge arrestor (such as a plurality of MOV disks).

The electrical connector 505 includes an insulating housing 510, which has an outer surface 511 and an inner wall 531. The insulating housing 510 has a thickness 512, measured between the outer surface 511 and the inner wall 531 in the direction 502. The inner wall 531 defines a groove 520. The groove 520 includes a groove wall 524, which extends into the insulating housing 510 to a groove depth 522. In the example of FIG. 5, the plug 350 (FIG. 3B) is received in the groove 520. In other examples, the cross-section of the groove 520 may be different, and a plug of a different shape (such as the plug 250 of FIG. 2C) may be received in the groove 520. The electrical component 240 is held in the cavity 530, and is electrically connected to the electrical conductor 270 at the contact assembly 260.

The electrical connector 505 includes a first portion 536 and a second portion 537. The first portion 536 extends perpendicularly from the second portion 537. The second portion 537 has two openings, an opening 508 and an opening 509, which is on an end of the second portion 537 opposite to an end that defines the opening 508. The ends 508 and 509 may be an opening that forms a bushing that also may be connected to, for example, a high-voltage electrical system or to measurement equipment.

Referring to FIG. 6, a flow chart of an example process 600 for assembling an electrical connector is shown. The process 600 is discussed with respect to the electrical connector 205 of FIG. 2B. However, the process 600 may be used to form other electrical connectors. For example, the process 600 may be used to assemble the electrical connector 305 of FIG. 3A.

The insulating housing 210 is provided (605). As shown in FIG. 2A, the insulating housing 210 has an inner wall 231, which defines a cavity 230 and a groove 220. The groove 220 radially extends from the cavity 230 into the insulating housing to a groove depth 222. The insulating housing 210 is open at the ends 206 and 208. Additionally, the insulating housing 210 is made from a non-conductive material that expands along the direction 203 when a force in the

direction 203 is applied. The material of the insulating housing 210 contracts along the direction 201 when the applied force is removed. The insulating housing 210 may be made from, for example, rubber.

The electrical component 240 is inserted into the cavity 230 (610). The electrical  
5 component 240 may be inserted into the cavity 230 at the end 206. The electrical component 240 is held in the cavity 230 by an interference fit. The plug 250 is inserted into the cavity 230 at the end 206 (515). As shown in FIG. 2C, the plug 250 includes a projection 254 that radially extends from the body 252 of the plug 250. The width of the projection 254 (the extent of the projection 254 in the direction 202) is greater than the diameter 232 of the cavity 230.  
10 Additionally, the width of the projection 254 is greater than the width of the body 252 (the extent of the body 252).

To place the projection 254 in the groove 220, an expanding force is applied to the insulating housing 210 in the direction 203 and toward the end 206 (620). Prior to the expanding force being applied, the insulating housing 210 is in a resting state and is not elongated. The  
15 expanding force may be applied to the insulating housing 210 by, for example, pulling the insulating housing 210 in the direction 203. The expanding force also may be applied in the direction 202. The insulating housing 210 expands along the direction that the expanding force is applied such that the groove 220 fits over the projection 254.

When the projection 254 is received in the groove 220, the expanding force is removed  
20 from the insulating housing 210 (625). Removing the expanding force causes the insulating housing 210 to contract in the direction 201 (opposite to the direction 203). However, due to the placement of the electrical component 240 and the plug 250 in the cavity 230, as well as the relative size of the housing 210, the housing 210 does not contract fully to the non-elongated condition of the housing prior to the application of the expansion force. Instead, the housing 210  
25 remains elongated by, for example 10-30% more as compared to the non-elongated, resting condition. For example, the portion 216 of the housing 210 may remain 20-30% elongated, or 25% elongated as compared to the non-elongated, resting condition. Because the portion 216 of the housing 210 remains elongated, the housing 210 continues to contract in the direction 201, thereby applying the force F on the projection 254 of the plug 250. In other words, the  
30 contraction in the direction 201 causes the groove wall 224 to apply the force F (FIG. 2B) to the projection 254. The force F acts along the direction 201. The force F is at least 35 lbs. For

example, the force F may be 35 to 200 lbs, 50 to 100 lbs, 100 to 200 lbs, or the force F may be greater than 200 lbs. Additionally, the insulating housing 210 may contract radially inward, compressing the electrical component 240 radially and improving the interference fit between the inner wall 231 and the electrical component 240.

5 Further, the insulating housing 210 is placed in the conductive shell 213. For example, the conductive shell 213 may be molded into an elbow shaped body or a T-shaped body. The semiconductive insert 262 also may be formed by molding and placed in the conductive shell 213. The material that forms the insulating housing 210 may be injected into the conductive shell 213 such that the insulating housing 210 fills the region between the conductive shell 213 and the semiconductive insert 262. Additionally, the insulating housing 210 occupies the region  
10 between the conductive shell 213 and the electrical component 240.

Other features are within the scope of the claims. For example, the insulating housing 410 is shown as having two grooves 420. Other implementations may have more grooves 420. For example, three or four grooves may be used. The insulating housings 210 and 310 may  
15 include more than one groove 220 and 320, respectively.

The insulating housings 210 and 310 of the electrical connectors 205 and 305, respectively, are shown as having portions that extend along perpendicular directions. However, other configurations are possible and the portions may extend along directions that are different but not perpendicular.

