US 20070147004A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2007/0147004 A1**

(43) **Pub. Date: Jun. 28, 2007**

Caines et al.

(54) **ELECTRONIC CONTROL ENCLOSURE**

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(21) Appl. No.: **11/706,908**

(22) Filed: **Feb. 13, 2007**

Related U.S. Application Data

(62) Division of application No. 10/968,438, filed on Oct. 19, 2004, now Pat. No. 7,190,589.

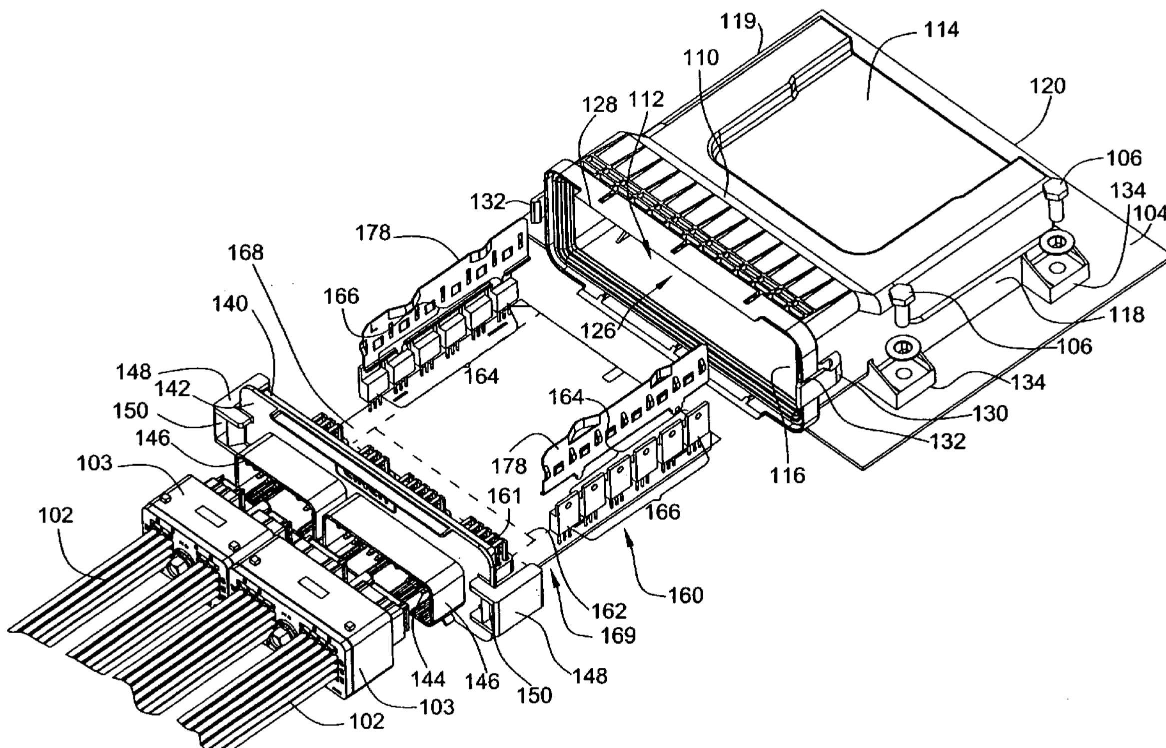
Publication Classification

(51) **Int. Cl.**
H05K 7/20 (2006.01)

(52) **U.S. Cl.** **361/707**; 361/715; 361/719; 174/16.1

(57) **ABSTRACT**

The electronic control enclosure includes devices and methods for removing heat energy from the electronic components of an electronic control unit. The components are mounted to a substrate and are protectively housed in an interior chamber of an environmentally sealed enclosure housing. Electrical communication is established with the components via a header assembly that includes plug receptacles. To remove heat generated by the components from the enclosure housing, one or more heat sinks are disposed through the enclosure housing such that the heat sinks have an interior surface exposed to the interior chamber and an exterior surface exposed to the exterior of the enclosure housing. In other embodiments, the enclosure housing may be made of a heat conductive material and the heat sink is integral with the enclosure housing. In one aspect, a spring urges the components against the interior surface. In another aspect, the components are mounted to and directly contact the interior surface.



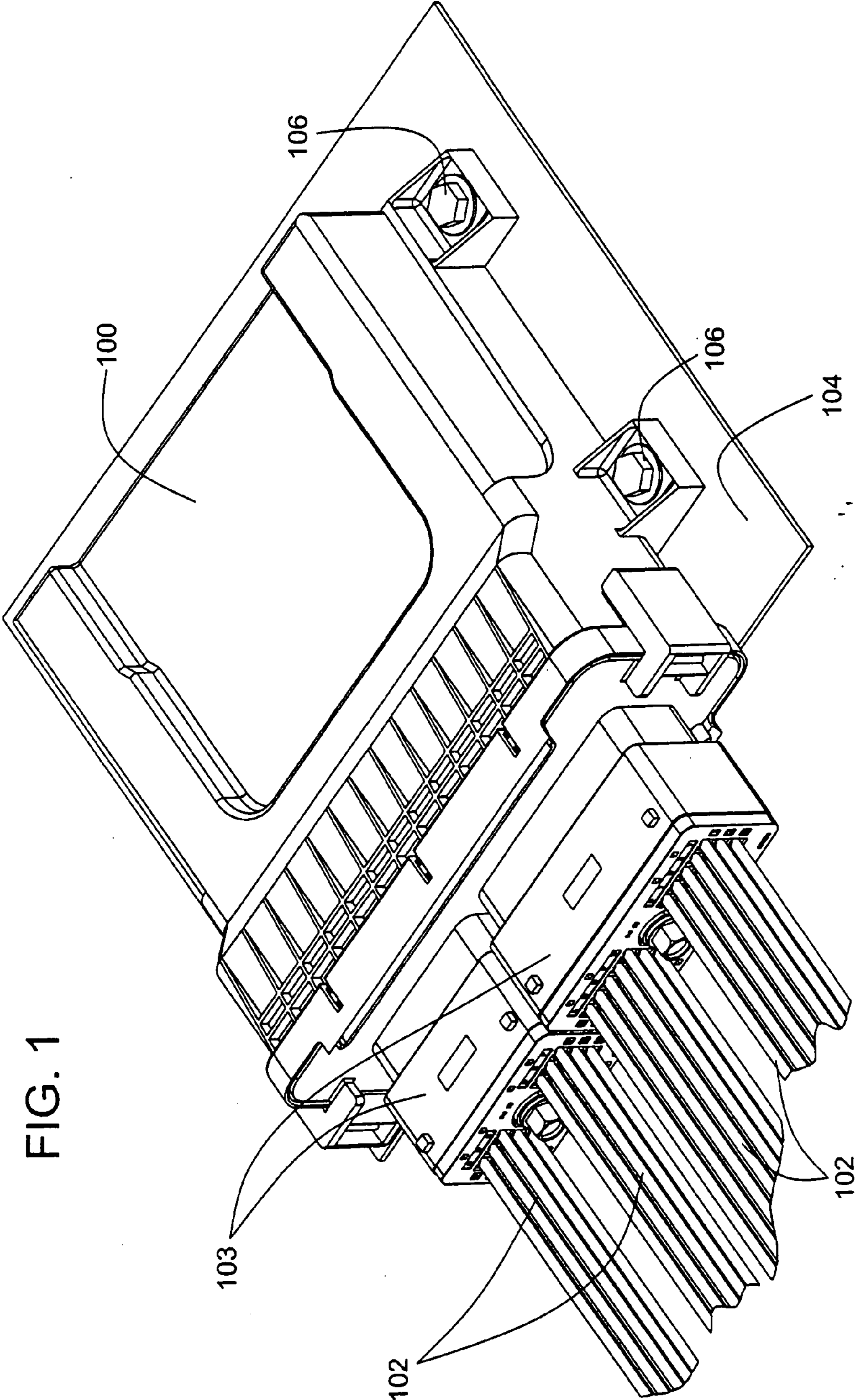


FIG. 1
100
106
106
104
103
102
102

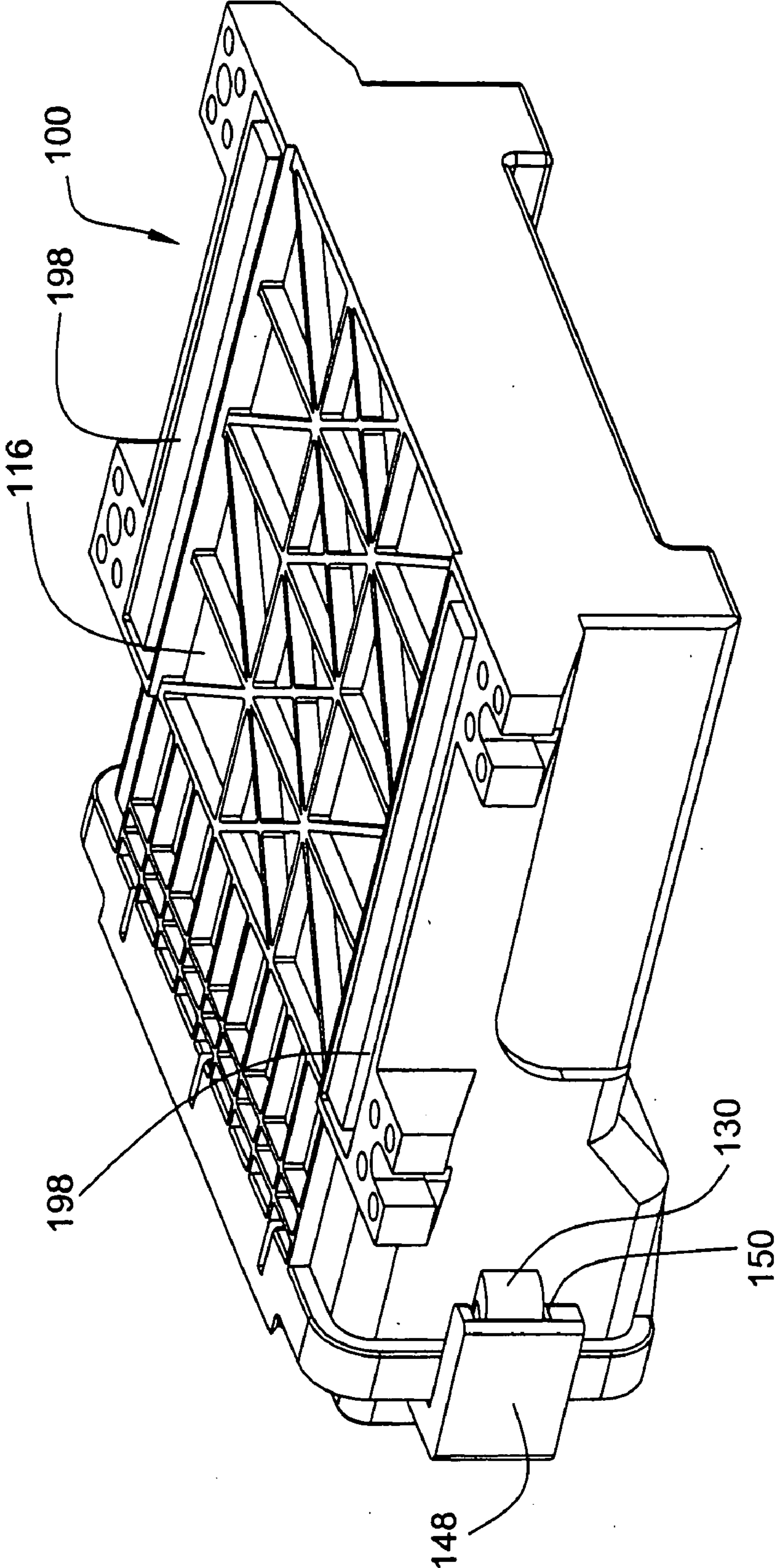
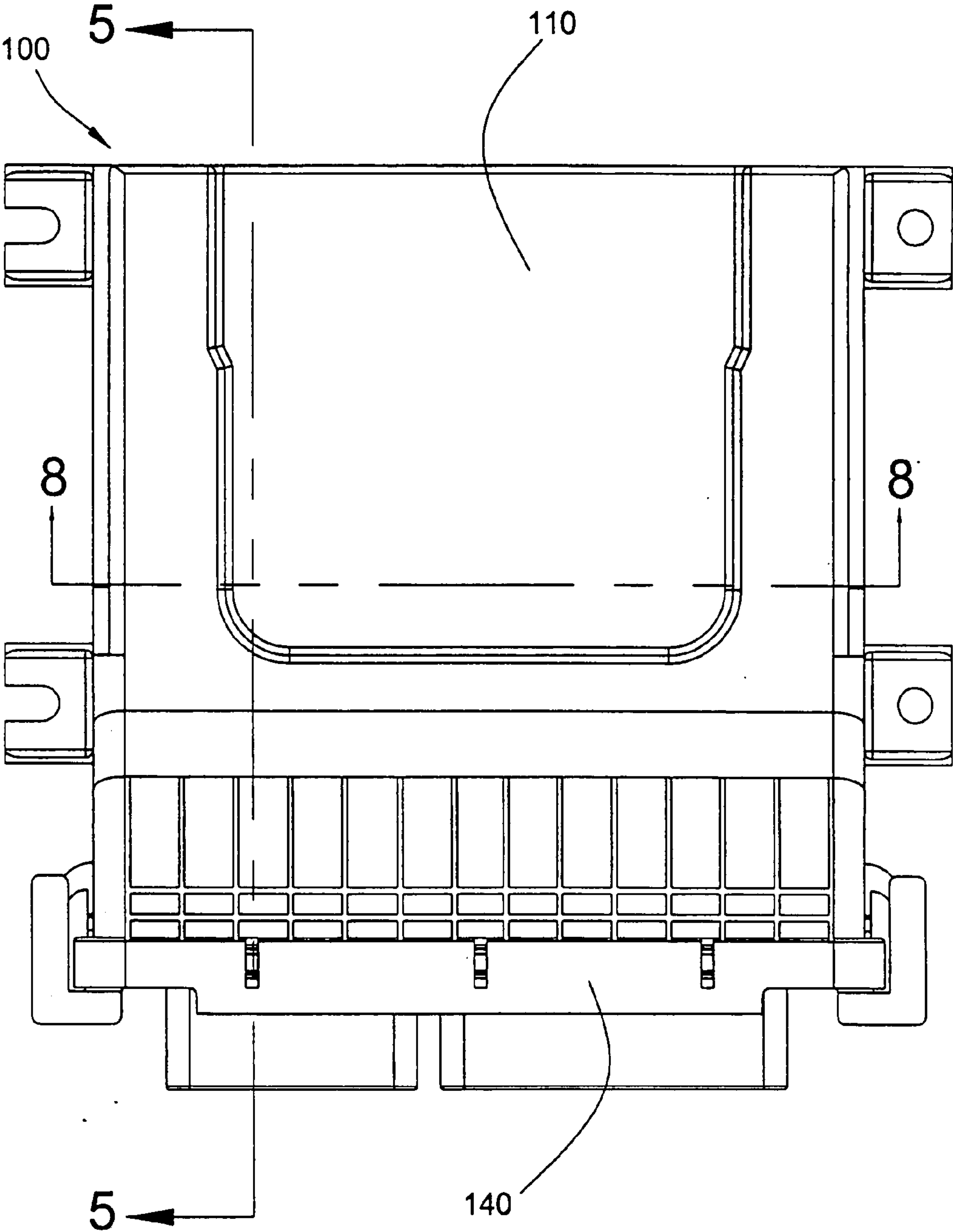


FIG. 2

FIG. 3



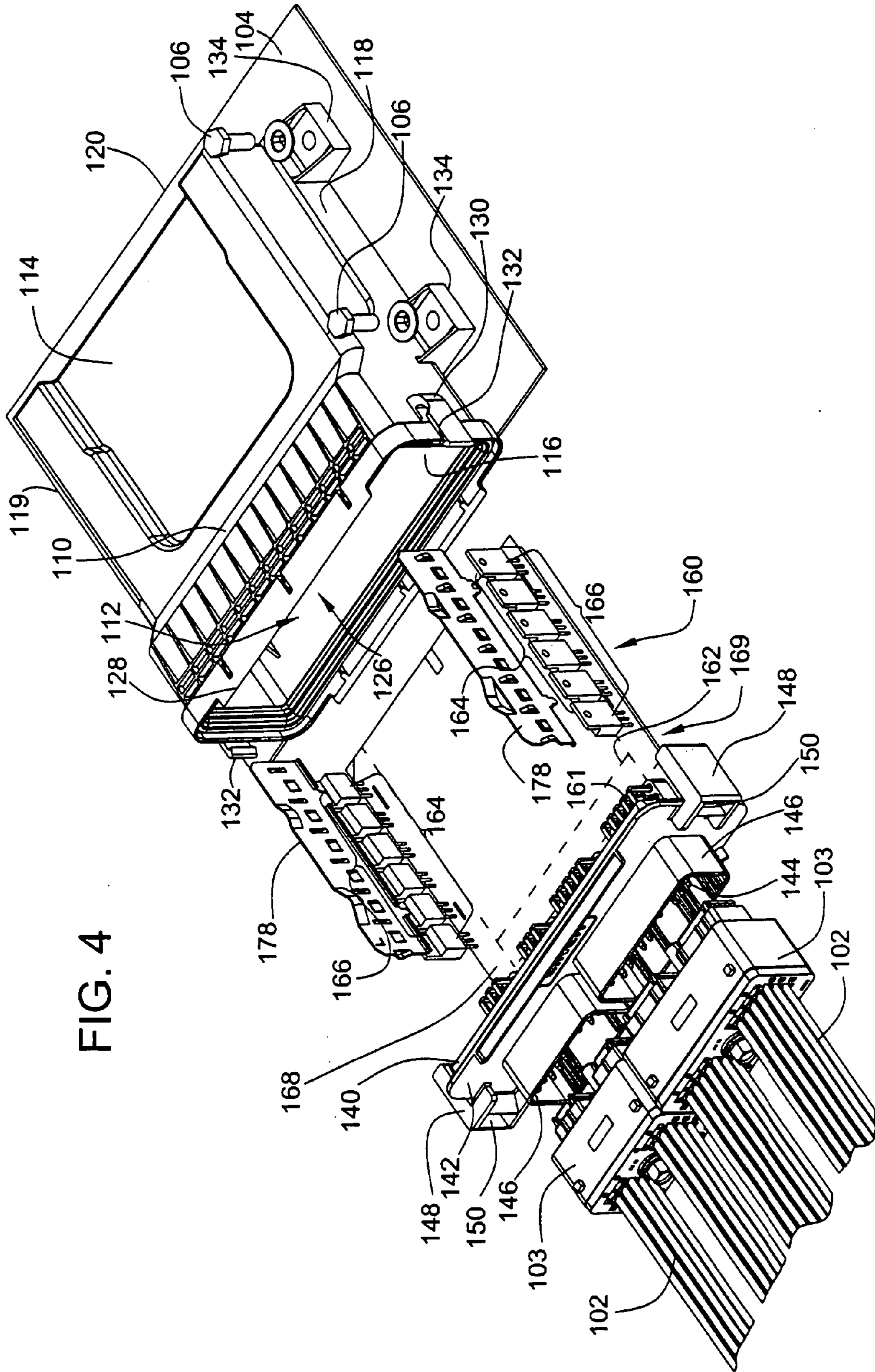


FIG. 4
104
106
134
118
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169
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142
148
150
146
103
102

