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(54) **COMPUTER SERVER HEAT REGULATION UTILIZING INTEGRATED PRECISION AIR FLOW**

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(52) **U.S. Cl.**
 CPC *H05K 7/20745* (2013.01); *H05K 7/20727* (2013.01); *H01L 35/28* (2013.01); *F16K 27/00* (2013.01); *F16K 27/003* (2013.01); *H05K 7/20181* (2013.01); *H05K 7/20736* (2013.01); *F16K 3/03* (2013.01); *F16K 3/0209* (2013.01)

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(73) Assignee: **DHK Storage, LLC**, Sterling, VA (US)

(21) Appl. No.: **16/840,318**

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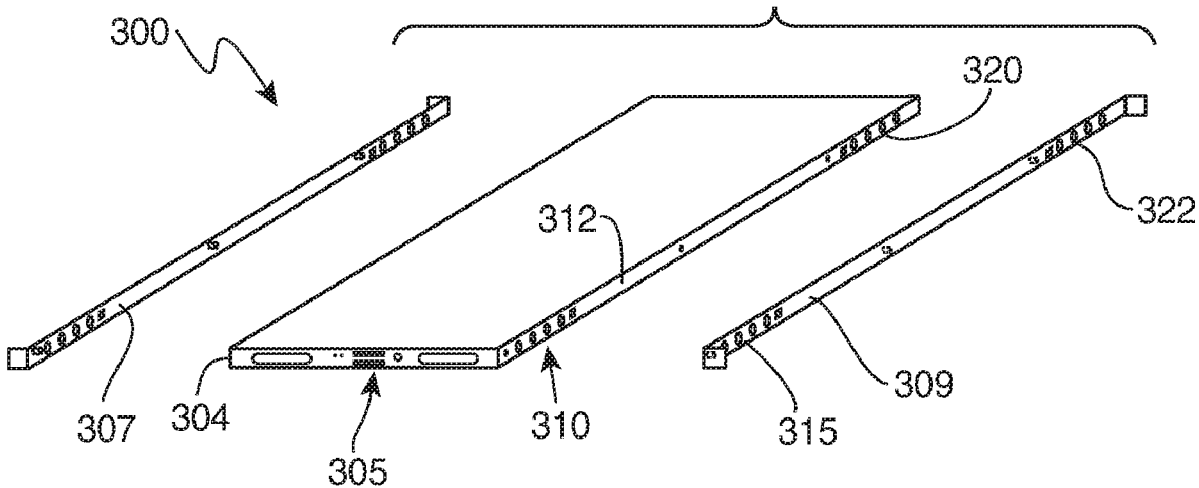
Related U.S. Application Data

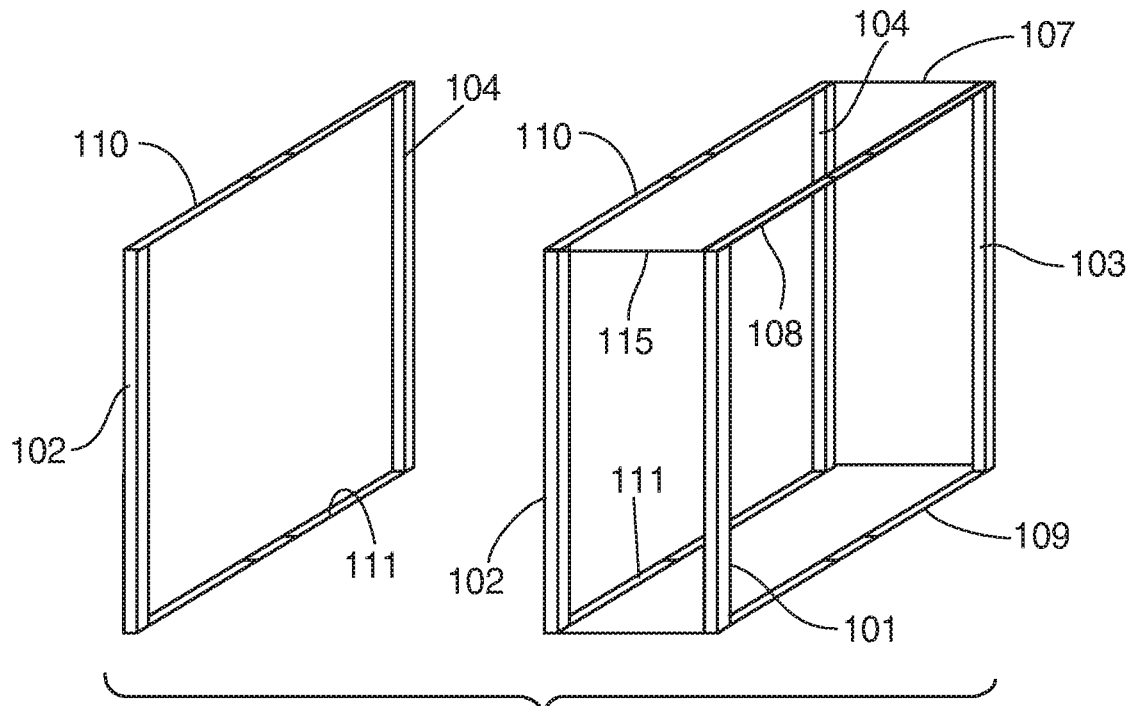
(63) Continuation of application No. 15/144,788, filed on May 2, 2016, now Pat. No. 9,832,912, Continuation of application No. 15/792,663, filed on Oct. 24, 2017, now Pat. No. 10,426,061, Continuation of application No. 16/577,886, filed on Sep. 20, 2019.

(60) Provisional application No. 62/158,529, filed on May 7, 2015.

(57) **ABSTRACT**

Disclosed is system, method, and rack stand portion for the advantageous cooling of computer equipment. The rack stand includes a hollow body that may be formed of cartridges. Gas from an airflow source is guided into the rack stand body and then into a sealed case of the computer equipment. Air flow is then guided out of the computer equipment for recirculation, exhaust, or other purpose.