20 The electrical connectors 205 and 305 include the electrical component 240, which is a collection of MOV blocks 240a-240f stacked along the directions 201 and 301, respectively. However, other electrical components may be used in the electrical connectors 205 and 305. For example, the electrical component 240 may include any number of MOV blocks, and may include more or fewer MOV blocks than shown in FIGS. 2B and 3A. In some implementations,  
25 the electrical component 240 may be a single MOV, and the cooperation between the plug 250, 350 and the respective groove 220, 320 provides a longitudinally compressive force that may help to ensure that the single MOV remains intact and operates properly.

In some implementations, the conductive shell 213 may be, for example, a metallic coating that is placed on the outer surface 211 of the insulating housing or a metallic material  
30 placed on the outer surface 211.

## WHAT IS CLAIMED IS:

1. An electrical connector comprising:
  - an insulating housing comprising an inner wall, a first end, and a second end, the inner
  - 5 wall of the insulating housing defining a cavity and a groove, the groove comprising a groove
  - wall, the groove wall extending from the cavity radially into the insulating housing to a groove
  - depth;
  - an electrical component in the cavity;
  - an electrically conductive shell at an outer surface of the insulating housing; and
  - 10 a plug in the housing, the plug comprising a body and projection that radially extends
  - from the body, the projection being received in the groove, wherein the groove wall applies more
  - than 35 pounds (lbs) of force on the plug in a direction that is toward the electrical component.
2. The electrical connector of claim 1, wherein the groove wall applies more than 70 lbs of
- 15 force on the plug in the direction.
3. The electrical connector of claim 1, wherein the groove wall applies between 70 and 200
- lbs of force on the plug in the direction.
- 20 4. The electrical connector of claim 1, wherein the projection of the plug has a partial cone
- shape.
5. The electrical connector of claim 1, wherein
  - the groove wall comprises a radially extending portion of the inner wall of the insulating
  - 25 housing at an end of the groove,
  - the radially extending portion of the inner wall of the insulating housing makes physical
  - contact with the projection of the plug and applies the force to the projection of the plug, and
  - the direction toward the electrical component comprises an axial direction.

6. The electrical connector of claim 5, wherein the electrical component comprises a plurality of metal oxide varistors (MOVs), the MOVs being held in direct physical contact with each other by the force.
- 5 7. The electrical connector of claim 6, wherein the electrical component lacks an additional mechanism that holds the MOVs in physical contact with each other.
8. The electrical connector of claim 1, wherein  
the cavity comprises a first cavity portion that extends along a first direction, and a  
10 second cavity portion that extends along a second direction, and  
the first cavity portion and the second cavity portion are fluidly sealed from each other.
9. The electrical connector of claim 8, wherein the electrical connector further comprises an electrical contact that is electrically connected to the electrical component, the electrical contact  
15 being configured to connect to a high-power electrical system, and  
the electrical contact extends into the second cavity portion and toward the second end of the insulating housing, and the electrical component is in the first cavity portion.
10. The electrical connector of claim 8, further comprising a semiconductive insert in the  
20 cavity between the first cavity portion and the second cavity portion, and wherein the semiconductive insert fluidly seals the first cavity portion from the second cavity portion.
11. The electrical connector of claim 1, wherein  
the insulating housing has a thickness in a direction that extends radially from the  
25 electrical component, and  
a ratio of the thickness of the insulating housing to the diameter of the electrical component is at least 0.4.
12. The electrical connector of claim 11, wherein the ratio of the thickness of the insulating  
30 housing to the diameter of the electrical component is at least 0.5.

13. The electrical connector of claim 11, wherein the ratio of the thickness of the insulating housing to the diameter of the electrical component is between 0.5 and 0.7.

14. The electrical connector of claim 1, wherein  
5 the insulating housing has a thickness in a direction that extends radially from the cavity,  
and  
a ratio of the thickness of the insulating housing to the groove depth is less than 3.

15. The electrical connector of claim 14, wherein the ratio of the thickness of the insulating  
10 housing to the groove depth is 2.3-2.6.

16. The electrical connector of claim 1, wherein the insulating housing defines a plurality of  
grooves, each groove comprising a groove wall that extends radially from the cavity into the  
insulating housing, and a projection of a plug is received in each groove.

15  
17. The electrical connector of claim 1, further comprising  
an electrically conductive connection between the plug and the electrically conductive  
shell.

20 18. A method of assembling an electrical connector, the method comprising:  
providing an insulating housing, the insulating housing comprising a material that  
expands under applied force and contracts when the applied force is removed, the insulating  
housing defining a cavity that is open at least at one end of the housing and a groove radially  
extending from the cavity into the insulating housing;  
25 inserting an electrical component into the cavity;  
inserting a plug into the open end of the insulating housing, the plug comprising a  
projection having a first width and a second width, the first width being larger than a diameter of  
the cavity and larger than the second width; and  
applying a force to the insulating housing to place the projection of the plug in the  
30 groove, the force being in a first direction that is parallel to a longitudinal axis of the cavity and  
toward the first opening, and the force expanding the insulating housing in the first direction;

removing the applied force to allow the insulating housing to contract in a second direction that is away from the first opening such that a radially extending portion of the groove exerts force on the plug in the second direction to hold the electrical component in the cavity, wherein the radially extending portion of the groove exerts between 35 and 200 pounds (lbs) of  
5 force on the plug in the second direction.

19. The method of claim 18, further comprising:  
placing the insulating housing inside an electrically conductive shell; and  
electrically connecting the plug to the electrically conductive shell through an electrically  
10 conductive connection.

20. An electrical connector comprising:  
an insulating housing comprising an inner wall, a first end, and a second end, the inner wall of the insulating housing having a thickness and defining a cavity and a groove, the groove  
15 comprising a groove wall extending from the cavity radially to a groove depth;  
an electrical component in the cavity;  
an electrically conductive shell at an outer surface of the insulating housing; and  
a plug in the housing, the plug comprising a body and projection that radially extends  
from the body, the projection being received in the groove, wherein the thickness of the  
20 insulating housing is at least 1.3 centimeters, and the ratio of the insulating housing to a radius of the electrical component is at least 0.4.