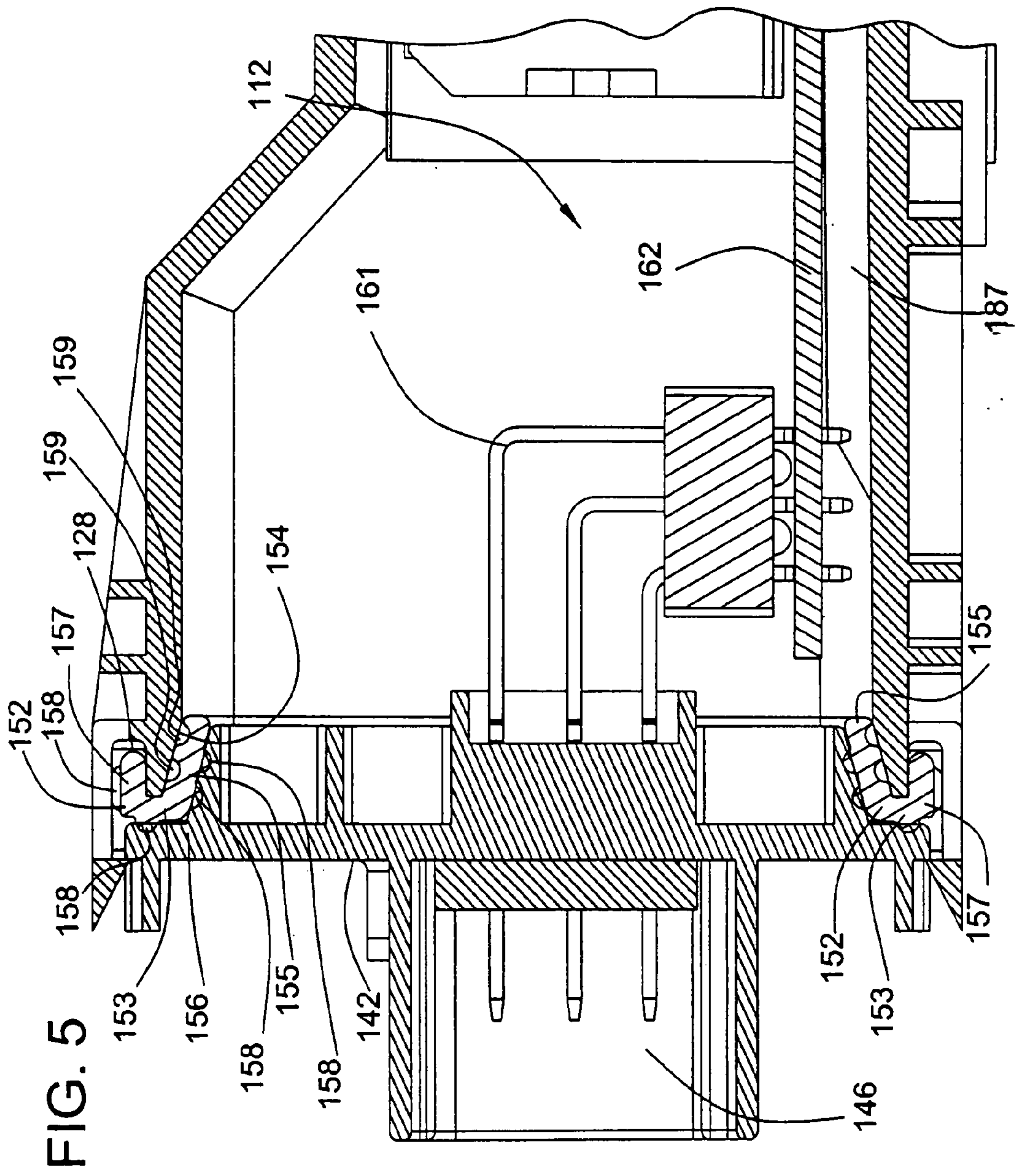

FIG. 5

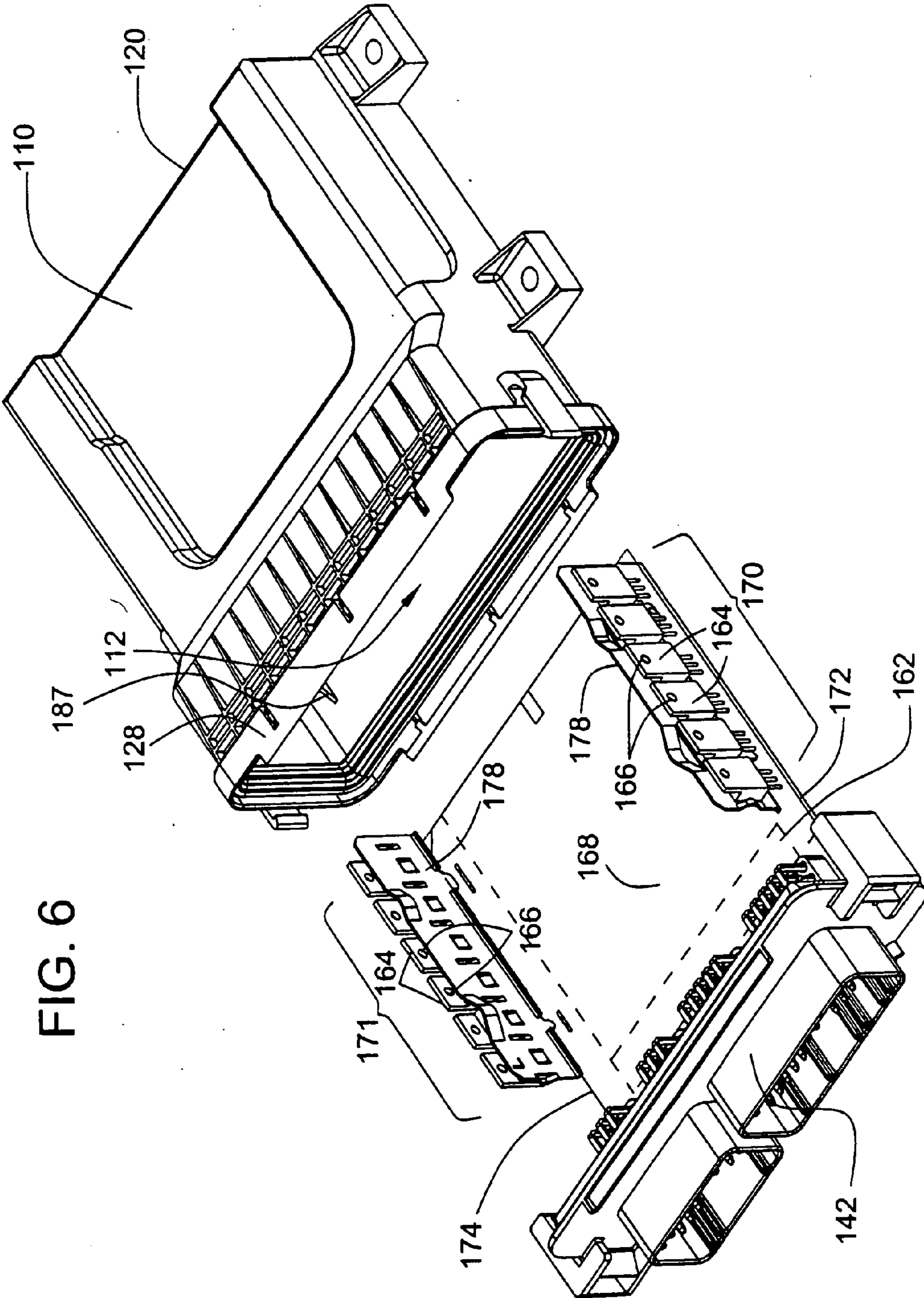
FIG. 6
110
120
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187
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171
174
142

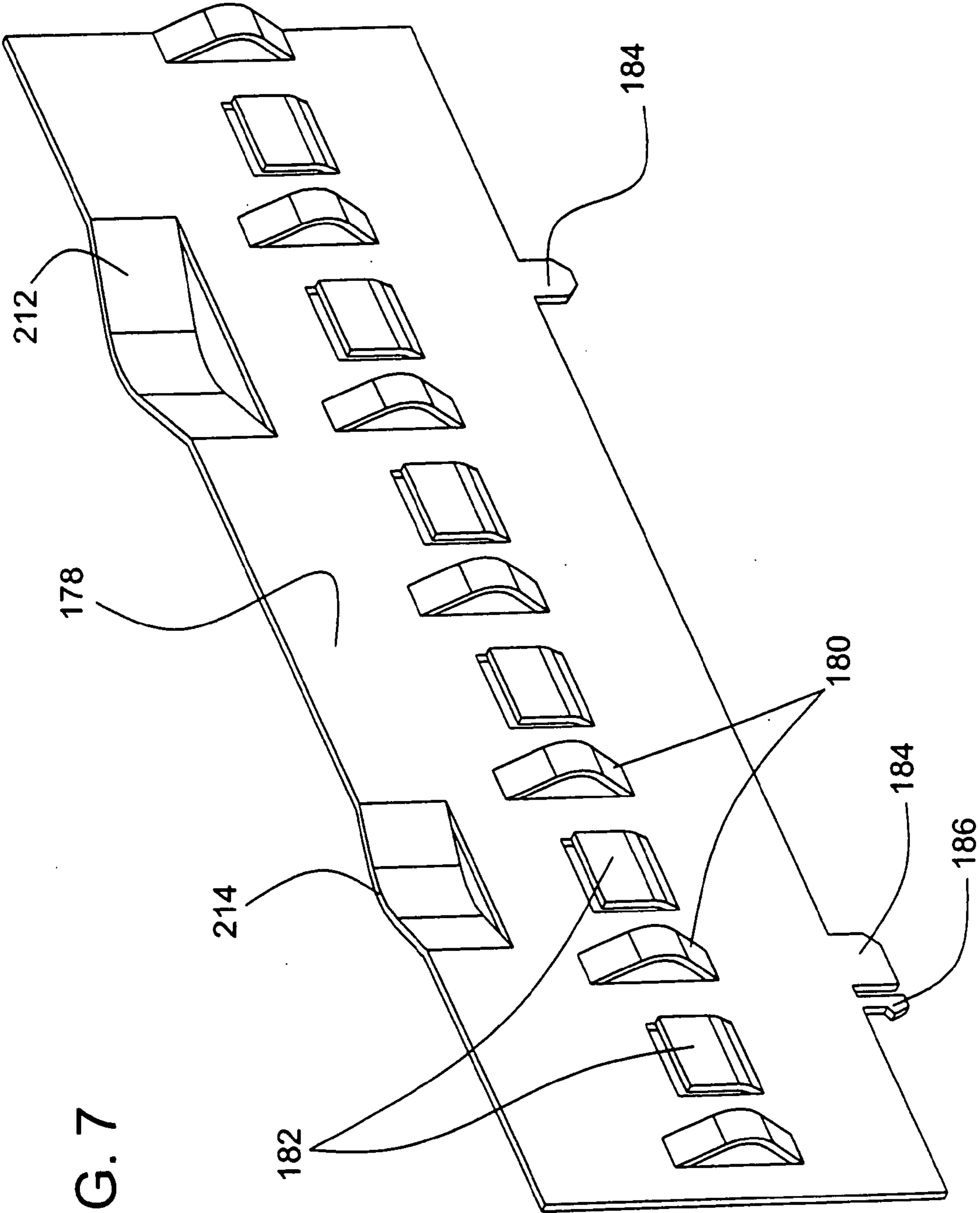

FIG. 7

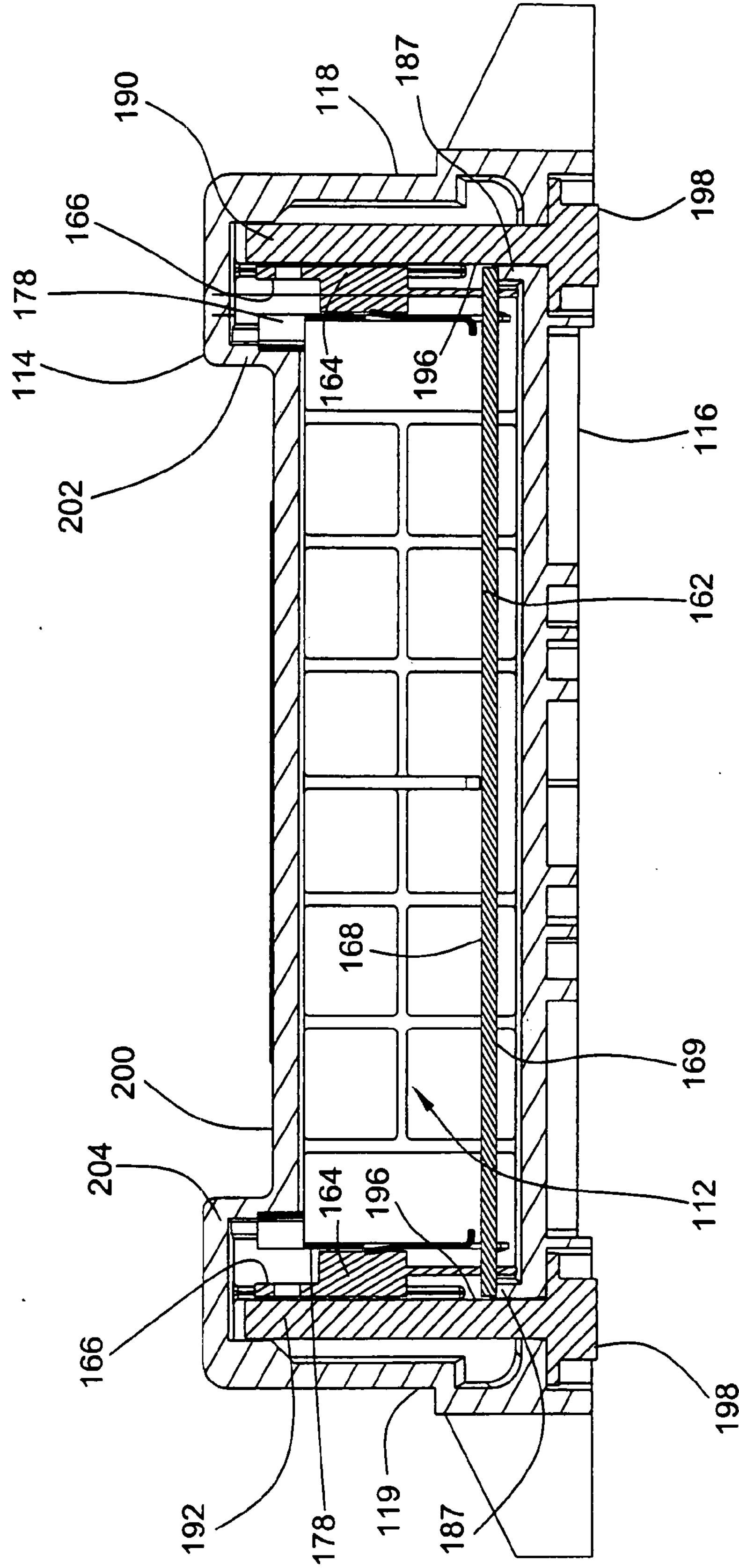
FIG. 8
190
118
187
198
166
178
114
164
196
116
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162
168
169
200
204
112
164
196
166
198
192
178
119
187

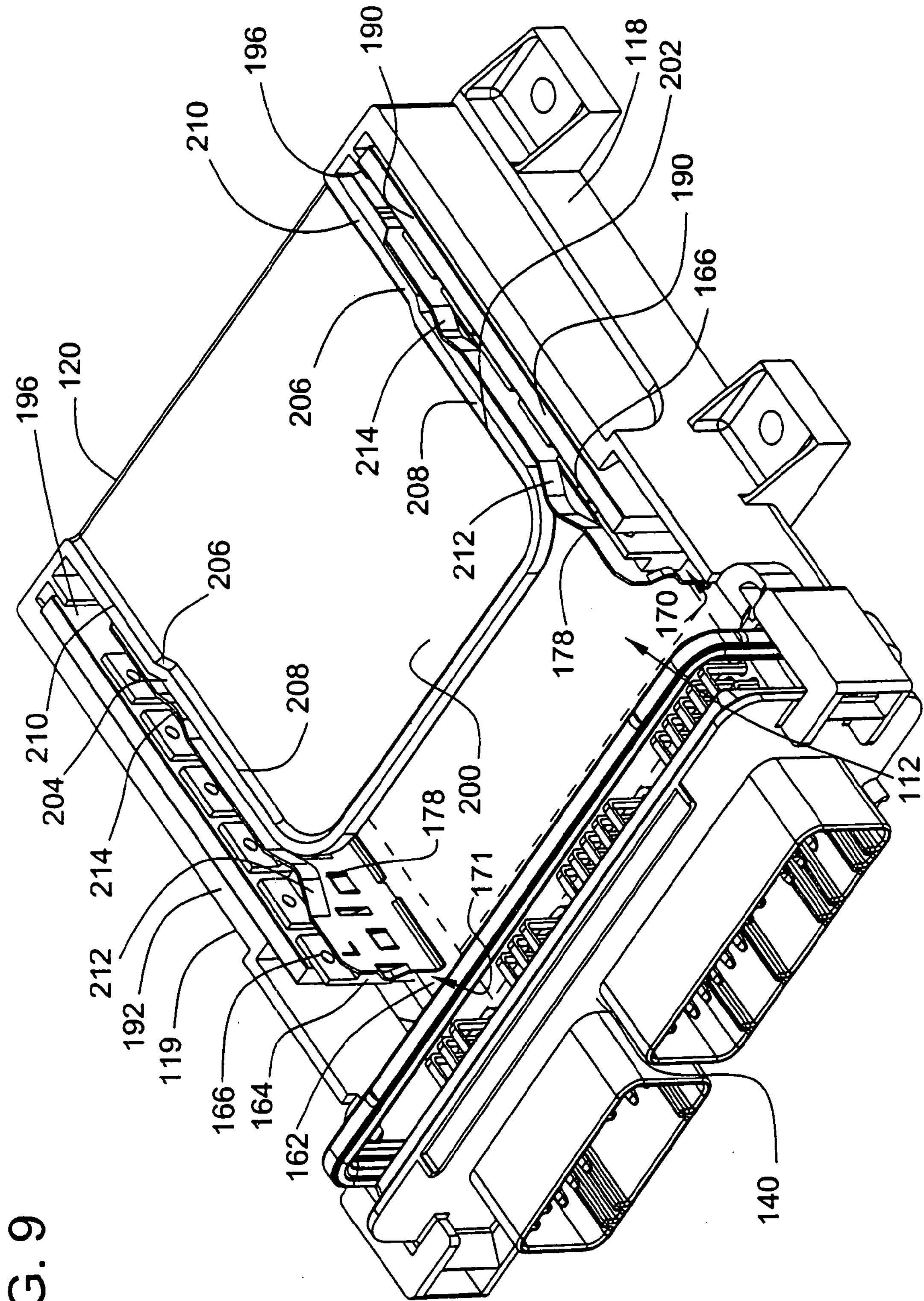
FIG. 9
196
120
210
196
190
118
202
190
166
206
214
208
212
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204
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178
171
112
212
192
119
166
164
162
140