Prior Art
FIG. 1

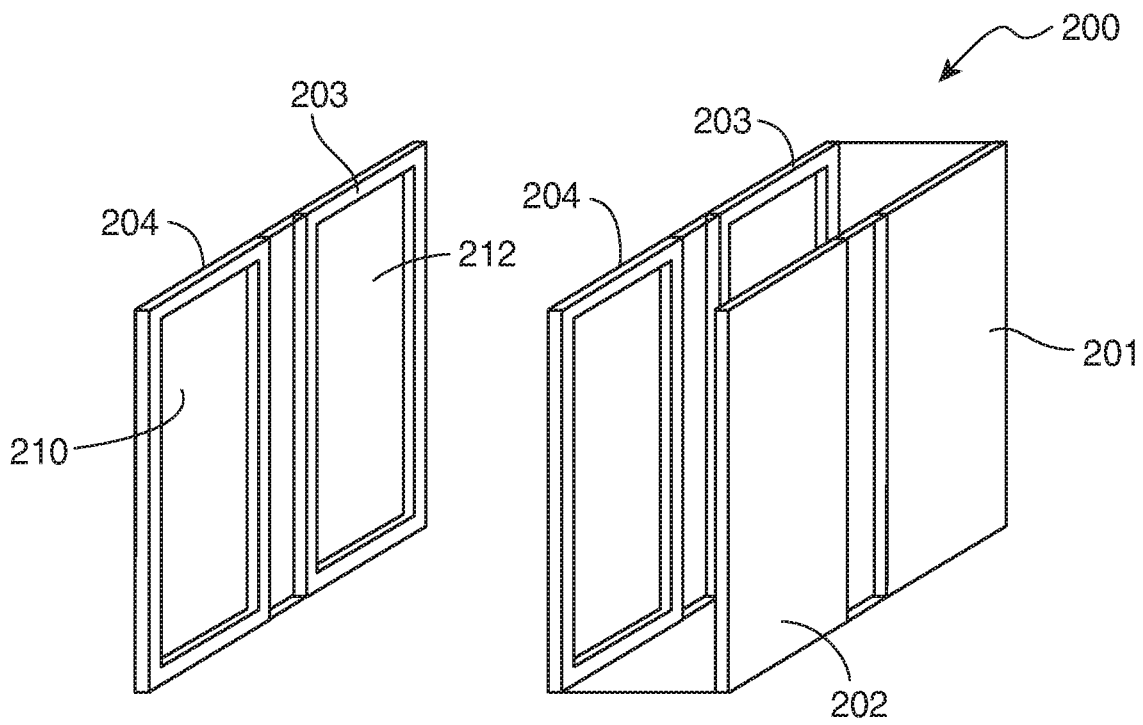


FIG. 2B

FIG. 2A

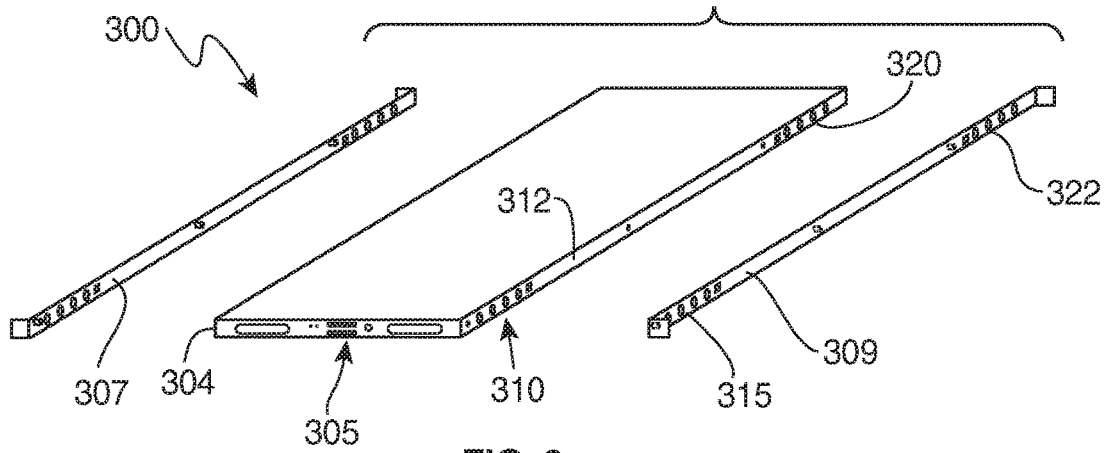


FIG. 3