21. The electrical connector of claim 20, wherein the thickness of the insulating housing is at least 1.9 centimeters.  
25

22. The electrical connector of claim 20, wherein a ratio of the thickness of the insulating housing to a diameter of the electrical component is greater than 0.5.

23. The electrical connector of claim 20, wherein a ratio of the thickness of the insulating  
30 housing to a diameter of the electrical component is greater than 0.55.

24. The electrical connector of claim 20, wherein the electrical component in the cavity comprises a plurality of MOVs, and the groove wall applies a force to the plug in an axial direction, the force holding the MOVs in physical contact with each other.

5 25. An electrical connector comprising:

an insulating housing comprising an inner wall and an outer surface, the insulating housing having a thickness between the inner wall and the outer surface, the inner wall of the insulating housing defining a cavity, the insulating housing comprising a material being associated with a resting state and being configured to elongate in a longitudinal direction  
10 relative to the resting state;

an electrical component in the cavity, the electrical component having a diameter in a direction that is perpendicular to the longitudinal direction;

an electrical conductor configured to connect to a high-voltage electrical system;

15 an electrically conductive shell at the outer surface of the insulating housing, the electrically conductive shell being configured to connect to ground;

a connection junction electrically connected to the electrical component and to the electrical conductor, the insulating housing being between the connection junction and the electrically conductive shell; and

20 an electrically conductive plug in the housing, the plug being electrically connected to the electrical component and being configured to connect to ground, wherein

a portion of the housing is elongated at least 10% more than the resting state, and a ratio of the thickness of the housing to the diameter of the electrical component is greater than 0.4.

25 26. The electrical connector of claim 25, wherein the plug applies a force that is greater than 35 lbs on the electrical component, the applied force being toward the semiconductive insert.

27. The electrical connector of claim 25, wherein the electrical component comprises a plurality of MOVs, the MOVs being held in direct physical contact with each other by the force,  
30 and the electrical component lacks an additional mechanism that holds the MOVs to each other.

28. The electrical connector of claim 25, wherein the ratio of the thickness of the housing to the diameter of the electrical component is greater than 0.5.

29. The electrical connector of claim 25, wherein the ratio of the thickness of the housing to  
5 the diameter of the electrical component is between 0.55 and 0.65.

