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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY. DOCKET NO	TOT CLAIMS	IND CLAIMS
61/266,724	12/04/2009		220	0112903.00277US1		

CONFIRMATION NO. 1327

23483
WILMERHALE/BOSTON
60 STATE STREET
BOSTON, MA 02109

FILING RECEIPT



OC000000039197465

Date Mailed: 12/17/2009

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Applicant(s)

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If Required, Foreign Filing License Granted: 12/11/2009

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 61/266,724**

Projected Publication Date: None, application is not eligible for pre-grant publication

Non-Publication Request: No

Early Publication Request: No

Title

AUTOMOTIVE BATTERY WITH INTEGRATED POWER MANAGEMENT SYSTEM AND
SCALABLE BATTERY CUTOFF COMPONENT

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Automotive Battery with Integrated Power Management System and Scalable Battery Cutoff Component

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application refers to U.S. Patent Application No. 12/628,809, filed on December 1, 2009, entitled “Prismatic Automotive battery With Scalable Architecture,” (the “Related Application”) the entire content of which is incorporated herein by reference.

TECHNICAL FIELD

[0002] The present invention relates to automotive batteries and scalable architectures for manufacturing automotive batteries.

BACKGROUND OF THE INVENTION

[0003] A rechargeable battery may be used in terrain, marine, or aeronautic vehicles in various applications. One application is as a starter battery to drive the starter motor of the vehicle. Starter battery applications may require high electrical currents to drive the starter motor, and the ability to be recharged from the vehicle’s alternator. Most current automotive starter batteries are of lead acid construction. However, lithium-ion (Li-Ion) batteries may be used instead of lead acid batteries. Li-Ion batteries can provide improved power-to-weight ratios, longer cycle lives, and environmental benefits due to the lack of lead.

[0004] A second application for Li-Ion batteries in vehicles is to provide power for ‘micro-hybrid’ (start-stop) drive systems. Unlike some hybrid cars, where a relatively high-voltage battery is used to drive an electric motor that is used for vehicle propulsion, cars with micro-hybrid systems are propelled by conventional internal combustion engines. However, in micro-hybrid cars, the engine is automatically turned off when the car is stopped (e.g., at a traffic light) and then started back up when the driver presses the accelerator to drive off. This start-stop technique reduces emissions without requiring significant infrastructure changes to existing car designs. However, micro-hybrid applications also require batteries that can withstand the frequent charge-discharge cycles caused by constantly re-starting the engine. Li-Ion batteries

have performance characteristics that are better matched for such applications than lead-acid batteries.

BRIEF DESCRIPTION OF THE FIGURES

[0005] For a fuller understanding of the nature and objects of the present invention, reference should be made to the following detailed description taken in connection with the accompanying drawings in which the same reference numerals are used to indicate the same or similar parts wherein:

[0006] FIG. 1 shows a battery automotive battery.

[0007] FIG. 2 shows an automotive battery with the outer casing removed and cell subassemblies exposed.

[0008] FIG. 3 shows a system level block diagram of an automotive power system.

[0009] FIG. 4 shows a power management system for an automotive battery.

[0010] FIG. 5 shows a resistance-temperature relationship for a MOSFET (metal-oxide-semiconductor field-effect transistor) device.

[0011] FIG. 6 shows a scalable cutoff component integrated into an automotive battery.

DETAILED DESCRIPTION OF THE INVENTION

[0012] An automotive battery consists of an assembly of cell subassemblies, each containing prismatic Li-Ion battery cells, where the cells are electrically connected to the other cells in the module to form the battery. The term ‘prismatic’ refers to the shape of the battery cell that is described herein and it differentiates this module from other modules with cylindrical battery cells. The battery has an integrated power management system that provides passive (through control of components external to the battery) and active (through internal controls) protection against over-charge, over-discharge, over-temperature, and over-current. The battery also includes a scalable battery cutoff component controlled by the power management system.

[0013] FIG. 1 shows an automotive battery 100 with a outer case 110, a negative terminal 102 and a positive terminal 104, and a LIN (Local Interconnect Network) management interface 106. Case 110 is molded, and lead-free terminals 102 and 104 are insert-molded in place into the case. The case consists of a top cover that includes the terminals, and an enclosure base.

[0014] FIG. 2 shows the inside of automotive battery 100 with the enclosure base removed. The battery is shown from a perspective flipped 180 degrees upside-down in relation to FIG. 1. The battery contains one or more cell subunits 202. As described in more detail in the Related Application identified in the section above entitled “CROSS-REFERENCES TO RELATED APPLICATIONS”, the cell subassemblies are a basic building block from which automotive batteries of arbitrary scales may be constructed. The cell subassemblies contain Li-Ion prismatic battery cells (not visible), each of which provides a portion of the battery’s electrical power and storage capacity. The cell subassemblies 202 are held together by pressure plate 206, top cover 200, and bands 206. The individual battery cells are electrically connected in parallel and/or series by busbars (described in the Related Application) which connect the cells to one another and to the terminals of the battery. One such busbar 208 is shown in FIG. 2 connecting one respective terminal of each of four different battery cells together. Busbar 208 also connects the four terminals to positive terminal 104.

[0015] The prismatic automotive battery described herein has a group of identical cells. The quantity of cells per module and the module’s electrical connection configuration (parallel count versus series count) defines the module’s electrical characteristics and performance ratings. For example, battery 100 is configured in a ‘4S4P’ configuration which has 16 cells in 4 subgroups, where the subgroups are electrically connected in series, and with 4 cells in each subgroup that are electrically connected in parallel. Depending on the configuration, automotive batteries may contain either an even or an odd number of battery cells.

[0016] FIG. 3 shows a system-level block diagram of battery 100 within an automotive electrical system. Battery 100 comprises several battery cell subunits 324 and a cutoff component 322. Here, each subunits 324 represents a group of four parallel battery cells making up the 4S4P battery. Battery 100 is connected in parallel with a combination of a starting solenoid switch 304 and starter motor 306. Battery 100 is also connected in parallel with an

alternator 308 which is used to charge the battery. Alternator 308 has a control input for controlling its output power, which is connected directly or indirectly to the battery's LIN interface (not shown). Battery 100 is shown as four battery cell elements in series, internal to the battery housing. Although the battery uses an electronic power management system to maintain balance between individual battery cells and to detect cell voltage, the internal cutoff component 322 is used as a last resort to protect the battery from alternator runaway or other abusive overcharging. The internal cutoff component may also be used to prevent damage to the battery due to over discharge.

[0017] Load controller 310 selects one or more electrical loads 304 to be connected in parallel to and driven by battery 100. Load controller 310 can disconnect one or more loads to implement load shedding in situations where the battery cannot provide a sufficiently high voltage if connected to all of the loads. The load controller may shed loads automatically or due to a request from the battery power management system (described in more detail below) through the battery's LIN interface. In some embodiments, one or more loads may be directly connected in parallel with the battery without being connected in series with a load controller.

POWER MANAGEMENT SYSTEM

[0018] FIG. 4 shows a component-level view of battery 100, including power management system 400, battery cell assembly 320, LIN interface 106, fuse 420, and cutoff component 322. Battery cell assembly 320 is electrically connected in series with cutoff component 322 and fuse 420. Power management system 400 is connected directly or indirectly through an intermediate analog-to-digital interface to battery cell assembly 320, and is also communicatively connected to LIN interface 106 and to cutoff component 322. Power management system 400 provides several capabilities, including passive charge control, passive load control and active charge and discharge control.

[0019] Specifically, power management system 400 includes microprocessor 402, which is configured through firmware to perform the following functions, some of which are described in more detail in subsequent sections:

1. Provide input protection and control of charging, including over-voltage and over-current protection.

2. Provide under-voltage protection by control of external load-shedding or by active control of an in-line cutoff switch.
3. Sense and supervise the overall battery voltage, including active control of an in-line cutoff switch to limit the current though and voltage across the battery.
4. Sense individual battery cell temperature.
5. Sense individual battery cell voltage.
6. Control each battery cell's connection to individual small resistive loads placed in parallel with each cell in order to balance the cell's voltages within battery cell assembly 320.
7. Enable/disable circuitry to decrease current consumption.
8. Determine control signals for the alternator.
9. Process watchdog timing signals as a failsafe mechanism to ensure the power management system is operating.
10. Interact with external components through a LIN and/or RS232 interface and/or other digital or analog signals.

PASSIVE CHARGE CONTROL

[0020] Power management system 400 communicates directly or indirectly to the automobile's alternator to passively control the amount of charge current to the battery. In this manner, the battery pack is able to optimize the amount of current flow to passively control the battery's state of charge. This is accomplished by the power management system internally monitoring the voltage, current, temperature, and other relevant parameters of the system. Microprocessor 402 processes this information to determine appropriate charging parameters, and then communicates to and/or controls the alternator to increase or decrease the amount of charge current into the battery pack.

PASSIVE LOAD CONTROL

[0021] Power management system 400 communicates with the automobile's body/load controller to control the amount of discharge current to passively control the battery's state of charge. In this manner, the battery pack is able to optimize the amount of current flow to passively control the battery's state of charge. This is also accomplished by the power management system internally monitoring the voltage, current, temperature, and other relevant

parameters of the system. Microprocessor 402 processes this information to determine appropriate charging parameters, and then communicates to and/or controls the load controller to increase or decrease the discharge current from the battery by selectively connecting or disconnecting certain loads to to/from the battery.

ACTIVE CURRENT CONTROL

[0022] In addition to the above passive control of the battery's state by controlling the battery's external power sources and loads, power management system 400 also detects and actively prevents excessive current flow through the battery, in order to actively control the state of charge of the battery. Microprocessor 402 internally monitors the voltage, current, temperature, and other relevant parameters of the system. Microprocessor 402 uses this information to control a very high power cutoff switch (described below) to actively control the flow of current through the battery pack.

CUTOFF COMPONENT

[0023] As part of performing the above functions, the microprocessor 402 is configured to control and monitor a cutoff component 322 that can be used to selectively connect or disconnect the battery from the load(s) connected to its terminals. Cutoff component 322 provides over-voltage, under-voltage, over-current and over-temperature protection. The cutoff component 322 is effectively a bi-directional switch that can be used to control whether the cells in battery cell assembly 320 are electrically connected to the terminals for charging, and separately control this connection for discharging. The cutoff component may also be configured to be a uni-directional switch, used only to control battery charging.

[0024] Cutoff component 322 includes two groups of parallel MOSFET devices, each of which the power management system 400 operates as a single, uni-directional switch to selectively allow or disallow current flow to the battery depending on whether the MOSFETs are switched to an ON or OFF state. One MOSFET group controls whether current can flow in a direction that charges the battery, and the second group controls whether current can flow in a direction that discharges the battery. The parallel arrangement of each group splits the current flow across the MOSFETs, allowing the use of MOSFETs with lower current-carrying ratings than the maximum currents expected for charging and discharging of the battery. Examples of

ruggedized MOSFETS for this application include the Infineon IPB180N03S4L-H0 and IPB180N03S4L-01, the International Rectifier IRF2804SPBF, and the Fairchild FDB8860.

[0025] Each MOSFET is electrically connected in parallel with the other MOSFETS within its group, with its drain and source terminals oriented so that when the MOSFET is in an ON state, current is allowed to flow to charge/discharge the battery. The gate terminals of each MOSFET in a group are connected together to effect a single switching control. The two groups of parallel MOSFETs are electrically connected in series with each other and in series with the battery cells within the battery. The MOSFETS are also closely thermally coupled to the cells and to each other with one or more conductors, as is described in more detail below.

[0026] When only one MOSFET group is switched to its OFF state, current is effectively blocked in one direction. Current may still flow in the opposite direction. This occurs because each MOSFET effectively has a body diode which allows current to flow in one direction, but not in the other (unless the MOSFET is in its ON state). A separate diode may also be connected in parallel with each group of MOSFETs to provide an additional current path around the MOSFET group when the current flows in the opposite direction to that controlled by the group.

[0027] Cutoff component 322 can provide an indication of the current flow through the component (and thus of the current through the battery) in one of two ways. First, the voltage across a shunt resistor 436 of known resistance can be used to provide a voltage signal proportional to the current, as is shown in FIG. 4.

[0028] Second, the current may be measured by determining the voltage across the drain-source resistance in the MOSFET's ON state ($R_{DS(on)}$) using a temperature-compensated resistance measurement. This is accomplished by using temperature measuring devices 438 packaged in close thermal proximity to the MOSFET devices, which are themselves packaged in close thermal proximity to each other.

[0029] Specifically, power management system 400 uses the measured temperature to determine a temperature-calibrated $R_{DS(on)}$, which is the used to convert the voltage measured across the drain-source terminals into a current without the need for a relatively expensive precision current sensor. To measure current, the system measures the voltage across the drain

and source of the MOSFETs (V_{DS}). If the resistance (R_{DS}) of the MOSFETs is known, the current is calculated as $[V_{DS}/R_{DS}]$. In general, however, the resistance of MOSFETs will vary significantly with temperature. Temperature variations can occur due to changes in ambient temperature or due to power being dissipated within the device (due to current flow through the device). To account for this, the MOSFET resistance is found and calculated the following way:

Resistance = $R_i + \Delta R_t$, where R_i is the initial resistance and ΔR_t is the change in resistance due to temperature.

[0030] First, the initial resistance is found via calibration during the battery pack manufacturing process. Specifically, a known current (I_a) is applied at a constant temperature and V_{DS} is measured precisely. The initial resistance (R_i) is found to be V_{DS}/I_a . Second, the change in resistance due to temperature can be determined in several ways, including:

1. By direct measure (i.e. measuring the temperature of the device).
2. By deducing the change in temperature.

[0031] Method 2 involves understanding the change in ambient temperature, measuring the power dissipation within the device, and inferring the resultant temperature. The ambient temperature is measured at a convenient and more cost-effective location. The power dissipation within the device is determined with empirical study, based on the amplitude and duration of current through the device ($P = I^2t$).

[0032] Once the temperature of the MOSFET is understood, the resistance is inferred based on the resistance-temperature relationship listed in the datasheet for the particular device or through empirical study. An example of the resistance-temperature relationship 500 for a MOSFET is shown in FIG. 5.

SCALABLE ARCHITECTURE OF THE CUTOFF COMPONENT

[0033] FIG. 6 shows a cutoff component 322 built with a scalable architecture and integrated into one of the busbars 102 of battery 100. The MOSFET devices 630 are positioned between two long conductors 610, and 612 that make up a portion of the busbar. The conductors and MOSFETs are also positioned on a printed circuit board 620 or a similar substrate. The two

conductors are selected and configured to provide close thermal coupling between the MOSFETs and the temperature sensors (not visible). The MOSFET devices are chosen in part so that the drain and source terminals are on opposite sides of the device, with each attached to a respective one of the conductors of the busbar 610 or 612. This configuration creates a scalable architecture for the cutoff component 322 that complements the scalable architecture of the rest of the battery. In other words, one can readily change the size and/or performance of the module by simply adding or subtracting identical parts or subassemblies, e.g., the MOSFETs. The orientation of the MOSFETs is easily configured to accommodate either uni-directional (e.g., to prevent charging) or bi-directional (e.g., to prevent charging and discharging) protection for the battery by simple orientation of the conductors. The number of MOSFETs can easily be adjusted in the design in order to accommodate differing current limits of the battery in relation to the individual current-carrying capacities of the MOSFETs.

[0034] The cutoff component and/or power management system may also be used separately from the battery. Systems of multiple batteries that use just a single series cutoff component and/or power management system may also be used, for example, in telecom applications.