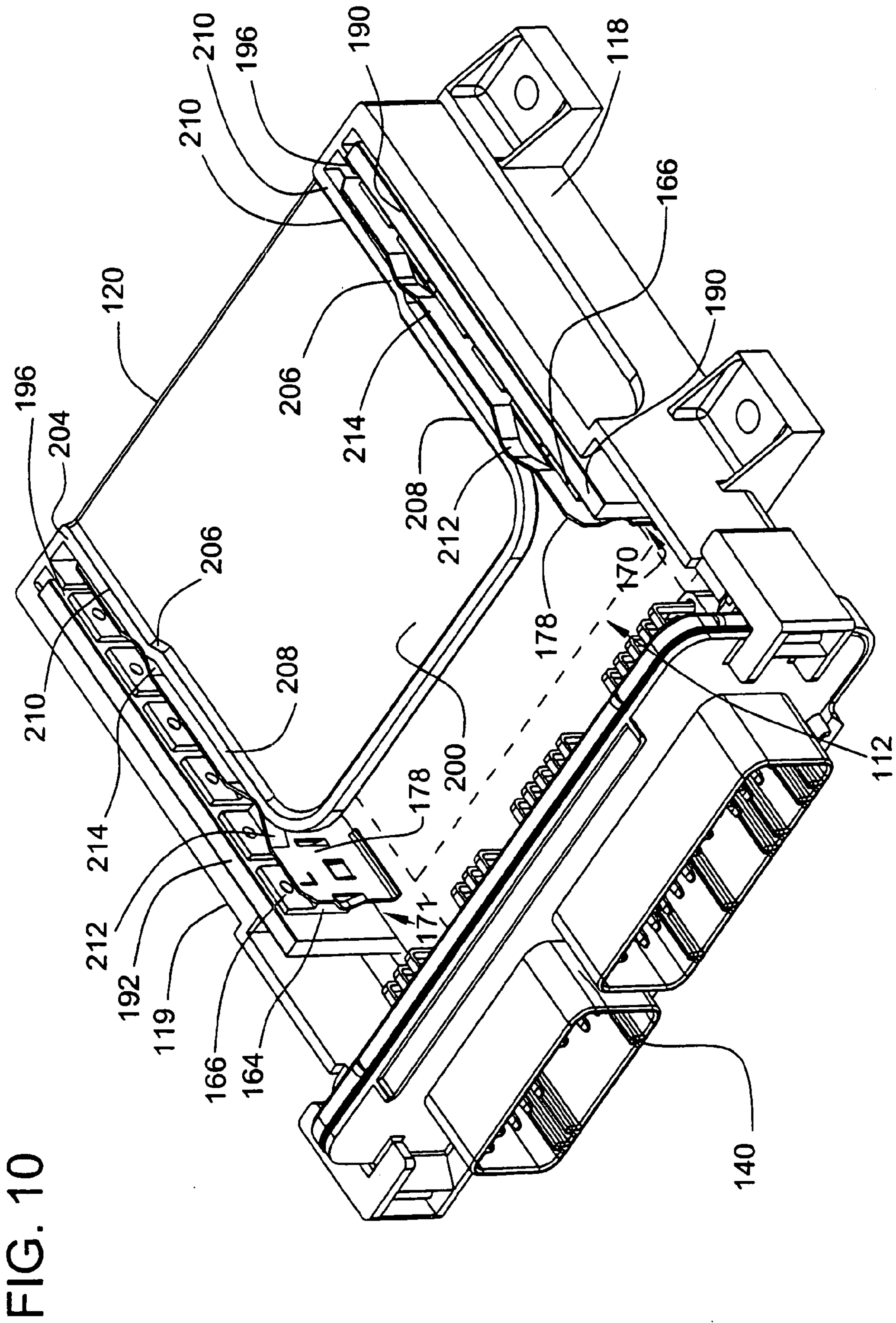
FIG. 10
120
196
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206
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212
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190
206
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118
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112
140

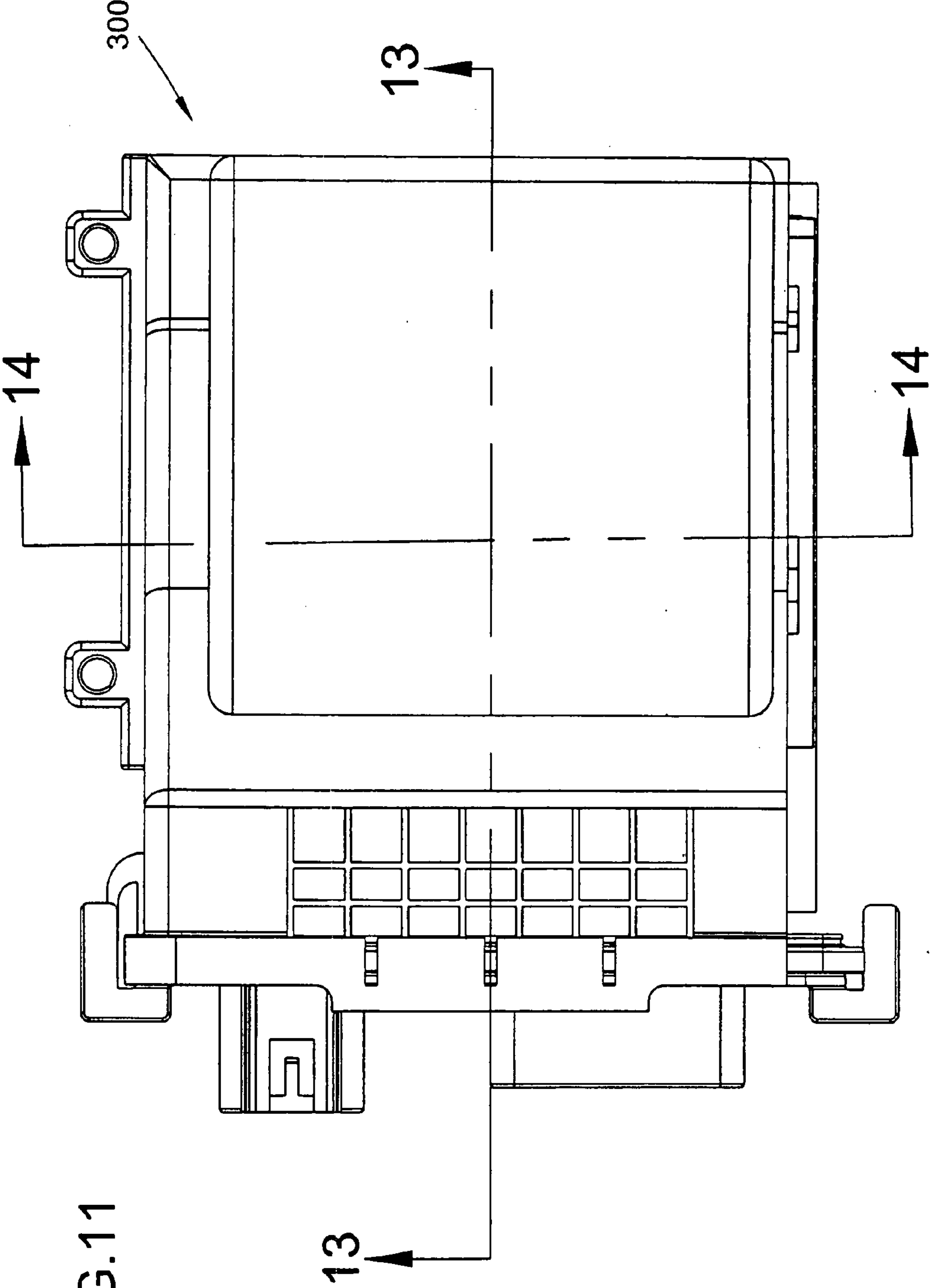

FIG.11

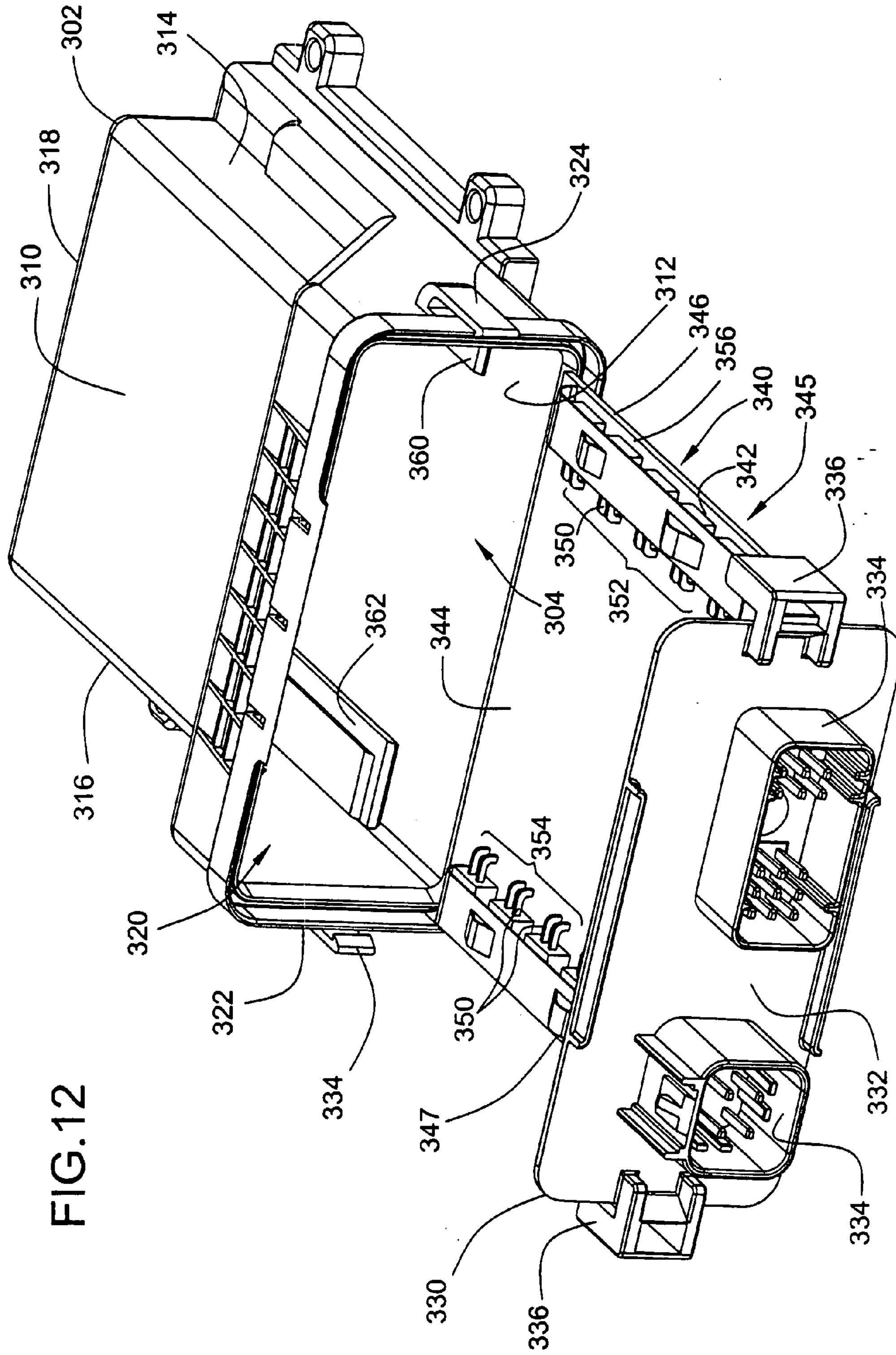
FIG.12
302
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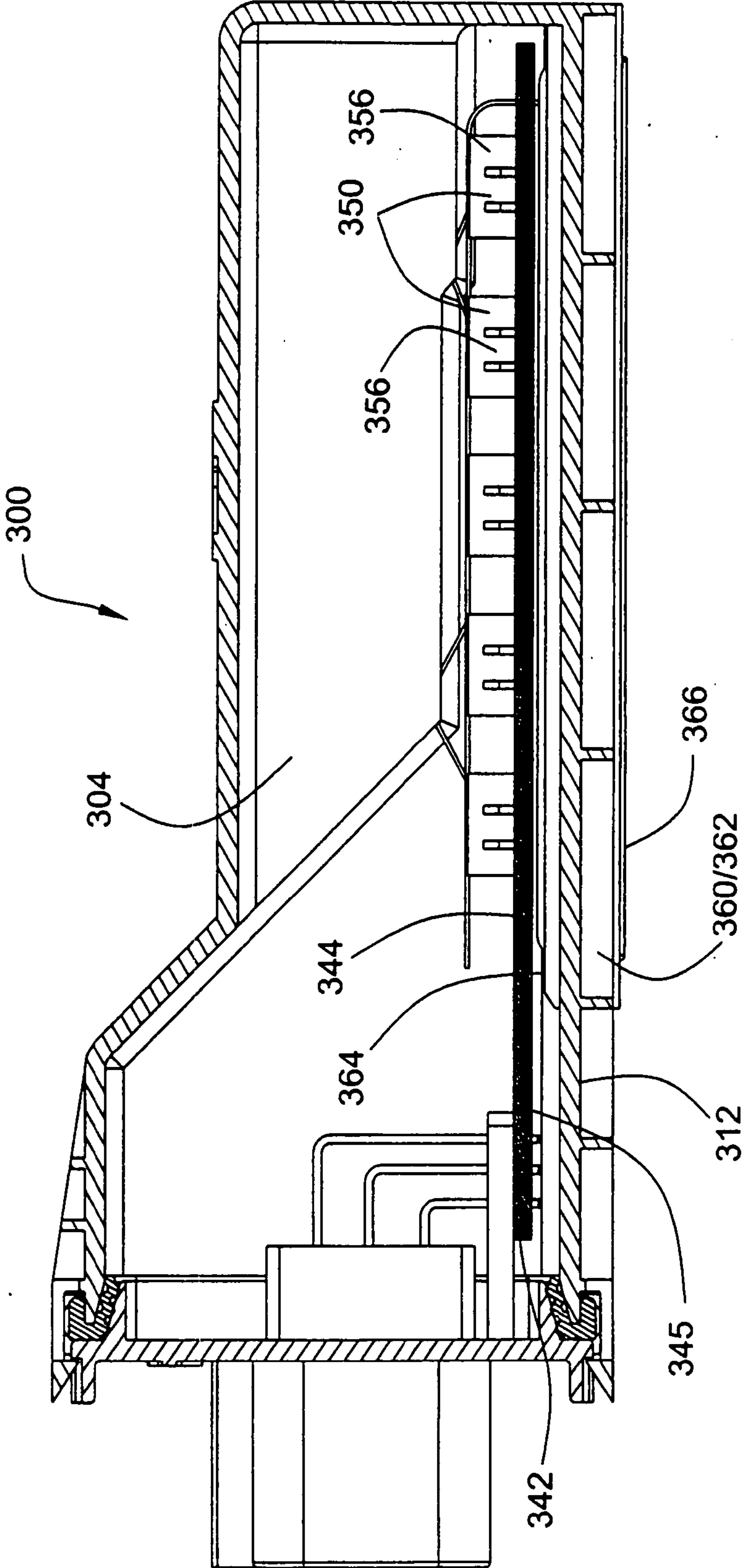
FIG.13
300
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342

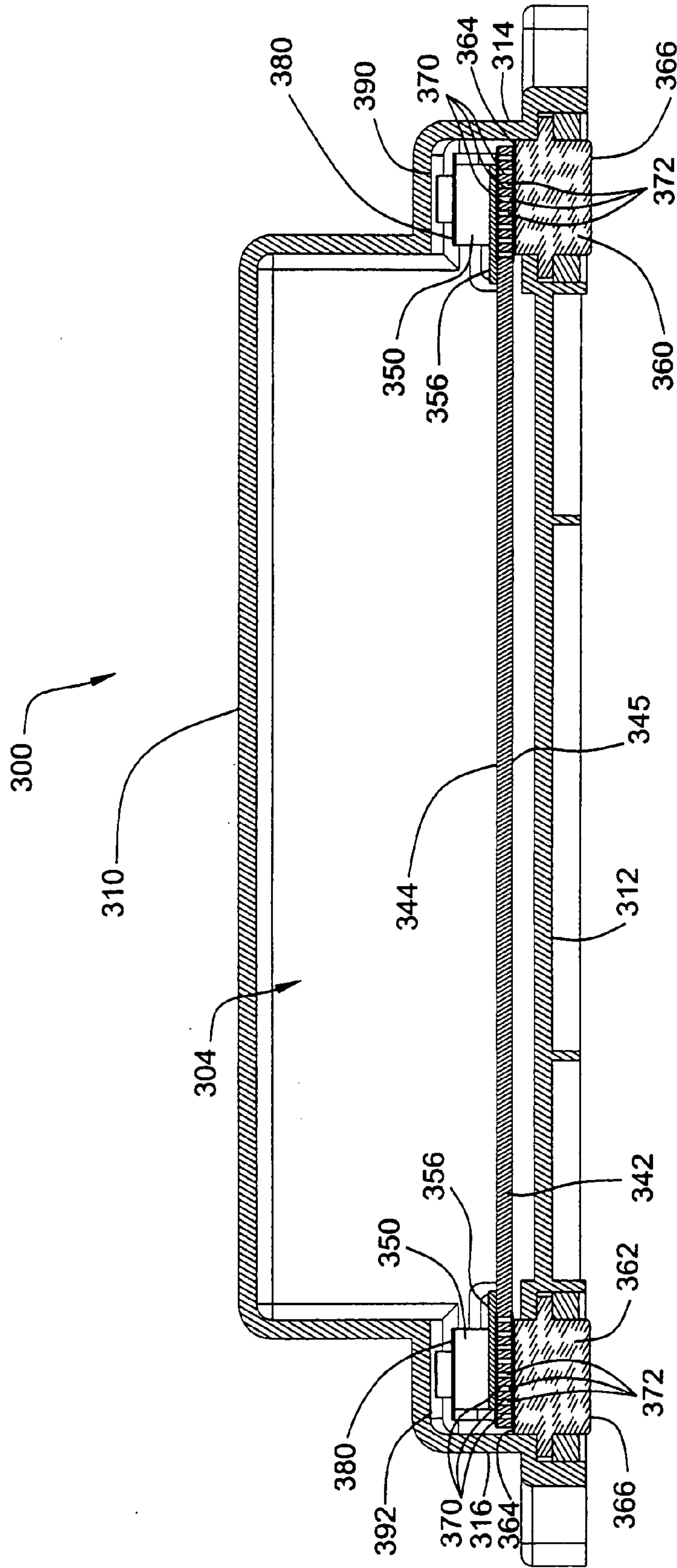
FIG. 14
300
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392
316