100

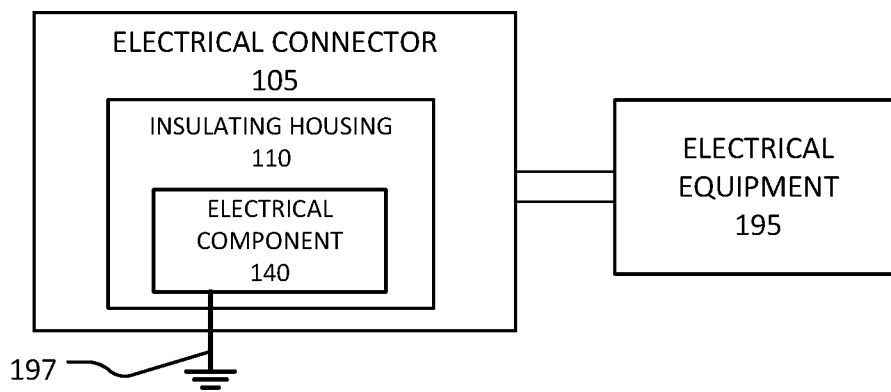


FIG. 1

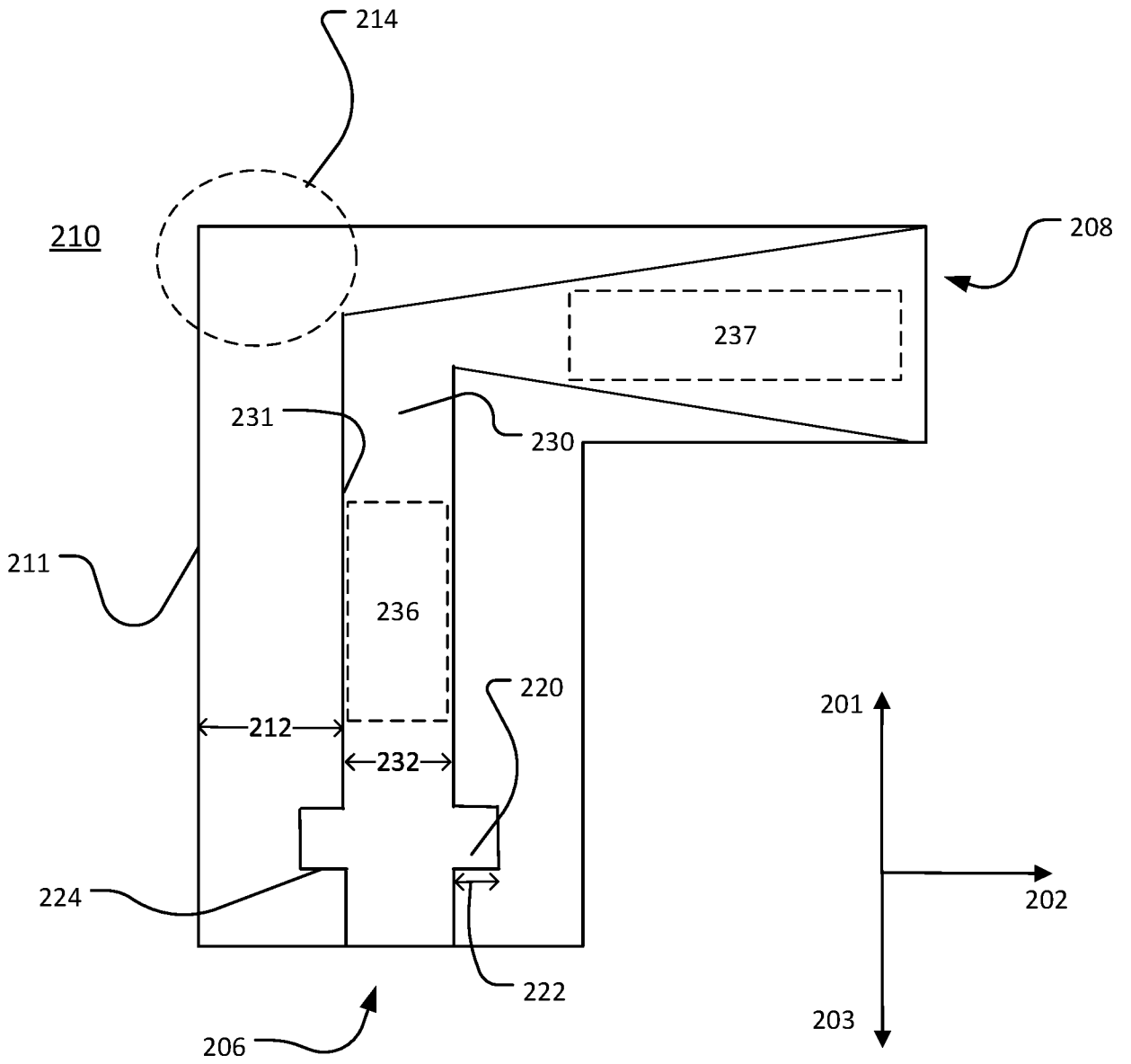


FIG. 2A

205

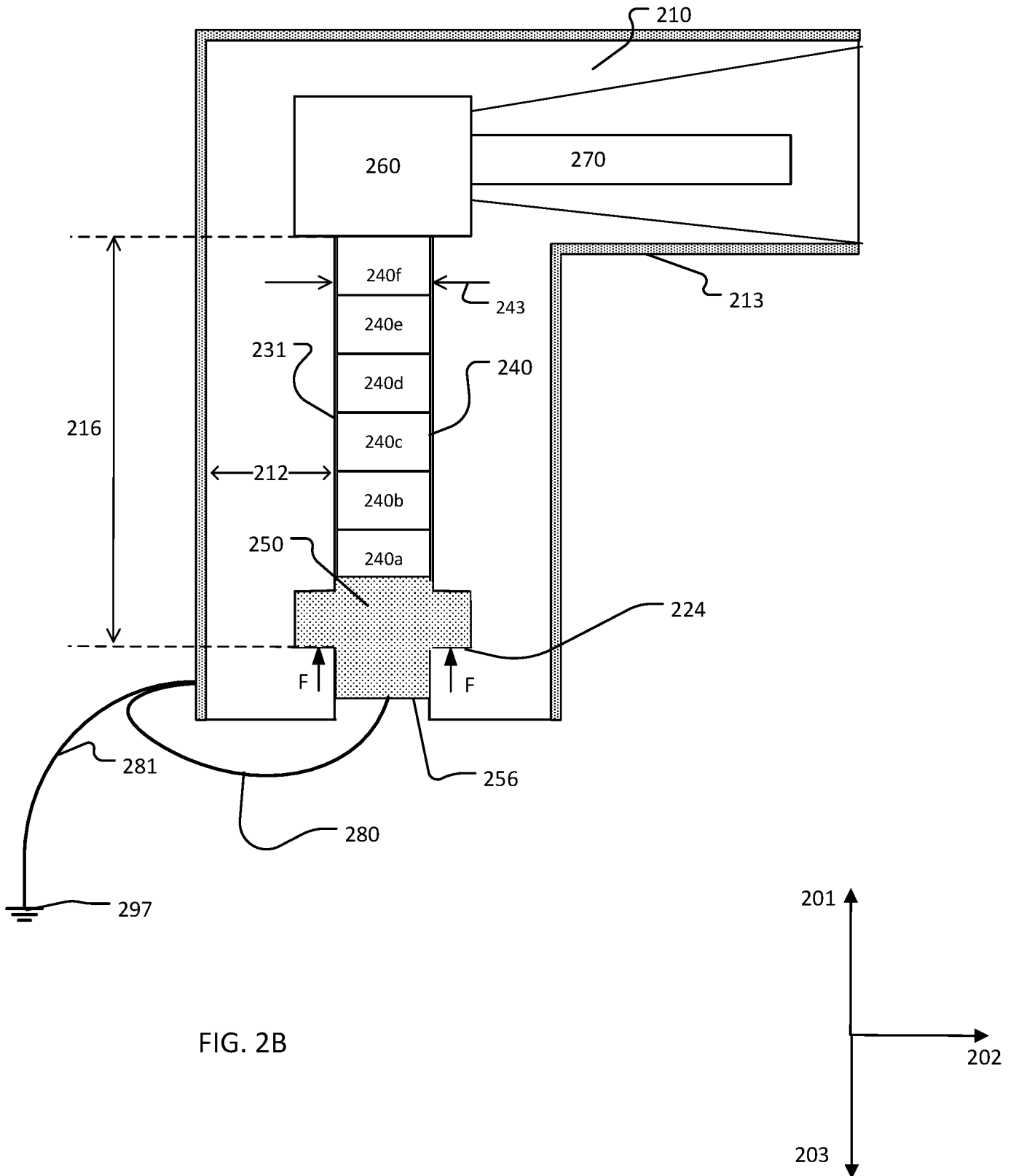