FIG. 1

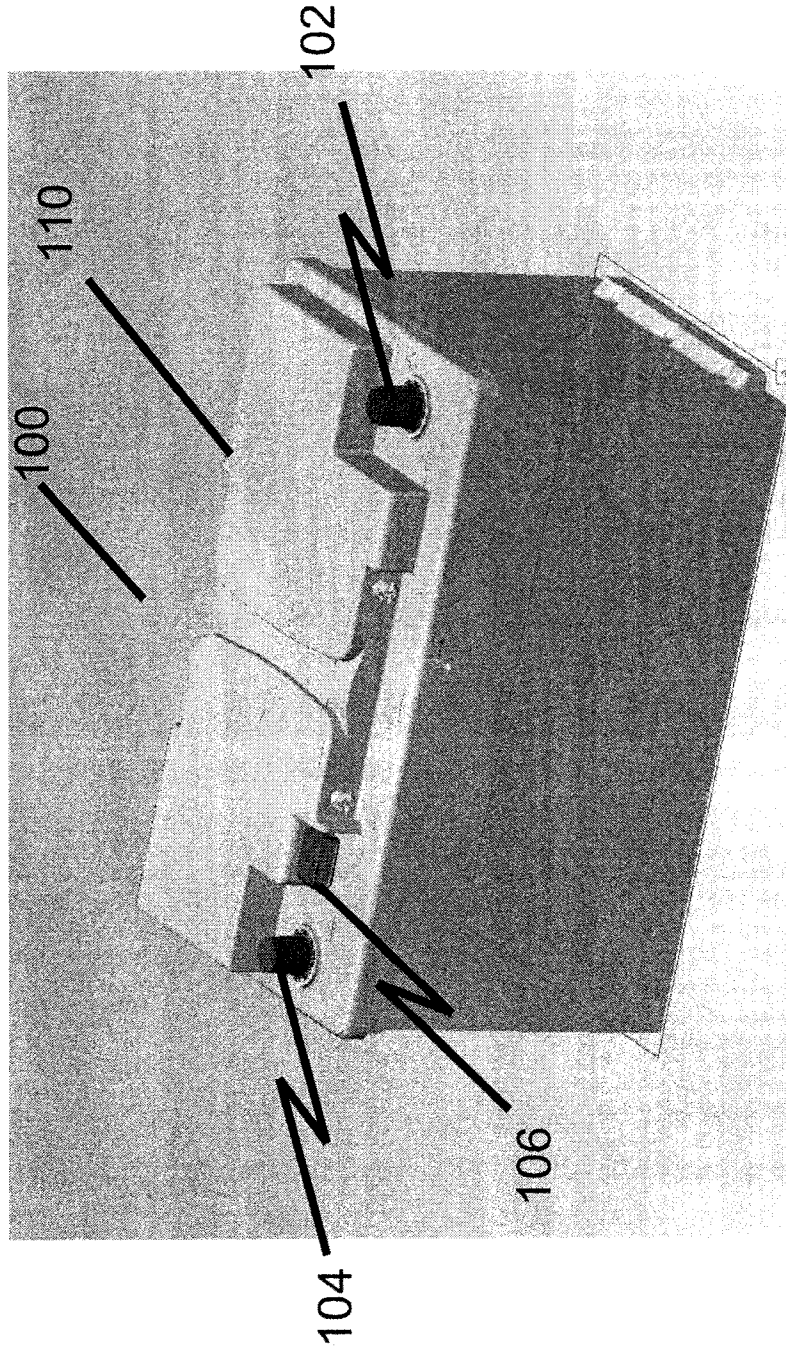


FIG. 2

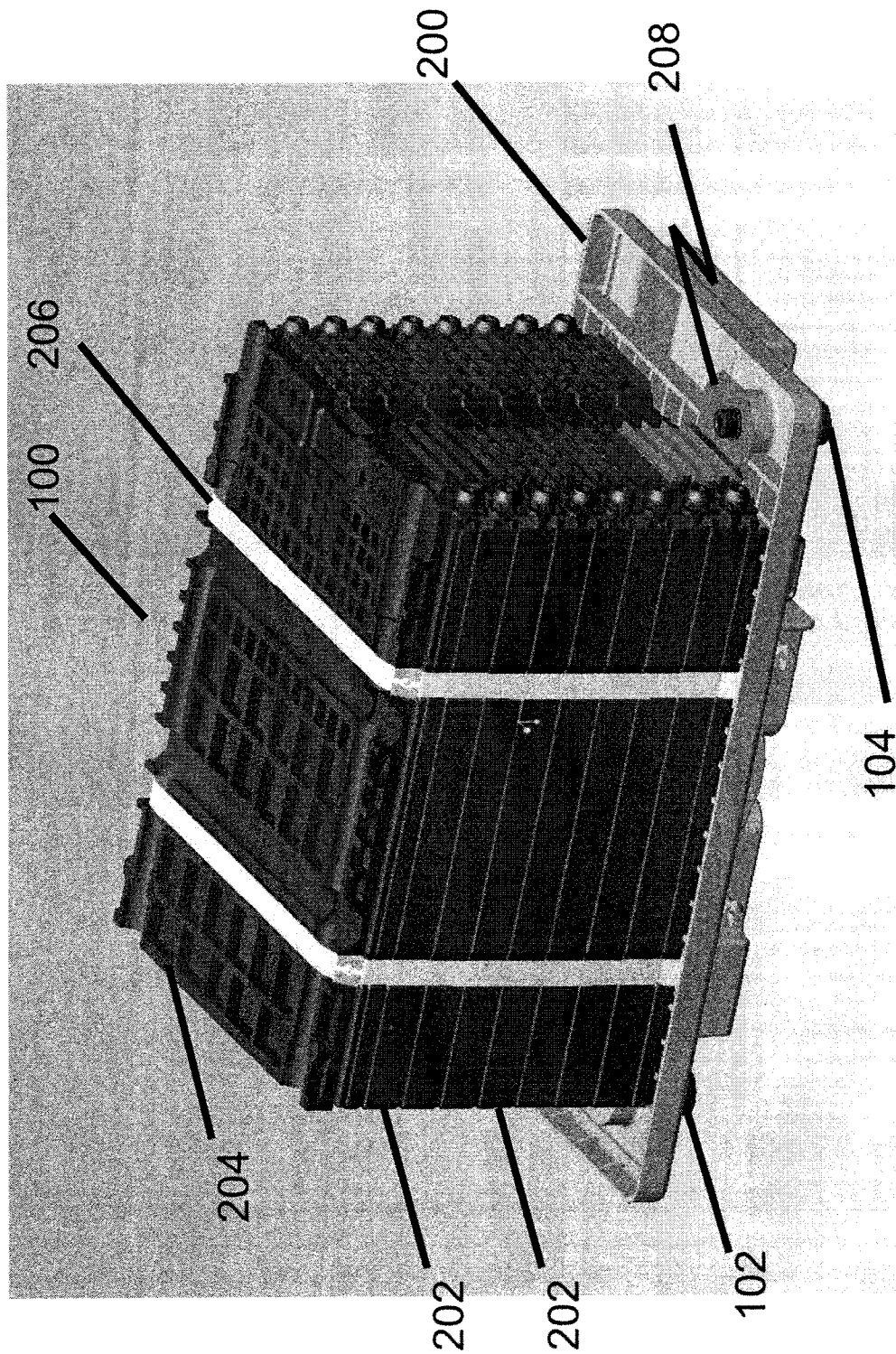
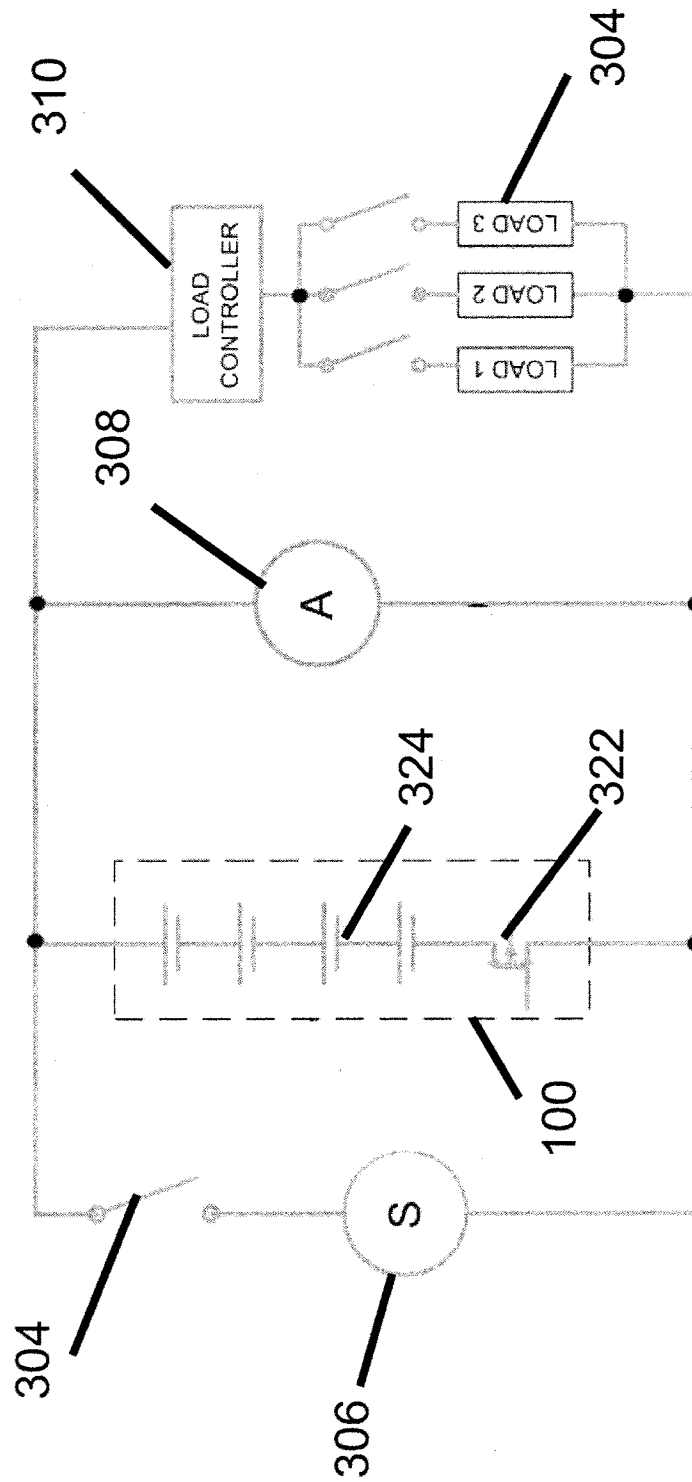


FIG. 3



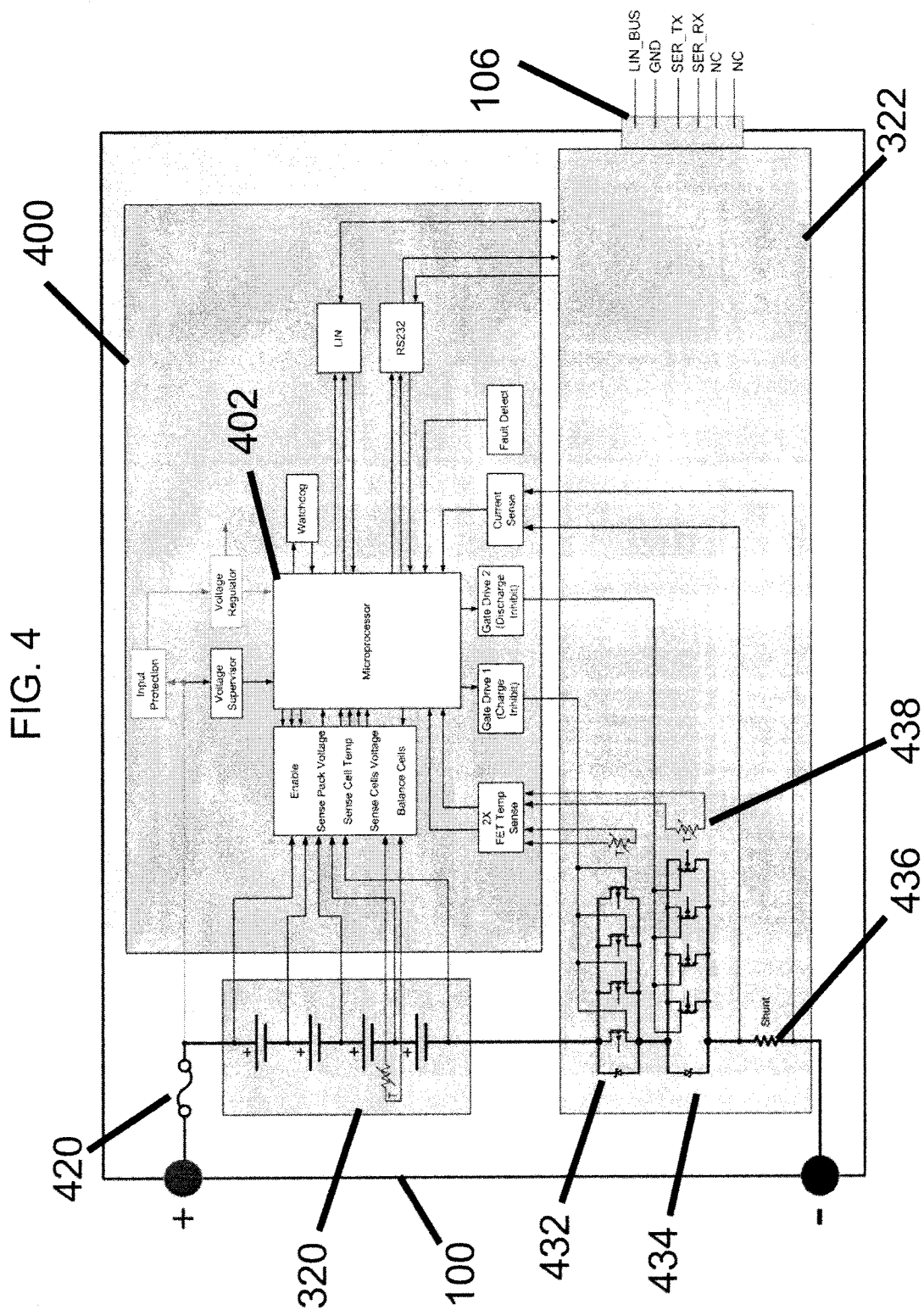


FIG. 5

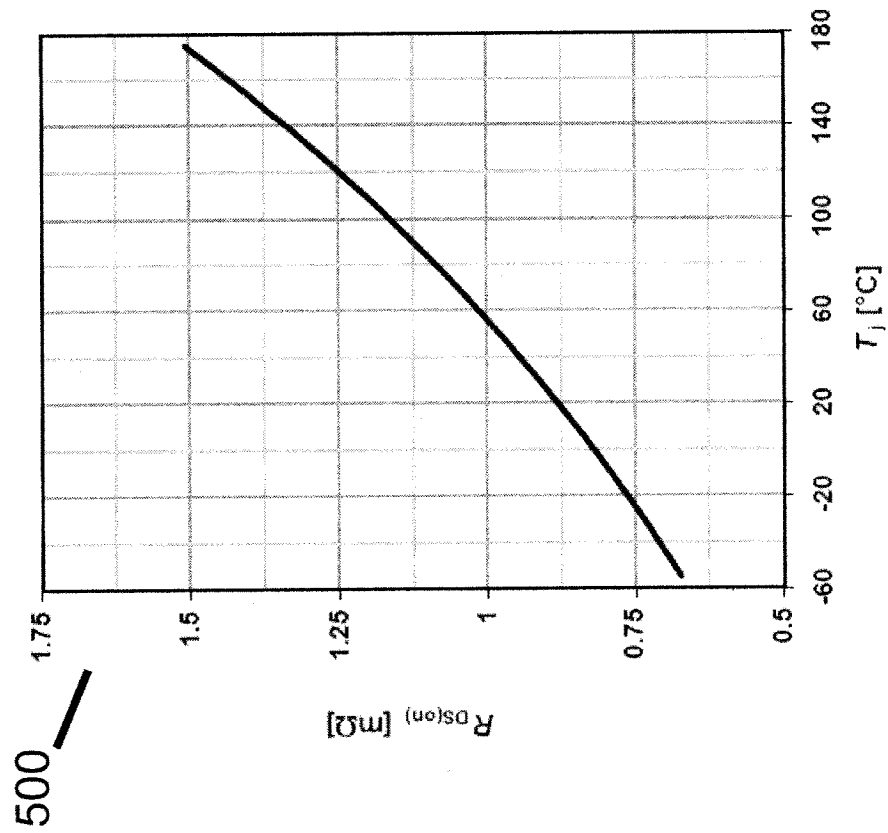
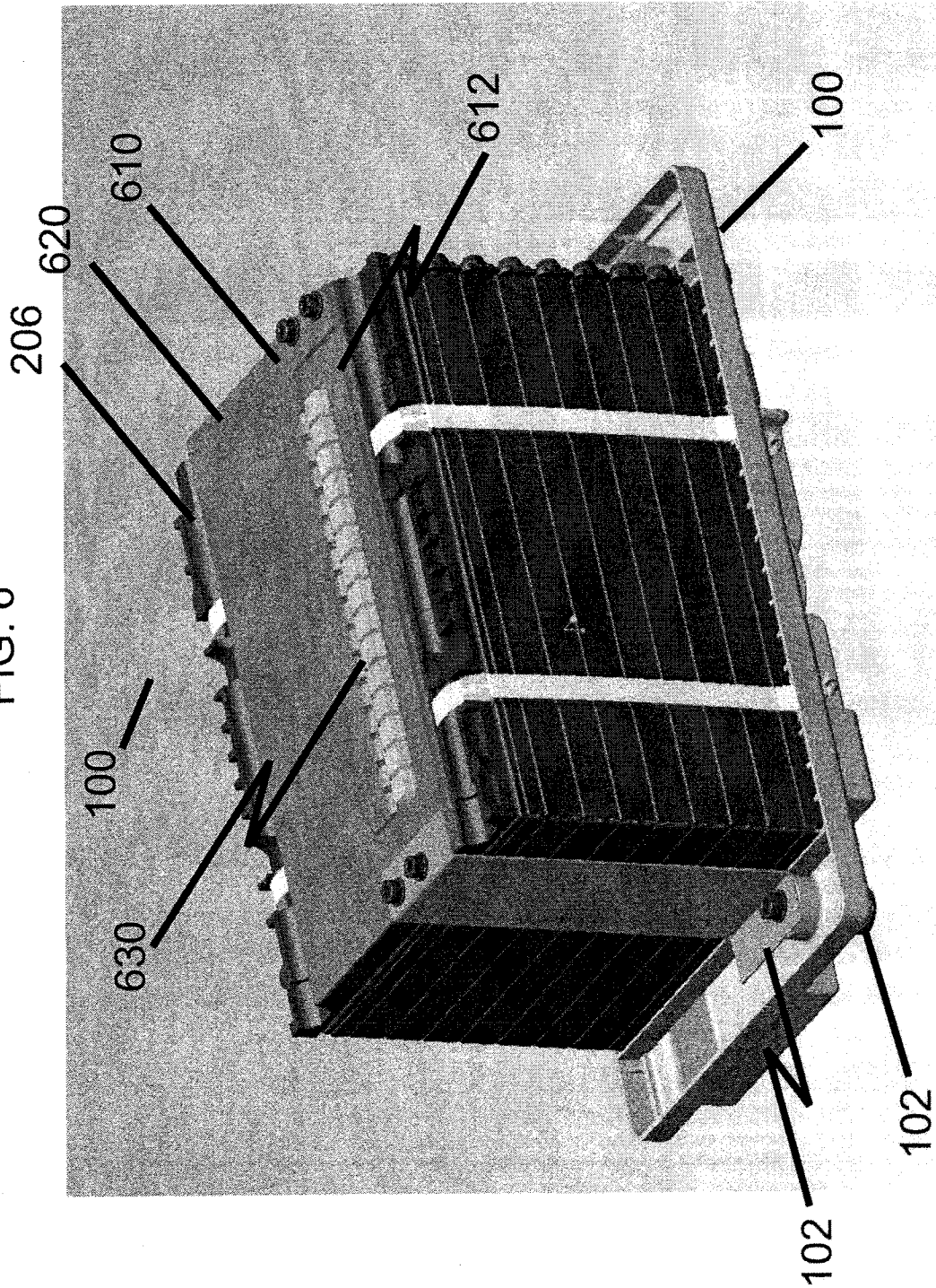


FIG. 6



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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0112903.00277US1
		Application Number	
Title of Invention	AUTOMOTIVE BATTERY WITH INTEGRATED POWER MANAGEMENT SYSTEM AND SCALABLE BATTERY CUTOFF COMPONENT		
The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76. This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.			

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Title of the Invention	AUTOMOTIVE BATTERY WITH INTEGRATED POWER MANAGEMENT SYSTEM AND SCALABLE BATTERY CUTOFF COMPONENT		
Attorney Docket Number	0112903.00277US1	Small Entity Status Claimed	☐
Application Type	Provisional		
Subject Matter	Utility		
Suggested Class (if any)		Sub Class (if any)	
Suggested Technology Center (if any)	N/A		
Total Number of Drawing Sheets (if any)	6	Suggested Figure for Publication (if any)	

PETITIONERS EX. 1008

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0112903.00277US1
		Application Number	
Title of Invention	AUTOMOTIVE BATTERY WITH INTEGRATED POWER MANAGEMENT SYSTEM AND SCALABLE BATTERY CUTOFF COMPONENT		

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☐	Request Early Publication (Fee required at time of Request 37 CFR 1.219)
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Prior Application Status		Remove	
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the Add button.			Add

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			Remove
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			☐ Yes ☒ No
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Assignee 1	Remove

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	0112903.00277US1
		Application Number	
Title of Invention	AUTOMOTIVE BATTERY WITH INTEGRATED POWER MANAGEMENT SYSTEM AND SCALABLE BATTERY CUTOFF COMPONENT		

If the Assignee is an Organization check here. ☒			
Organization Name	A123 Systems, Inc.		
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Signature:

A signature of the applicant or representative is required in accordance with 37 CFR 1.33 and 10.18. Please see 37 CFR 1.4(d) for the form of the signature.					
Signature	/Matthew J. Leary/			Date (YYYY-MM-DD)	2009-12-04
First Name	Matthew	Last Name	Leary	Registration Number	58593

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PRISMATIC BATTERY MODULE WITH SCALABLE ARCHITECTURE

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Application No. 61/143976, filed January 12, 2009 and entitled “Prismatic Battery Module With Scalable Architecture,” the entire contents of which are incorporated herein by reference.

This application is also related to the following applications, filed concurrently herewith, the entire contents of which are incorporated herein by reference:

U.S. Patent Application No. (TBA), filed on December 1, 2009, entitled “Methods of Welding Battery Terminals,”

U.S. Patent Application No. (TBA), filed on December 1, 2009, entitled “Structure of Prismatic Battery Modules with Scalable Architecture,”

U.S. Patent Application No. (TBA), filed on December 1, 2009, entitled “Safety Venting Mechanism For Batteries,”

U.S. Patent Application No. (TBA), filed on December 1, 2009, entitled “Bi-metallic Busbar Jumpers for Battery Systems,”

U.S. Patent Application No. (TBA), filed on December 1, 2009, entitled “Fuse For Battery Cells,” and

U.S. Patent Application No. (TBA), filed on December 1, 2009, entitled “Busbar Supports And Methods Of Their Use for Battery Systems,”

TECHNICAL FIELD

[0002] The present invention relates to battery modules and scalable architectures for manufacturing battery modules.

BACKGROUND OF THE INVENTION

[0003] A 'battery module' is a subassembly that is typically installed inside a 'battery pack', which is an assembly that is installed in a terrain, marine, or aeronautic vehicle. These vehicles typically have a variety of high power electric loads, such as a computer-controlled power inverter driving an electric motor that is used for vehicle propulsion or some form of mechanical actuation.

[0004] A large group of battery modules can also be used by an electric utility company to help equalize a local power distribution network's worst-case supply fluctuation episodes. The modules are installed inside a 'battery station', which is a large rigid stationary weather-proof climate-controlled enclosure that is secured to a concrete foundation. The modules are mounted and electrically connected via racks with docks so that any module can be rapidly connected or disconnected.

[0005] Battery packs and battery stations typically have other subassemblies and components installed inside them in order to deliver complete end-item battery packs to vehicle manufacturers or complete end-item battery stations to electric utility companies. These subassemblies and components include electronic sensor modules, electronic control modules, electrical charging modules, electrical interface connectors, electrical fuses, electrical wiring harnesses, and thermal management means.

BRIEF SUMMARY OF THE INVENTION

[0006] In general, in one aspect, a battery system with a scalable architecture includes a group of subunits, each of which includes a heatsink and a battery cell having a top end and first and second voltage terminals which extend out of the top end of the battery cell, where the first and second terminals of each battery cell are symmetrically positioned with respect to a centerline of the battery cell, and where all of the battery cells among the plurality of subunits are arranged so that their first voltage terminals are aligned along a first row and their second voltage terminals are aligned along a second row. The system further includes a set of identical busbar supports equal in number to the plurality of subunits, where each busbar support has two slots and is mounted on a corresponding subunit, with each of the first and second terminals of the battery cell for that subunit extending up through a corresponding different one of the two slots.

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The system also includes a group of bimetallic busbars, each one supported by the busbar supports and electrically connected directly to either a first or second terminal of each of the battery cells of each modules on which those busbar supports are mounted.

[0007] Other embodiments include one or more of the following features. The battery cells used in the system are prismatic battery cells. Both the first row and the second row of terminals are situated on the same side of the battery system. Each of the subunits are identical to one another except for the orientation of each of the subunit's battery cells with respect to the cell's centerline. All of the heatsinks are identical to each other except one or two heatsinks. Each of the busbars is electrically connected to at least two adjacent terminals in the same row of terminals.

[0008] In certain embodiments, the battery system includes two pressure plates where the subunits are arranged as a stack between the pressure plates. In one such embodiment, one or more compliant pads are located between the first pressure plate and the neighboring subunit. In another such embodiment, a band encircles the first and second pressure plates and the subunits.

[0009] In embodiments of the battery system, each of the plurality of subunits further comprises a second battery cell having a top end and first and second voltage terminals both of which extend out of the top end of the second battery cell, where the first and second terminals of each second battery cell being symmetrically positioned with respect to a centerline of that battery cell wherein each of the second battery cells among the plurality of subunits are arranged so that their first voltage terminals are aligned along the first row and their second voltage terminals are aligned along the second row.

[0010] The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE FIGURES

[0011] For a fuller understanding of the nature and objects of the present invention, reference should be made to the following detailed description taken in connection with the accompanying

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drawings in which the same reference numerals are used to indicate the same or similar parts wherein:

[0012] FIG. 1 shows a battery module.

[0013] FIG. 2 shows a battery module with busbar covers and busbars removed and with cell subassemblies exposed.

[0014] FIG. 3 shows a prismatic battery cell.

[0015] FIG. 4 shows a zipper fuse of a prismatic battery cell.

[0016] FIG. 5 shows a more detailed view of a cell subassembly.

[0017] FIG. 6 shows another view of a cell subassembly.

[0018] FIG. 7 shows an alternative heatsink and cell subassembly.

[0019] FIG. 8 shows another alternative heatsink and cell subassembly.

[0020] FIG. 9 shows a heatsink with attached pressure relief teeth.

[0021] FIG. 10 shows a view of a battery module pressure plate.

[0022] FIG. 11 shows a portion of a band component of a battery module.

[0023] FIG. 12 shows several busbar supports, attached to cell subassemblies in a battery module, including a reduced-height cell subassembly.

[0024] FIG. 13A shows a busbar support attached to a heatsink.

[0025] FIG. 13B shows an alternative busbar support to support one battery cell.

[0026] FIG. 14 shows several busbar supports attached to cell subassemblies in a battery module, each retaining at least a portion of a busbar jumper.

[0027] FIG. 15 shows a side profile of a busbar jumper.

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- [0028]** FIG. 16 shows a busbar terminal in relation to pressure plate and cell subassemblies.
- [0029]** FIG. 17 shows a busbar terminal attached to a pressure plate and a busbar bridge.
- [0030]** FIG. 18 shows a busbar terminal with two variations of clips for attachment of wiring.
- [0031]** FIG. 19 shows a side view of a wiring attachment clip.
- [0032]** FIG. 20 shows a support clip for attachment of a thermistor.
- [0033]** FIG. 21 shows a cutaway view of a busbar cover.
- [0034]** FIG. 22 shows a family of battery modules incorporating a scalable architecture.
- [0035]** FIG. 23 shows pressure relief teeth.
- [0036]** FIG. 24 shows several arrangements of busbar components that may be used to achieve various configurations of battery modules.
- [0037]** FIG. 25 shows views of a configuration of a welding laser with respect to a busbar component.
- [0038]** FIG. 26 shows before and after views of the attachment of a busbar component to a battery cell terminal.