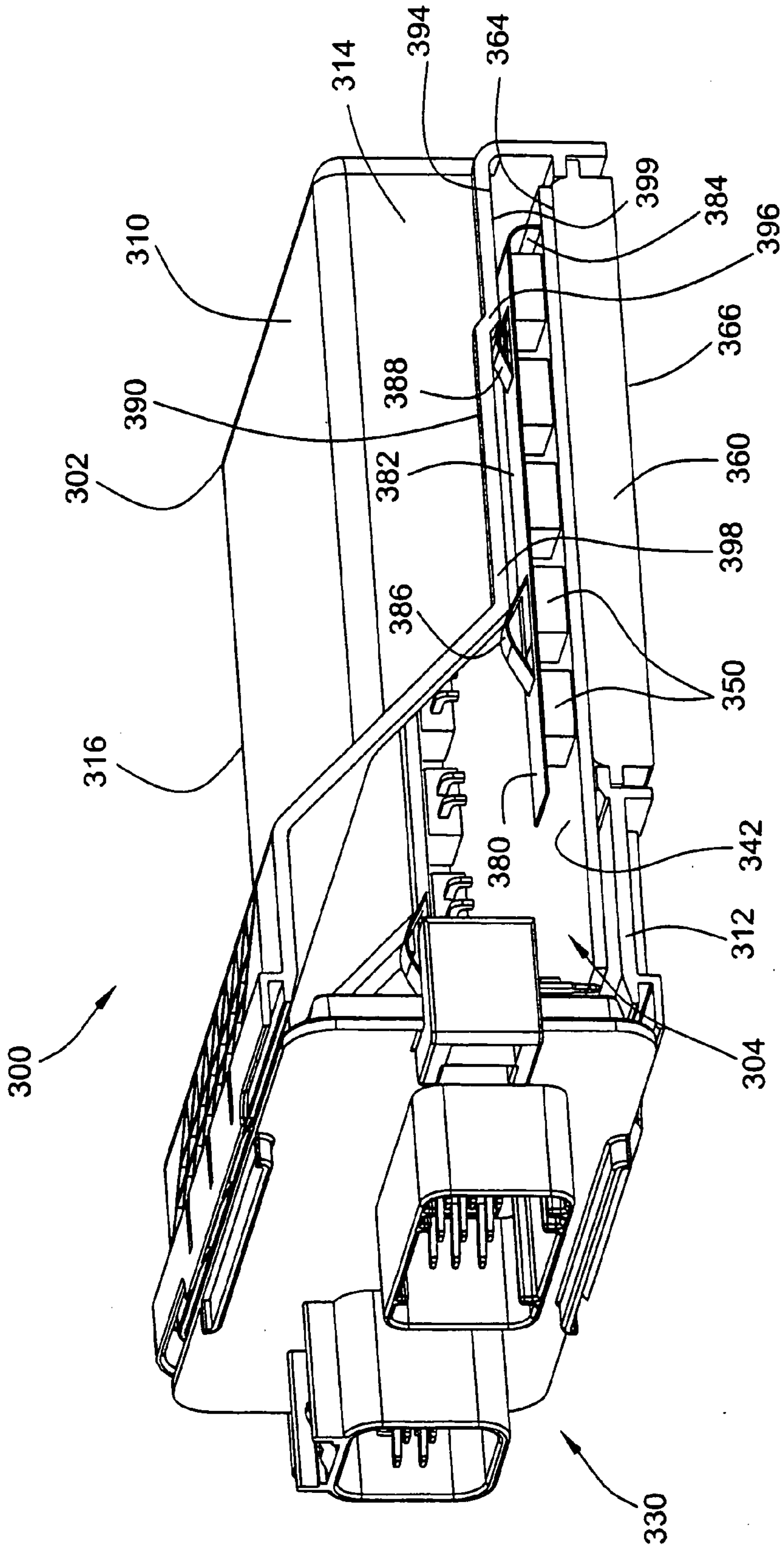
FIG.15
300
302
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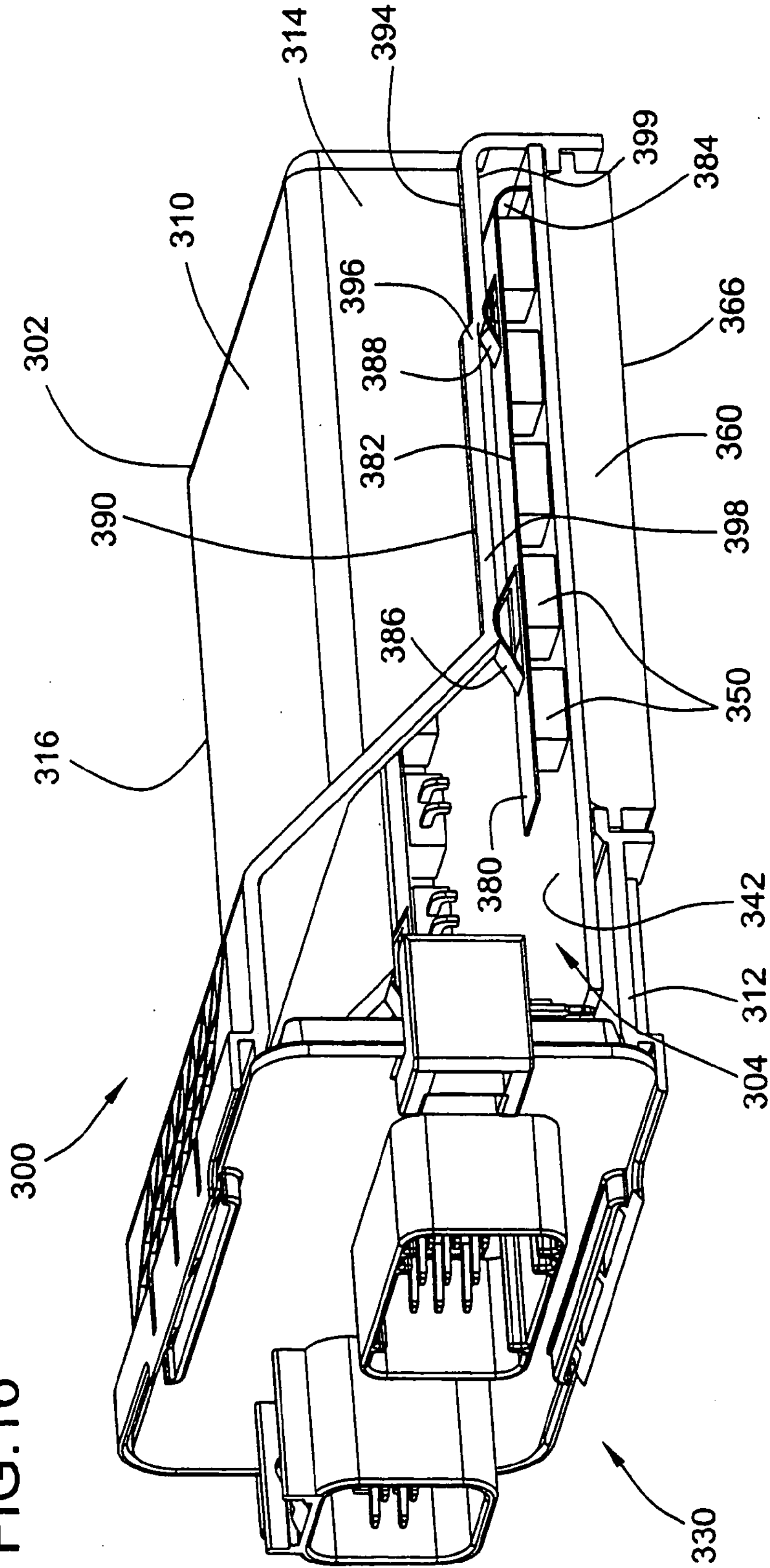
FIG.16
300
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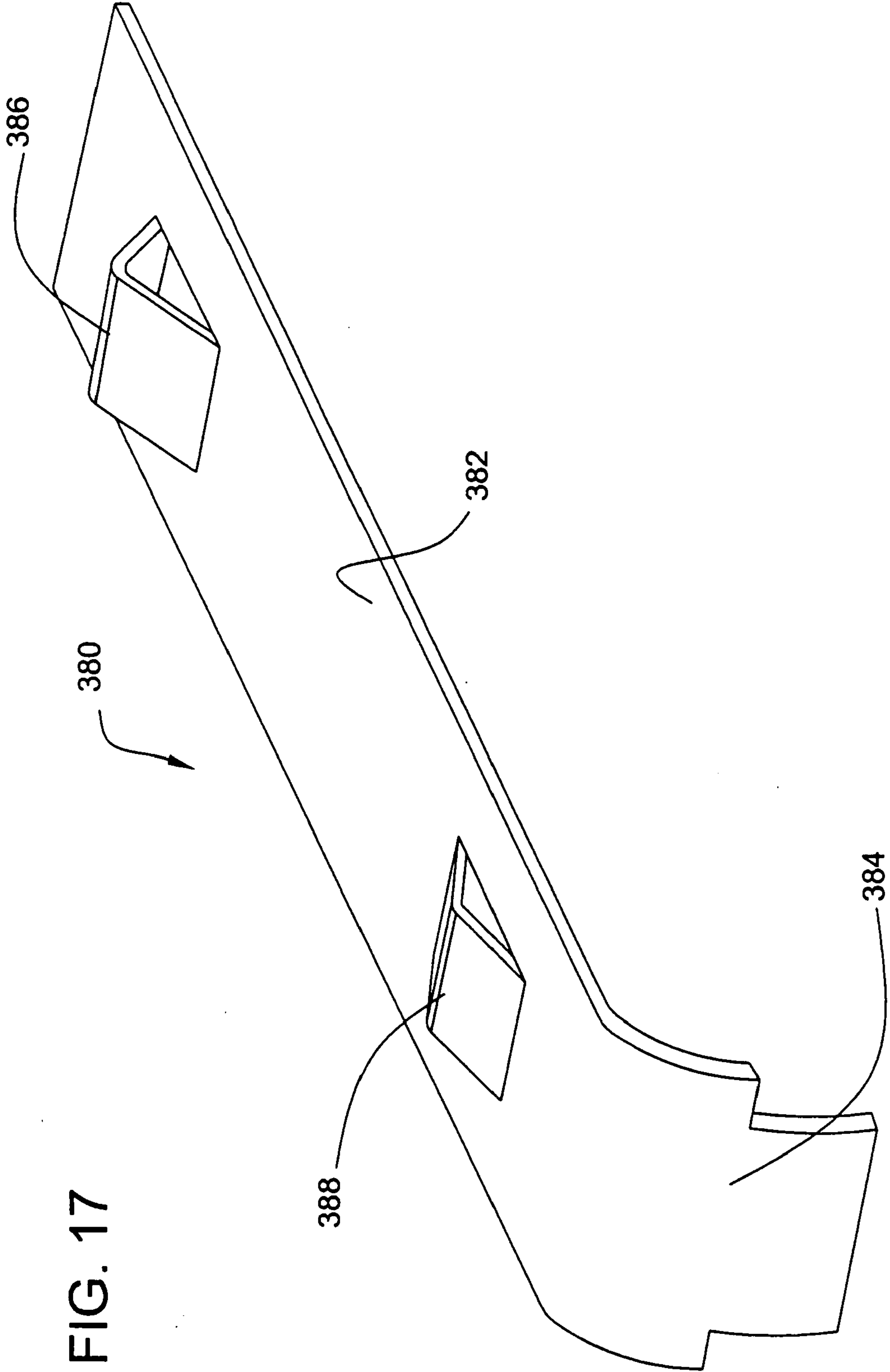