FIG. 2B

250

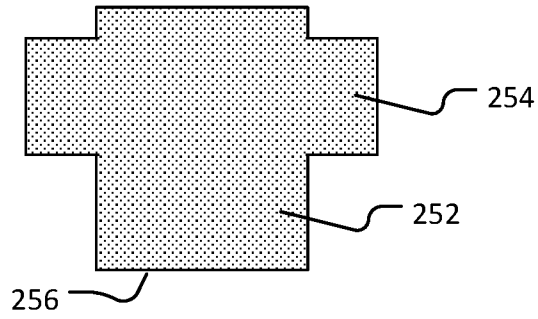


FIG. 2C

260

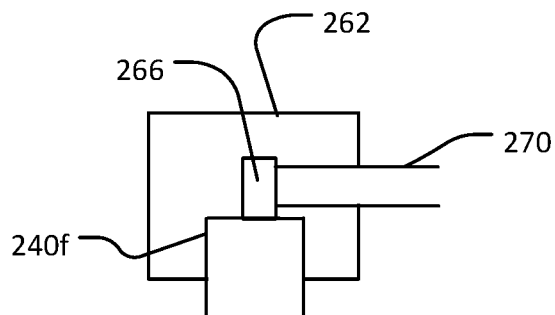
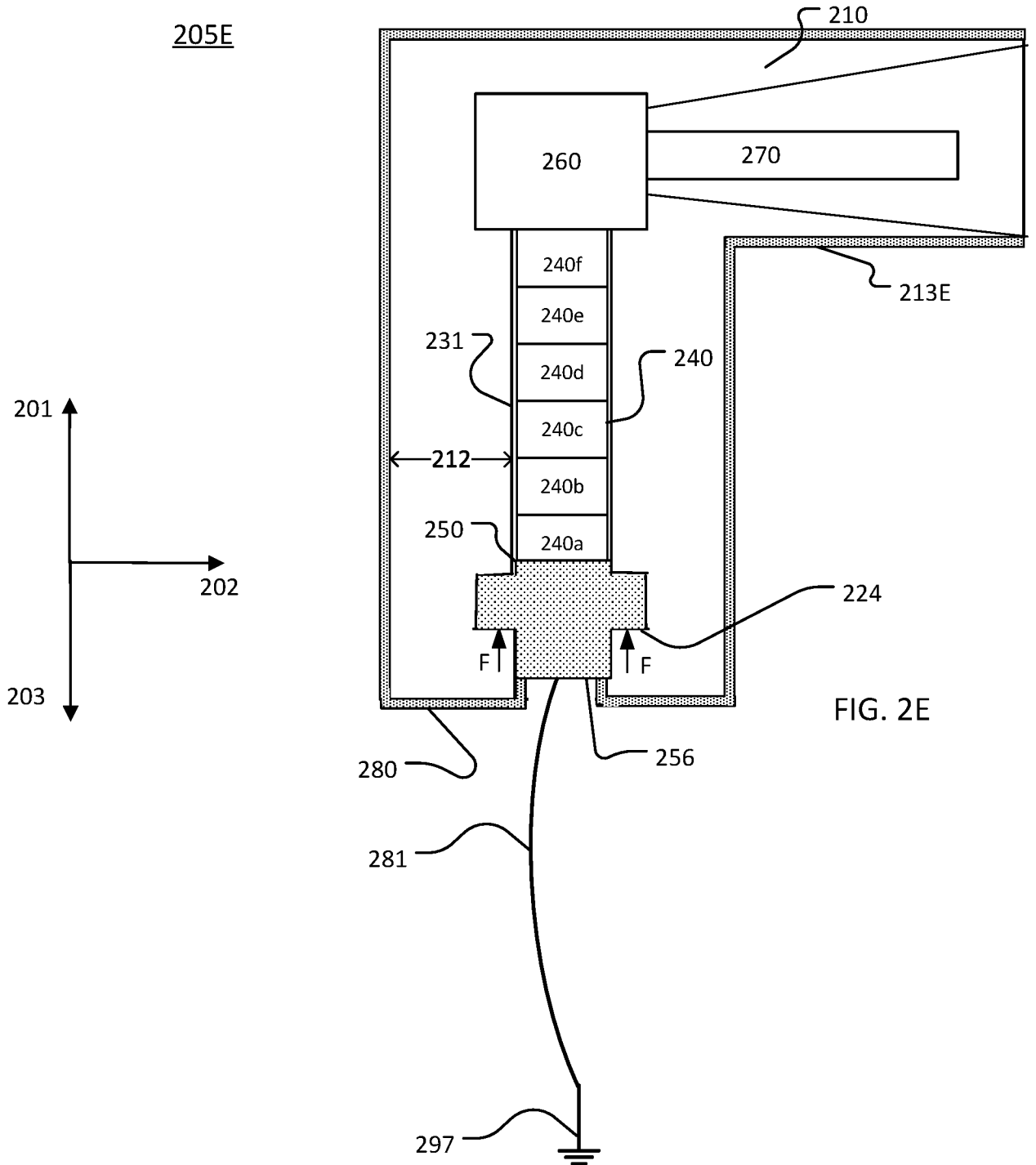