DETAILED DESCRIPTION OF THE INVENTION

[0039] A battery module consists of an assembly of cell subassemblies, each containing prismatic battery cells, where the cells are electrically connected to the other cells in the module to form the battery module. The term ‘prismatic’ refers to the shape of the battery cell that is described herein and it differentiates this module from other modules with cylindrical battery cells.

[0040] FIG. 1 shows a battery module 10 with a negative terminal 20 and a positive terminal 21. The battery module 10 contains one or more cell subassemblies 30. As described in more detail below, the cell subassemblies are a basic building block from which battery modules of

arbitrary scales may be constructed. The cell subassemblies contain prismatic battery cells (not shown), each of which provides a portion of the battery's electrical power and storage capacity. The cell subassemblies 30 are held together by pressure plates 50 and bands 51. Pressure plates 50 act as a mounting mechanism for the battery module, and contain one or more mounting passages 52 to allow the module to accept hardware (not shown) to mount the battery module 10 within, for example, a battery pack enclosure or on a battery station's rack in various mounting orientations. The individual battery cells are electrically connected in parallel and/or series by busbars (described below) which connect the cells to one another and to the terminals of the battery, all of which are on one side of the battery module. That side of battery module 10 is covered with one or more busbar covers 40.

[0041] FIG. 2 shows a battery module 10 with busbars and busbar covers removed to reveal a view of the inside of cell subassemblies 30. Each subassembly contains one or two prismatic battery cells 300, each cell having a positive terminal 301 and negative terminal 302. Terminals 301 and 302 are connected electrically in series and/or parallel by busbar jumpers (not shown). Busbar terminals (also not shown) connect some of the battery terminals to either the battery module's negative terminal 20 or positive terminal 21.

[0042] The prismatic battery module described herein has a group of identical cells. The quantity of cells per module and the module's electrical connection configuration (parallel count versus series count) defines the module's electrical characteristics and performance ratings. For example, a module with a '23S3P' configuration has sixty-nine (69) cells, twenty-three (23) subgroups that are electrically connected in series, and three (3) cells in each subgroup that are electrically connected in parallel. Depending on the configuration, battery modules may contain either an even or an odd number of battery cells.

PRISMATIC BATTERY CELL

[0043] FIG. 3 shows a prismatic battery cell 300. A prismatic cell has two large flat surfaces, top surface 306 and bottom surface 307 (not visible), that are basically parallel to each other and which are used for mechanical retention and thermal management inside the module. The cell's enclosure may be referred to as a 'pouch' because it is a non-rigid flexible sheet that is folded and bonded to create a cost-effective environmentally-sealed housing. The pouch's

material is a thin aluminum foil with a polymer coating applied to both surfaces. The pouch is folded at the bottom edge which provides a seal boundary 303. The polymer coated pouch is formed into a thermally-bonded flange at the two sides, which creates two more seal boundaries 304 and 305. This arrangement decreases the module's physical volume without a decrease in net performance. The side flange's size is selected so as to ensure long-term robustness. The cell's side flanges are folded to create a compact width.

[0044] The cell's two flat electrical terminals, positive terminal 301 and negative terminal 302, protrude from one of the pouch's edges and the terminals are environmentally-sealed using electrically-isolative polymeric perimeter seals. The remaining portion of the pouch's terminal edge is thermally-bonded to create a fourth environmentally-sealed boundary, which completes the cell's perimeter seal. The terminals are positioned symmetrically with respect to the center axis 315, and preferably the terminals are in the center plane of the battery cell. Accordingly, battery cell 300 may be "flipped" 180 degrees around center axis 315 with the result that each terminal is in the same position that the opposite terminal held prior to "flipping" the cell (relative to viewing the cell along axis 315 facing the edge containing the cell terminals). This symmetry allows one to stack up a series of cells without regard to whether the negative terminal is on the left or right side (as viewed along center axis 315), and in either orientation the resulting rows of terminals will each be aligned in a straight row, and thus may be easily interconnected to one another. Specifically, battery modules can be built with different combinations of series and parallel connections by (1) selectively orienting the battery cells so that the terminals on the same left/right side of adjacent battery cells have either the same or opposite polarities; and (2) electrically connecting groups of these adjacent terminals using busbar components (described below) with connections between terminals of opposite polarities forming series configurations and connections between same-polarity terminals forming parallel configurations. The negative terminal's material is copper and the positive terminal's material is aluminum to compliment the cell's chemistry and internal construction. The terminal length is small compared to other commercially-available designs. The opportunity to use compact terminals is clarified in the subsection entitled 'Busbar Components'. For the purpose of explanation, ancillary negative and positive symbols have been added to the cell of FIG. 3.

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[0045] The battery cell's non-rigid flexible pouch will physically expand if a worst case electrical overload incident occurs. Pressure relief (also known as out-gassing) during an electrical overload incident may be provided through the use of a "tooth" mounted externally to the cell, either as alternative to or in combination with pressure relief vent feature 309. The tooth will puncture the cell in a controllable manner if the cell were to expand into contact with it. This tooth is described further below.

[0046] FIG. 4 shows zipper fuse 308 integrated into an electrical terminal 302 of battery cell 300. Zipper fuse 308 includes two rows, each row made up of a slot-shaped hole 310 at one end of the row and circular-shaped holes 311 between the slot-shaped hole 310 and the other end of the row. This fuse is referred to as a 'zipper' fuse because looks like a zipper. The zipper fuse is incorporated in the cell's negative terminal. The geometry, number and position of the zipper fuse slot holes 310 and circular holes 311 are selected so that the fuse actuates within a specified time period that prevents a cascading failure mode with the adjacent cells or potentially all of the cells in a module. Specifically, the fuse slot holes help to ensure a consistent pattern of fuse activation by concentrating current "hot spots" near the region around the holes, to promote fuse activation to start in those areas. The use of circular holes in addition to the slots helps, among other things, to maintain the structural integrity of the terminal prior to fuse activation. The positioning of the two parallel rows of slot holes and circular holes creates a region 312 between the rows that is partially thermally isolated from the remainder of the terminal, which concentrates the heat developed during fuse activation to help make the activation more complete and consistent.

BATTERY SUBASSEMBLY

[0047] FIG. 5 shows a group of cell subassemblies, including subassemblies 30a and 30b. Subassembly 30a includes a heatsink 400a having two large, flat surfaces, as well as a battery cell 300a which also has two large, flat surfaces. Battery cell 300a is adjacently mounted to heatsink 400a such that the second large, flat surface of battery cell 300a abuts the first large, flat surface of heatsink 400a. Subassembly 30a also includes a compliant pad 401a having two large, flat surfaces and a second battery cell 310a having two large, flat surfaces. Compliant pad 401a is adjacently mounted to battery cell 300a such that the first large, flat surface of battery cell

300a abuts the second large, flat surface of compliant pad 401a. Compliant pad 401a is also adjacently mounted to battery cell 310a such that the first large, flat surface of compliant pad 401a abuts the second large, flat surface of a second battery cell 310a. This arrangement forms a repeating “cassette” configuration of a battery cell, a heatsink, another battery cell, and a compliant pad, followed by another grouping of a battery cell, a heatsink, another battery cell, and a compliant pad, and so on. Compliant pad 401a helps to distribute pressure between the subassemblies when they are banded together between the pressure plates, as well as allowing expansion/contraction of cells during use. Similarly, subassembly 30b is mounted adjacently to subassembly 30a. Subassembly 30b includes a heatsink 400b having two large, flat surfaces, as well as a battery cell 300b which also has two large, flat surfaces. Heatsink 400b is adjacently mounted to battery cell 310a such that the first large, flat surface of battery cell 310a abuts the second large, flat surface of heatsink 400b. Battery cell 300b is adjacently mounted to heatsink 400b such that the second large, flat surface of battery cell 300b abuts the first large, flat surface of heatsink 400b. Subassembly 30b also includes a compliant pad 401b having two large, flat surfaces and a second battery cell 310b having two large, flat surfaces. Compliant pad 401b is adjacently mounted to battery cell 300b such that the first large, flat surface of battery cell 300b abuts the second large, flat surface of compliant pad 401b.

[0048] As shown in both FIG. 5 and FIG. 2, all of the heatsinks are bonded to the adjacent cells during the module’s assembly process via a dispensed cure-after-assembly adhesive that is also used to bond the compliant pads to the adjacent cells. The group of cells, pads, and heatsinks creates the main stack subassembly for every module, which fosters a scalable architecture. In other words, one can readily change the size of the module by simply adding or subtracting identical subassemblies. The subassemblies may or may not be pre-assembled as such and then later assembled together as sub-units into the battery module’s main stack. The assembly of the main stack may be accomplished as a one-step process where all of the battery cells, heatsinks and compliant pads are assembled together in one process. The concept of a ‘subassembly’ is used as a convenient label for a logical group of components when describing the overall structure of the battery module.

[0049] Also as shown in FIG. 5, each of the battery cells (e.g., 300a, 310a, 300b and 310b) are mounted on respective heatsinks (e.g., 400a and 400b) with their positive terminals oriented

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on the left or right as viewed end on at the terminals. For example, in FIG. 5, battery cells 300a, 310a, and 300b are each oriented with their negative terminals to the right from the perspective of FIG. 5, while battery cell 310b is mounted with its positive terminal to the right. Other orientations of groups of battery cells (e.g., flipping battery cell 310b 180 degrees so that its positive and negative terminals exchange positions) allow different combinations of series or parallel connections between the terminals depending on which groups of adjacent terminals are electrically connected by the busbar jumpers and terminals described below.

[0050] FIG. 6 shows a view of a cell subassembly 30 from which battery module 10 is built. FIG. 6 shows a heatsink 400 joined to a battery cell 300, which in turn is joined to a compliant pad 401. FIG. 6 does not show the adjacent cell that would be joined to compliant pad 401 as described above and in FIG. 5. Referring still to FIG. 6, when subassembly 30 is stacked adjacent to another subassembly, the metallic heatsink 400 contacts two cells 300 and 310. Each cell contacts the heatsink via one of the cell's two flat surfaces to facilitate thermal management via conduction or forced convection heat transfer. This results in requiring only about half the number of heatsinks per module as compared to using a heatsink for each cell. The benefit is a compact module which has an improved power output / physical volume ratio compared to other commercially available modules some of which have larger and more elaborate heatsinks.

[0051] The heatsink is made from an aluminum sheet that is stamped and formed using standard tooling practices. The heatsink has an electrically-isolative coating to ensure that a worst-case electrical overload incident does not allow an electrical short circuit path to any or all of the heatsinks. The coating thickness is preferably chosen so as to not substantially impede heat transfer. Protective coatings and application processes may be selected to simultaneously provide the electrical short circuit protection during an electrical overload incident, permit effective heat transfer, and reduce cost.

[0052] Another function of the heatsink is to protect the cells from foreign objects during a severe vehicle crash. As discussed previously, the heatsink's formed wings 403 nest with an adjacent heatsink's profile to provide a satisfactory level of cell protection with respect to complexity, cost, and the module's physical volume. These wings are formed by folding three of the heatsink's edges at approximately a right angle to the large flat surfaces of the heatsink.

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[0053] Referring now to FIG. 5, an indentation (404a, 404b) is formed from the heatsink by using additional bends near the area of the wing that meets the large flat surfaces of the heatsink to receive a portion of an adjacent heatsink's wings. For example, indentation 404b is formed to receive a portion of wing 403a. This makes the heatsinks with their internal components easier to stack on top of one another. The battery pack's enclosure may be the major protection barrier during a crash, so the heatsinks are another barrier to further improve the battery module's safety capability.

[0054] A second type of heatsink with short formed wings that envelop only one battery cell (as opposed to the "full-height" heatsinks that envelop two cells) is used if a module has an odd cell count, where the second type of heatsink is located at one end of the stack of subassemblies. In these odd cell count configurations, no battery cell is attached to the bottom of the bottom-most heatsink, as is shown in FIG. 5.

[0055] FIG. 7 shows this second type of heatsink 420 that nests into an adjacent cell subassembly 421. Heatsink 420 is joined to battery cell 320 in the same manner as the full-height heatsinks are attached to adjacent cells. FIG. 7 also shows the use of two compliant pads, 422a and 422b, which are used at both ends of a module's main stack in order to distribute and equalize the clamp force imparted to the stack by the pressure plates. This second type of heatsink is also used if a module has an even cell count, but even cell count modules also use a third type of heatsink.

[0056] A third type of heatsink with medium-height formed wings that envelop only one battery cell may also be used if a module has an even cell count, where the third type of heatsink is located at one end of the stack of subassemblies opposite the end with the second type of heatsink. In these even-cell-count configurations, this third type of heatsink is nested adjacent to a heatsink that would otherwise have an exposed battery cell. For example, referring to FIG. 8, this third type of heatsink 430 rests beneath the lower-most heatsink 429 to help protect a single battery cell 321 located between heatsinks 429 and 430. Two compliant pads (not shown) are adjacently mounted to each other, and one side of one of the compliant pads is adjacently mounted to heatsink 430 at the end of the module's main stack of subassemblies.

[0057] While these additional types of heatsinks cause additional components to be released and produced in the manufacturing process, they fully respect the principle that a heatsink contact every cell via one of the cell's two large flat surfaces, and that every cell be protected from foreign objects during a severe vehicle crash.

[0058] FIG. 9 shows a heatsink 400 with pressure release teeth 410 and 411 mounted through holes in the heatsink. One tooth 410 is oriented so that its sharp end points toward one of the heatsink's attached battery cells, and if a second cell is joined to the heatsink, the other tooth 411 is pointed toward that cell. An additional pair of teeth may be positioned elsewhere on the heatsink 400 or on the busbar support connected to the heatsink. The tooth's material is molded plastic and it is either heat-staked or ultrasonically-welded to a plain hole in the stamped aluminum heatsink. If an electrical overload incident occurs, the cell's non-rigid flexible pouch will physically expand due to rapid internal gas generation. As it expands, the force of the internal pressure will press the pouch against the tooth, puncturing the cell and providing a controlled relief of the internal pressure. The battery cell has a port that helps define a specific region in which the pouch can expand, and within which the sharp point or edge of the tooth is at least partially situated to puncture the pouch when it expands. Although the battery cell can expand along multiple expansion paths, the port helps to define and promote expansion along at least one such path. The expansion of the pouch may be also be partially controlled by creating a region of the pouch of increased expandability relative to the rest of the battery cell. In some embodiments the port may expose a region of increased expandability. In any of these embodiments, the sharp point of the tooth is situated along at least one of the expansion paths of the pouch.

[0059] FIG. 23 shows two additional alternative embodiments of pressure release teeth. Tooth 450 includes a point 451 and two channels 452. Tooth 455 includes two points 456 and two channels 457 extending away from the region of the point. The structure of tooth 455 (along with other embodiments that use a sharp edge instead of a point) may help promote the formation of a 'tear' or rip in the pouch to promote gas escape. In each of these types of teeth, the channels help to provide a path for the gases to escape from the battery cell and to ensure the pouch does not inadvertently re-seal itself closed (despite the puncture) against the tooth. Other orientations

and combinations of sharp points and channels may also be used, as may other combinations of sharp edges and/or channels.

[0060] The tooth is produced from a non-conductive material to help prevent a short between the interior of the battery cell and the heatsink.

[0061] As indicated in FIGS. 5 and 6, a compliant pad 401 contacts every cell via one of the cell's two large flat surfaces to provide the following functions: (a) Provide uniform pressure distribution for cell life and performance, (b) provide constant pressure on the cell's active area throughout the life of the cell, (c) compensate for the cell's thickness changes due to the inherent nature during charge and discharge cycles, and (d) compensate for the module's length changes due to the thermal expansion and contraction of the cell and other module components such as the heatsinks, pressure plate, and clamping bands.

PRESSURE PLATE COMPONENT

[0062] FIG. 10 shows a pressure plate 50. Pressure plate 50 is a rigid structure imparts a static clamp force to the module's main stack of cells, compliant pads, and heatsinks. The structure also provides means by which the module can be attached inside a battery pack's enclosure. This component may be referred to as a 'pressure plate' to accentuate the primary function. The plate's material is a molded plastic polymer with defined temperature exposure and flammability ratings. The plate has a prominent flat surface to mate with one end of the module's main stack, which has two compliant pads at both ends to help distribute and equalize the clamp force.

[0063] The side of pressure plate 50 that faces away from the subassemblies has a matrix of reinforcing ribs 520 to enhance its structural rigidity and complement the molded part design practice of targeting a uniform wall thickness. The matrix has a non-uniform pattern because the ribs also form pockets which accommodate large electronic components that are soldered to the module's active control printed-circuit board (PCB) subassembly (not shown). The PCB subassembly includes a circuit board and components, where the majority of the components are on one side of the board. The PCB subassembly is mounted component-side down on pressure

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plate 50. The nesting of the electronic components preserves valuable space and contributes to a compact module length at the plate, which helps achieve an excellent power output to physical volume ratio. The plate's pockets are also valuable because they can be used as receptacles for vibration dampening elements (not shown) to grip the upper surfaces of the large electronic components that are soldered to the module's active control PCB subassembly. The elements prevent excess stress and fatigue at the solder joints on the PCB. The preferred vibration dampening element is a die-cut pad with an elastomeric closed-cell non-hydroscopic polyurethane foam material and pressure-sensitive adhesive material on one side, which both have defined temperature exposure and flammability ratings.

[0064] The PCB assembly may be either passive or active. Passive PCB assemblies may be sufficient for smaller battery modules, while larger modules use one or two active PCB assemblies, with one assembly mounted on each of the pressure plates at each end of the module. The active PCB control subassembly has three right-angle PCB electrical connector headers that are selectively-soldered to industry-standard plated through holes in the PCB. All other electronic components are SMT (Surface Mount Technology) devices which are reflow-soldered to industry-standard pads on both sides of the PCB. Precautions are taken to ensure a proper electrical isolation between the module's steel bands and the PCB because the bands are routed nearby. PCB trace, via, and component keep-in and keep-out zones are carefully defined for both sides of the PCB to avoid electrical interference. The module's life capability may be improved by applying a silicone-based or polyurethane-based conformal coating to both sides of the PCB, which will reduce the growth of dendrites between adjacent low-current high-impedance copper traces.

[0065] Side 510 of pressure plate 50 is opposite the side with the matrix of reinforcing ribs 520, and faces the stack of subassemblies. Side 510 may be flat, or may form a non-flat shallow convex or concave domed profile to further optimize the force distribution within the module's main stack.

[0066] Pressure plate 50 has two shallow tracks 501 to receive thin steel retention bands which impart the static clamp force to the module's main stack. The tracks have a domed profile to help distribute and equalize the clamp force. Appropriate dome profiles may be determined

by measurements taken using existing sensing products specifically developed and marketed for this type of instrumentation application.

Pressure plate 50 also has four passages with recessed sockets 503, 504, 505, and 506 (also known as counter-bores) to receive steel fastener components such as cylindrical sleeves, washers, bushings, and retention bolts to foster a flexible attachment strategy. The present configuration permits a module to be mounted inside a battery pack's enclosure or on a battery station's rack via one of three mounting orientations, which is adequate for the majority of existing and predicted applications and customer requirements.

[0067] The pressure plate may be formed from two separate portions which are vibration-welded together. Each portion would have half of the attachment hole and recessed socket profiles. After welding, complete circular holes and sockets would be formed. The benefit of this approach would be that the two portions could be molded without long active slides in the molding tool that are perpendicular to the tool's principle die draw direction.

[0068] Pressure plate 50 has two recessed areas 508 to receive a steel busbar nut or nuts (not shown). The nut's design is intentionally simple to be a cost-effective solution. The nut has three threaded holes for attachment. The center hole grips a steel fastener (not shown) that retains the busbar nut to the pressure plate. The two other holes grip steel fasteners that attach an external power lug and wiring harness to the module's negative or positive busbar, which are explained in subsequent sections.

BAND COMPONENT

[0069] FIG. 11 shows steel band 530, which is one of two steel bands used to envelop the module's main stack of cells, compliant pads, heatsinks, and pressure plates. Each steel band 530 sits in one of the shallow tracks 501 of pressure plate 50. Two bands are sufficient and three bands are not necessary, if the module has seventy-six (76) cells or less. More bands can be used if desirable. The length of steel band 530 is defined by the required clamp force to properly compress all of the compliant pads in the main stack, and it is retained via an existing released and qualified steel buckle 531 that is permanently crimped onto the band. A hand-held pneumatic applicator with a pneumatic actuator may be used to tension the band and crimp

buckle 531, and the applicator may also have a mechanism to trim the band's extra tail after buckle 531 is crimped. Compared to an alternative approach that uses very long steel tie rods and retention nuts at both ends, using the bands and buckles is a more compact approach. The use of the same band and buckle and installation process for every module fosters a scalable architecture. Another approach is to tension and weld the band, instead of using the crimped buckle. The pressure plate 50 may incorporate flat or indented areas within the shallow tracks 501 to accommodate the clamping band buckles and to more evenly distribute the pressure in the region of the buckles. Pressure plate 50 may also have four corner rounds along each track 501 to ensure that the tensile forces are equalized in the straight portions of the two bands.

[0070] An existing released and qualified hand-held computer-controlled electric applicator with a closed-loop servo control may be used instead of the standard pneumatic actuator. This may increase applied static clamp force precision and reduce band installation and buckle crimping process cycle times. While the pressure plates and bands help hold the battery module together physically, the module's busbars (described next) connect the system electrically.

BUSBAR SUPPORT COMPONENT

[0071] The electrical interconnection between the module's adjacent cells is an important feature, which includes the registration of the flexible and fragile cell terminals relative to each other, and includes preventing an accidental contact between adjacent terminals that will not be electrically connected for the intended application. FIG. 2 shows how all of the cells are securely retained and registered relative to each other in the module's main stack, except for the cell terminals, e.g., 101 and 102.

[0072] FIG. 12 shows a robust, compact, and cost-effective solution using a molded plastic component. The component may be referred to as a 'busbar support' to accentuate its primary function. The standard busbar support 600a mates with the upper edge of one heatsink 600a and also envelops the two cells 300a and 310a. Cells 300a and 310 are each affixed to respective a side of the heatsink, and each has two electrical terminals (the negative terminals of each battery cell 300a and 310a are shown in FIG. 12) which extend through ports in the busbar support. A busbar support is used for every subassembly and fosters a scalable architecture. For example, busbar support 600b mates with the edge of the second type of heatsink, heatsink 400b.