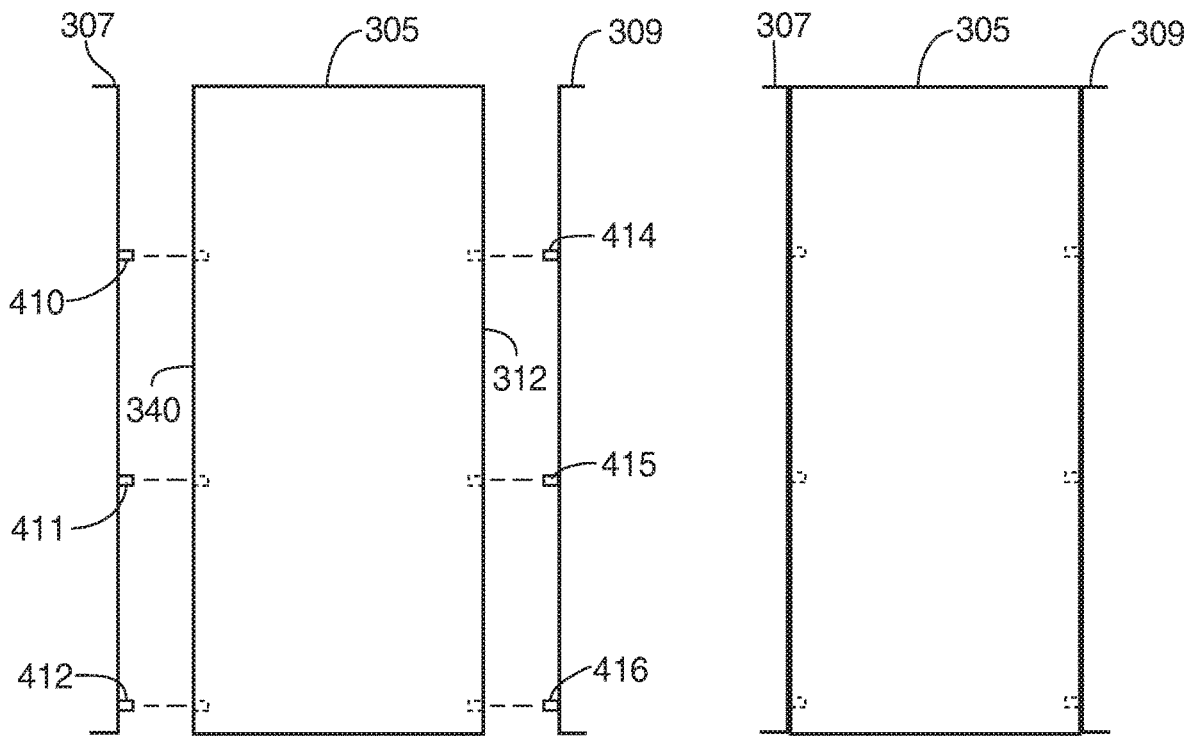


FIG. 4A

FIG. 4B

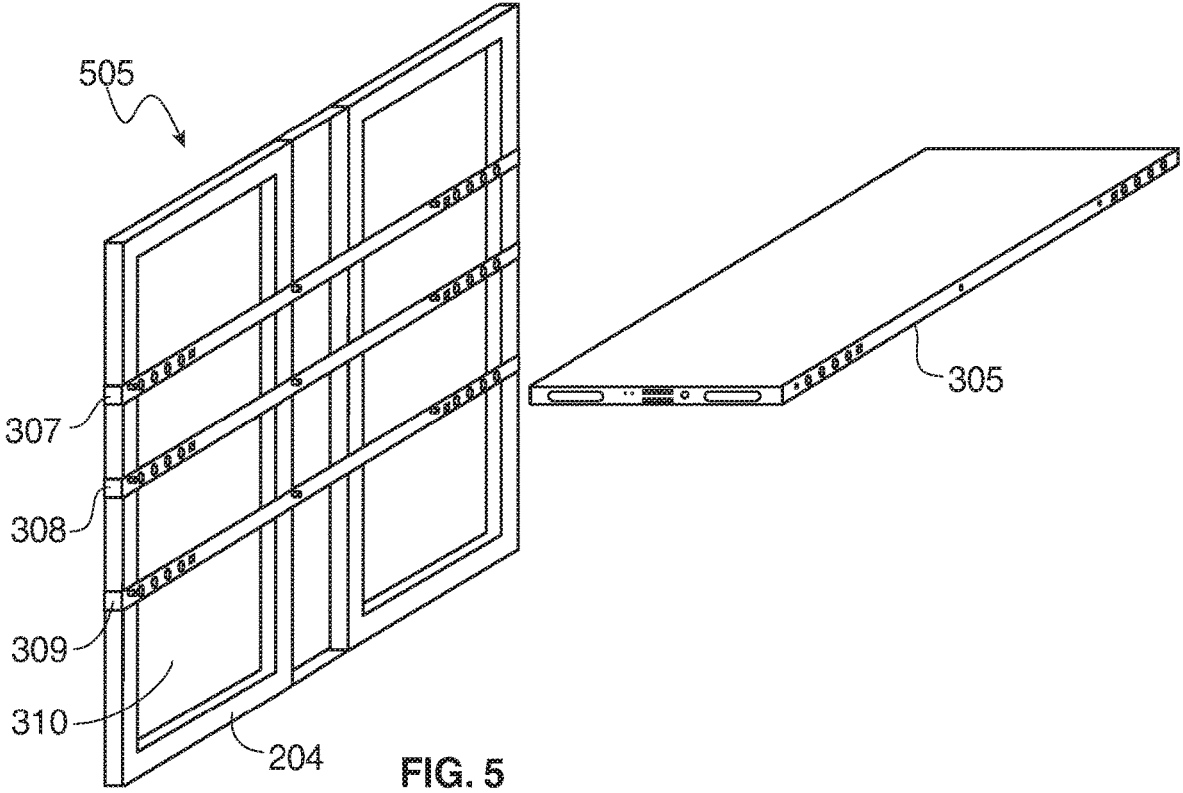


FIG. 5