FIG. 2D



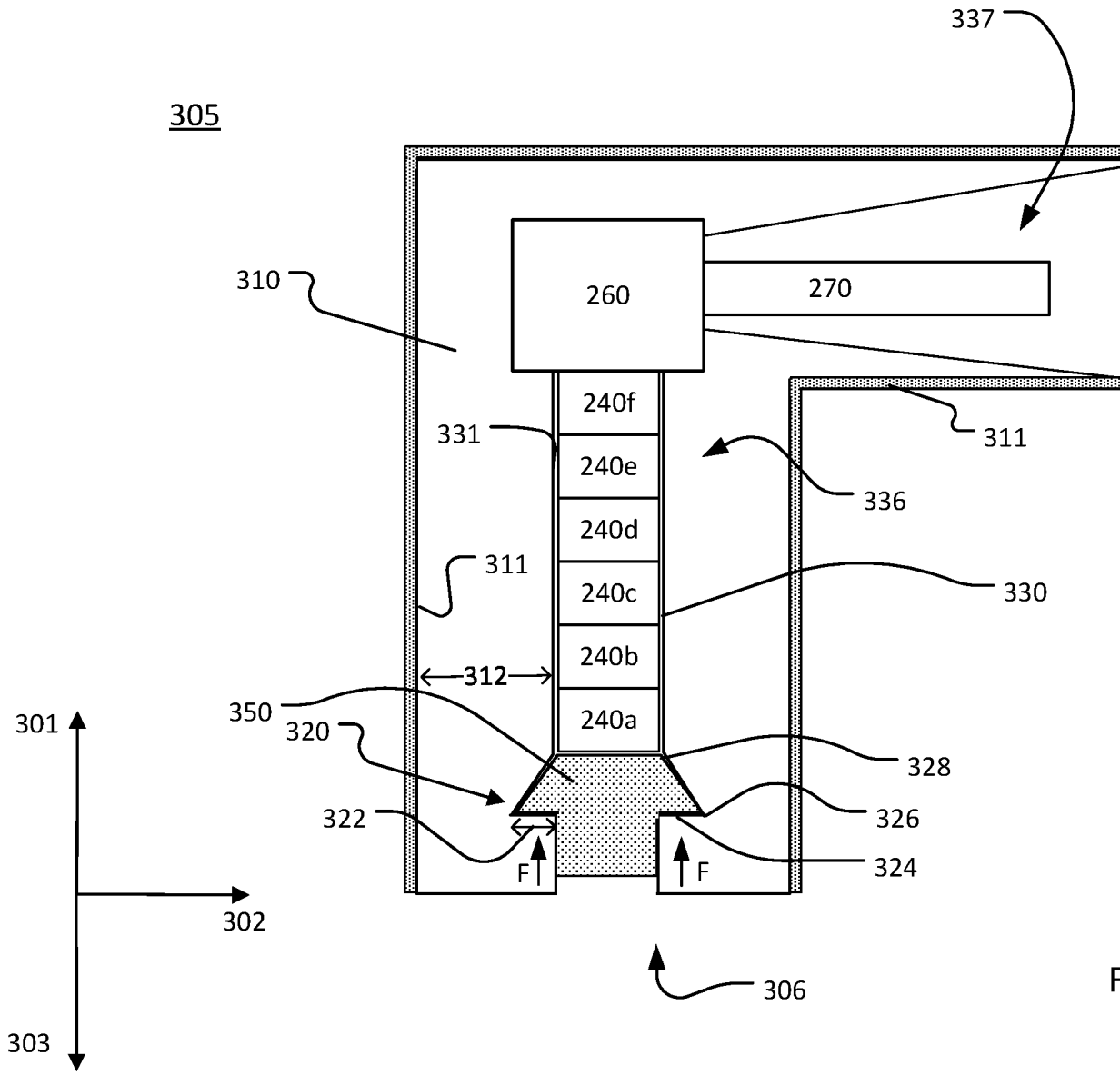


FIG. 3A

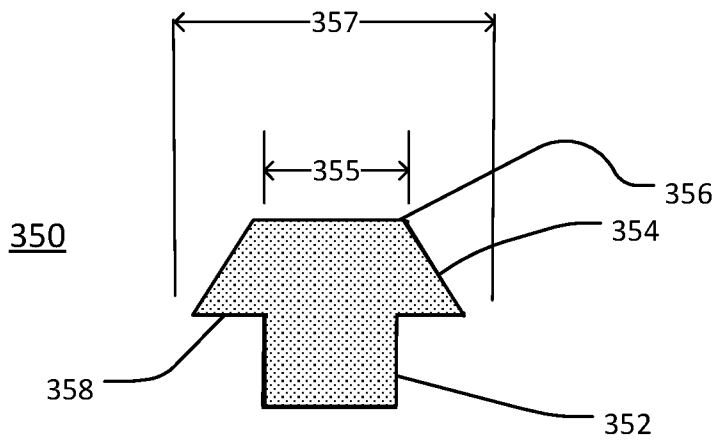


FIG. 3B