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[0073] FIG. 13A shows another view of a busbar support 600 mounted to heatsink 400. The standard busbar support has nine features/functions:

1. Seven flex tabs 608 (four shown) as well as two wedge-shaped latches 609 to grip two slots (component 406 in FIG. 5) in a heatsink.
2. Rectangular central port 604 to interface with a thermistor 605 that has an over-molded elastomeric grip.
3. Four tapered ports 601 to permit the simultaneous insertion and registration of four cell terminals.
4. Main body 610 that supports a busbar during a cell zipper fuse actuation incident. By maintaining a separation between any remainder of the terminal and the busbar, the busbar support prevents an accidental reconnection of the faulty cell to the busbar, which could cause a cascading failure mode with the adjacent cells.
5. Two fixed latches 602 and two flex latches 603 to grip two separate busbar components (not shown) during the laser welding of the busbars to the cell terminals. This feature helps eliminate the need for a special laser welding fixture. As described below, it functions as an assembly jig that secures the busbar components in registration with the cell terminals prior and during welding. These latches retain each busbar component in a substantially fixed position relative to the heatsink and the attached battery cells. The tapered ports and main body retain the terminals of each of the battery cells in a substantially fixed position relative to the heatsink and to the busbar component.
6. Eighteen reliefs 607 to ensure adequate clearance to any busbar electrical connection rivet.
7. Central channel 606 to permit the routing of the module's voltage sense wiring harness and thermistor wiring harness.
8. Four flex fingers (611) to retain the two wiring harnesses (not shown) before the busbar covers are installed.

9. Two screw bosses 612 at the ends for the attachment of the busbar covers.

[0074] In addition, FIGS. 13B and 16 show a second busbar support 650 that has been developed to envelop only one cell if a module has an odd cell count. While this decision causes another component to be released and produced, it fully respects the principle that every cell terminal be registered and protected from an accidental contact with an adjacent terminal. The module's vibration endurance robustness may be improved by adding two or more additional slots in the heatsink near the center and/or adding two more wedge-shaped latches in the busbar support.

BUSBAR COMPONENTS

[0075] Busbar components consist of busbar jumpers, which electrically connect the module's adjacent cells, and busbar terminals, which electrically connect one or more battery cell terminals to each of the external terminals of the battery module. FIG. 14 shows a robust, compact, and cost-effective interconnection approach using these busbar components to enhance the module's life capability. This approach avoids using threaded fasteners for any of the electrical connections inside the module and to instead use precision welds that are produced with adaptive automatic computer-controlled processes.

[0076] FIG. 14 shows several busbar jumpers 700 each held by busbar supports 600. For each of the busbar supports through which a battery cell's terminal extends, the busbar jumper connected to that terminal is gripped between the support's fixed latch and its opposing flexible latch. The latches retain the busbar jumper against the terminal and prevent its movement.

[0077] FIG. 15 shows a bimetallic busbar jumper 700. The battery module uses a group of busbar jumpers 700, each including a copper portion 701 that is laser welded to a group of cell negative terminals which are made of a copper material, and an aluminum portion 702 that is laser welded to a group of cell positive terminals made of an aluminum material. The busbar jumper's 180-degree bends 703 define an inside surface 704 in which the cell terminals are nested during assembly. The portions of the busbar that have the bends are continuous pieces of metal. Precision laser welding is used to partially melt and metallurgically connect the busbar jumpers to the terminals in order to avoid ultrasonic welding that could inflict too much energy

into a cell terminal and in turn damage a cell's internal electrical connections. A liquid welding treatment is applied to the outer surface (opposite inner surface 704) of the busbar jumper's bends 703. During welding, laser energy will be aimed at this surface. This treatment creates a finish that decreases the reflectivity of the laser beam during laser welding of the highly reflective surfaces of both aluminum and copper. This treatment may be a Nickel or Tin coating that provides for better absorption of the Nd-YAG laser beam wavelength. This allows one to minimize the energy required to weld and allows for the welding of cell terminals to be conducted without exceeding a maximum temperature limit of the cell terminal's seal. The laser beam's energy penetrates the busbar's 180-degree bend 703 and creates a molten bead inside the busbar's bend 704 and at the tip of the cell's terminal (not shown). The welding laser is aimed at the busbar's bend 703 at an angle substantially head-on to the end of the battery terminal and toward the outer surface of the bend as shown by angle of attack 708.

[0078] FIG. 25 shows an additional view 735 of the configuration of a welding laser 730 and a bimetallic busbar jumper 700, with the laser beam 733 directed at the busbar's bend at an angle of attack 708 that is substantially head-on to the end of the battery terminal. A second view 740 shows the configuration of view 735 as seen along line of reference 736 (i.e., view 735 rotated 90 degrees around the vertical z axis). View 740 shows laser 730 moving from the right side end of the busbar's bend 742 to the left, where the laser beam 733 moves in a direction of travel parallel to the channel, with the laser beam 733 directed at a slight angle 741 with respect the bend 742, with angle 741 opposing the direction of travel of the laser 730 to prevent the laser beam from backreflecting into the laser optics and causing damage. This results in laser beam 733 directed at an angle slightly less than perpendicular to the direction of travel of the laser beam. During welding, the laser 730 may move relative to the busbar and battery terminal being welded, the busbar and battery terminal assembly may move relative to the laser, or both may be moved relative to each other. The result in any case is that the busbar and battery terminal are attached to each other along the length of the channel in which the battery terminal resides.

[0079] FIG. 26 shows side views of the attachment of a busbar component to battery cell terminal both before and after attachment. View 770 shows a bend 704 in a busbar 700 forming a channel in which battery terminal 771 is positioned,. View 775 shows these components after

welding in which the battery terminal 776 is attached to an inside corner of a bend in a busbar 777 by a resolidified pool of metal 778.

[0080] Welding processes such as laser welding or other conventional welding processes may not be practical to use to join a bimetallic jumper busbar's two portions together due to the dissimilar materials and known metallurgical constraints. Instead, busbar jumper 700 employs an ultrasonic roller seam welding process to create a linear weld 705. The ultrasonic welding of the jumper busbar's two portions is performed separately from the module so that ultrasonic energy is not introduced into a cell terminal, in turn risking damage to a cell's internal electrical connections. As noted above, the busbar supports act as welding jigs. The busbar supports hold the busbar components in place with the cell terminals nested in the slots defined by the bends in the busbars until the busbars are laser welded to the terminals as discussed above.

[0081] To further balance and optimize the electrical current characteristics of the bimetallic jumpers, the cross-sections, widths and/or thicknesses of the jumper busbar's two portions—whose materials are aluminum and copper—may be independently tailored to achieve similar resistances through each portion. In manufacturing the busbar jumpers, extruded cut-to-length profiles for one or both of the bimetallic jumper busbar's two portions may be used instead of sheet stamping and forming processes in order to reduce cost. In one configuration, the copper portion of the busbar jumper is stamped and the aluminum portion is extruded.

[0082] FIG. 16 shows a busbar terminal 750 secured in part by busbar supports 600 and 650. Busbar supports retain the busbar terminals in the same manner as the supports retain the busbar jumpers. Busbar terminal 750 is laser welded to a corresponding terminal of battery cells 300a, 310a, and 320. Battery modules use a monometallic negative busbar terminal with a copper material at one end of the module's main stack and a monometallic positive busbar terminal with an aluminum material at the other end of the module's main stack. The busbar terminals are secured by steel busbar nuts 760 that are attached to the sockets 508 of the pressure plate 50. The busbar terminal 750 has a tapered central portion 751 that acts as a module fuse if a worst-case electrical overload incident occurs. The fuse will have a tendency to melt at the narrow portion where the current density is the highest. The module's safety capability may be improved by adjusting the actuation response time of the two module fuses by adding zipper fuse

holes and slots to the busbar terminals in a similar manner to the way zipper fuses are integrated into the battery cell terminals.

[0083] FIG. 17 shows the installation of busbar terminal 750 to pressure plate 50. Busbar terminal 750 is attached to a steel busbar nut (not visible under busbar terminal in FIG. 17). The busbar nut is attached to one of the pressure plate's sockets 508a. Busbar terminal 750 is connected to an external power lug and wiring harness (not shown) as described earlier. In addition, a stamped copper busbar nut bridge 780 may be connected to busbar terminal 750 and also connected to pressure plate socket 508b through busbar nut 760b. Busbar nut 760b is secured to pressure plate 50 through a center hole that grips a steel fastener disposed in pressure plate socket 508b. The bridge is an accessory that permits an optional attachment site for the module-to-module high-power wiring harness.

WIRING ATTACHMENTS

[0084] FIG. 18 shows a busbar terminal 750 with two variations of clips used to attach wiring, such as voltage sense wiring harnesses, to busbar terminals and busbar jumpers. From one side, clip 791 is u-shaped and substantially convex, while clip 790 is w-shaped. Either or both of clips 790 and 791 may be used to connect wiring. Voltage sense wires are ultrasonically welded to the clips prior to attaching the clips to the busbar components. The clips have one or more teeth 793 that bite into the busbar jumpers or terminals so that the clips can be positioned and retained in place until a laser welding operation fastens the clips to the busbar. The clips may be of stamped copper or aluminum corresponding to and compatible with the type of busbar to which they will be attached. Clips have notching 792 for one metal type to indicate the type of clip for manufacturing using automatic vision systems. These clips are laser welded to the busbar components at the same time the busbar components are welded to the battery cell terminals and share a common weld. Using the same welding technique described above for attaching busbar components to battery terminals, a laser is directed through the clip and the underlying busbar component and pointed at the end of the terminal that rests in the u-shaped bend of the busbar component. In so doing, a single welding operation welds all three components (the clip, the busbar component, and the battery terminal) at the same time. The u-shaped clips may also be laser welded to the busbar component without sharing a common weld.

[0085] FIG. 19 shows a side-view of w-shaped clip 790 with the clip's teeth 793 bent slightly inward for installation on a busbar. Teeth may or may not be required to secure the clip to the busbar until it is welded if the clip is designed with an interference fit such that the interference would provide the retaining function.

[0086] FIG. 20 shows a busbar terminal 750 with a clip 794 for attaching a thermistor 795 to the busbar terminal. The thermistor's head is bonded inside the clip's retainer with a dispensed cure-after-assembly epoxy adhesive. The neck of the thermistor's head contacts the adjacent tab 796 so that the head has a defined repeatable location. Coined chamfers 797 to the retainer's upper edges help prevent damage to the thermistor's head when it is installed.

BUSBAR COVERS

[0087] FIG. 1 shows three busbar covers 40. Battery modules use a group of molded plastic covers to protect the module's busbars and other internal components, such as the voltage sense wiring harness and thermistor wiring harness, from any accidental contact by external foreign objects, especially if they are metallic.

[0088] FIG. 21 shows a busbar cover 40a without the cover's main flat skin so that the relative fits may be witnessed. Busbar cover 40b is also shown, including the cover's main flat skin. Each of the covers has a matrix of reinforcing ribs, including 801, 802 and 803, to enhance its structural rigidity and to also redirect and distribute any adverse external forces to the module's busbar supports and heatsinks instead of the busbar terminals 750, busbar jumpers 700 and/or cell terminals. Busbar covers envelop the module's busbars to help prevent adjacent busbars from contacting each other and causing electrical short circuit paths during a worst-case electrical overload incident or severe vehicle crash. Certain ribs, e.g., rib 802, extend deeper into the battery module than other ribs and in between the busbar jumpers, e.g., 803, to help prevent contact between adjacent busbars, while ribs such as 803 are less deep to avoid distributing forces to the busbar terminals, busbar jumpers or cell terminals. Alternatively, the battery module may use lower-cost, simpler covers which have an overlap joint and fewer vertical contact tabs. The disadvantage with this latter approach is that the module's robustness to withstand vertical external forces may be diminished.

SCALABLE ARCHITECTURE

[0089] The above described features yield a scalable architecture. The term ‘scalable architecture’ refers to a flexible configuration which facilitates the rapid engineering, development, qualification, and production of battery modules that have different quantities of battery cells, subgroups with cells that are electrically connected in parallel, and subgroups that are electrically connected in series. This flexibility enables a battery supplier to tailor the electrical characteristics of many different modules and to satisfy diverse customer performance specifications. For example, the present A123Systems prismatic battery module family with the ‘3P’ configuration is shown in FIG. 22. The seven members of this family are the 23S3P, 22S3P, 16S3P, 13S3P, 11S3P, 6S3P, and 1S3P modules, identified respectively in FIG. 22 as 907, 906, 905, 904, 903, 902, and 901.

[0090] FIG 24 shows various busbar component configurations for the following members of the A123Systems prismatic battery module family, 13S3P, 23S2P, 4S2P, and 4S6P identified respectively in FIG. 23 as 950, 951, 952, and 953.

WHAT IS CLAIMED IS:

1 1. A battery system comprising:

2 a plurality of subunits each of which comprises a heatsink and a battery cell having a top
3 end and first and second voltage terminals both of which extend out of the top end of the battery
4 cell, said first and second terminals of each battery cell being symmetrically positioned with
5 respect to a centerline of that battery cell, wherein all of the battery cells among the plurality of
6 subunits are arranged so that their first voltage terminals are aligned along a first row and their
7 second voltage terminals are aligned along a second row;

8 a plurality of identical busbar supports equal in number to the plurality of subunits, each
9 busbar support among the plurality of busbar supports having two slots and being mounted on a
10 corresponding different one of the subunits with each of the first and second terminals of the
11 battery cell for that subunit extending up through a corresponding different one of the two slots;
12 and

13 a plurality of bimetallic busbars, each one supported by a different corresponding subset
14 of the busbar supports and electrically connected directly to either a first or second terminal of
15 each of the battery cells of each of the modules on which those busbar supports are mounted.

1 2. The battery system of claim 1, wherein the battery cells are prismatic battery cells.

1 3. The battery system of claim 2, wherein both the first row and the second rows are
2 situated on the same side of the battery system.

1 4. The battery system of claim 3, wherein each of the plurality of subunits are identical
2 to one another except for the orientation of each of the battery cells of the subunits with respect
3 to the battery cell's centerline.

1 5. The battery system of claim 3, wherein all but one of the heatsinks are identical to
2 each other.

1 6. The battery system of claim 3, wherein all but two of the heatsinks are identical to
2 each other.

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1 7. The battery system of claim 3, wherein each of the plurality of busbars electrically
2 connects at least two adjacent terminals of the same row.

1 8. The battery system of claim 3, further comprising a first pressure plate and a second
2 pressure plate wherein the plurality of subunits is arranged as a stack of subunits and wherein the
3 stack of subunits is located between the first pressure plate and the second pressure plate.

1 9. The battery system of claim 8, wherein one or more compliant pads are located
2 between the first pressure plate and the neighboring subunit.

1 10. The battery system of claim 8, further comprising a band wherein the band encircles
2 the first and second pressure plates and the plurality of subunits.

1 11. The battery system of claim 3, wherein each of the plurality of subunits further
2 comprises a second battery cell having a top end and first and second voltage terminals both of
3 which extend out of the top end of the second battery cell, said first and second terminals of each
4 second battery cell being symmetrically positioned with respect to a centerline of that battery cell
5 wherein each of the second battery cells among the plurality of subunits are arranged so that their
6 first voltage terminals are aligned along the first row and their second voltage terminals are
7 aligned along the second row.

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ABSTRACT OF THE DISCLOSURE

A battery system including: a plurality of subunits each of which has a heatsink and a battery cell and two voltage terminals symmetrically positioned with respect to a centerline of that battery cell, wherein all of the battery cells are arranged so that their voltage terminals are aligned along two rows; a plurality of identical busbar supports equal in number to the plurality of subunits, each having two slots and mounted on a corresponding different one of the subunits with each of the terminals of the battery cell extending up through the two slots; and a plurality of bimetallic busbars, each one supported by a different corresponding subset of the busbar supports and electrically connected directly to either a first or second terminal of each of the battery cells of each of the modules on which those busbar supports are mounted.