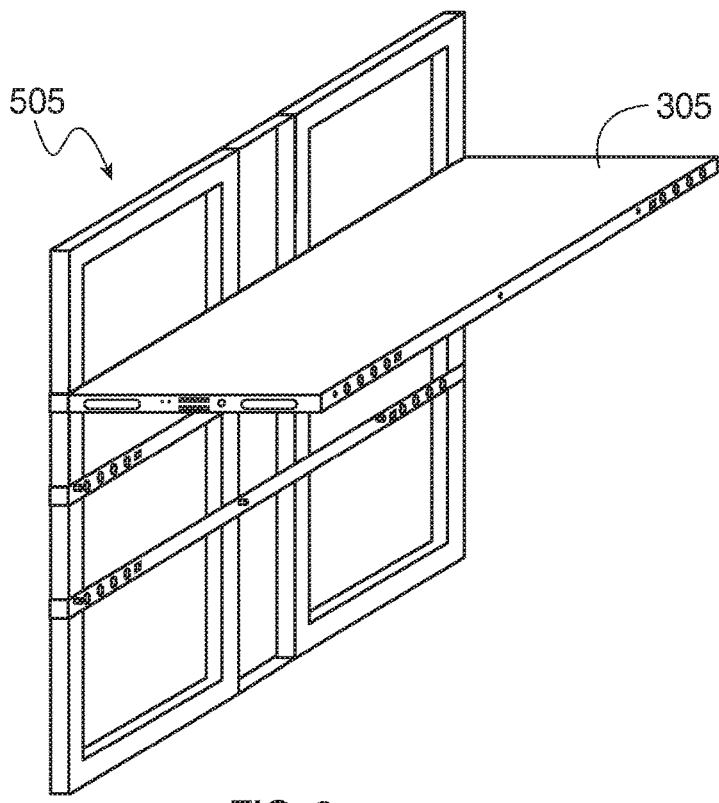


FIG. 6

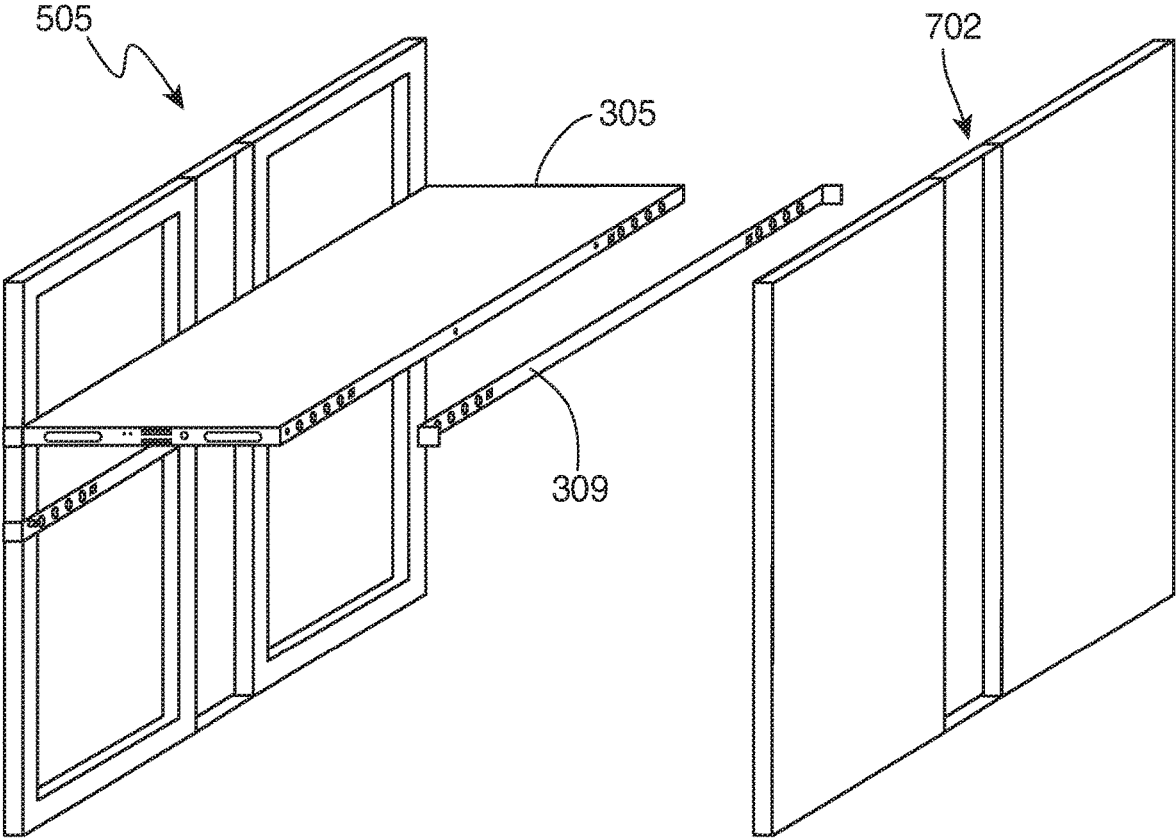


FIG. 7

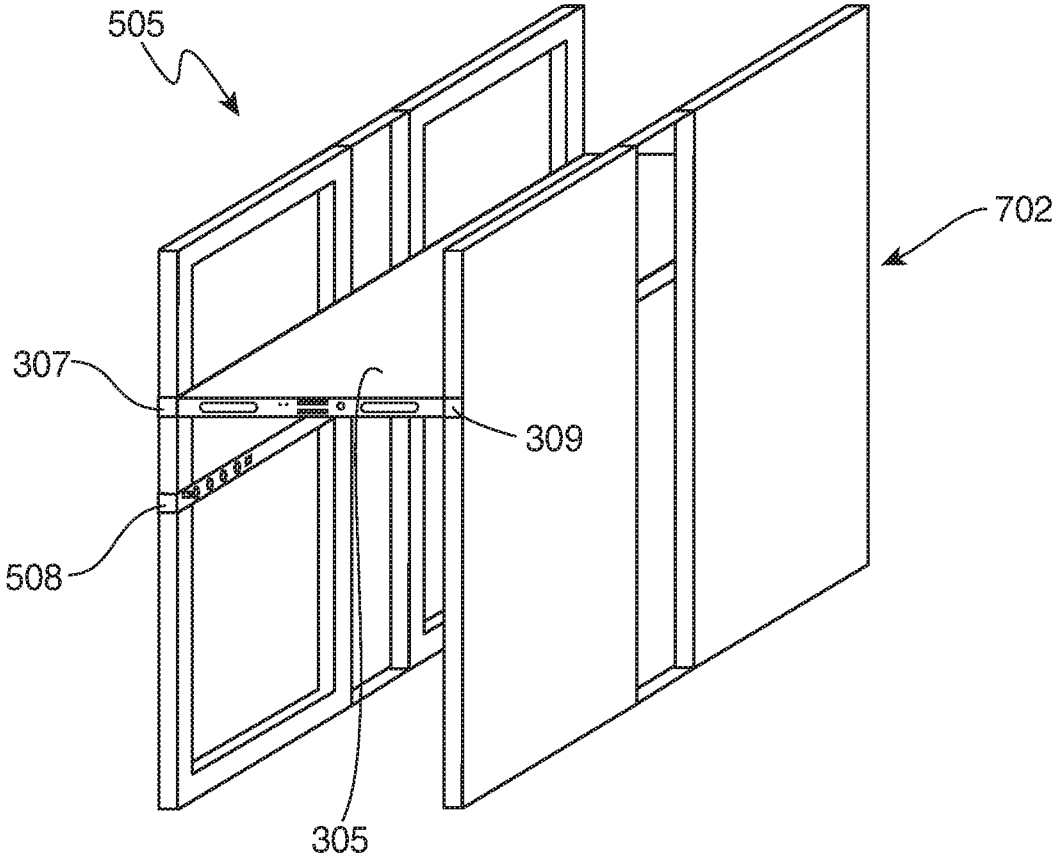


FIG. 8