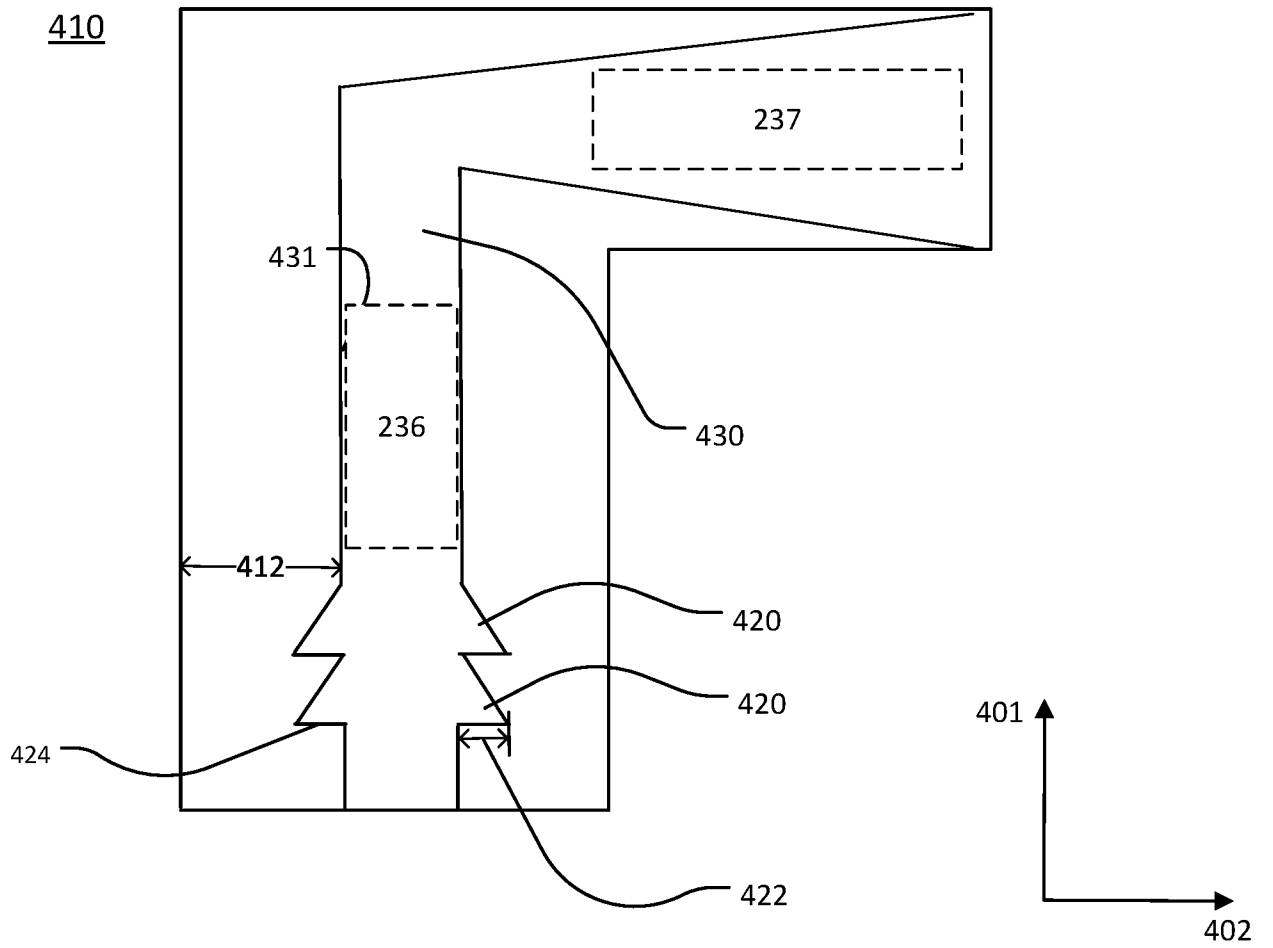


FIG. 4

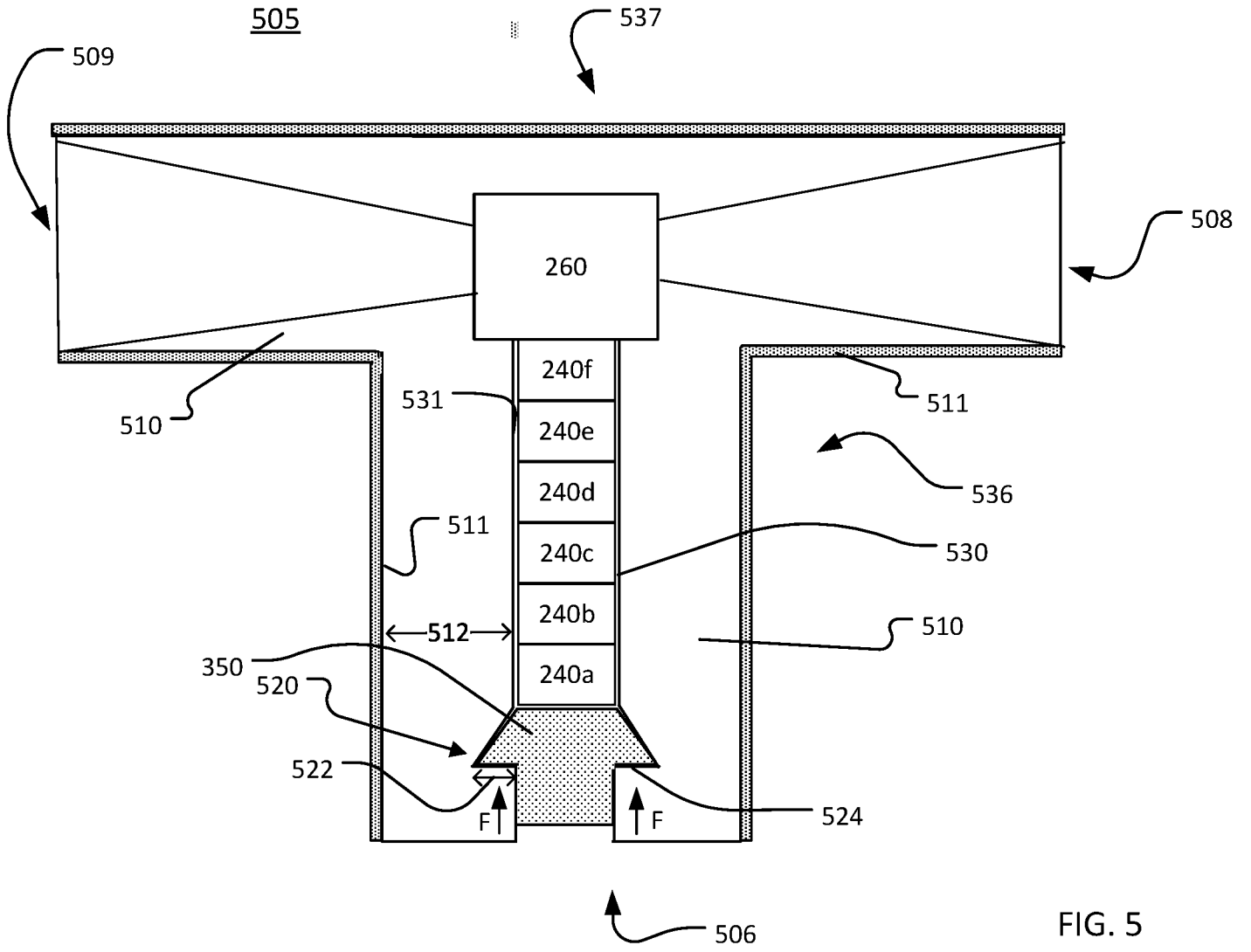
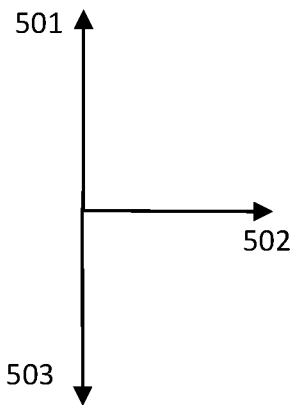