FIG. 17

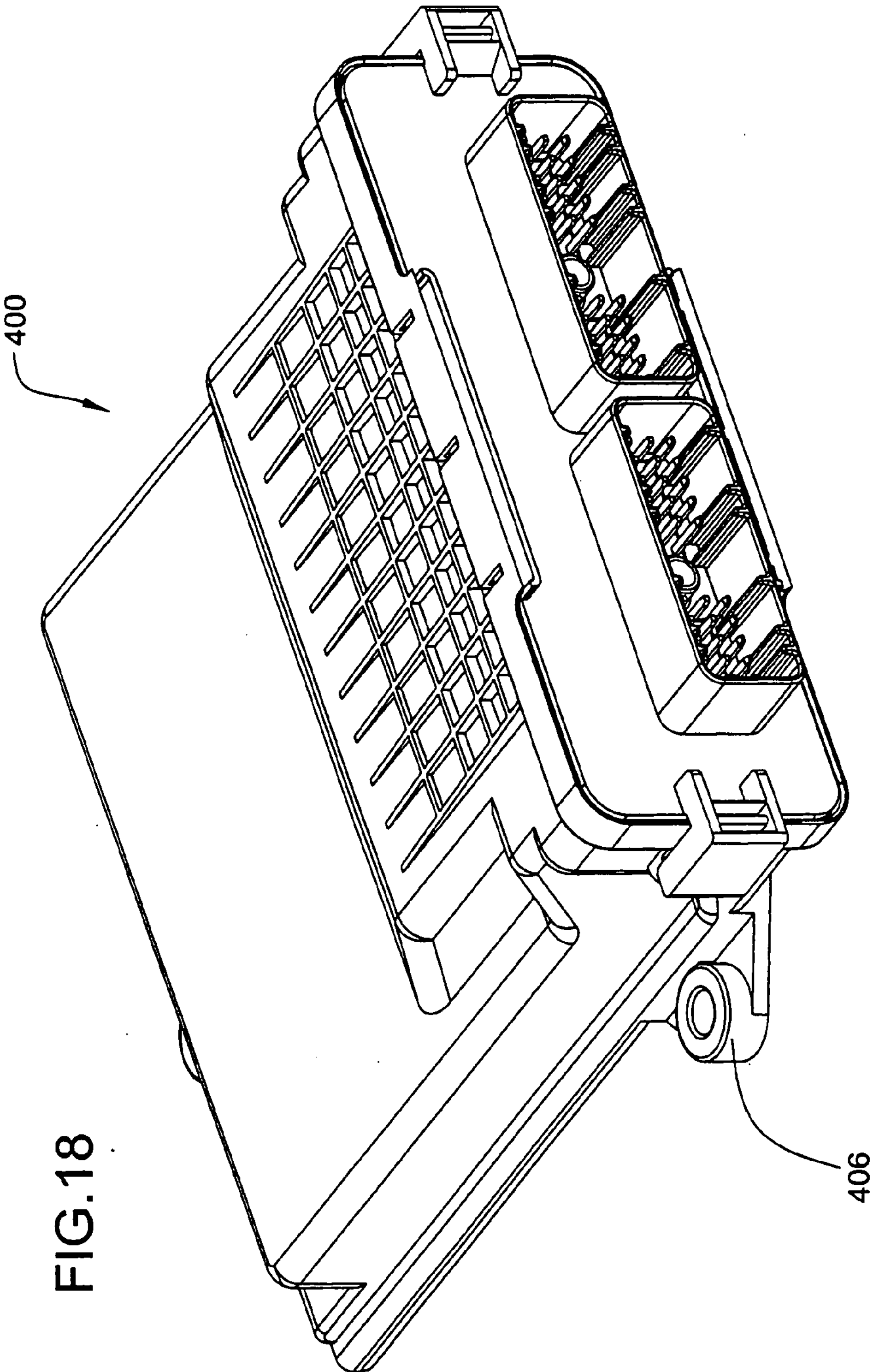

FIG.18

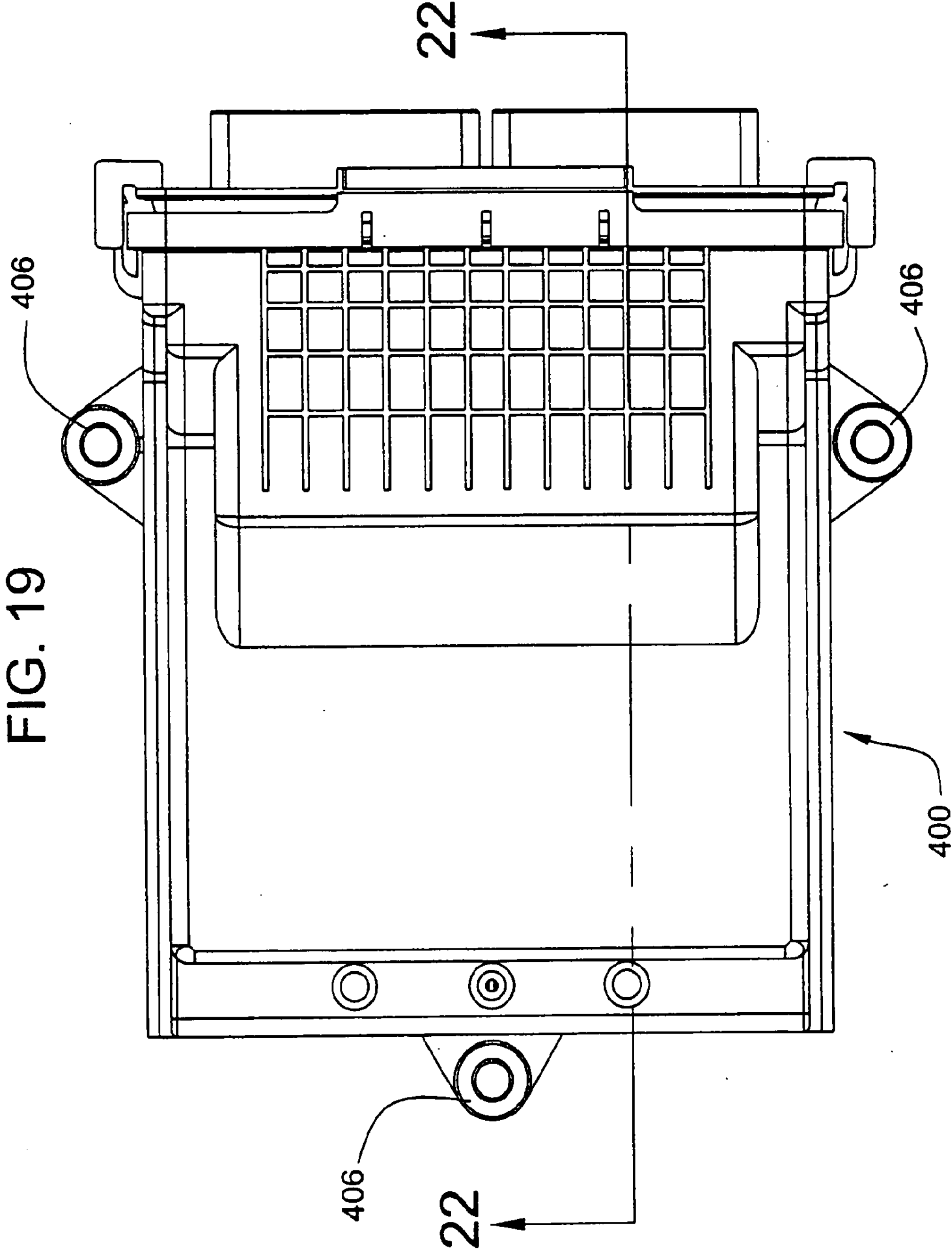

FIG. 19

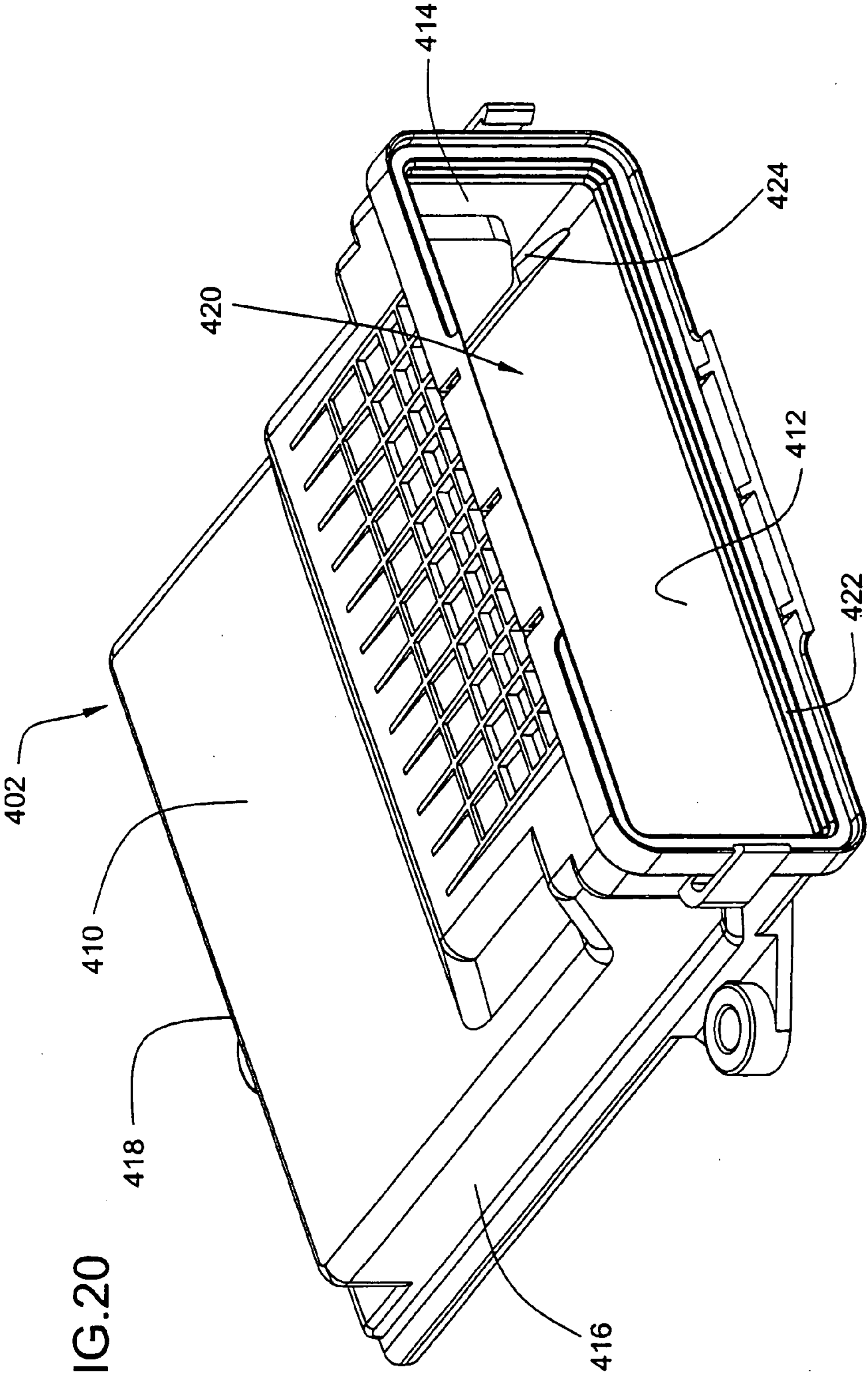

FIG.20

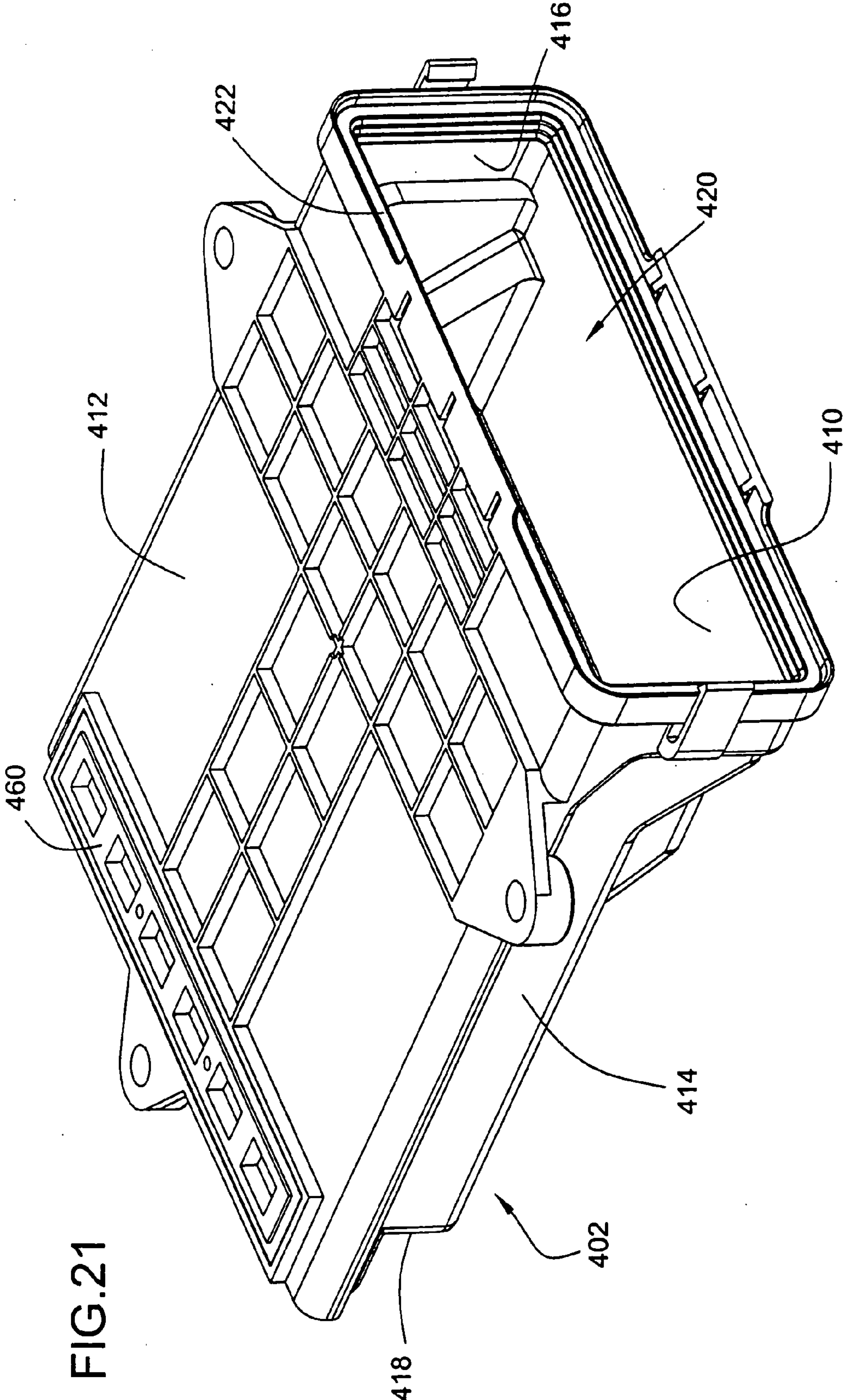

FIG.21

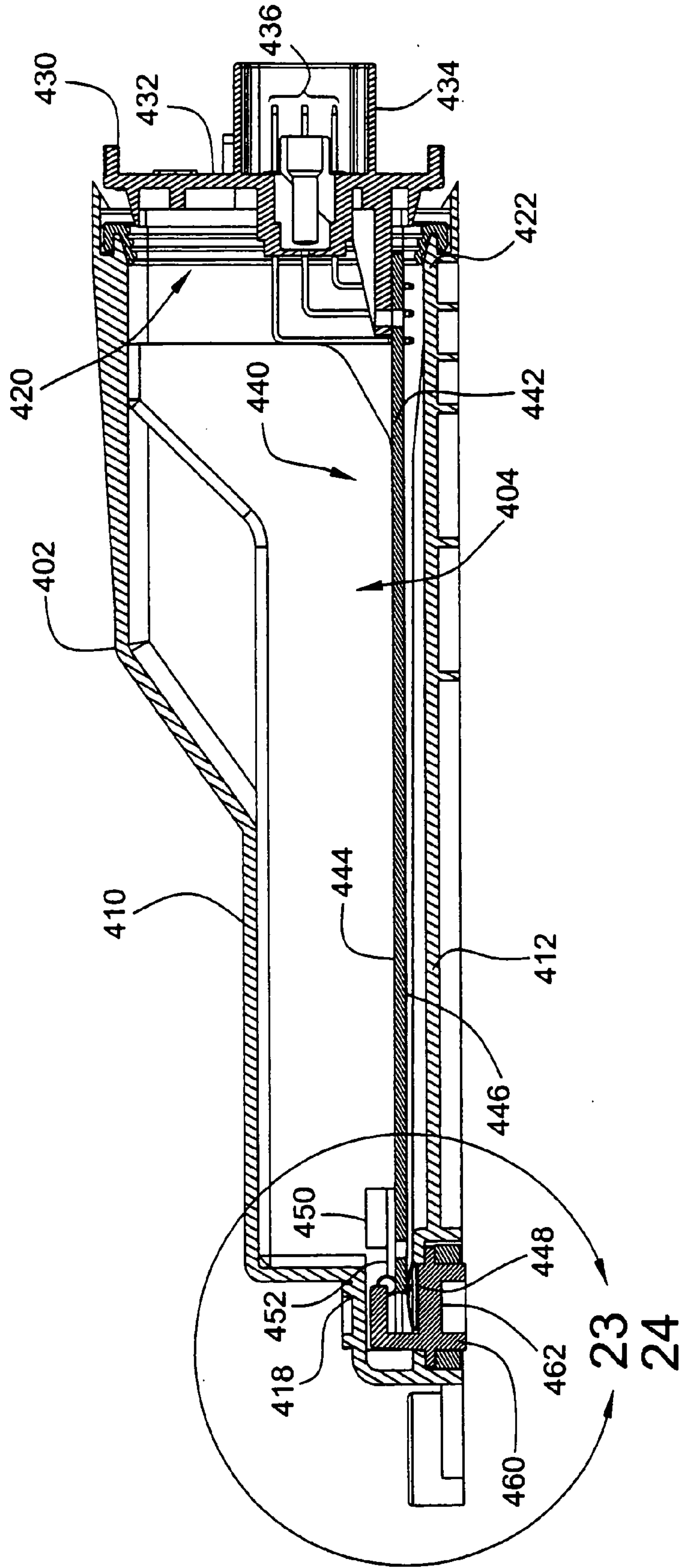
FIG. 22
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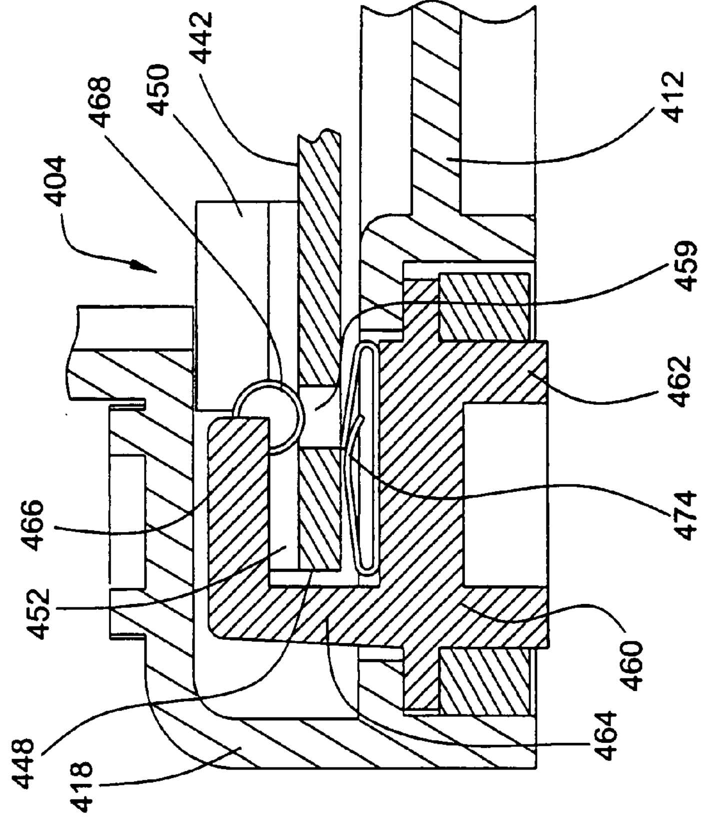
FIG. 24
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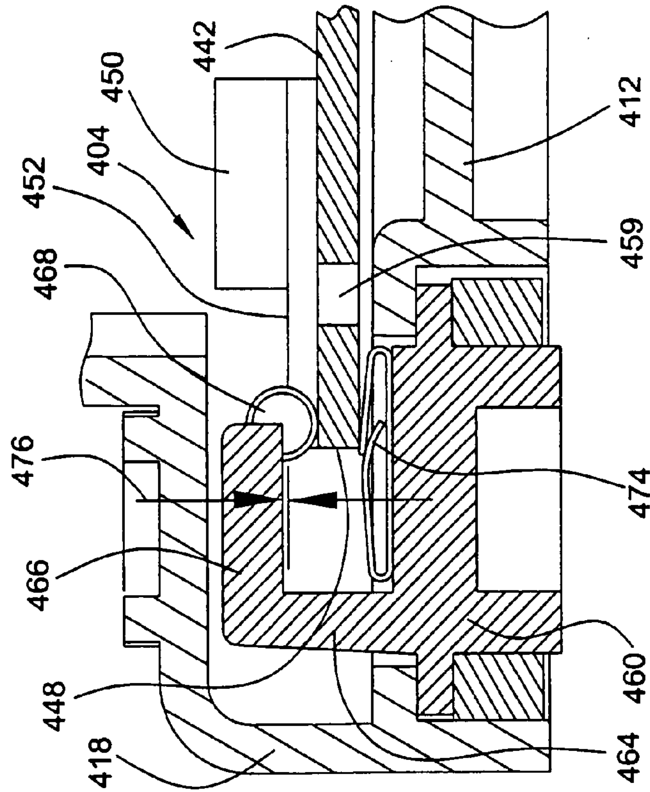
FIG. 23
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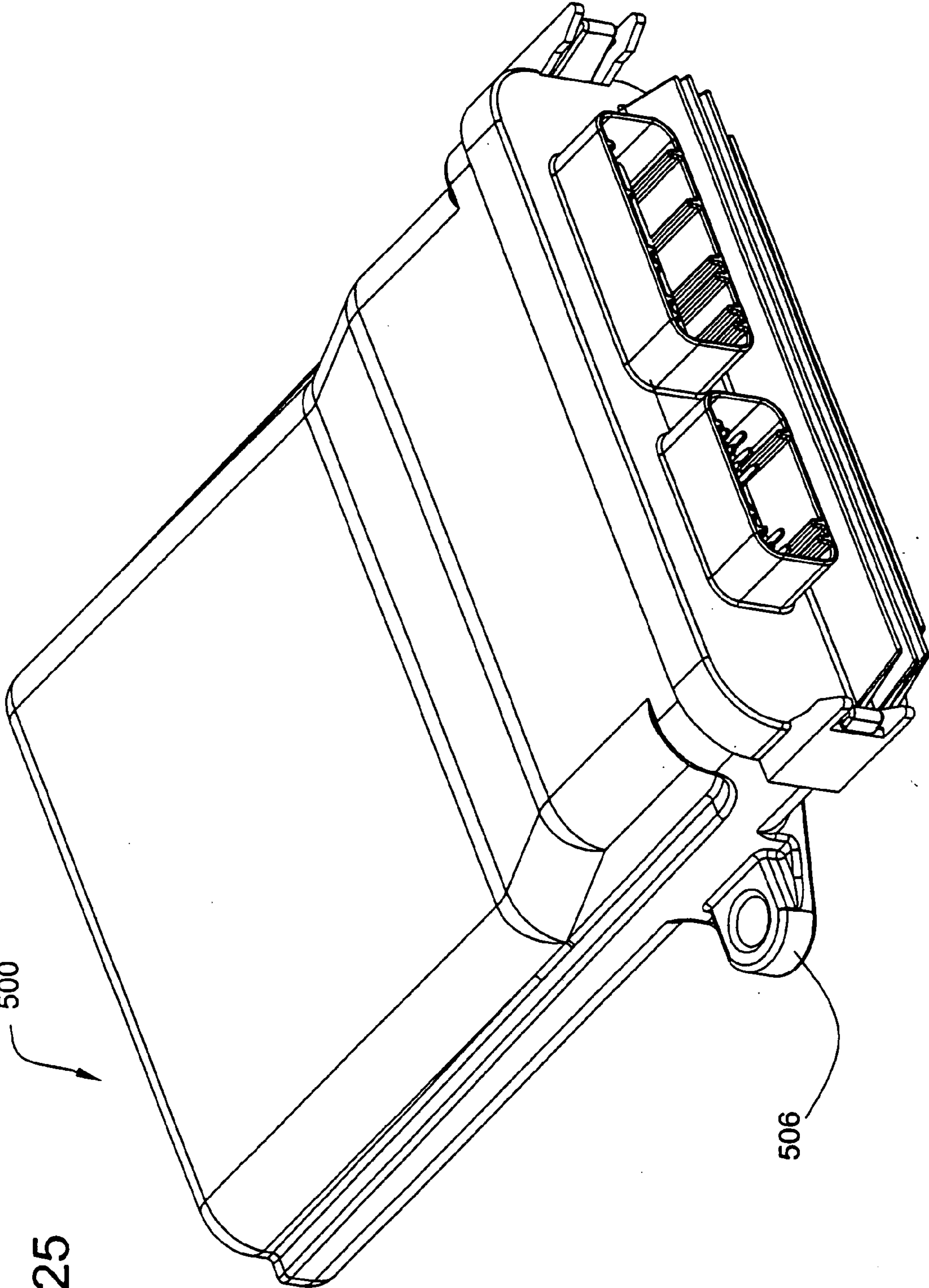