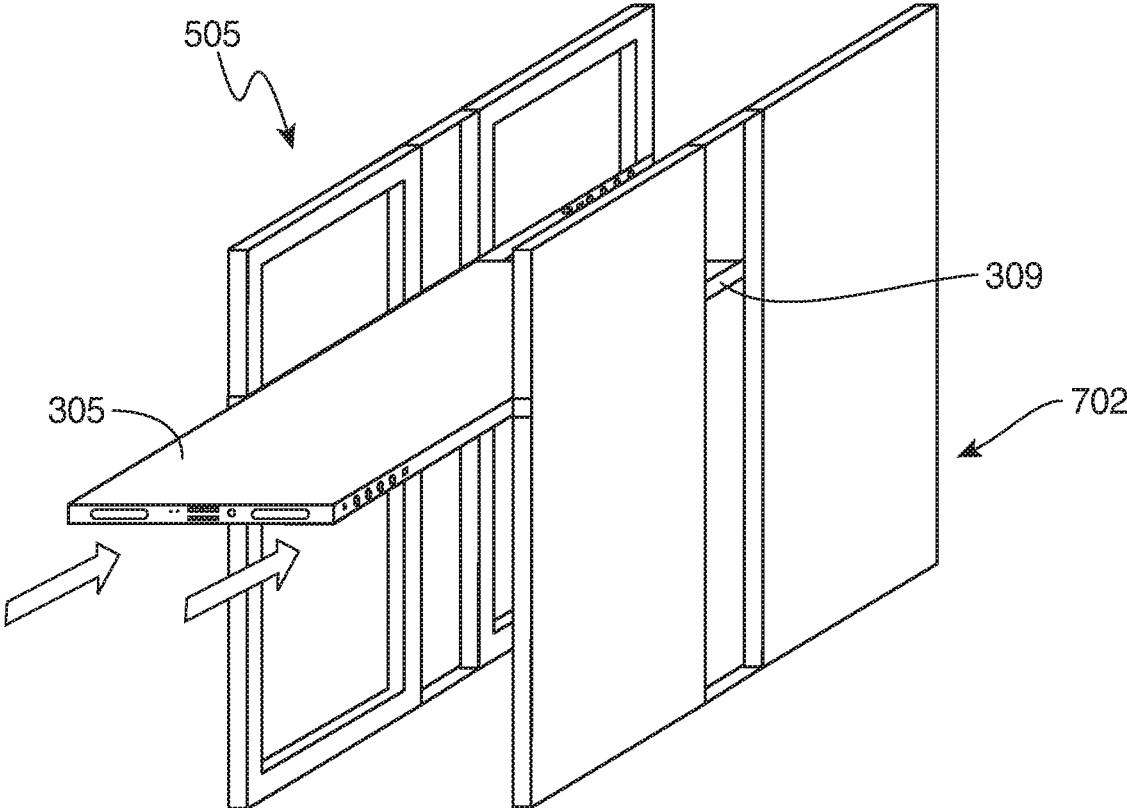


FIG. 9

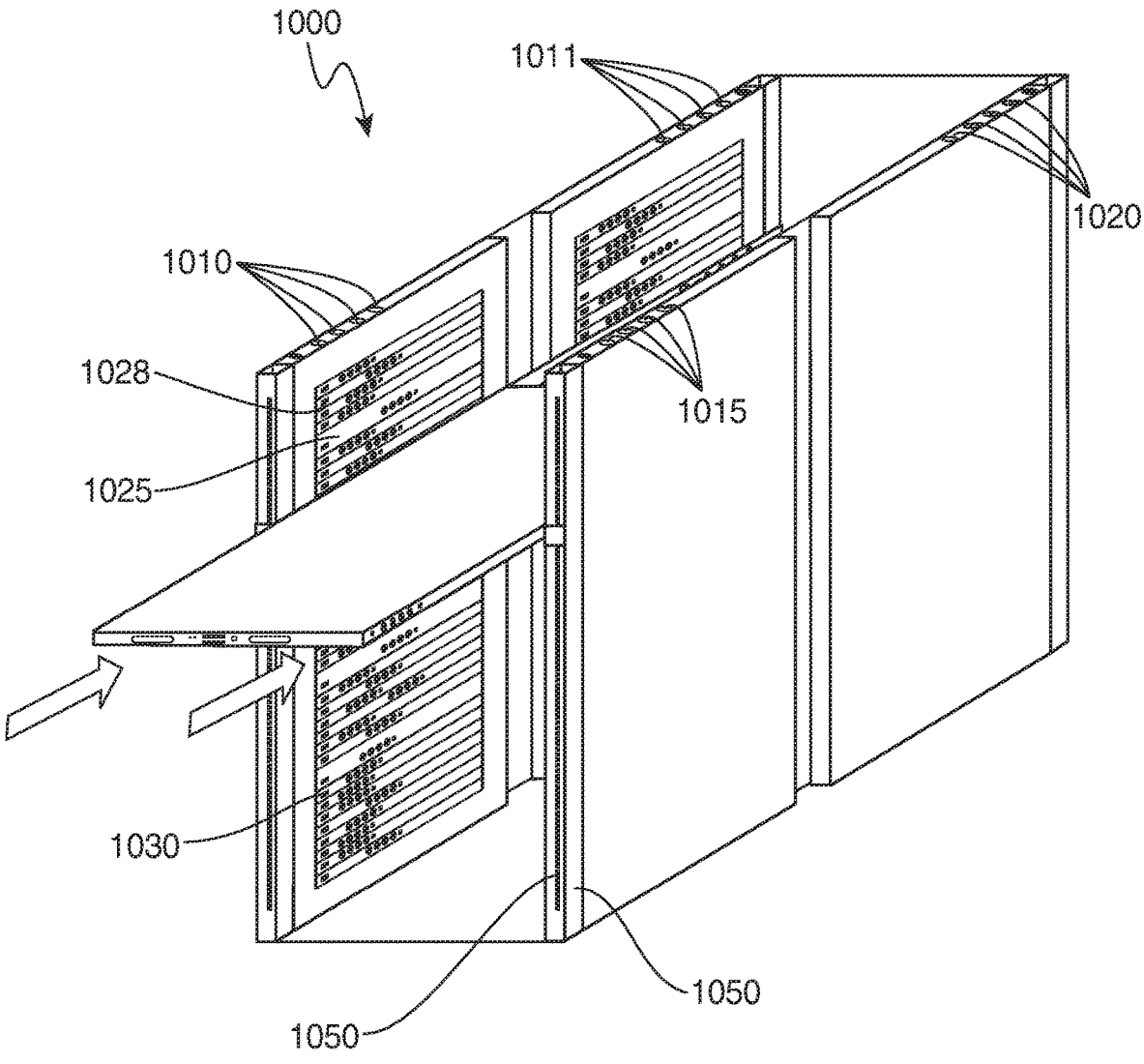


FIG. 10

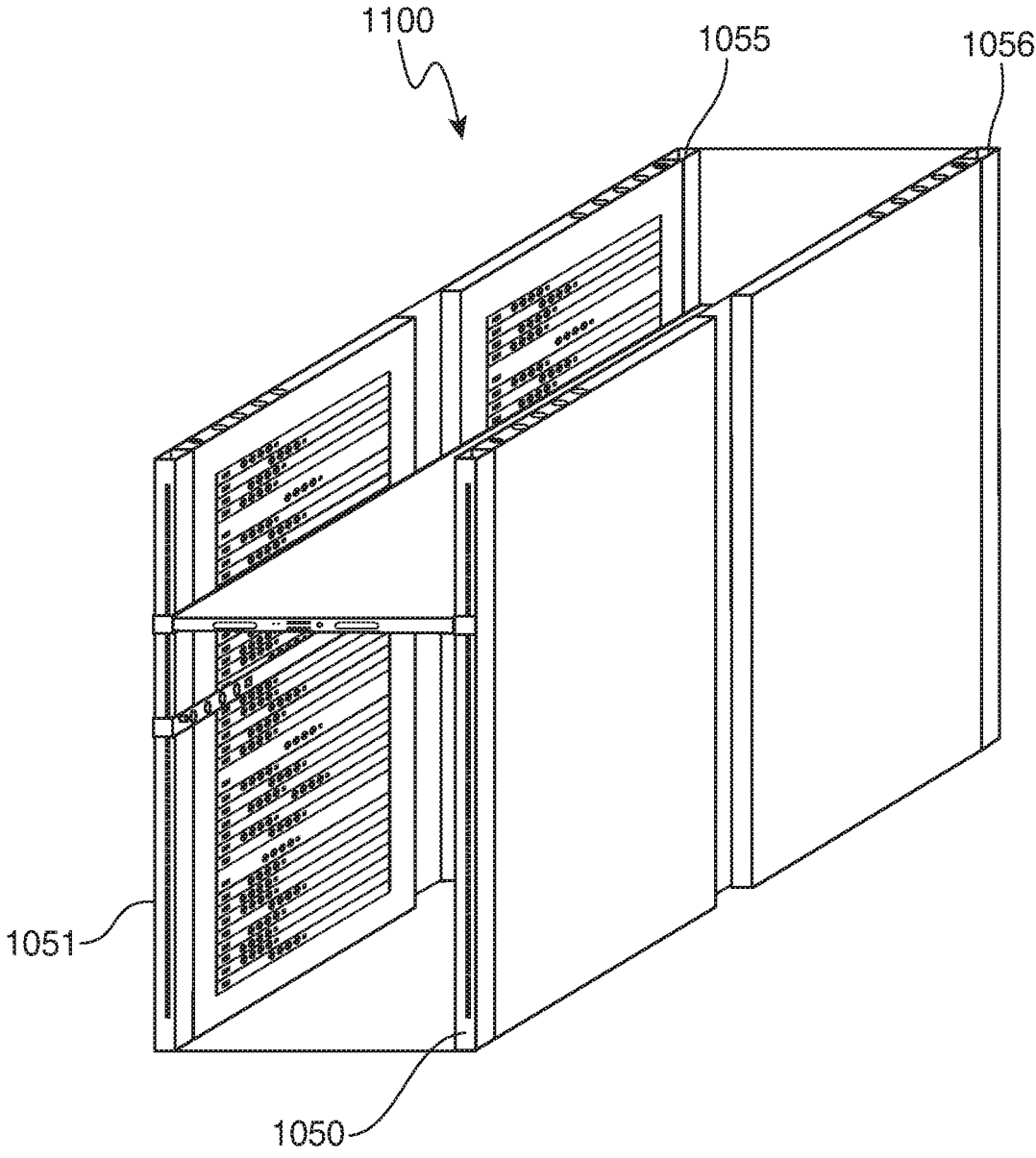