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FIG. 1

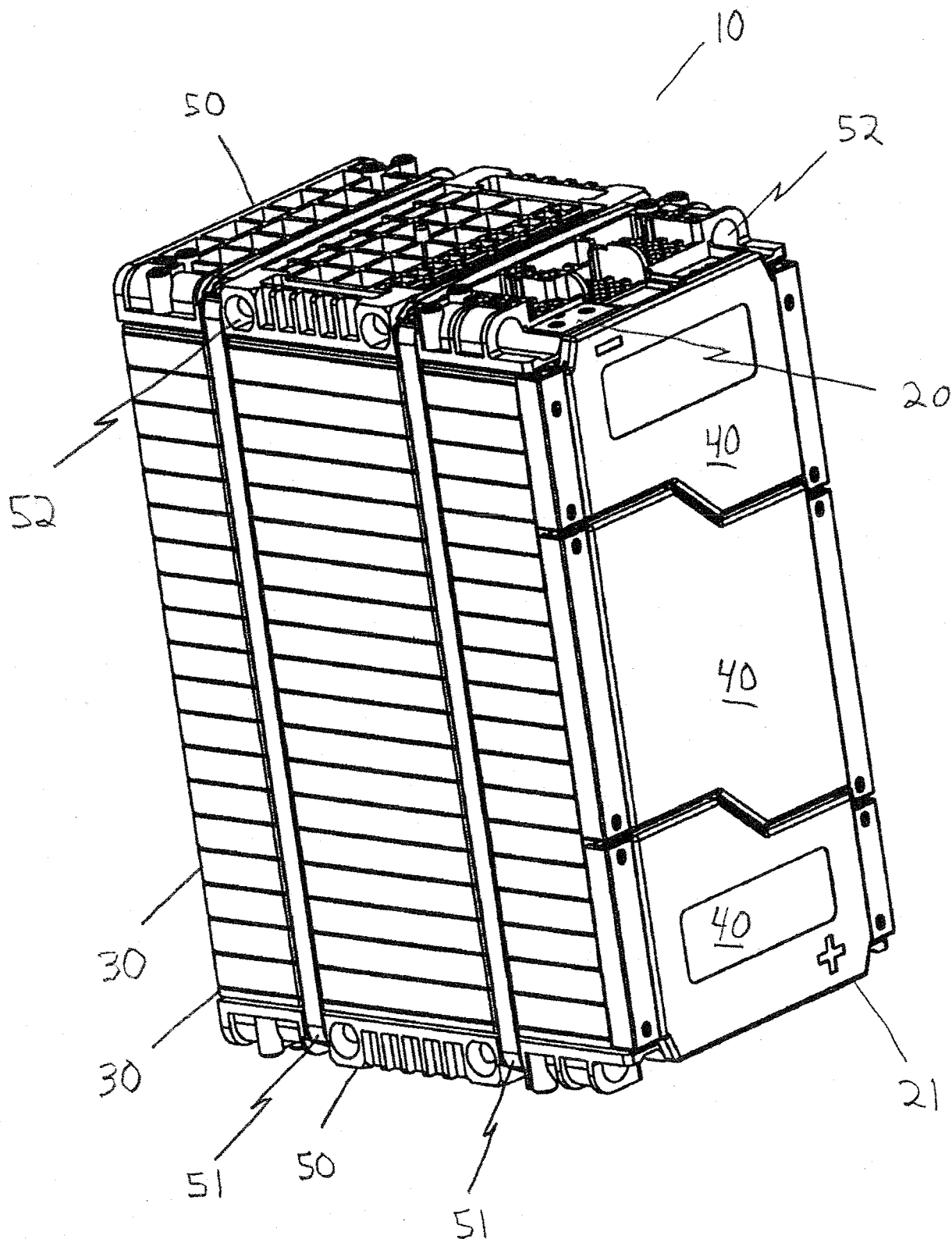


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FIG. 2

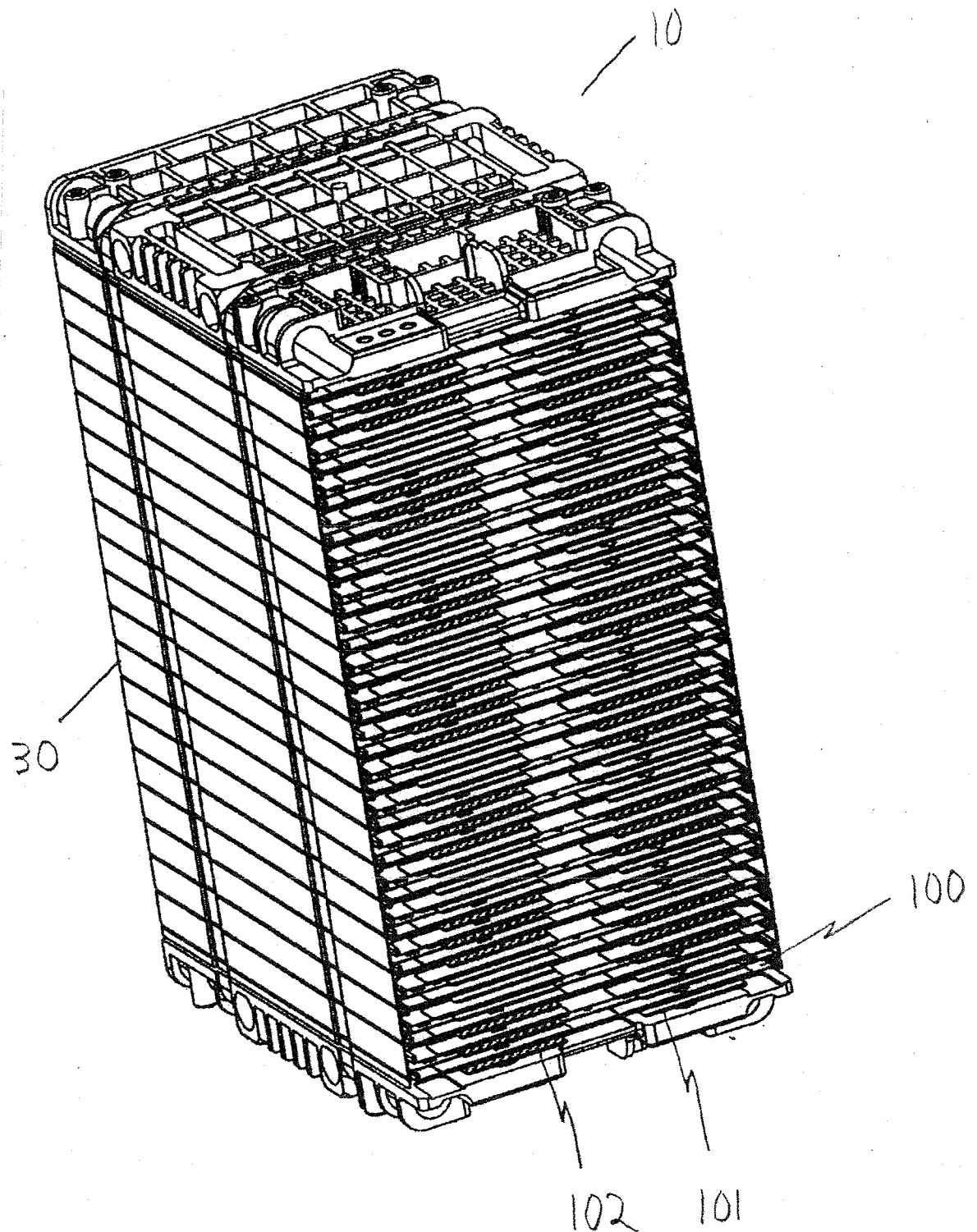


FIG. 3

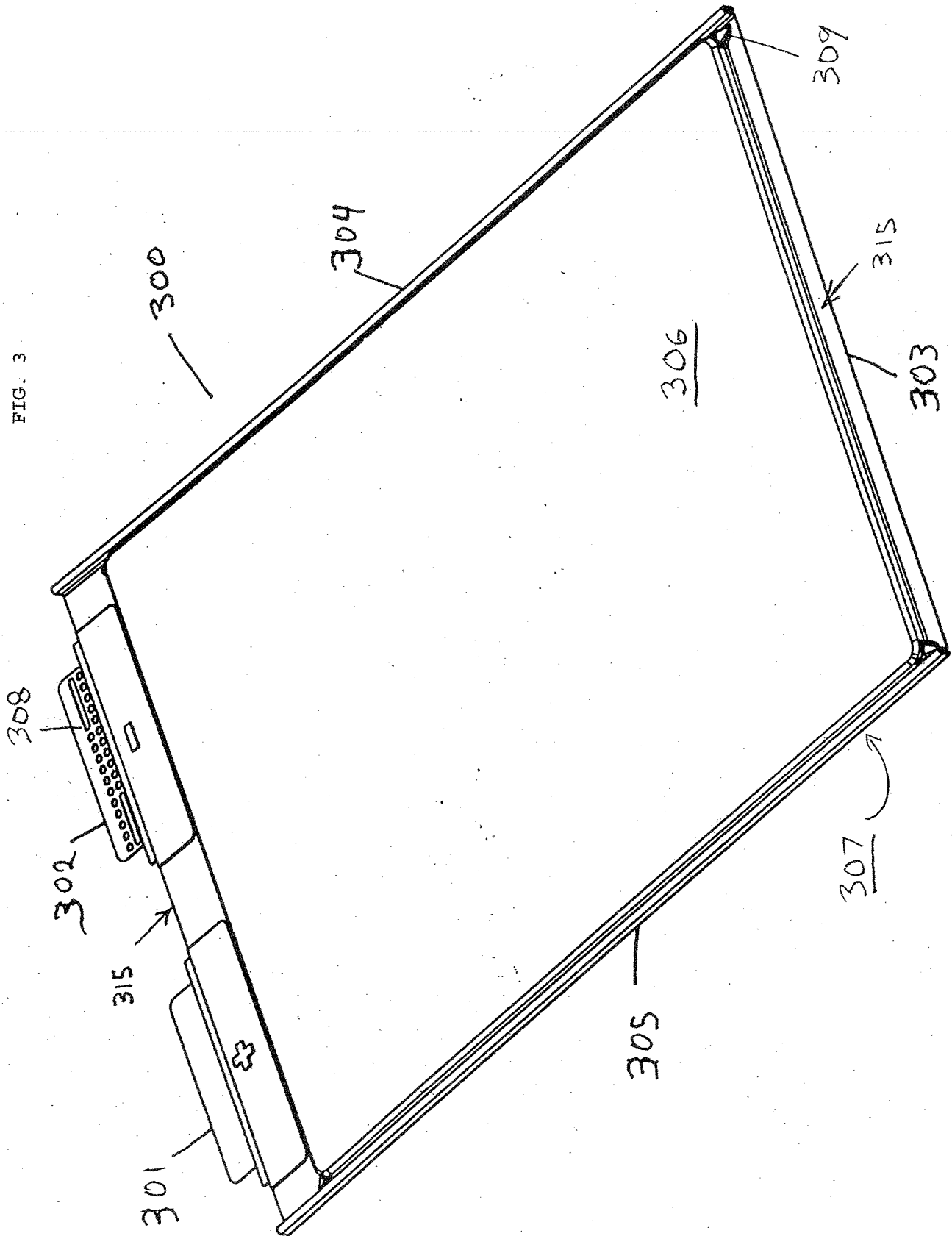


FIG. 4

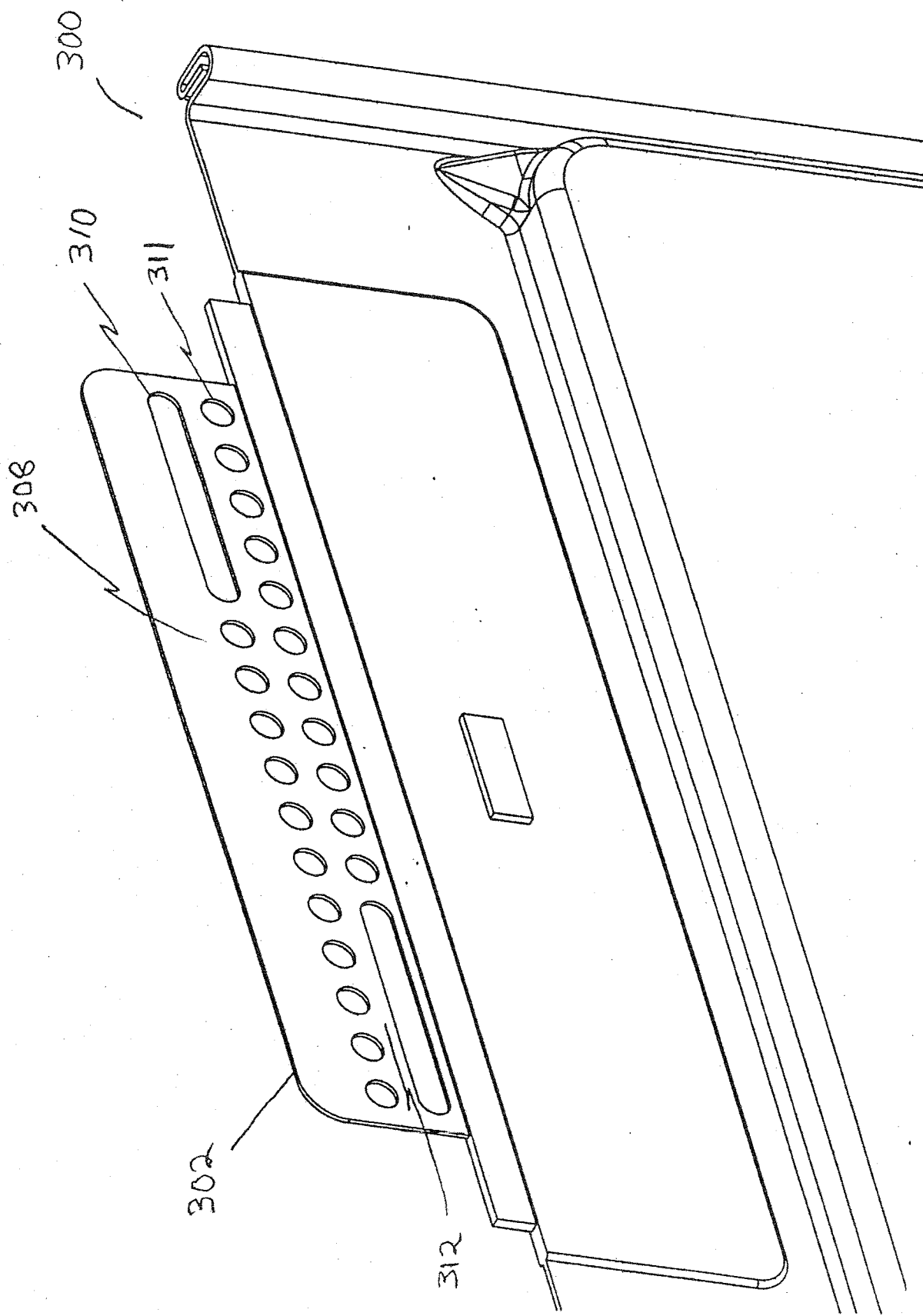


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FIG. 5

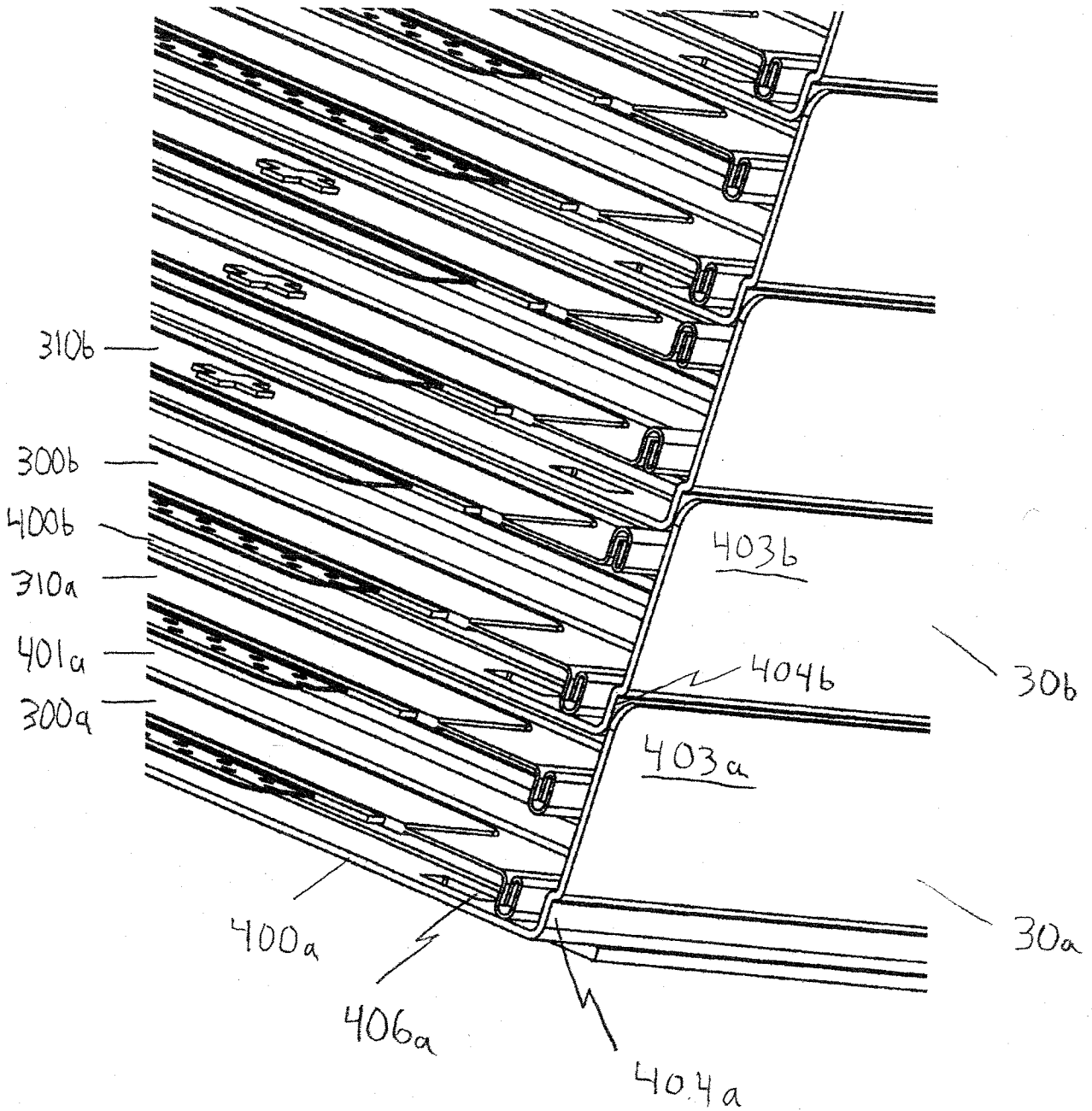


FIG. 6

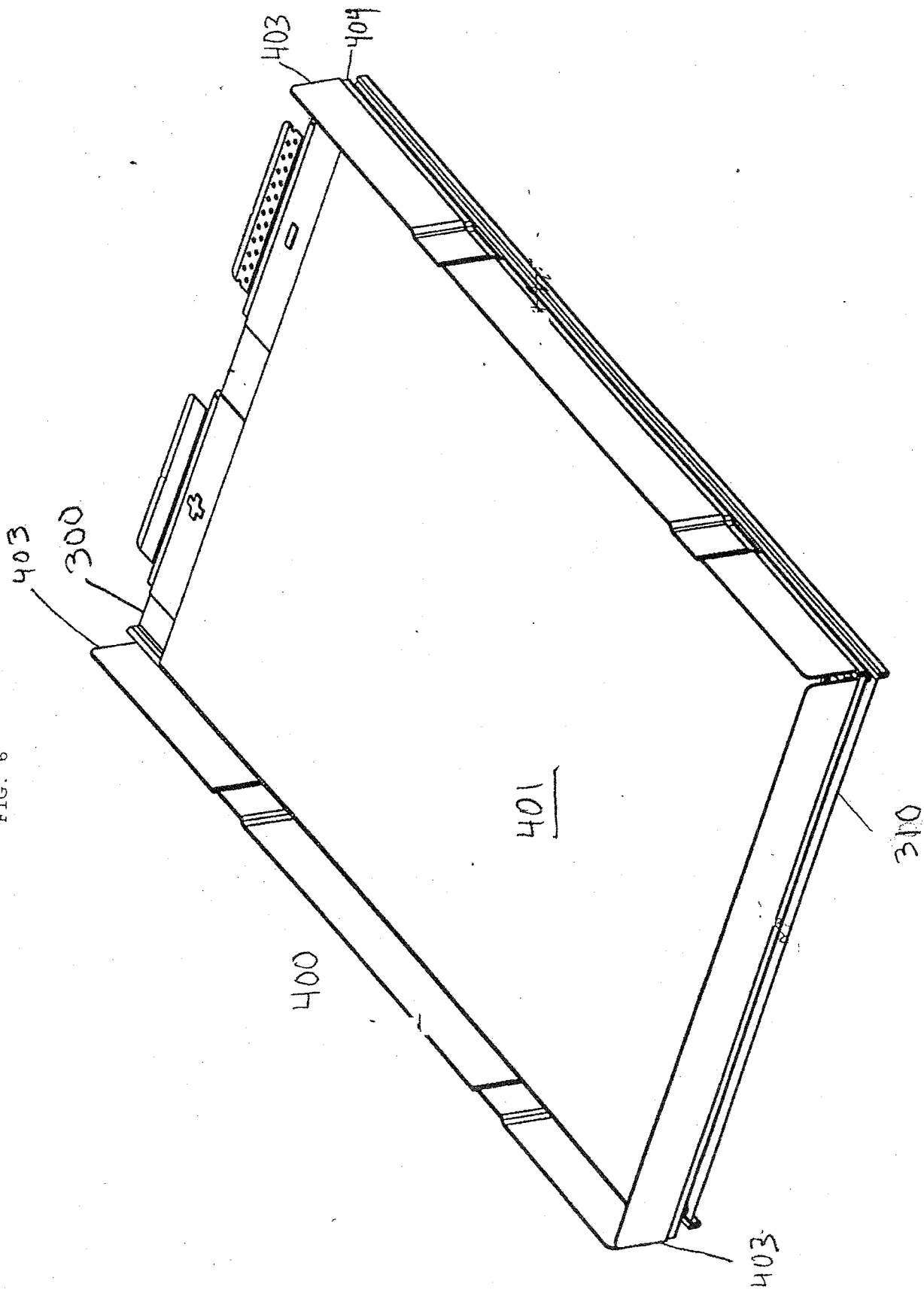


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FIG. 7

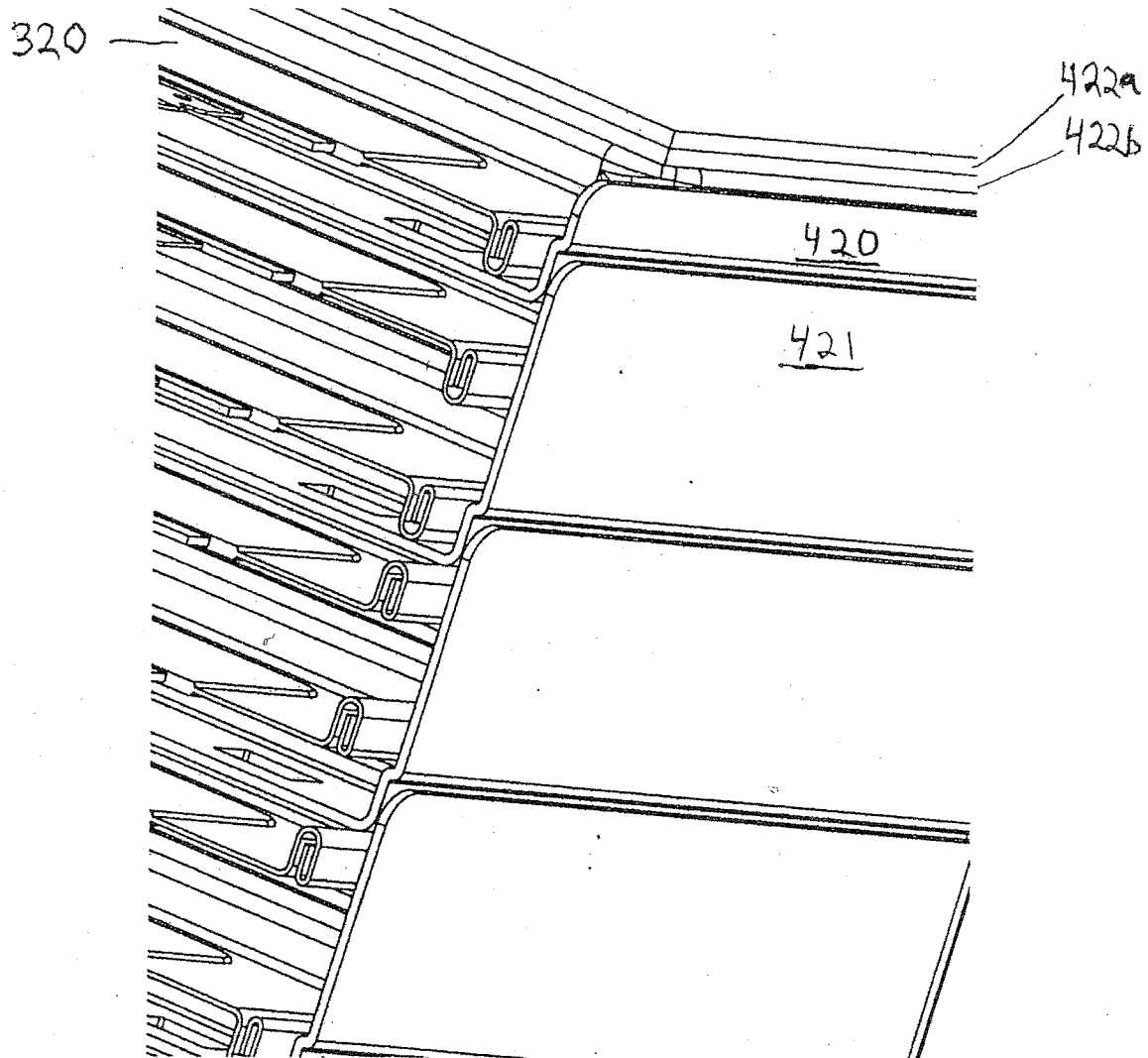


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FIG. 8

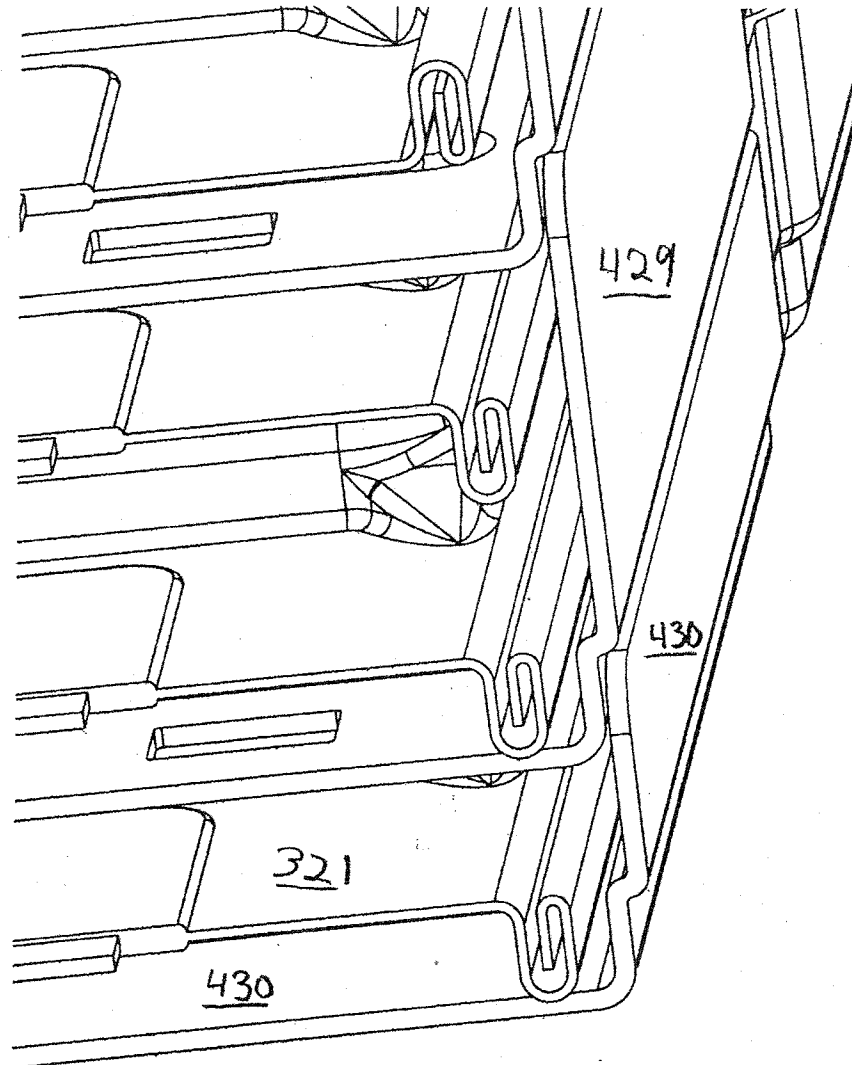


FIG. 9

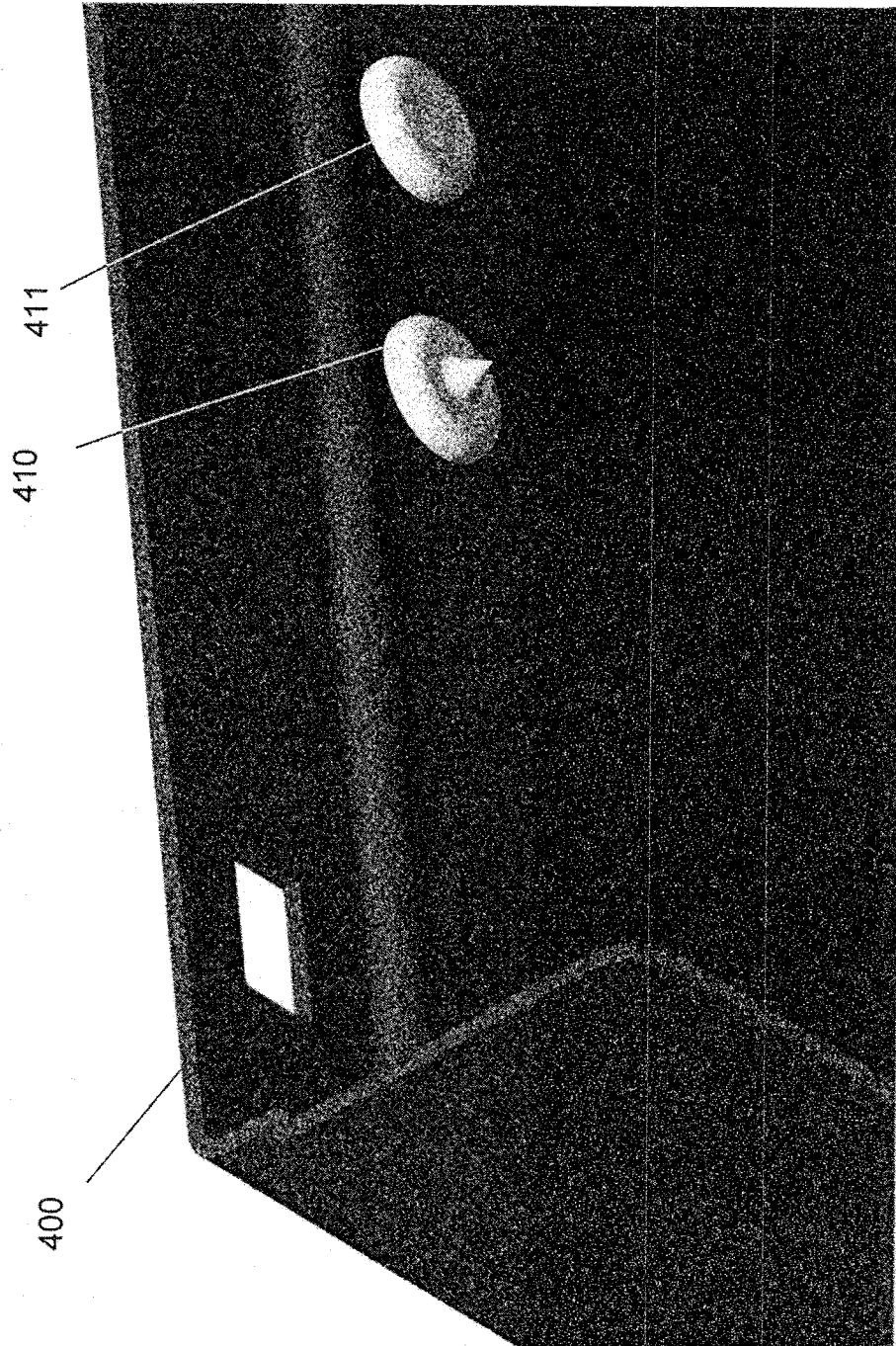


FIG. 10

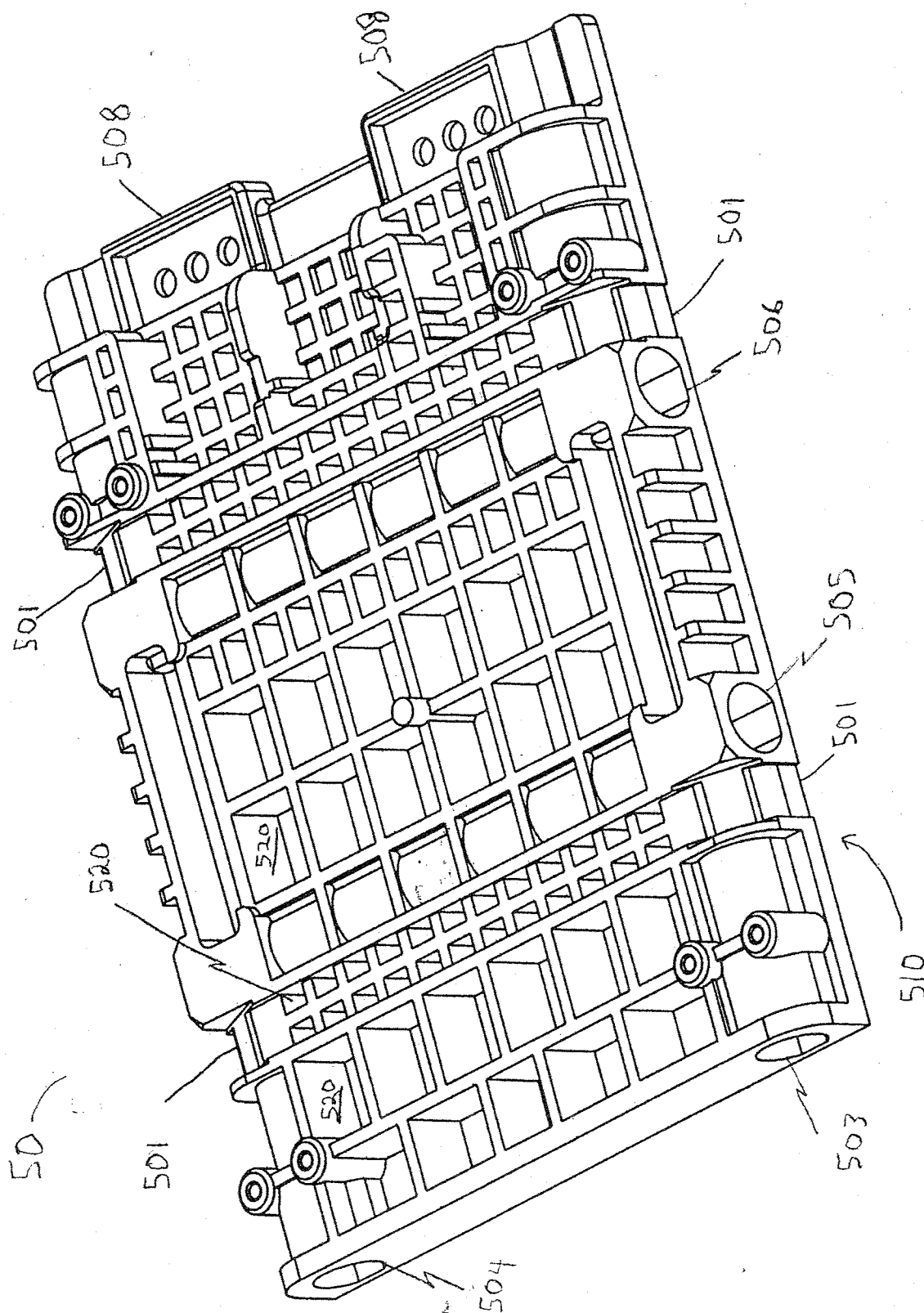


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FIG. 11

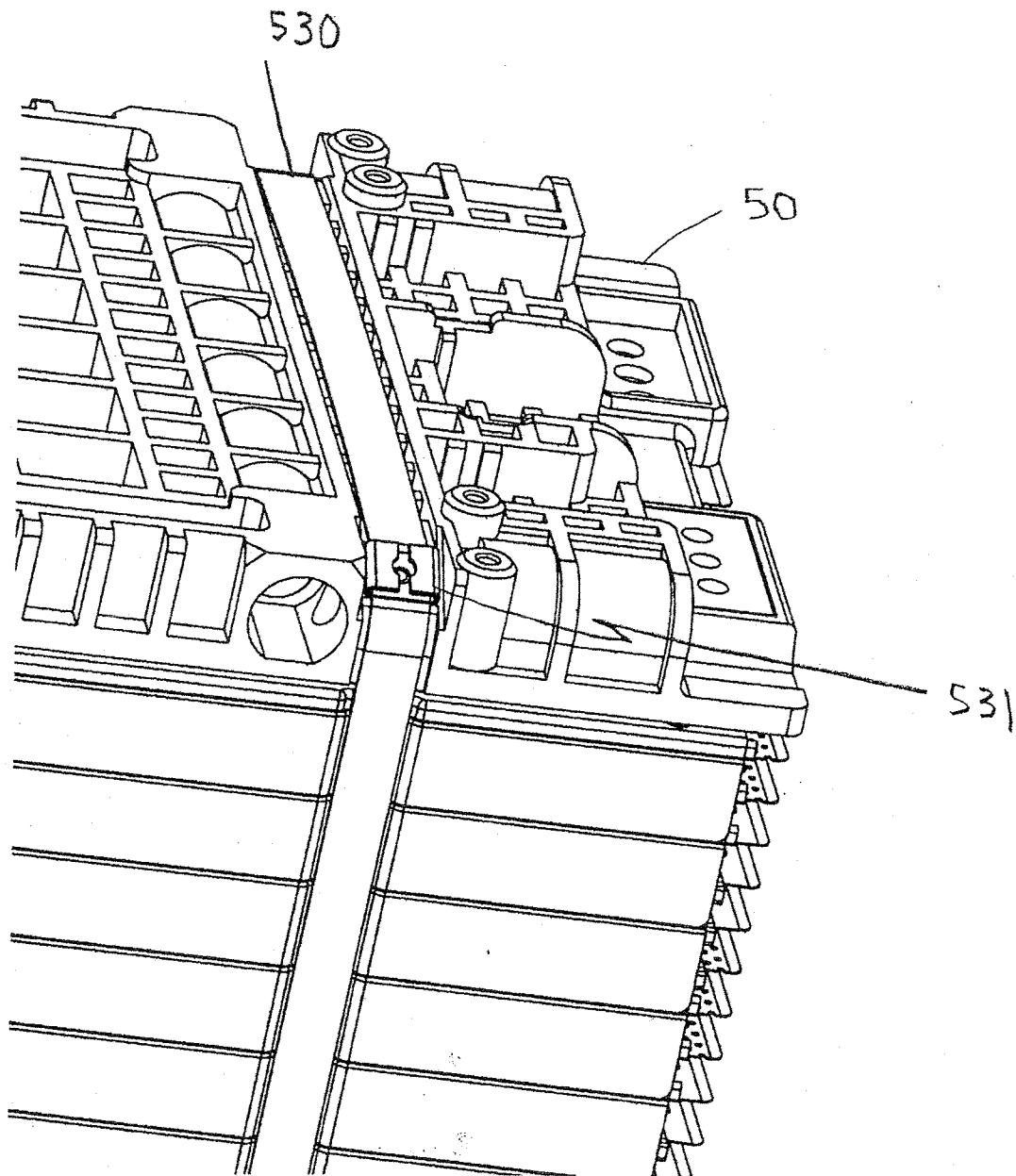


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FIG. 12

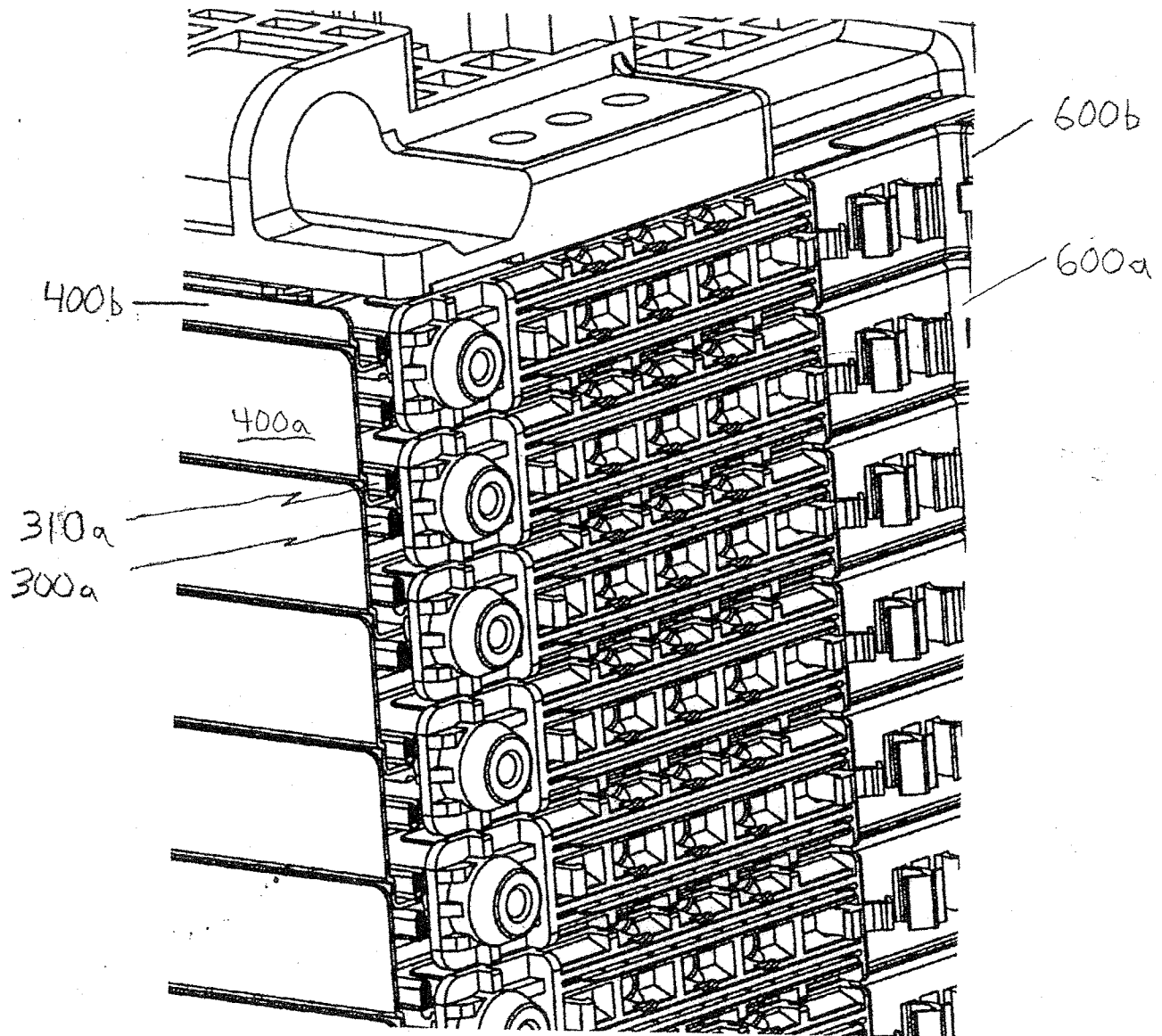


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FIG. 13

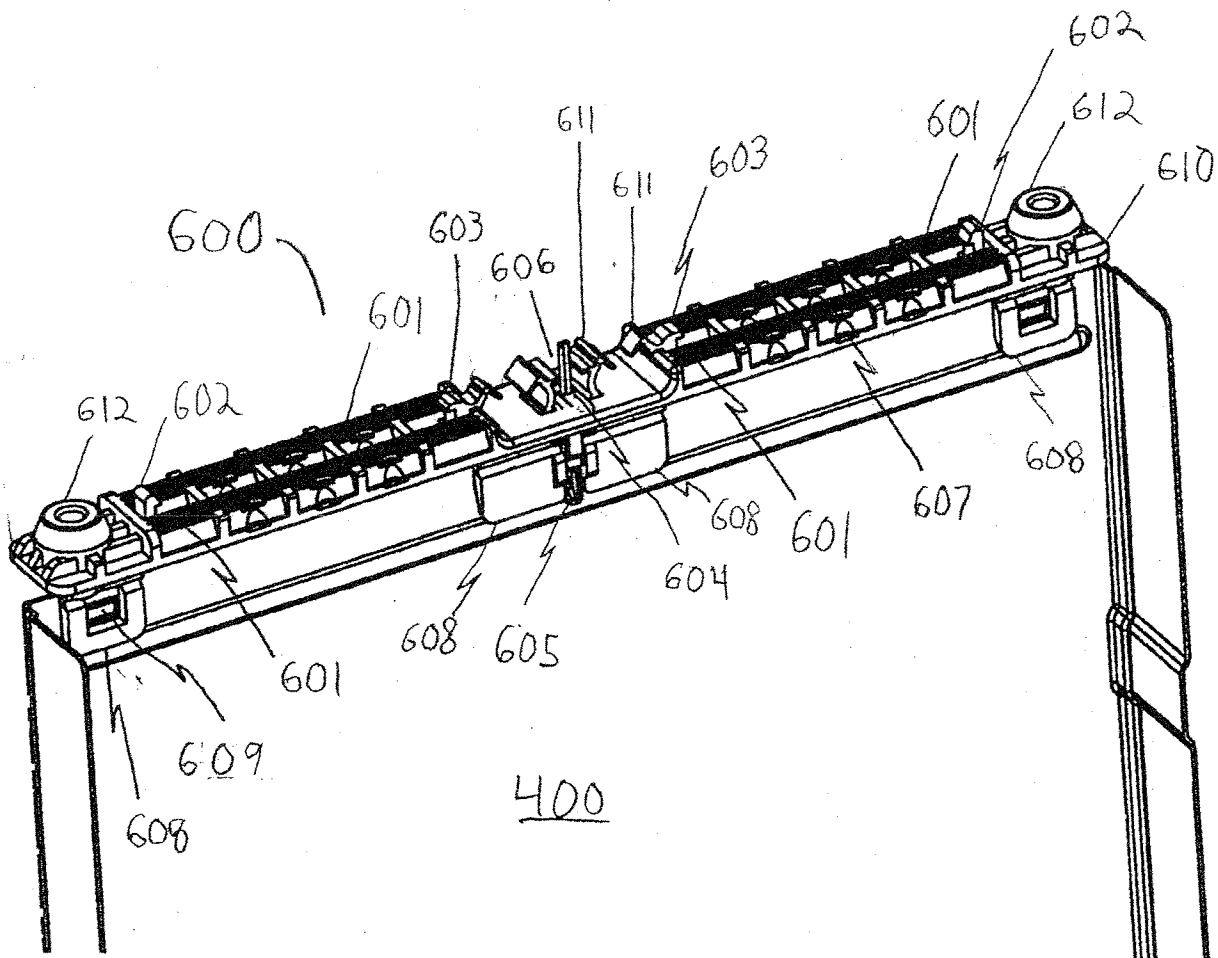


FIG. 13B

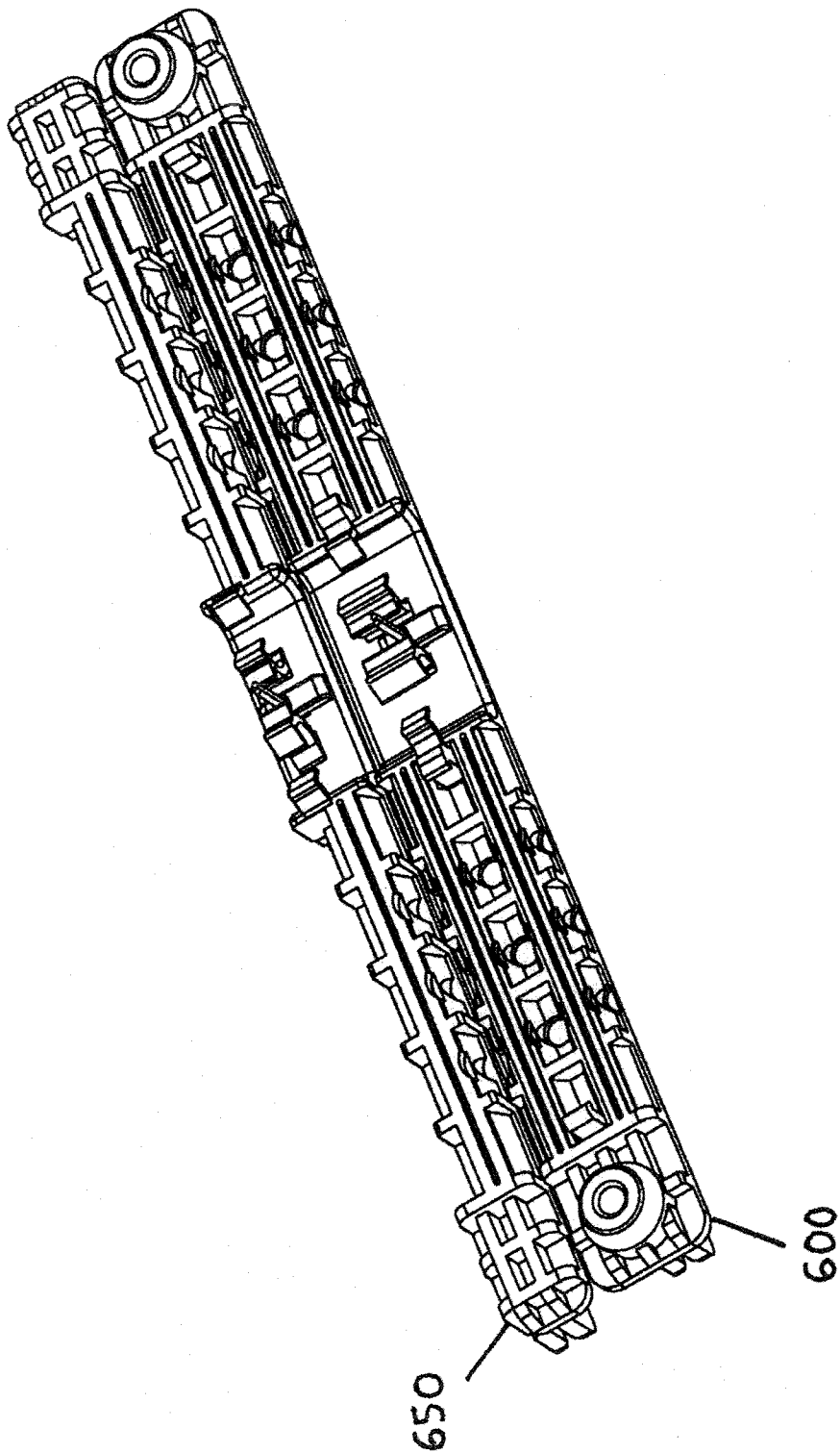


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FIG. 14

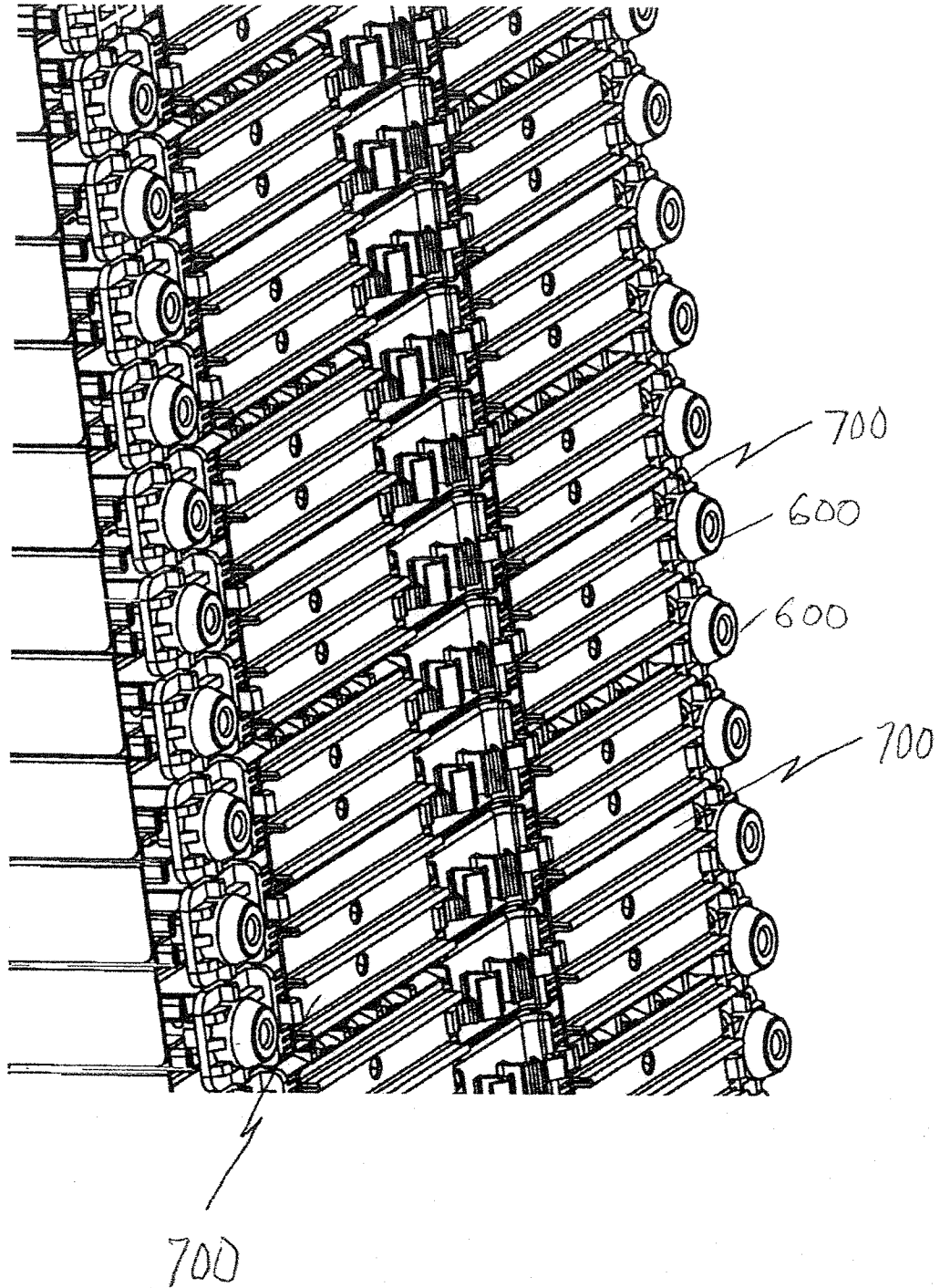