FIG.25

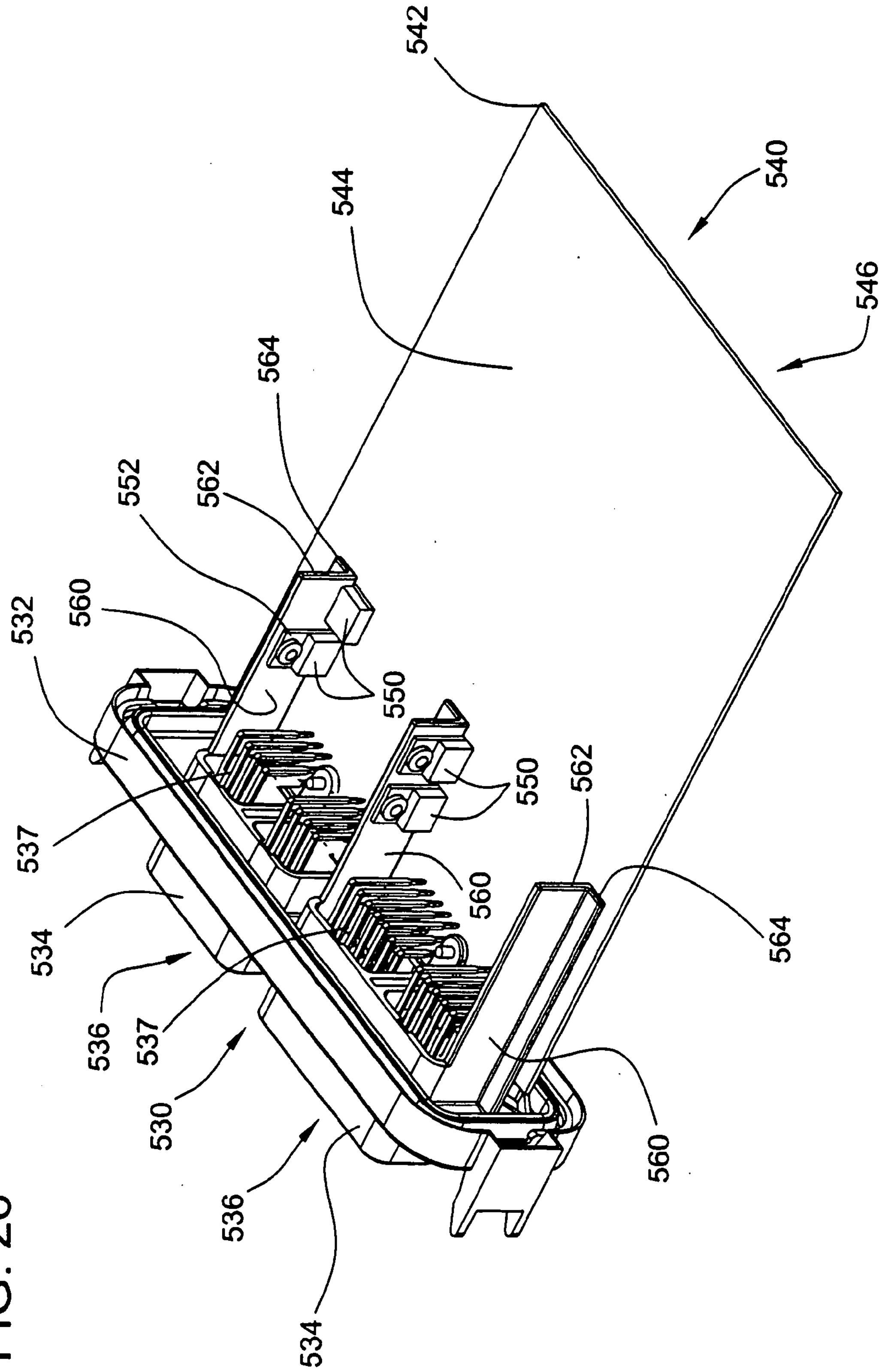

FIG. 26
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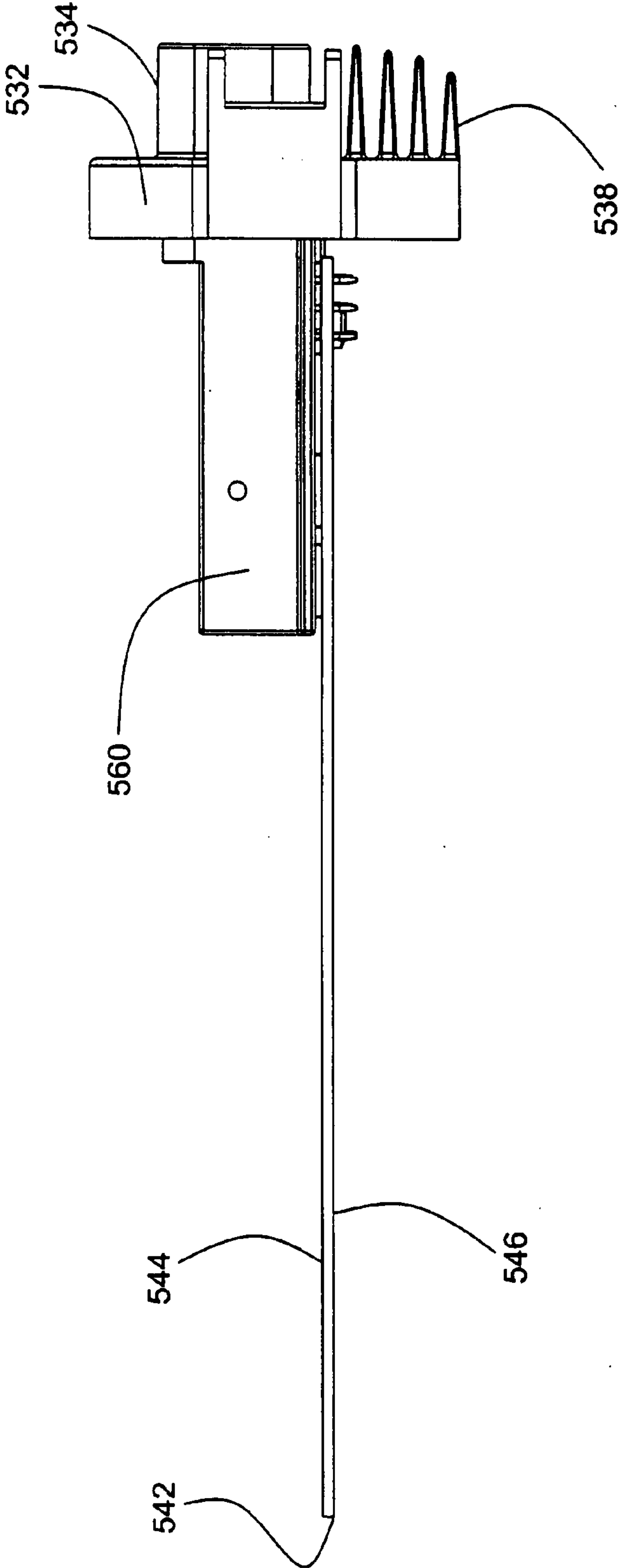

FIG. 27

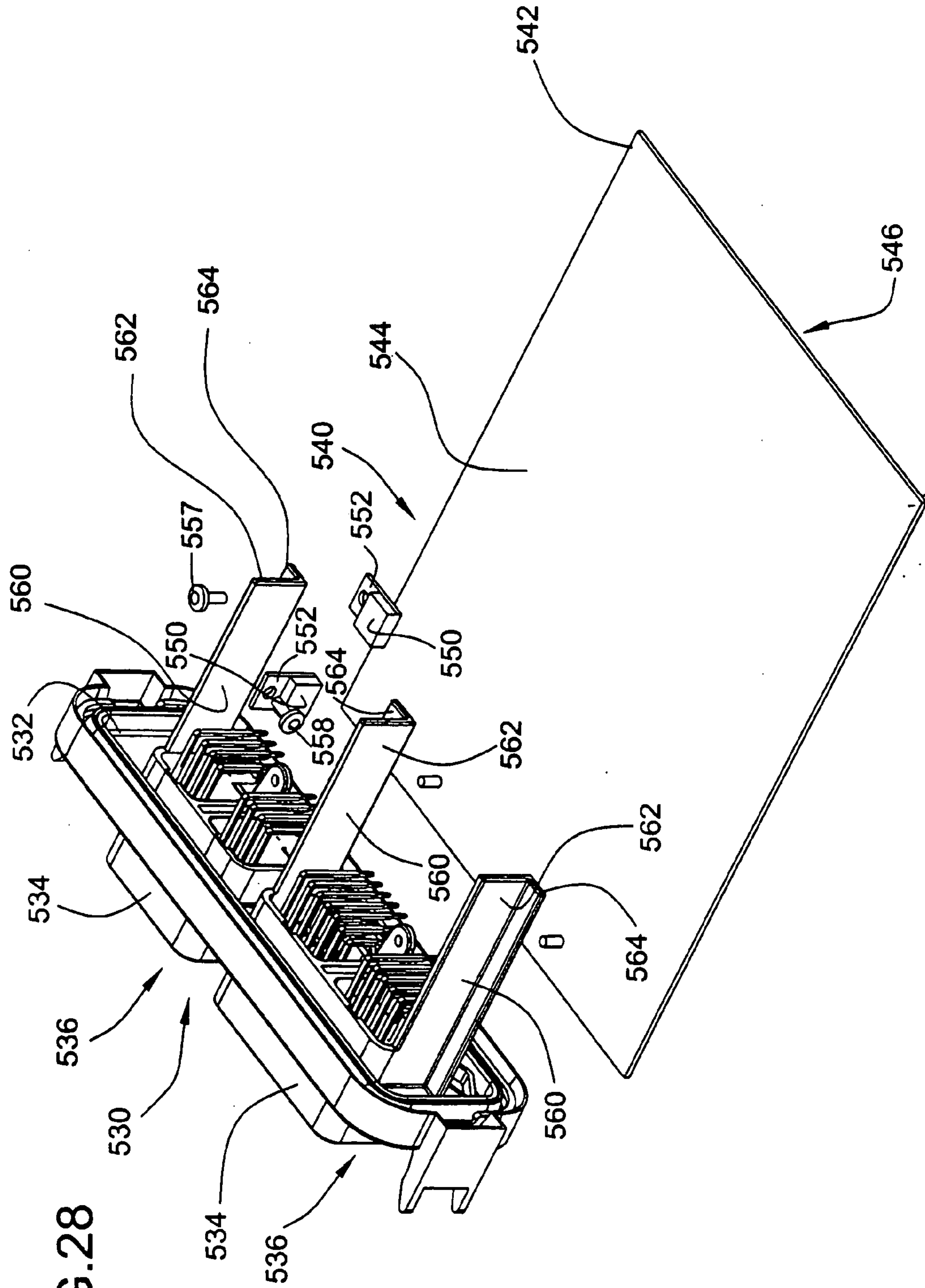

FIG.28

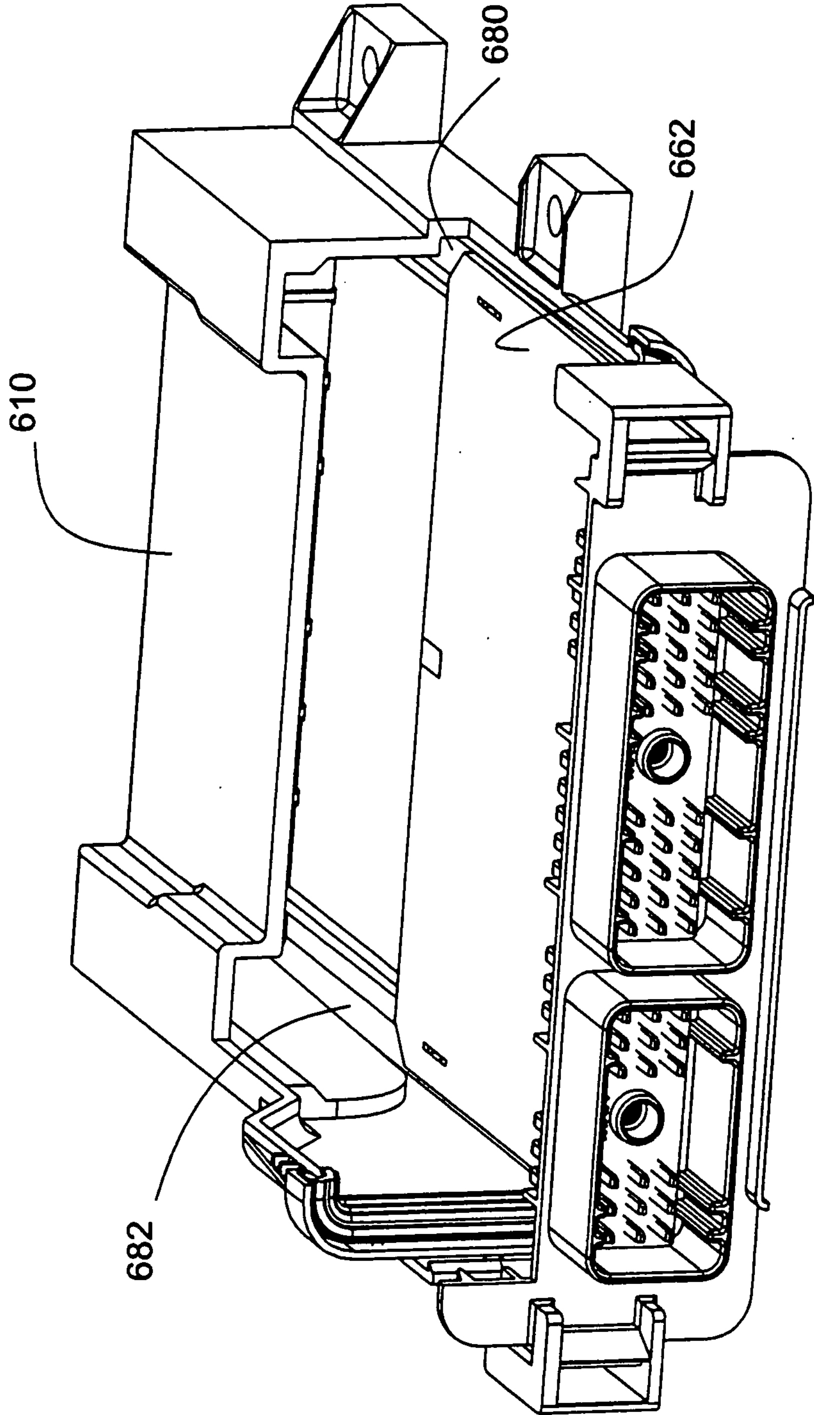

FIG.29

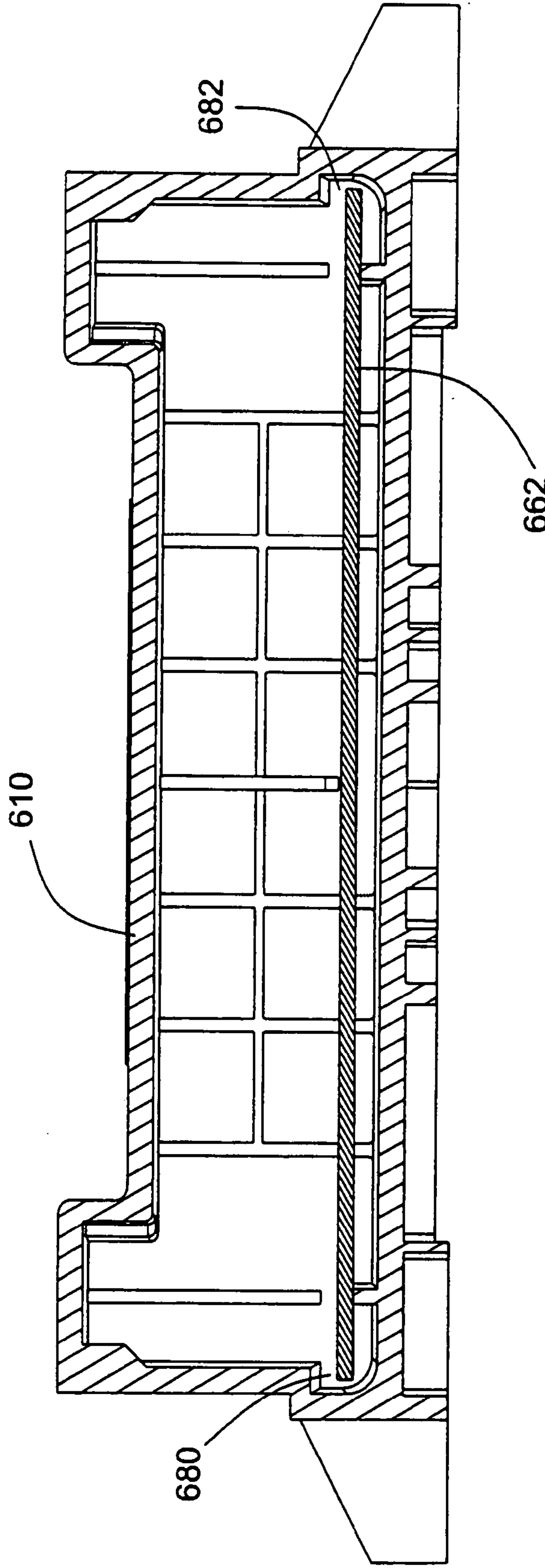
FIG.30
682
662
610
680

ELECTRONIC CONTROL ENCLOSURE

FIELD OF THE INVENTION

[0001] This invention pertains generally to electronic control units and more particularly to an electronic control enclosure for housing the electronic components of an electronic control unit and that is configured to dissipate heat from within the enclosure.

BACKGROUND OF THE INVENTION

[0002] Electronic control units are typically used in various applications to control electronic or electrical devices and, accordingly, are made of many electronic components. Often, the electronic components are mounted to a printed circuit board to both establish electrical communication between the components and to keep the components in a tightly grouped assembly. To protect the electronic components from damage due to impact with external objects and to simplify distribution and attachment of the electronic control unit, the components are also often housed in a protective enclosure housing.

[0003] In some applications, the electronic control unit is required to be placed in a particularly harsh environment. For instance, the electronic control unit may be placed in or on an automobile or similar transportation mechanism to control, for example, the timing and operation of the engine. Such applications may expose the electronic control unit to airborne dirt and grime that, if allowed to enter the enclosure housing, could damage the electronic components. Therefore, it is often desirable that the enclosure housing be environmentally sealed. However, because the electronic components located in the enclosure housing typically generate heat energy during operation that could potentially damage the components, measures must be taken to cool the components.

BRIEF SUMMARY OF THE INVENTION

[0004] The invention provides an electronic control enclosure for protectively housing and removing heat energy from the components of an electronic control unit. The electronic control enclosure includes an enclosure housing that defines an interior chamber in which the electrical components can be protectively placed. To establish electrical communication between the electrical components and one or more external electrical sources, the electronic control enclosure also includes a header assembly and a substrate assembly. The header assembly includes a front plate into which receptacles are formed that can receive electrical cables and plugs from the external sources. Attached to the header assembly is a substrate of the substrate assembly that has conductive traces formed thereon. Mounted to the substrate in an integrated fashion are various elements that make up the electronic control unit. Among these elements are electronic components that, because they generate heat energy during their operation, include exposed heat transfer surfaces for dissipating the heat energy. An example of such electronic components are discrete transistors such as MOSFET devices.

[0005] To remove the generated heat from the electronic components, in one aspect of the invention, the electronic control unit includes a heat sink having both an interior surface exposed to the interior chamber and an exterior surface exposed at the exterior of the enclosure housing. The heat sink can be disposed through the enclosure housing. In other embodiments, the enclosure housing may be made of a heat conductive material, such as metal, and the heat sink is integral with the enclosure housing. When the header assembly is inserted into the interior chamber, the electronic components mounted to the substrate align along the heat sink. To ensure that heat energy is adequately transferred from the electronic components to the heat sink and thereby removed from the interior chamber to the exterior surface, a spring is located within the interior chamber that urges the heat transfer surfaces toward the interior surfaces.

[0006] In another aspect of the invention, the heat sink can be formed as part of the header assembly. The electronic components are mounted to or otherwise in direct contact with the heat sink. The substrate, with its electrical traces, is also attached to the header assembly and electrical communication is established between the electronic components and the substrate. Once the header assembly is inserted into the interior chamber, heat generated from the electronic components is transferred via the heat sinks to the exposed portions of the header assembly where the heat energy is dissipated to the exterior environment.

[0007] An advantage of the invention is that it provides an electronic control enclosure for protectively enclosing the electronic components of an electronic control unit. Another advantage is that the invention removes heat energy generated by the electronic components and transfers that heat energy to the exterior of the electronic control enclosure. Another advantage is that the invention is configured to improve the transfer of heat energy between an exposed heat transfer surface of the electronic components and a heat sink. These and other advantages and features of the invention will become apparent from the foregoing detailed description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** is a top perspective view of an electronic control enclosure for protectively housing the electronic components of an electronic control unit, including two plugged-in cables.

[0009] FIG. **2** is a bottom perspective view of the electronic control enclosure of FIG. **1**, illustrating the exterior surfaces of two heat sinks for transferring heat from an interior chamber.

[0010] FIG. **3** is a top plan view of the electronic control enclosure of claim **1**.

[0011] FIG. **4** is an exploded view of the electronic control enclosure of claim **1**, illustrating the parts of the control enclosure including the electronic components.

[0012] FIG. **5** is a cross-sectional view taken along line **5**-**5** of FIG. **3** illustrating a header assembly environmentally sealing an enclosure housing.

[0013] FIG. **6** is a perspective view of the electronic control enclosure of FIG. **1**, illustrating the header assembly and an attached substrate assembly being inserted into the enclosure housing.

[0014] FIG. **7** is a perspective view of a spring plate for urging the electronic components against heat sinks in the electronic control enclosure of FIG. **1**.

[0015] FIG. **8** is a cross-sectional view of the electronic control enclosure taken along line **8-8** of FIG. **3**.

[0016] FIG. **9** is a top perspective view of the electronic control enclosure with the top wall removed and the header assembly and substrate assembly substantially inserted to a pre-load position.

[0017] FIG. **10** is a top perspective view of the electronic control enclosure with the top wall removed and the header assembly and substrate assembly fully inserted to a loaded position.

[0018] FIG. **11** is a top plan view of another embodiment of an electronic control enclosure for protectively housing the electronic components of an electronic control unit.