FIG. 11

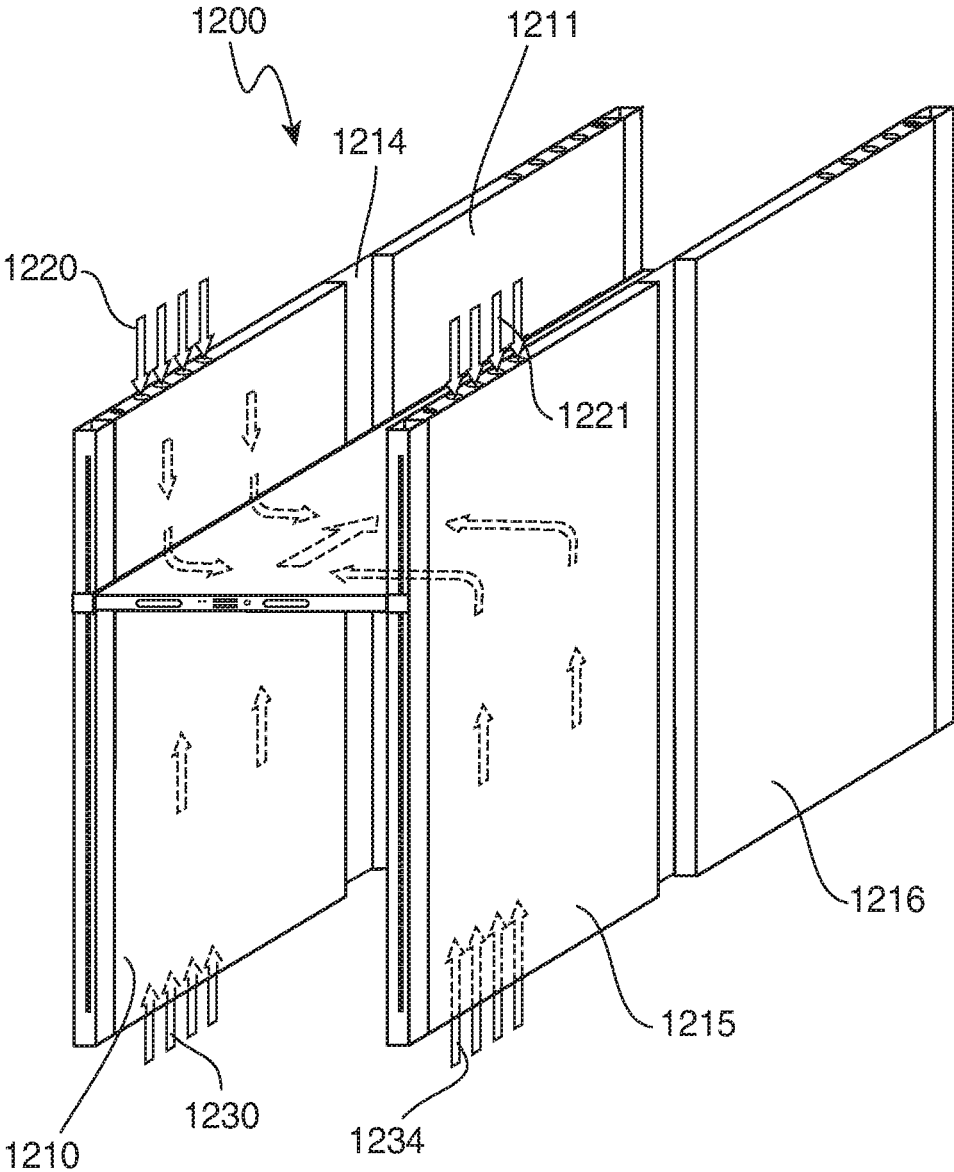


FIG. 12

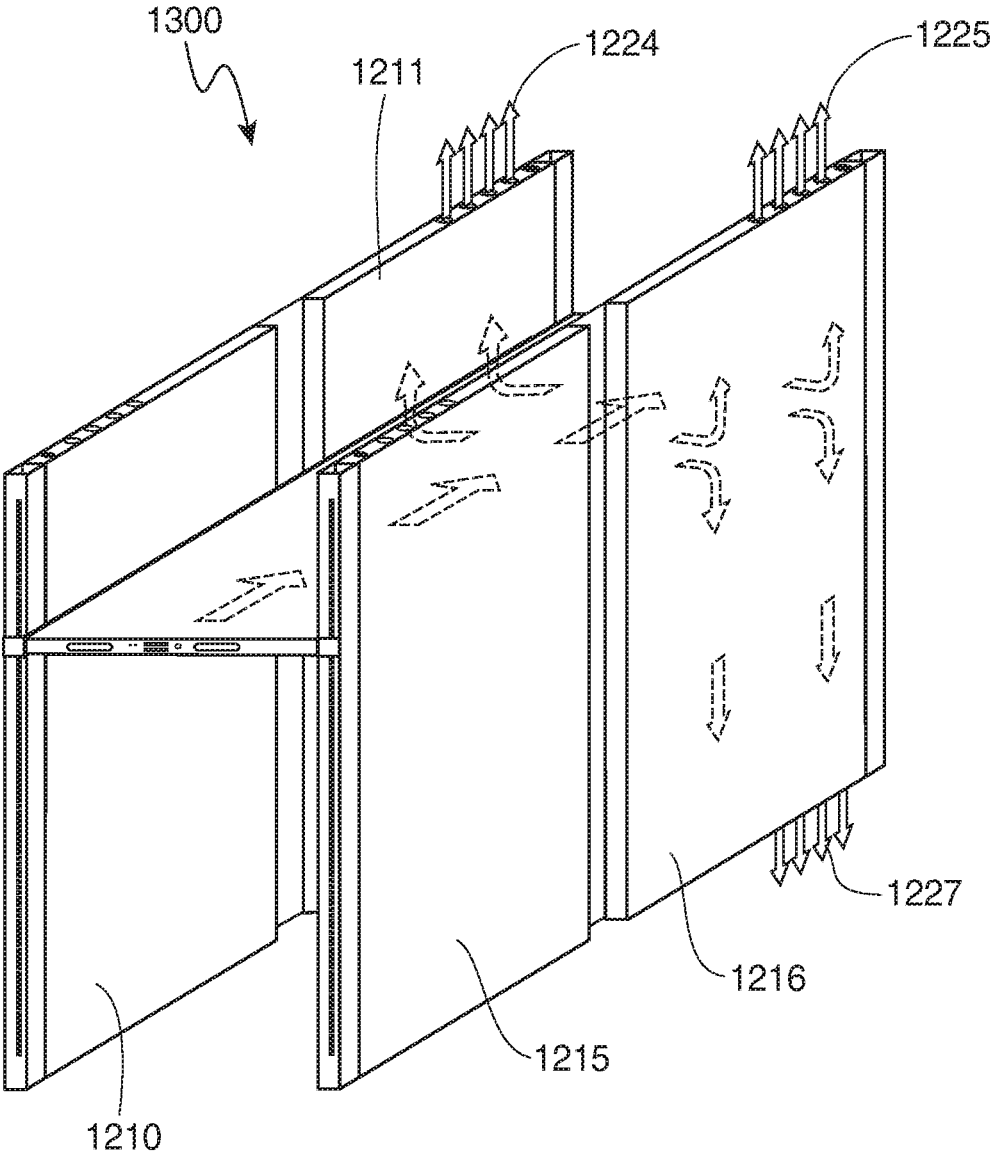


FIG. 13