FIG. 15

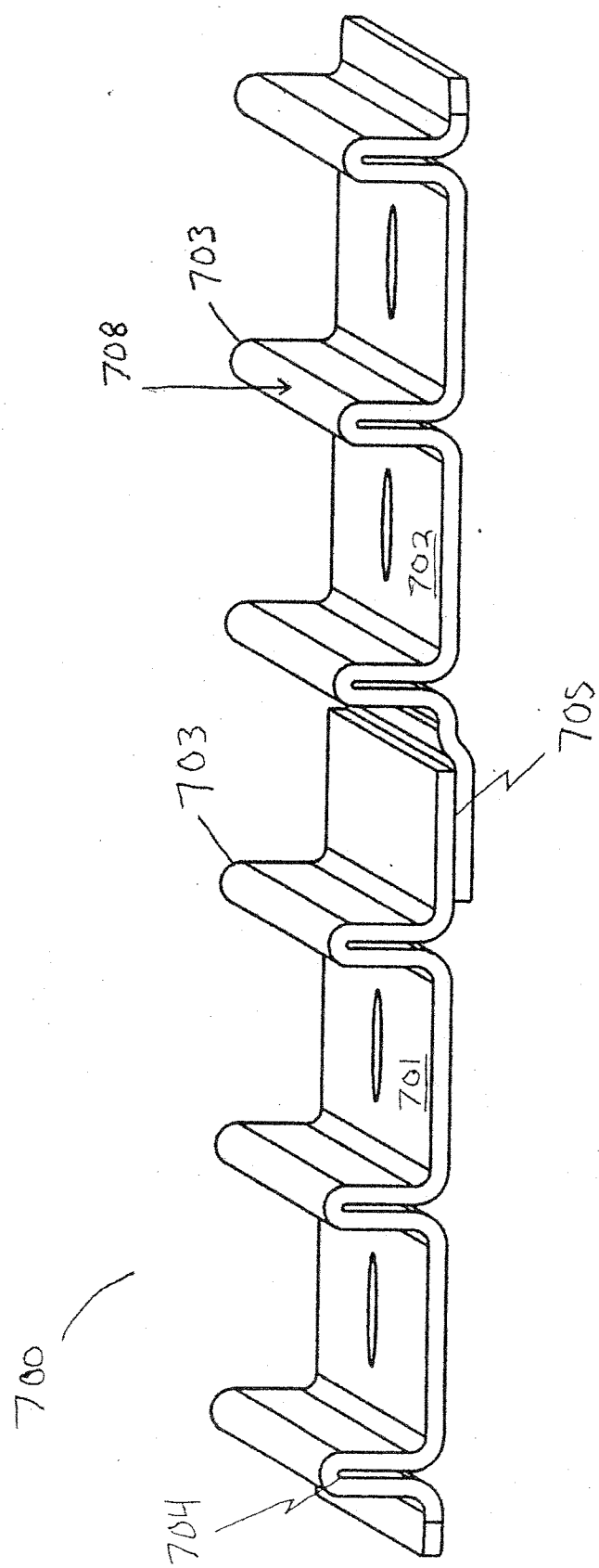


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FIG. 16

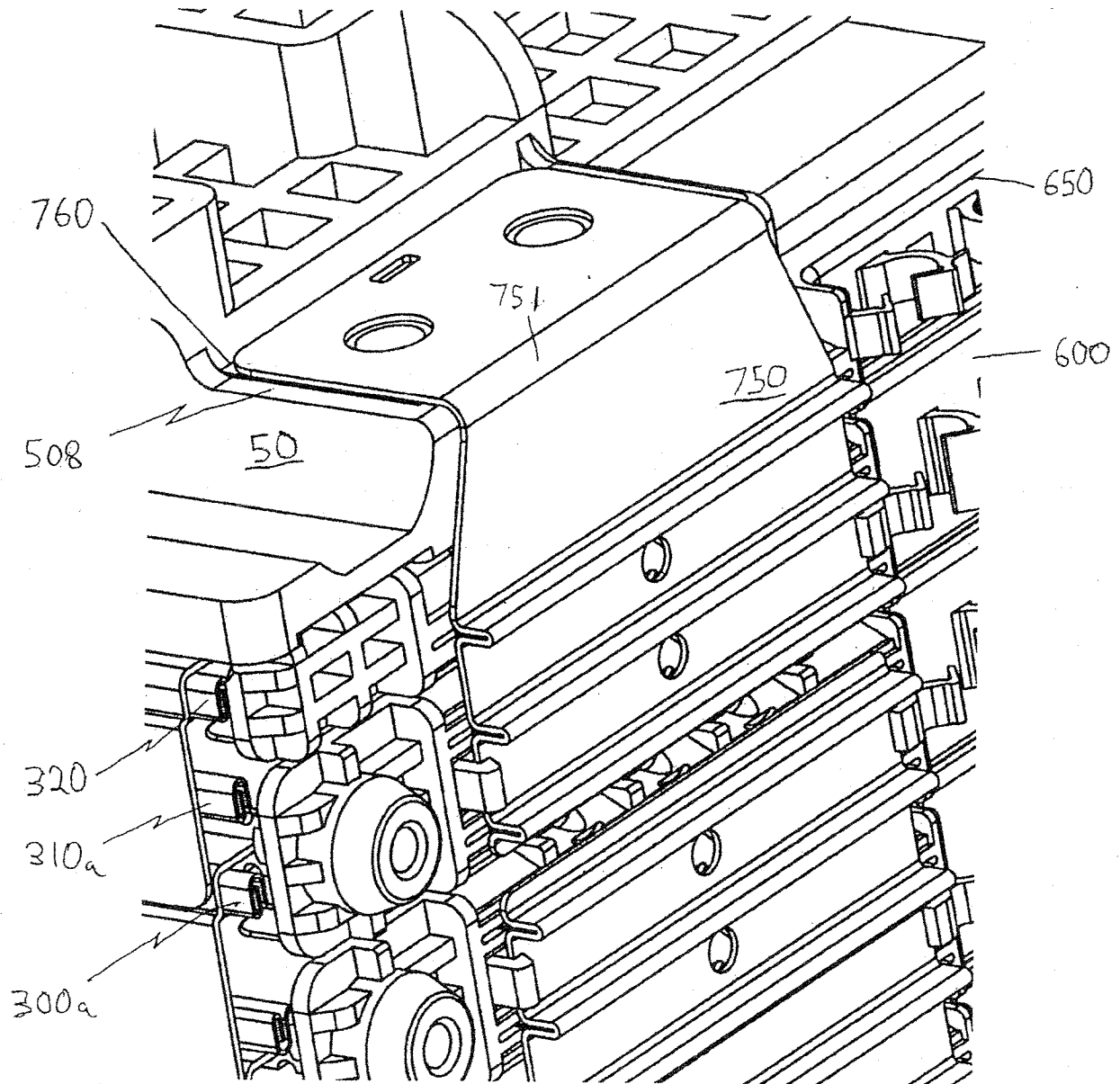


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FIG. 17

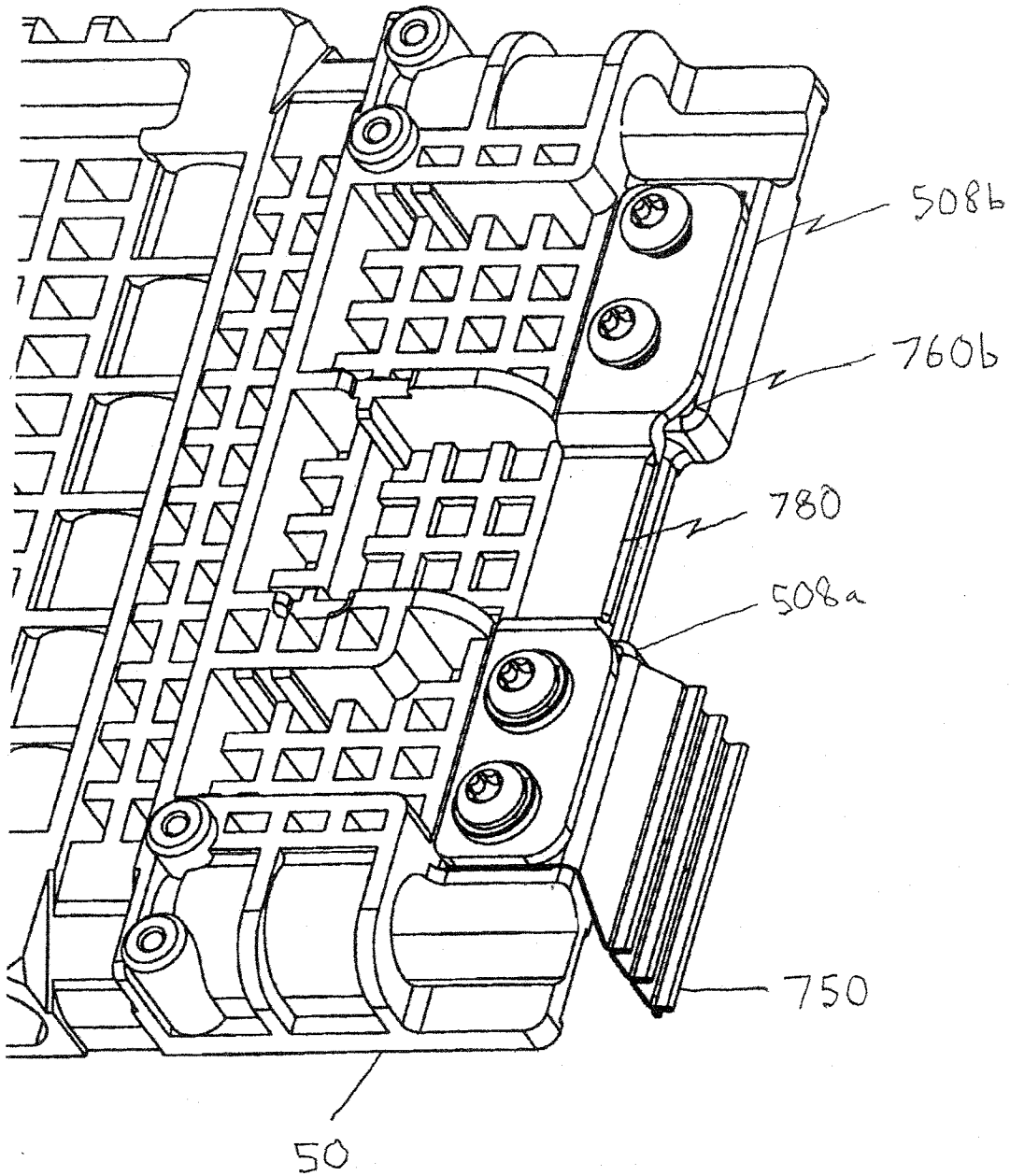


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FIG. 18

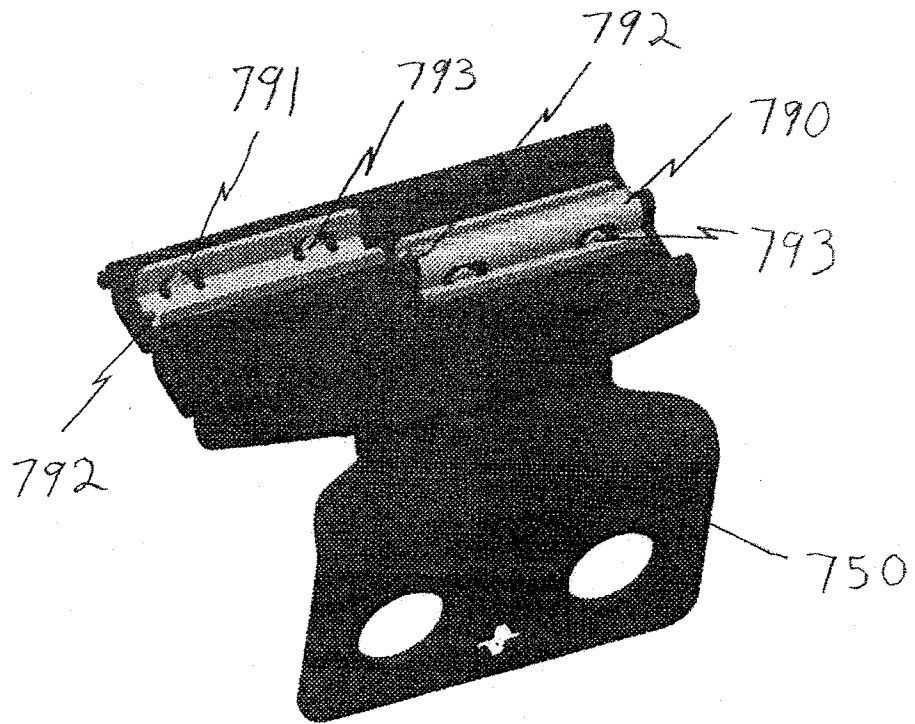


FIG. 19

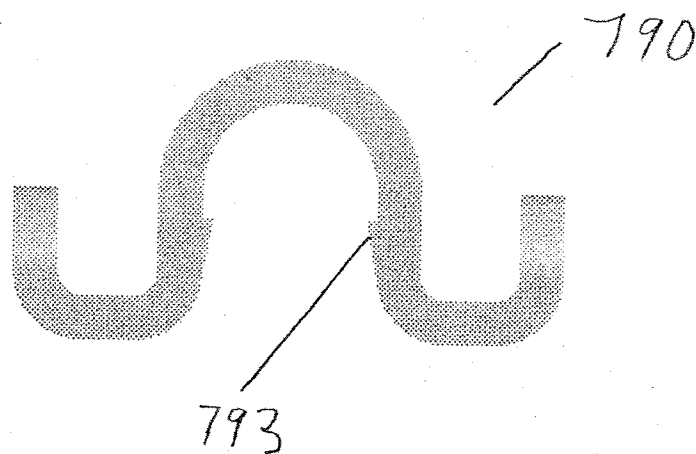


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FIG. 20

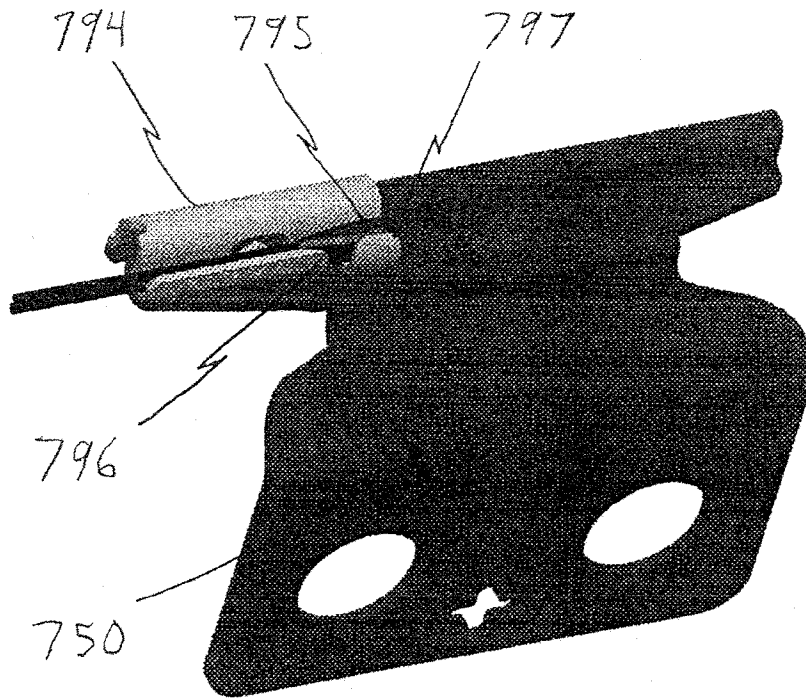


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FIG 21

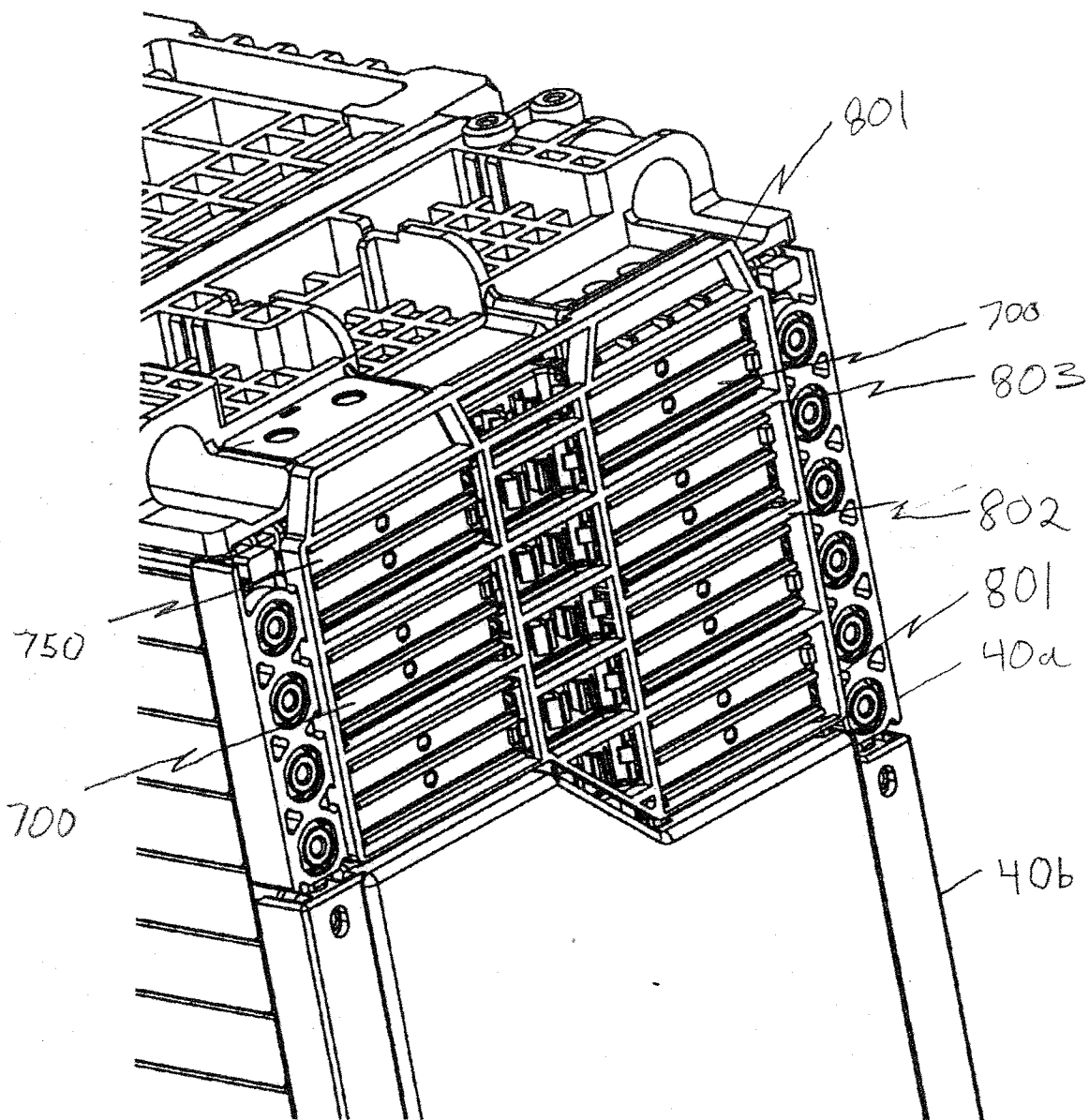
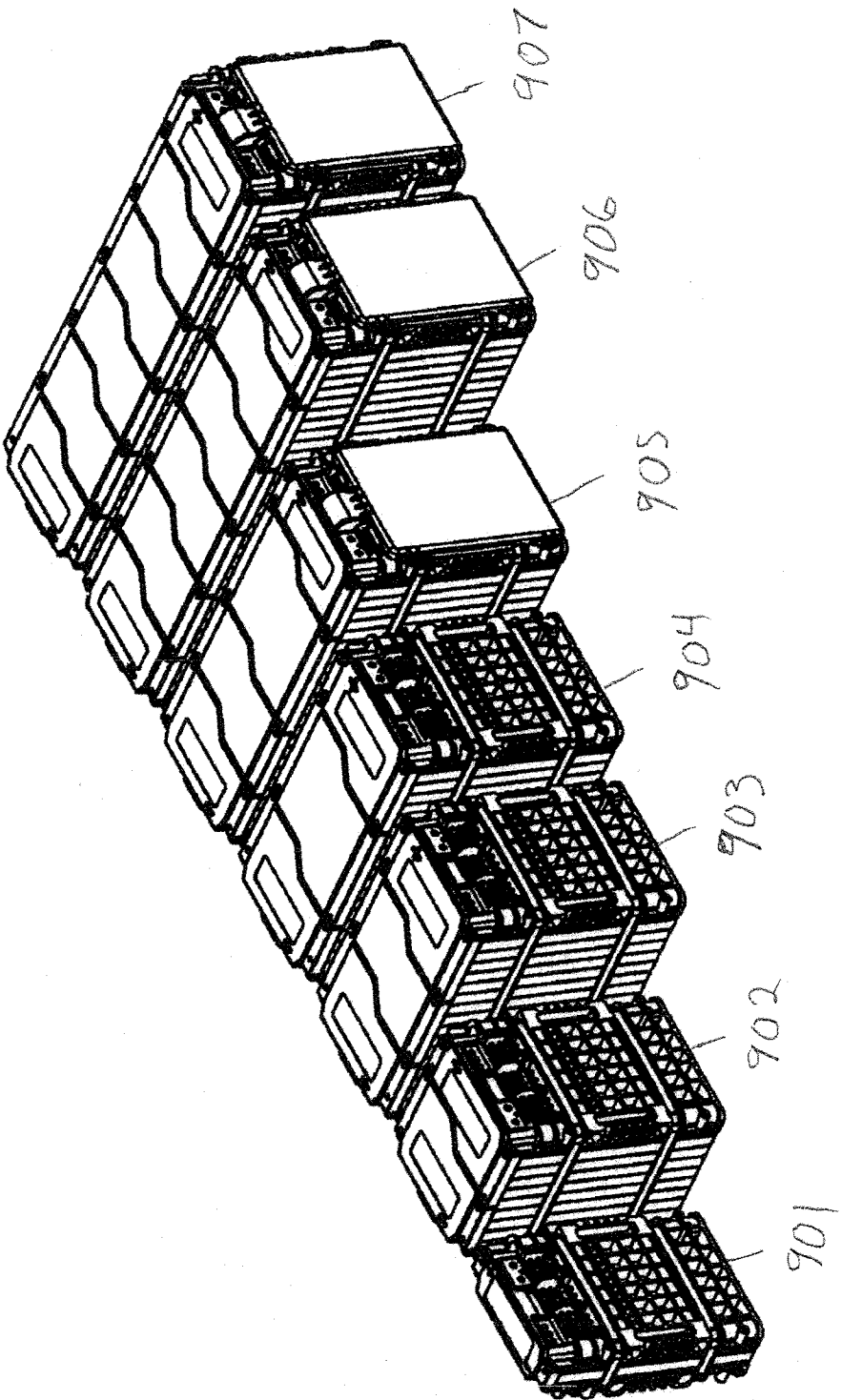


FIG. 22



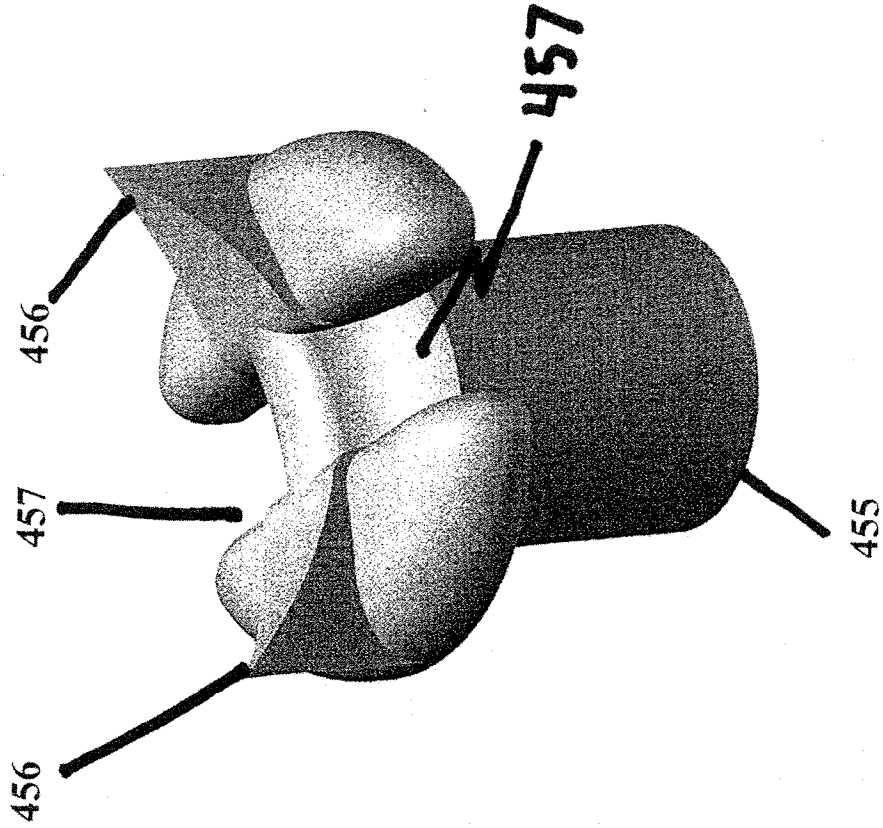


FIG. 23

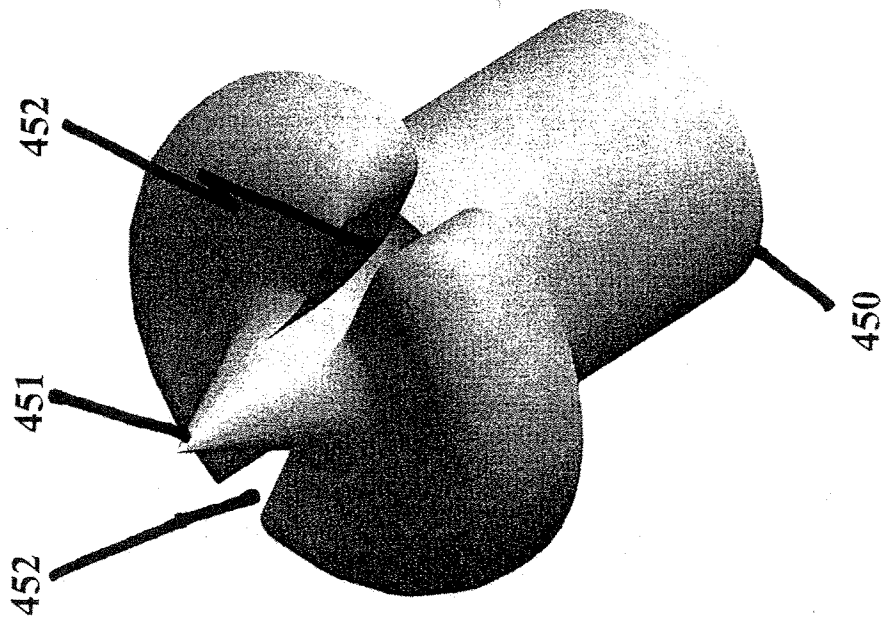
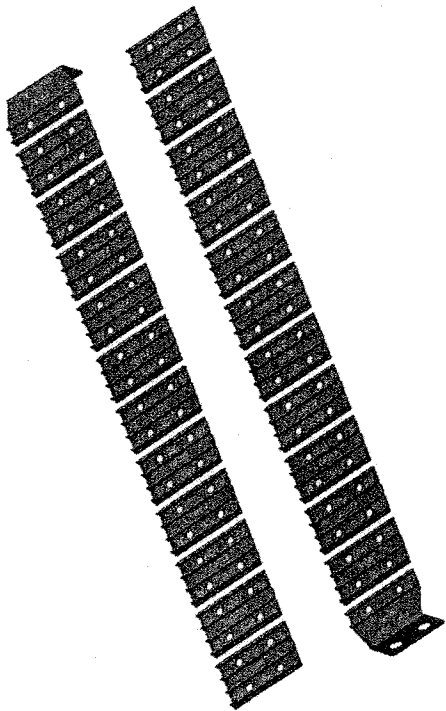
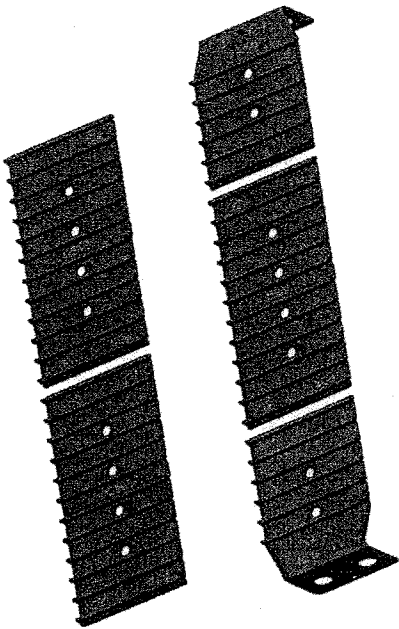


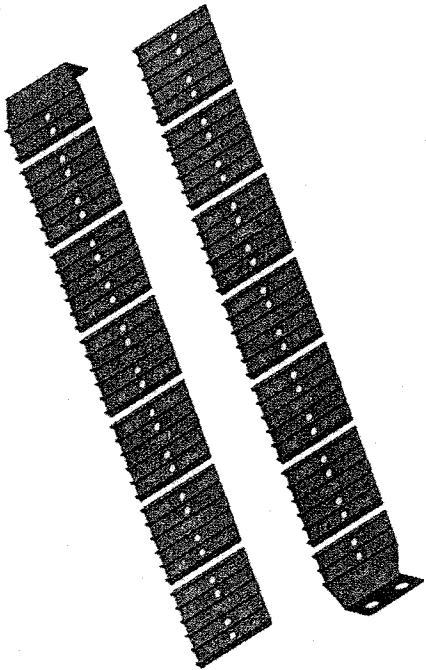
FIG. 24



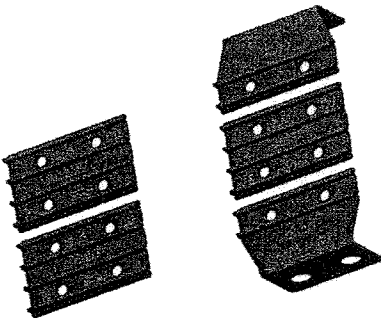
951



953



950



952

FIG. 25

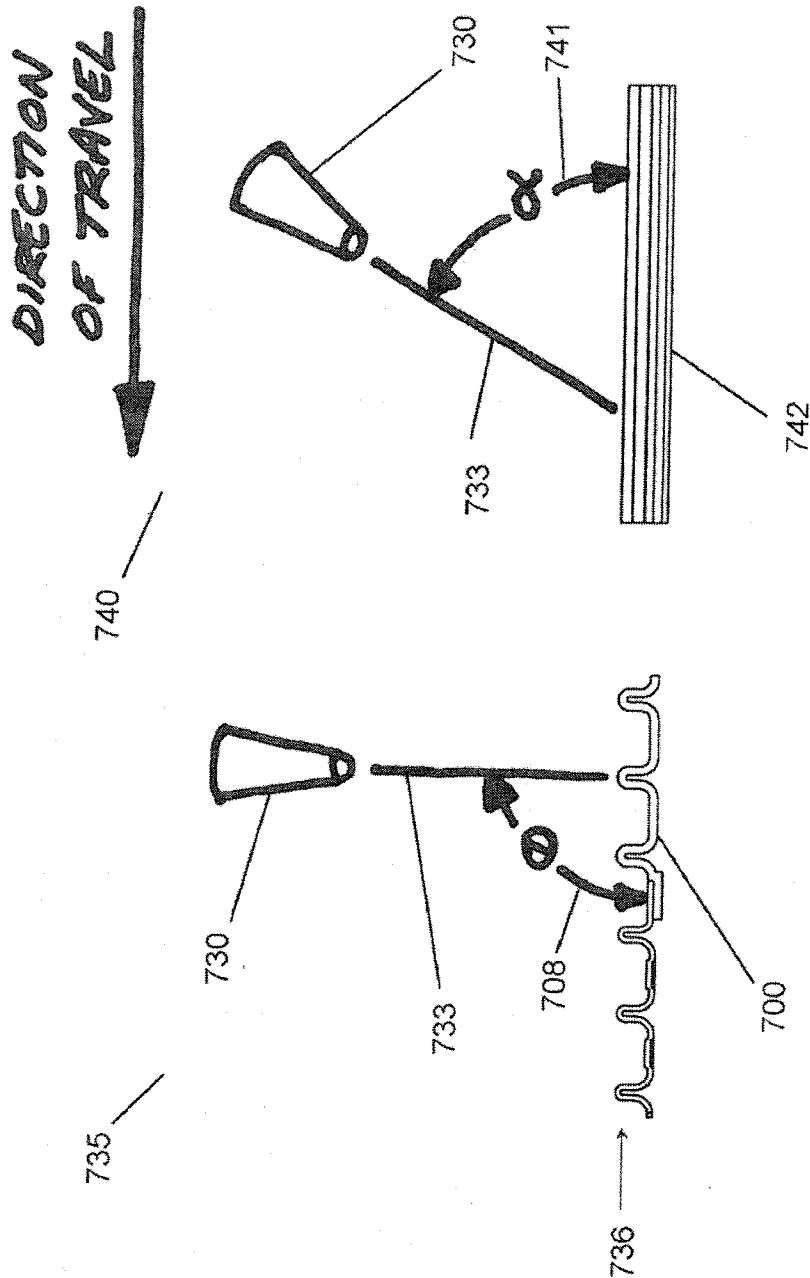
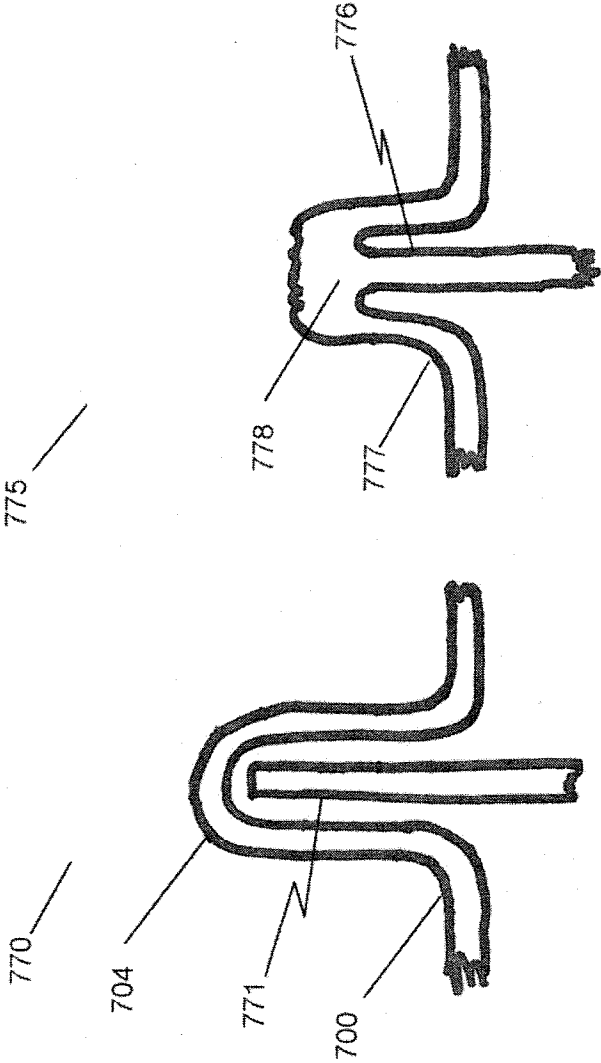


FIG. 26



Electronic Patent Application Fee Transmittal

Application Number:

Filing Date:

Title of Invention:

AUTOMOTIVE BATTERY WITH INTEGRATED POWER MANAGEMENT SYSTEM