FIG. 5



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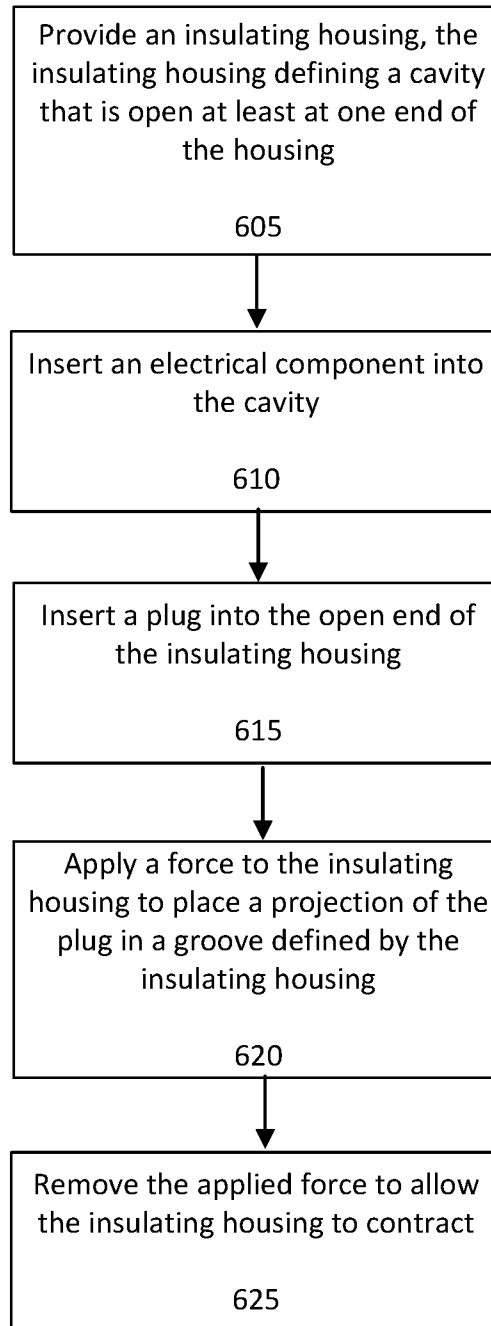
600

FIG. 6

**A. CLASSIFICATION OF SUBJECT MATTER****H01R 13/516(2006.01)i, H01R 13/6582(2011.01)i**

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

H01R 13/516; H01R 13/66; H01R 27/02; H01R 13/53; B23P 19/02; G02B 6/36; H01R 4/60; H01R 13/6582

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) &amp; Keywords: plug, groove, cavity, force, ground

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	US 2010-0098380 A1 (MARK G. GORDON et al.) 22 April 2010 See paragraphs [0020]-[0040], claim 1 and figures 1-4.	1-19, 26
Y	US 2009-0255106 A1 (DAVID CHARLES HUGHES et al.) 15 October 2009 See paragraphs [0025]-[0044], claim 1 and figures 1-3.	8-10
A	US 2011-0021040 A1 (JEFFREY W. GARB et al.) 27 January 2011 See paragraphs [0055]-[0080], claim 1 and figures 1-4.	1-29
A	US 2011-0244702 A1 (GLEN J. BERTINI et al.) 06 October 2011 See paragraphs [0038]-[0048], claims 1-8 and figures 1A-1E.	1-29

 Further documents are listed in the continuation of Box C. See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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

Date of the actual completion of the international search

12 May 2017 (12.05.2017)

Date of mailing of the international search report

**12 May 2017 (12.05.2017)**

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

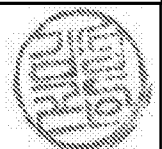
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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2017/016794**

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