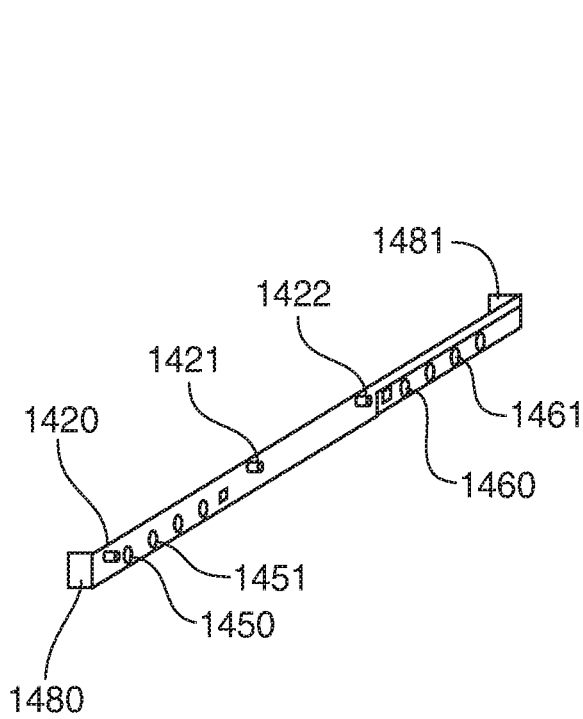


FIG. 14

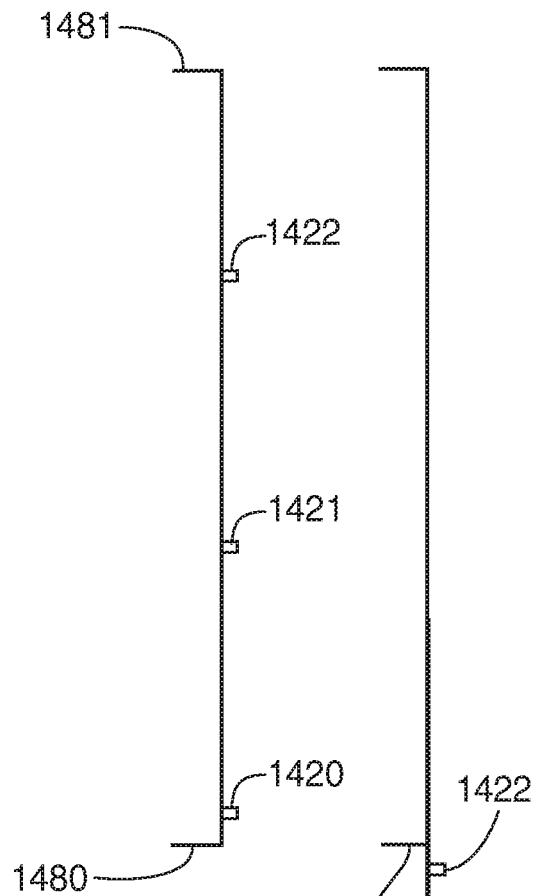


FIG. 15

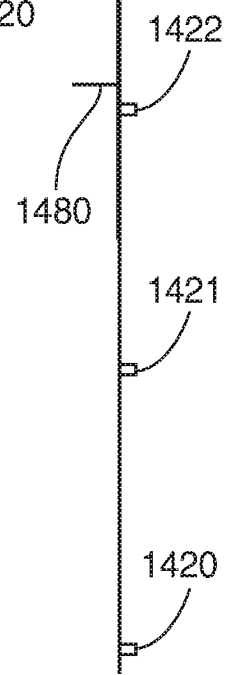