AND SCALABLE BATTERY CUTOFF COMPONENT

First Named Inventor/Applicant Name:

Brian J. Pevear

Filer:

Matthew J. Leary/maureen divito

Attorney Docket Number:

112903.277US1

Filed as Large Entity

Provisional Filing Fees

Description

Fee Code

Quantity

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**Sub-Total in
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Basic Filing:

Provisional application filing

1005

1

220

220

Pages:

Claims:

Miscellaneous-Filing:

Petition:

Patent-Appeals-and-Interference:

Post-Allowance-and-Post-Issuance:

Extension-of-Time:

Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
Miscellaneous:				
Total in USD (\$)				220

Electronic Acknowledgement Receipt

EFS ID:	6573768
Application Number:	61266724
International Application Number:	
Confirmation Number:	1327
Title of Invention:	AUTOMOTIVE BATTERY WITH INTEGRATED POWER MANAGEMENT SYSTEM AND SCALABLE BATTERY CUTOFF COMPONENT
First Named Inventor/Applicant Name:	Brian J. Pevear
Customer Number:	23483
Filer:	Matthew J. Leary/maureen divito
Filer Authorized By:	Matthew J. Leary
Attorney Docket Number:	112903.277US1
Receipt Date:	04-DEC-2009
Filing Date:	
Time Stamp:	15:00:09
Application Type:	Provisional

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Submitted with Payment	yes
Payment Type	Credit Card
Payment was successfully received in RAM	\$220
RAM confirmation Number	1367
Deposit Account	
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Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part / Zip (if appl.)	Pages (if appl.)
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1	Specification	112903_277US1_specification_120409.pdf	105349 cabd6133a0baf2ca416c6a2d78c904ebf864b506	no	9
Warnings:					
Information:					
2	Drawings-only black and white line drawings	112903_277US1_drawings_120409.pdf	5878749 7df96d8c6ad5315b5b6ea1d9b479b60f68489630	no	6
Warnings:					
Information:					
3	Application Data Sheet	112903_277US1_ApplicationDataSheet_120409.PDF	838687 d5a64548a950eca94bb4cd07be6767ce47865ab	no	4
Warnings:					
Information:					
4	Appendix to the Specification	112903_277US1_ExhibitA_120409.PDF	7981134 073b6d043a98c7390cff27d1e5a332dd17db1c5d	no	52
Warnings:					
Information:					
5	Fee Worksheet (PTO-875)	fee-info.pdf	29990 2265ec21888ed0b356f66038a7a93ae1504d84d4	no	2
Warnings:					
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Total Files Size (in bytes):			14833909		
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