[0019] FIG. **12** is a top perspective view of the electronic control enclosure of FIG. **11**, illustrating a header assembly and a substrate assembly being inserted into an enclosure housing.

[0020] FIG. **13** is a cross-sectional view taken along line **13-13** of FIG. **11** illustrating the header assembly and substrate assembly inserted into the enclosure housing.

[0021] FIG. **14** is a cross-sectional view taken along line **14-14** of FIG. **11** with the header assembly and substrate assembly inserted into the enclosure housing.

[0022] FIG. **15** is a first side perspective view of the electronic control enclosure with the side removed to illustrate the header assembly and substrate assembly as substantially inserted to a pre-load position.

[0023] FIG. **16** is a first side perspective view of the electronic control enclosure with the side removed to illustrate the header assembly and substrate assembly as fully inserted to a loaded position.

[0024] FIG. **17** is a perspective view of a spring plate for urging electronic components toward heat sinks in the electronic control enclosure of FIG. **11**.

[0025] FIG. **18** is a front perspective view of another embodiment of an electronic control enclosure for protectively housing the electronic components of an electronic control unit.

[0026] FIG. **19** is a top plan view of the electronic control enclosure of FIG. **18**.

[0027] FIG. **20** is a top perspective view of an enclosure housing defining an interior chamber for receiving the electronic components of the electronic control enclosure of FIG. **18**.

[0028] FIG. **21** is a bottom perspective view of the enclosure housing illustrated in FIG. **20**.

[0029] FIG. **22** is a cross-sectional view taken along line **22-22** of FIG. **19** illustrating a header assembly and a substrate assembly inserted into the enclosure housing.

[0030] FIG. **23** is a detailed view of the indicated area of FIG. **22** illustrating the substrate assembly as substantially inserted in the enclosure housing to a pre-load position.

[0031] FIG. **24** is a detailed view of the indicated area of FIG. **22** illustrating the substrate assembly as fully inserted in the enclosure housing to a loaded position.

[0032] FIG. **25** is a top perspective view of another embodiment of an electronic control enclosure for protectively housing the electronic components of an electronic control unit.

[0033] FIG. **26** is a rear perspective view of a header assembly and a substrate assembly for the electronic control enclosure of FIG. **25**.

[0034] FIG. **27** is a side elevational view of the header assembly and substrate assembly of FIG. **26**.

[0035] FIG. **28** is an exploded view of the header assembly and substrate assembly of FIG. **26**.

[0036] FIG. **29** is a perspective view of another embodiment.

[0037] FIG. **30** is a cross-sectional view of the embodiment shown in FIG. **29**.

DETAILED DESCRIPTION OF THE INVENTION

[0038] Now referring to the drawings, wherein like reference numbers refer to like elements, there is illustrated in FIGS. **1**, **2** and **3** the exterior of an embodiment of an electronic control enclosure **100** for an electronic control unit designed in accordance with the teachings of the invention. The electronic control unit can be used to control externally situated electrical devices. The electrical elements and components making up the electronic control unit are located in the interior of the electronic control enclosure **100**, where they are protected from the exterior environment. To establish communication between the internal elements and components and the externally situated electrical devices, one or more electrical cables **102** that terminate in plugs **103** are plugged into the electronic control enclosure **100**.

[0039] The electronic control enclosure **100** can be secured to a panel **104** situated proximate to the external electrical devices with one or more fasteners **106**, though, in other embodiments, the electronic control enclosure can be secured by other appropriate securing methods. Referring to FIGS. **1**, **2**, and **3**, the electronic control enclosure **100** preferably has a generally overall rectangular shape with a low profile so that the electronic control unit will not interfere with other devices situated the surrounding environment. Because the elements and components making up the electronic control unit are protectively housed in the electronic control enclosure **100**, the electronic control unit can be secured within harsh or dirty environments, such as the engine compartment of an automobile.

[0040] Illustrated in FIG. **4** are the various parts that make up the electronic control enclosure **100**. To define an interior chamber **112** for the electronic components, an enclosure housing **110** is provided. The enclosure housing **110** has a top wall **114**, an opposing bottom wall **116**, and first and second sidewalls **118**, **119** that extend between the top and bottom walls **114**, **116**. The top, bottom, and sidewalls are integrally joined and arranged generally orthogonally with each other to produce the rectangular shape of the electronic control enclosure. To enclose the interior chamber **112**, a rear wall **120** extends adjacent to and is likewise integrally joined with the top, bottom, and sidewalls. As will be appreciated, the terms "top,""bottom,""side," and "rear" are

exemplary only and are not intended to limit the orientation of the enclosure housing or the electronic control enclosure in any way.

[0041] The enclosure housing can be made from any suitable material such as, for instance, molded plastic that preferably demonstrates corrosion resistant properties. To shield the components of the electronic control unit that are housed in the interior chamber from electrical-magnetic interference, the inner surfaces of the top, bottom, side, and rear walls can be coated with an EMI shielding material. In other embodiments, the enclosure housing can be made from a metallic material.

[0042] To access the interior chamber, the portion of the enclosure housing **110** opposite the rear wall **120** is formed as an opening **126**. The opening **126** is defined by a rectangular rim **128** that is formed by the forward-most edges of the top, bottom, and sidewalls **114**, **116**, **118**, **119**. Extending from either sidewall **118**, **119** and projecting forward of the rim **128** are cantilevered latch arms **130** that terminate in inclined barbs **132**. To secure the electronic enclosure housing to the panel, there is projecting from either sidewall **118**, **119** proximate to the bottom wall **116** one or more mounting feet **134** through which the fasteners **106** can be inserted.

[0043] To enclose the opening **126** while establishing electronic communication with the interior chamber **112**, the electric control enclosure also includes a header assembly **140**. The header assembly **140** has a generally planar front plate **142** that is sized to be received in the opening **126** and constrained within the rim **128**. One or more electrical terminals **144** extend through the front plate **142** and are retained by the front plate in a predetermined arrangement. To protect the external portions of the terminals **144** from damage and to appropriately align the plugs **103** with the arranged terminals, there extend from the front plate **142** one or more receptacle walls **146** that surround the terminals.

[0044] The front plate **142** and receptacle walls **146** can be manufactured from any suitable material, such as plastic, cast aluminum or magnesium. To fasten the header assembly **140** to the enclosure housing **110**, there are extending from either side of the front plate **142** latch catches **148**. When the front plate **142** is aligned with the rim **128** that defines the opening **126**, the latch catches **148** likewise align with the latch arms **130**. Referring to FIGS. **2** and **4**, as the header assembly **140** and enclosure housing **110** are moved together, the cantilevered latch arms **130** are received in and extend through slots **150** defined by the latch catches **148**. The latch catches **148** and the inclined barbs **132** at the end of the latch arms **130** are configured to initially deflect the cantilevered latch arms outward from the sidewalls **118**, **119**. However, once the front plate **142** is constrained within the rim **128**, it will be appreciated that the inclined barbs **132** extend around and hook onto the latch catches **148**, thereby retaining the header assembly and enclosure housing together. It will be appreciated that by using the appropriate tools, the inclined barbs **132** can be unhooked from the latch catches **148** to remove the header assembly from the enclosure housing. It will further be appreciated that in other embodiments, the latch arms can be included on the front plate and the latch catches can be included on the enclosure housing.

[0045] To environmentally seal the interior chamber **112** when the header assembly and enclosure housing are retained together, referring to FIG. **5**, a peripheral seal **152** is included between the front plate **142** and rim **128**. The peripheral seal **152** can be made from any suitable material, such as a natural or elastomeric rubber. To facilitate the setting and engagement of the peripheral seal **152**, the rim **128** is formed with a seating surface **154** that may invertedly slope rearward into the interior chamber **112**. The seal **152** may have a C-shaped cross-section which includes a center portion **153**, an inner leg **155** and an outer leg **157**. The seal **152** may include protrusions **158** and/or recesses **159** which assist in creating a seal between the housing and the front plate. The peripheral seal may be placed against the rim of the enclosure housing before the front plate and the enclosure housing are retained together. The seal **152** fits over the seating surface **154** and the inner rim of the housing. The front plate **142** includes a complementary boss **156** projecting from the side of the front plate opposite the receptacle walls **146**. The boss **156** may slope rearward into the interior chamber **112**. As will be appreciated, when the front plate **142** is set within the rim **128**, the peripheral seal **152** is compressed between the boss **156** and the seating surface **154**. Because the interior chamber is environmentally sealed, dirt and grime from the exterior environment cannot enter the enclosure housing.

[0046] Referring to FIG. **4**, to mount and interconnect the various electronic components of the electronic control unit, the electronic control enclosure includes a substrate assembly **160**. The substrate assembly **160** is arranged around a substrate **162**, such as a printed circuit board, on which electrically conductive circuit traces are formed. The substrate **162** has a generally planar shape with opposing first and second surfaces **168**, **169**. The substrate **162** can be rigidly attached to the header assembly **140** so as to extend rearwardly from the lower edge of the front plate **142**.

[0047] As illustrated in FIGS. **4** and **5**, to establish electrical communication between the cables from the external devices and the substrate assembly **162**, the terminals **144** include terminal leads **161** on the rear side of the front plate **142** that are formed with right angles directing the terminals toward the substrate. The terminal leads **161** are soldered to and make electrical contact with the conductive circuit traces on the substrate **162**. To prevent cross-talk or inductive interference between the terminals **144**, in an embodiment, the header assembly **140** can also include an inductive ferrite filter block through which the terminal leads **161** pass. As will be appreciated by those of skill in the art, the filter block physically separates the terminals leads while it simultaneously shields the terminals from electromagnetic and inductive interference.

[0048] The electronic components that make up the electronic control unit are mounted to the substrate **162** so that the electronic components are in electrical communication with the conductive circuit traces. A typical electronic component included in the electronic control unit is a discrete transistor that, as is familiar to those of skill in the electronics arts, functions as an electrical switch. One type of transistor particularly well-suited for the electronic control unit is a metal-oxide semiconductor field effect transistor (MOSFET). The MOSFET includes one or more leads, such as a gate, source, or drain lead, that are soldered to lead holes disposed into the substrate **162**. Referring to FIG. **4**, because such MOSFET devices **164** generate heat energy during their operation that, if not removed, could adversely effect

and possibly damage the MOSFET device, the MOSFET device may be provided with an exposed heat transfer surface **166** made of a thermally conductive material.

[**0049**] Referring to FIG. **6**, in the illustrated embodiment, the MOSFET devices **164** project upright from the first surface **168** and are arranged in two rows **170**, **171** extending from approximately near the front plate **142** rearward. The rows **170**, **171** are aligned along a first and second side-edge **172**, **174** of the substrate **162** such that the heat transfer surfaces **166** are directed outward. Within the rows **170**, **171**, the MOSFET devices **164** are generally spaced-apart from each other.

[**0050**] Also included as part of the substrate assembly **160**, as illustrated in FIGS. **4** and **6**, are one or more spring plates **178** that are mounted to the substrate **162**. Referring to FIG. **7**, the spring plate **178** is a generally planar, elongated structure that can be made from any suitable material, such as stamped sheet metal. To keep the MOSFET devices spaced-apart, the spring plate **178** includes multiple spacer elements **180** that extend along the length of the spring plate. The width of the spacer elements **180** is approximately equal to the distance the MOSFET devices are spaced-apart, while the distance between the spacer elements is approximately equal to the width of a MOSFET device. Located between the spacer elements **180** and designed to individually contact the MOSFET devices are a plurality of engagement elements **182** that are also formed into the spring plate **178**.

[**0051**] As illustrated in FIG. **6**, when mounted to the substrate **162**, the spring plates **178** extend along the rows **170**, **171** of MOSFET devices **164** with the spacer elements and holder elements appropriately engaging the MOSFET devices. Referring to FIG. **7**, to mount the spring plate **178** to the substrate **162**, one or more attachment prongs **184** extend from the spring plate **178** that can be received within complementary slots disposed into the substrate. One of the attachment prongs **184** can also include a locking prong **186** for locking the spring plate **178** in an upright position on the substrate **162**.

[**0052**] As illustrated in FIG. **6**, to place the MOSFET devices **164** in the interior chamber **112** so that they are protectively enclosed within the enclosure housing **110**, the substrate assembly **160** is inserted through the opening **112** toward the rear wall **120** until the front plate **142** engages against the rim **128**. The housing **110** may include raised surfaces or rails **187**, **189** to support the substrate **162** as shown in FIGS. **5**, **6** and **8**. Referring to FIG. **8**, once inserted into the interior chamber **112**, the substrate **162** extends orthogonally between the first and second sidewalls **118**, **119** with the first surface **168** opposing and spaced-apart from the top wall **114** and the second surface **169** opposing the bottom wall **116**. Because of the sealing engagement between the header assembly and the opening, the electronic components **164** are all environmentally sealed within the interior chamber **112**.

[**0053**] Attaching the peripheral seal to the rim prior to engaging the front plate with the enclosure housing, as described above, facilities assembly of the substrate assembly by enabling reflow or wave soldering. Specifically, as will be appreciated by those of skill in the art, the terminal leads from the header assembly and the electronic components are mounted to the circuit traces on the substrate. The header assembly and substrate assembly may then be subjected to the reflow or wave soldering operation that permanently mounts the terminal leads and electrical components to the substrate in such a manner as to establish electrical communication between the various parts. Because the peripheral seal is safely mounted on the enclosure housing which does not undergo the soldering process, the peripheral seal will remain undamaged.

[**0054**] To remove heat energy from the electronic components and thereby prevent overheating of the sealed interior chamber, in accordance with an aspect of the invention, the enclosure housing includes one or more heat sinks. In the embodiments where the enclosure housing is plastic, the heat sinks may be disposed through the enclosure housing. In the embodiments with the plastic housings, the heat sinks are made from an appropriate, thermally-conductive material such as aluminum, magnesium, zinc, or alloys thereof, or a heat conductive plastic and are arranged in the enclosure housing so as to conduct heat energy from the interior chamber to the exterior environment. In the embodiments where the enclosure housing is heat conductive material, such as metal, the heat sinks may be integral with the enclosure housing. The heat conductive material may be aluminum, magnesium, zinc, or alloys thereof, or a heat conductive plastic.

[**0055**] Referring to FIG. **8**, there is illustrated a first and a second heat sink **190**, **192** that are disposed through the bottom wall **116** and therefore are partially located within the interior chamber **112**. Accordingly, the heat sinks **190**, **192** each include an interior surface **196** that is exposed within the interior chamber **112** and an exterior surface **198** that is exposed along the exterior of the bottom wall **116**, as illustrated in FIGS. **2** and **8**. Referring to FIGS. **8**, **9**, and **10**, the elongated first and second heat sinks **190**, **192** extend along the height of first and second sidewalls **118**, **119** such that the interior surfaces **196** oppose each other across the substrate **162**. To accommodate and retain the heat sinks **190**, **192**, slots can be formed through the bottom wall **120** to which the heat sinks are adhered with epoxy.

[**0056**] Referring to FIGS. **6** and **8**, due to the arrangement of the MOSFET devices **164** along the first and second edges **172**, **174** of the substrate **162**, when the substrate assembly is inserted into the interior chamber **112**, the rows **170**, **171** of MOSFET devices align with the elongated heat sinks **190**, **192**. Moreover, the exposed heat transfer surfaces **166** of the MOSFET devices oppose and are adjacent to the interior surfaces **196** of the heat sinks **190**, **192**. Heat energy generated by the MOSFET devices **164** is thereby conducted from the heat transfer surfaces **166** through the heat sinks **190**, **192** to the exterior surfaces **198**.

[**0057**] To ensure that the thermal energy is adequately transferred from the electronic components **164** to the heat sinks **190**, **192**, in accordance with another aspect of the invention, the spring plates **178** can urge the MOSFET devices **164** toward the interior surfaces **196**. To make the spring plates **178** urge the MOSFET devices **164**, referring to FIGS. **8**, **9**, and **10**, the enclosure housing **110** includes an embossment **200** projecting into the interior chamber **112**. In the illustrated embodiment, the embossment **200** projects from the top wall **114** towards the bottom wall **116** and can be formed when the enclosure housing is molded. The embossment **200** includes a first edge **202** that is oriented

toward and spaced-apart from the first sidewall **118** and further includes a second edge **204** that is oriented toward and spaced-apart from the second sidewall **119**. Furthermore, the first and second edges **202**, **204** extend generally parallel to the first and second sidewalls **118**, **119**.

[**0058**] When the substrate assembly is inserted into the interior chamber, as illustrated in FIG. **8**, the MOSFET devices **164** are located in the spaces between the first and second edges **202**, **204** and the first and second sidewalls **118**, **119**. The embossment **200** contacts the spring plates **178** urging the spring plates toward the respective first and second sidewalls **118**, **119**. Because of the arrangement of the MOSFET devices **164** on the substrate **162**, the heat transfer surfaces **166** are urged against the interior surfaces **196** of the heat sinks **190**, **192** thereby ensuring that the generated heat energy is adequately transferred.

[**0059**] To insert the substrate assembly into the interior chamber **112** without damaging the MOSFET devices **164**, the embossment **200** and spring plates **178** are configured to only engage each other after the substrate assembly is fully inserted to a loaded position. To accomplish this, as illustrated in FIGS. **9** and **10**, the first and second edges **202**, **204** both include a step **206** that divides the first and second edges into first and second edge portions **208**, **210**. The first edge portion **208** is spaced a greater distance from the first and second sidewalls **118**, **119** than the second edge portion **210** is spaced. Moreover, the first edge portion **208** is spaced from the rear wall **120** while the second edge portion **210** is proximate to the rear wall. Additionally, referring to FIG. **7**, the spring plate **178** also includes first and second compression features **212**, **214** that protrude from the spring plate **178**. Moreover, the first compression feature **212** protrudes further from the plane of the spring plate **178** than the second compression feature **214**, with the first compression feature oriented further forward on the spring plate than the second compression feature. The first and second compression features can be formed by displacing a portion of the spring plate through a stamping operation.

[**0060**] Referring to FIG. **9**, it will be appreciated that as the substrate assembly is inserted, the smaller second compression feature **214** is loosely received in the gap between the first edge portion **208** and the respective sidewall. This position is known as the pre-load position, which exists over a substantial range of insertion of the substrate assembly, wherein the embossment and spring plate do not significantly urge the MOSFET devices toward the heat sinks. Accordingly, as will be familiar to those of skill in the art, the electronic control enclosure demonstrates a zero insertion force effect in which no substantial resistance is encountered during insertion of the substrate assembly to the preload position. However, referring to FIG. **10**, as the second compression feature **214** passes over the step **206** and engages the second edge portion **210**, the spring plate **178** is directed toward the respective sidewall and against the MOSFET devices **164**. Additionally, once the substrate assembly is fully inserted, the larger first compression feature **212** engages the first edge portion **208** likewise causing the spring plate **178** to urge the MOSFET devices **164** against the heat sinks **190**, **192**. This is known as the loaded position, wherein once the substrate assembly is fully-inserted, the embossment and spring plate significantly urge the MOSFET devices towards the heat sinks.

[**0061**] Because the MOSFET devices **194** contact the heat sinks **164** after the compression features and edge portions have engaged, destructive sliding of the heat transfer surfaces **166** over the interior surfaces **196** is reduced. The edge portions and compression features can be configured to engage only over the last 0.1 inches of insertion. In an embodiment, to assist in transferring heat energy away from the MOSFET devices, a thermal conducting paste, adhesive, or pad can be placed between the heat transfer surfaces and the interior surfaces. Thermal conducting paste or pads may further reduce the destructive sliding.

[**0062**] In another embodiment, the heat sinks may be removed from the enclosure housing if the heat sinks are not needed. The openings in the housing where the heat sinks would extend through the housing would be covered with housing material. For example, FIGS. **29** and **30** show one embodiment with the heat sinks removed from the embodiment shown in FIGS. **8** and **9**. If desired, the heat sinks may be removed from the other embodiments as appropriate.

[**0063**] In addition, the enclosure housing may include a channel to engage the substrate. Referring to FIGS. **29** and **30**, the housing **610** may include channels **680**, **682** which will engage the substrate **662**. The channels **680**, **682** may assist in preventing the substrate **662** from moving vertically if the housing is subjected to movement.

[**0064**] Illustrated in FIGS. **11** through **16** is another embodiment of the electronic control enclosure **300** for housing the components of an electronic control unit. As illustrated in FIG. **11**, the electronic control enclosure **300** is generally rectangular with a low profile so that the electronic control enclosure will not interfere with other devices situated in the same environment. Referring to FIG. **12**, the electronic control enclosure **300** includes an enclosure housing **302** that defines an interior chamber **304** into which the electronic components can be inserted. The enclosure housing **302** includes a top wall **310**, an opposing bottom wall **312**, and first and second sidewalls **314**, **316** extending between the top and bottom walls. A rear wall **318** extends across and is joined to the rear edges of the top, bottom, and sidewalls to enclose the enclosure housing **302**. The enclosure housing can be made from injection molded plastic. In other embodiments, the enclosure housing may be made from a heat conductive material, such as metal.

[**0065**] To access the interior chamber **304**, the forward portion of the enclosure housing **302** opposite the rear wall **318** is formed as an opening **320**. The opening **320** is defined by a rim **322** made up of the forward-most edges of the top, bottom, and sidewalls **310**, **312**, **314**, **316**. To establish electronic communication with the electronic components inside the enclosure housing **302** while simultaneously enclosing the interior chamber **304**, there is included as part of the electronic control enclosure **300** a header assembly **330**. The header assembly **330** includes a front plate **332** that can be received within the opening **320** so as to environmentally seal the interior chamber **304**. Extending forward from the front plate **332** are one or more receptacle walls **334** in which plugs can be received. To attach the header assembly **330** to the enclosure housing **302**, latch arms **324** and latch catches **336** are provided that function as described above.

[**0066**] To mount and interconnect the various electronic components of the electronic control unit, the electronic

control enclosure **300** includes a substrate assembly **340**. The substrate assembly **340** includes a generally planar substrate **342** having a first surface **344** and an opposing second surface **345** to which electronic components, such as MOSFET devices **350**, can be mounted. In the illustrated embodiment, the MOSFET devices **350** are arranged into two rows **352**, **354**, each extending from the front plate **332** rearward along the first and second side-edges **346**, **347** of the substrate **342**. The MOSFET devices **350** are laid horizontally flat with their heat transfer surfaces **356** adjacent to the substrate **342**. Furthermore, the substrate **342** is rigidly attached to and extends rearward from the front plate **332** of the header assembly **330**.

[0067] To remove heat generated from the MOSFET devices **350**, referring to FIG. **12**, the electronic control enclosure **300** includes a first heat sink **360** and a second heat sink **362**. The first and second heat sinks **360**, **362** may be disposed through the bottom wall **312** so as to generally extend along the respective first and second sidewalls **314**, **316**. In the embodiment illustrated in FIGS. **13**, **14**, **15**, and **16**, the first and second heat sinks **360**, **362** each have an interior surface **364** and an exterior surface **366**. The interior surface **364** is generally parallel to and slightly offset above the bottom wall **312** while the exterior surface **366** is parallel to and offset below the bottom wall. Referring to FIG. **14**, when the substrate assembly is inserted into the interior chamber **304**, the substrate **342** extends between the first and second sidewalls **314**, **316** and overlies the interior surface **364** of the heat sinks **360**, **362**. In other embodiments, the enclosure housing may be made of a heat conductive material, such as metal, and the heat sink is integral with the enclosure housing.

[0068] Referring to FIG. **14**, to transfer the heat energy generated by the MOSFET devices **350** to the heat sinks **360**, **362**, the substrate **342** includes multiple apertures **370** disposed between the first and second surfaces **344**, **345** that align with the heat transfer surfaces **356** of the MOSFET devices. Located in each aperture **370**, so as to contact both the heat transfer surfaces **356** and the interior surface **364**, is a heat conductive element **372**, such as a solder, or other low melting heat transferable materials. Accordingly, the heat conductive elements **372** transfer the heat across the substrate **342**.

[0069] To ensure adequate thermal contact between the MOSFET devices **350** and the heat conducting elements **372**, as illustrated in FIGS. **14**, **15**, and **16**, the electronic control enclosure includes spring plates **380** and embossments **390**, **392** that are capable of engaging each other. Referring to FIG. **17**, the spring plate **380** includes an elongated compression leg **382** that terminates at one end in an attachment foot **384**. The attachment foot **384** curves approximately ninety degrees with respect to the orientation of the compression leg **382**. Protruding from the compression leg **382** are first and second compression features **386**, **388**, the first compression feature protruding a greater distance from the plane of the compression leg than the second compression feature. Additionally, the first compression feature **386** is located further away from the attachment foot **384** than the second compression feature **388**. The spring plate **380** can be made from any suitable material, such as, for example, sheet metal that has been stamped and formed.

[0070] Referring to FIGS. **15** and **16**, the spring plates **380** are mounted to the substrate **342** so that the compression leg **382** extends over the MOSFET devices **350** and the attachment leg **384** is attached to the substrate generally towards the rear of the interior chamber **304**. To engage the spring plates **380**, referring to FIG. **14**, the first and second embossments **390**, **392** extend along the respective first and second sidewalls **314**, **316** projecting from the top wall **310** toward the bottom wall **312**. As illustrated in FIGS. **15** and **16**, the embossments **390**, **392** each include a lower edge **394** that is generally parallel to and spaced-apart from the bottom wall **312** and the substrate **342**. The lower edge **394** furthermore is divided by a step **396** into a first lower edge portion **398** and a second lower edge portion **399**, wherein the first lower edge portion is spaced further apart from the bottom surface **312** than the second lower edge portion.

[0071] As will be appreciated from FIGS. **15** and **16**, when the substrate assembly **330** is inserted into the interior chamber **304**, the substrate **342**, the MOSFET devices **350**, and the spring plate **380** are received in the space between the lower edge **394** and the bottom wall **312**. To avoid damaging the MOSFET devices **350** during insertion, the spring plate **380** and embossments **390**, **392** are configured to only engage each other once the substrate **342** has been fully inserted into a loaded position. Referring to FIG. **15**, as the substrate assembly **330** is initially inserted, the smaller second compression feature **388** is loosely received in the gap between the first lower edge portion **398** and the bottom surface **312**. This position is the pre-load position, which exists over a substantial range of insertion of the substrate assembly, wherein the embossments and spring plates do not significantly urge the MOSFET devices toward the heat sinks. Accordingly, as mentioned above, the electronic enclosure demonstrates a zero insertion force effect during insertion of the substrate assembly to the preload position.

[0072] Referring to FIG. **16**, as the second compression feature **388** passes under the step **396** and engages the second lower edge portion **399**, the spring plate **380** is directed towards the bottom surface **312** and down upon the MOSFET devices **350**. Additionally, once the substrate assembly **330** is fully inserted, the larger first compression feature **386** engages the first lower edge portion **398** likewise causing the spring plate **380** to urge the MOSFET devices **350** toward the heat sink **360**. This position is the loaded position, which exists after fully inserting the substrate assembly, wherein the embossments and spring plates do significantly urge the MOSFET devices toward the heat sinks. Referring to FIG. **14**, urging the MOSFET devices **350** toward the heat sinks **360**, **362** places the heat conductive elements **372** located in the apertures **370** under compression between the heat transfer surfaces **356** and the interior surfaces **364**, thereby transferring the generated heat energy from the interior chamber. In some embodiments, to assist in transferring heat energy away, a thermal conducting paste, adhesive, or pad may be placed between the heat transfer surfaces and the interior surfaces.

[0073] Referring to FIGS. **18** and **19**, there is illustrated another embodiment of an electronic control enclosure **400** for housing the components of an electronic control unit. The electronic control enclosure **400** has a generally rectangular shape and a low profile so as to not interfere with other external devices situated in the same environment. To mount the electronic control enclosure **400** to a panel, mounting feet **406** project from the sides of the electronic control enclosure through which fasteners can be inserted.

[0074] To protectively house the electronic components of the electronic control unit, referring to FIGS. **20** and **21**, there is included an enclosure housing **402** that defines an interior chamber **404**. The enclosure housing **402** has a top wall **410**, an opposing bottom wall **412**, and first and second sidewalls **414**, **416** extending between the top and bottom walls. Extending across the rear of the enclosure housing **402** and joined to the rear edges of the top, bottom, and sidewalls **410**, **412**, **414**, **416** is a rear wall **418**. To access the interior chamber **404**, the front part of the enclosure housing **402** opposite the rear wall **418** is formed as an opening **420** defined by a rim **422** composed of the forward edges of the top, bottom, and sidewalls **410**, **412**, **414**, **416**. Formed on the interior side of each sidewall **414**, **416** proximate and extending parallel to the bottom wall **412** is a groove **424**. The enclosure housing **402** can be made of injection molded plastic or other suitable material such as metal.

[0075] To enclose the interior chamber and to provide electrical communication with the electronic components included therein, referring to FIG. **22**, the electronic control enclosure **400** includes a header assembly **430** that can be received within the opening **420** and constrained by the rim **422**. The header assembly **430** includes a front plate **432** from which one or more receptacle walls **434** extend. The receptacle walls **434** protectively surround a plurality of terminals **436** that extend through the front plate **432** and are configured to receive plugs from external electrical devices. A substrate assembly **440** is attached to and extends from a lower portion of the front plate **432**. The substrate assembly **440** includes a generally planar substrate **442** having a first surface **444**, an opposing second surface **446**, and conductive electrical traces formed thereon. The substrate **442**, when inserted into the interior chamber **404**, extends rearward and generally parallel to the bottom wall **412** with the first surface **444** oriented toward the top wall **410**. To align the substrate **442** within the interior chamber **404**, referring to FIG. **20**, it will be appreciated that the edges of the substrate can be received in the grooves **424** formed into the sidewalls.

[0076] Referring to FIG. **22**, there is mounted to the substrate **442** proximate to and aligned with the substrate's rear-most edge **448** a plurality of electronic components such as MOSFET devices **450**. The exposed heat transfer surfaces **452** of the MOSFET devices **450** are mounted adjacent to the first surface **444** of the substrate and directed toward the rear wall **418**. To remove the heat energy generated from the MOSFET devices, the electronic control enclosure **402** includes a heat sink **460** that maybe disposed through the bottom wall **412** to contact the heat transfer surfaces **452**. The heat sink **460** thereby transfers heat energy from the devices to an exterior surface **462** of the heat sink that is exposed along the exterior of the enclosure housing **402**. In other embodiments, the enclosure housing may be made of a heat conductive material, such as metal, and the heat sink is integral with the enclosure housing.

[0077] To facilitate the transfer of heat energy between the MOSFET devices and the heat sink, the exposed heat transfer surfaces of the MOSFET devices are urged against the heat sink by a spring force. Specifically, as illustrated in FIGS. **23** and **24**, a portion of the heat sink **460** is disposed within the interior chamber **404** by an upright transition arm **464** that extends through the bottom wall **412**. Connected to and extending forward from the transition arm **464** is a contact arm **466**, which extends parallel to and is spaced-apart from the bottom wall **412**. Preferably, the transition arm **464** and contact arm **466** extend along the length of the rear edge **448** of the substrate **442**. Located at the free end of the contact arm **466** is a circular-shaped locator **468** that protrudes down toward the bottom wall **412**. The heat sink **460** may include multiple locators **468** spaced-apart from each other along the length of the contact arm **466**. Also included is a leaf spring **474** proximate to the bottom wall **412** and which cambers upwards toward and generally aligned with the contact arm **466**.

[0078] Referring to FIG. **24**, when the substrate **442** is fully inserted into the interior chamber **404**, the rear edge **448** of the substrate is located between the contact arm **466** and the bottom surface **412** with the heat transfer surfaces **452** of the MOSFET devices **450** underneath the contact arms. Moreover, the leaf spring **474** biases the substrate **442** upwards thereby urging the heat transfer surface **452** against the contact arm **466**. To assist in transferring heat energy, in some embodiments, a thermal conducting paste, adhesive, or pad may be placed between the heat transfer surfaces and the interior surfaces.

[0079] Referring to FIG. **23**, to facilitate inserting the substrate **442** underneath the contact arm **466** without damaging the heat transfer surfaces **452**, it will be appreciated that as the locator **468** comes into contact with the rear edge **448** and the locator **468** deflects the substrate **442** down toward the bottom surface **412**. This deflection presses the substrate **442** against the leaf spring **474** while providing a gap between the contact arm **466** and the heat transfer surface **452** enabling movement between the two. The gap is indicated by arrows **476** in FIG. **23**. This position is the preload position, wherein the leaf spring can not urge the MOSFET device against the heat sink. To eliminate the gap, the substrate **442** includes one or more recesses **459** disposed into the first surface offset slightly forward of the rear edge **448**. Once the substrate **442** is fully inserted, as illustrated in FIG. **23**, the recess **459** aligns with and receives the locator **468** allowing the leaf spring **474** to project the substrate upwards. Accordingly, contact is made and adequate thermal transfer occurs between the heat transfer surfaces **452** and the contact arm **466**. This position is the loaded position, wherein the leaf spring urges the MOSFET device against the heat sinks.

[0080] Illustrated in FIG. **25** is another embodiment of an electronic control enclosure **500** for housing the components of an electronic control unit. The electronic control enclosure **500** has a generally rectangular shape with a low profile so as to not interfere with other devices that may be situated within the same environment. To mount the electronic control enclosure **500** to a panel, one or more mounting feet **506** project from the sides that can receive fasteners. The electronic control enclosure **500** defines an interior chamber in which the electronic components that make up the electronic control unit can be protectively housed.

[0081] Referring to FIG. **26**, to mount and interconnect the various electronic components of the electronic control unit together in a manner facilitating their insertion into the interior chamber, there is included a header assembly **530** to which there is attached a rearward-extending substrate assembly **540**. The header assembly **530** includes a planar front plate **532** from which projects one or more forward-

extending receptacle walls **534** that surround a plurality of terminals **536**. The terminals **536** each include a terminal lead **537** projecting rearward from the front plate **532** which are formed with right angles directing the terminal leads downward to contact the substrate assembly **540**. The front plate **532** and the receptacle walls **534** are preferably made from a thermally conductive material, such as a cast aluminum, magnesium, zinc, or alloys thereof or a heat conductive plastic.

[**0082**] The substrate assembly **540** includes a generally planar substrate **542** having a top surface **544**, an opposing bottom surface **546**, and a plurality of conductive circuit traces formed thereon, such as a printed circuit board. Also included as part of the substrate assembly **540** and electrically connected to the circuit traces on the substrate **542** are the electronic components such as, for example, MOSFET devices **550** with exposed heat transfer surfaces **552**.

[**0083**] To remove heat generated by the MOSFET devices, in accordance with another aspect of the present invention, the header assembly **530** also includes one or more heat sinks **560**. For example, as illustrated in FIGS. **26**, **27**, and **28**, the heat sinks **560** are shaped as elongated, parallel rails that are integrally joined to and extend rearward from the front plate **532**. Moreover, in the illustrated embodiment, the heat sinks **560** have generally "L-shaped" cross-sections, including a first, longer leg **562** and a second, shorter leg **564**. The heat sinks **560** are arranged so that the shorter legs **564** are adjacent to the top surface **544** of the substrate **542**. Because the heat sinks **560** and front plate **532** are integrally joined and made from a thermally conductive material, the heat sinks **560** conduct heat from the interior chamber to the exposed front plate **532**, which accordingly functions as the exterior surfaces described above. To dissipate the heat energy to environment, referring to FIG. **27**, the front plate **532** may include one or more projecting fins **538**.

[**0084**] To transfer heat energy from the MOSFET devices **550** to the heat sinks **560**, the heat transfer surfaces **552** are placed in direct physical contact with the heat sinks. Referring to FIGS. **26** and **28**, the MOSFET devices **550** are arranged with the heat transfer surfaces **552** either flat against the substrate **542** or projecting vertically upright from the substrate. For those MOSFET devices **550** arranged flatly, the heat transfer surface **552** is sandwiched between the heat sink **560** and the top surface **544**, and may be secured with a fastener **557**, thereby ensuring adequate thermal energy transfer. For those MOSFET devices **550** arranged vertically upright, the heat transfer surfaces **552** extend adjacently over the longer legs **562** of the heat sinks **560** and are secured thereto by a fastener **558**, likewise ensuring adequate thermal energy transfer.

[**0085**] Accordingly, the present invention provides an electronic control enclosure for an electronic control unit. The electronic control enclosure includes an enclosure housing defining an interior chamber for electronic components of the control unit. The enclosure housing can be enclosed and environmentally sealed by a header assembly across which electrical communication can be established. To remove the heat energy generated by the electronic components in the interior chamber, the electronic control enclosure includes one or more heat sinks that have exterior surfaces exposed on the exterior of the electronic control enclosure. In various embodiments the heat sink may be disposed through the enclosure housing or the heat sink may be formed integrally with the enclosure housing. In the embodiments in which the heat sink and enclosure housing are integral and the enclosure housing is comprised of a metallic material, the entire enclosure housing can absorb and dissipate the heat energy generated from the electronic components. Additionally, to ensure good thermal contact between the electronic components and the heat sinks, the electronic control enclosure may include features that urge the electronic components and heat sinks into contact

[**0086**] All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference was individually and specifically indicated to be incorporated by reference and was set forth in its entirety herein.

[**0087**] The use of the terms "a" and "an" and "the" and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms "comprising,""having,""including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[**0088**] Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

1-44. (canceled)

45. A method of making an electronic control enclosure comprising:

providing an enclosure housing defining an interior chamber, the enclosure housing including a rim defining an opening for accessing the interior chamber, the enclosure housing including a seal mounted to the rim;

providing a substrate assembly including a substrate and a front plate; and

inserting the substrate into the interior chamber and compressing the seal between the front plate and the rim to environmentally seal the interior chamber.

46. The method of claim 45 wherein the seal includes a protrusion.

47. The method of claim 45 wherein the seal includes a recess.

48. The method of claim 45 wherein the seal has a generally C-shaped cross-section.

49. The method of claim 45 wherein the seal is non-planar.

50. The method of claim 45 wherein the seal is rubber.

51. The method of claim 45 wherein the rim comprises a seating surface for the seal, the seating surface comprising a slope.

52. The method of claim 51 wherein the seal is compressed between the front plate and the seating surface.

53. The method of claim 45 wherein the seal covers an interior surface and an exterior surface of the rim.

54. The method of claim 45 wherein the seal comprises an outer leg, an inner leg, and a center portion.

55. The method of claim 45 wherein the front plate is removably coupled to the housing.

56. The method of claim 45 further comprising engaging a latch on the housing with a latch catch on the front plate.

57. The method of claim 56 wherein the latch comprises an inclined barb.

58. The method of claim 45 further comprising engaging a latch on the front plate with a latch catch on the housing.

59. The method of claim 58 wherein the latch comprises an inclined barb.

60. The method of claim 45 wherein the substrate includes at least one electrical component.

61. The method of claim 45 wherein at least one of the housing and the front plate comprises a heat sink.

62. The method of claim 45 wherein the front plate comprises a plurality of terminals surrounded by a receptacle wall.

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