FIG. 17

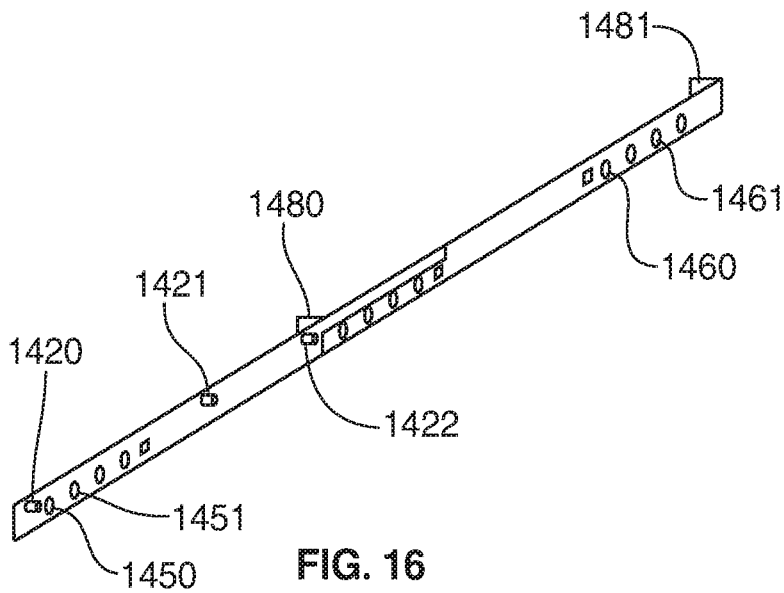


FIG. 16

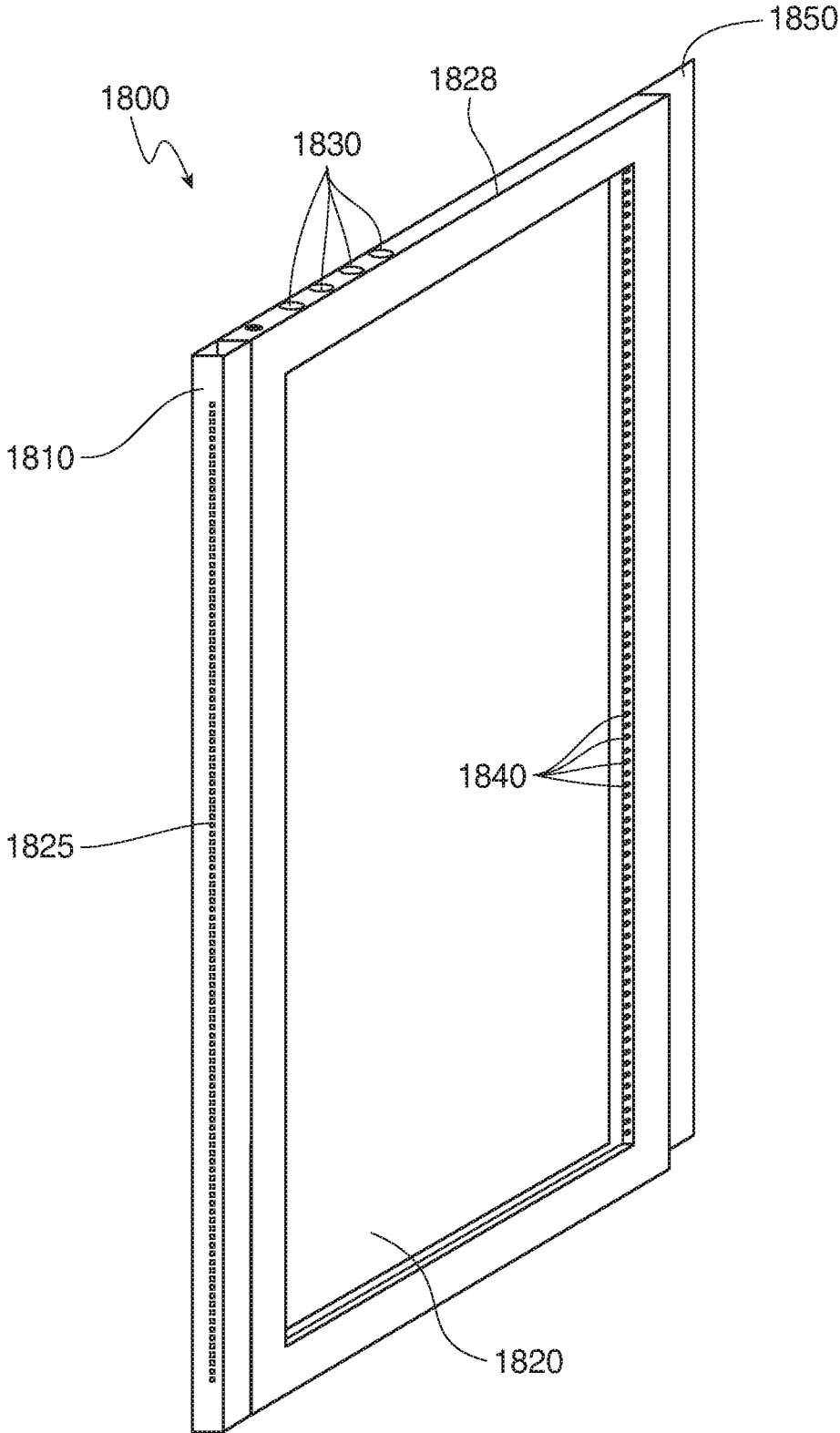


FIG. 18

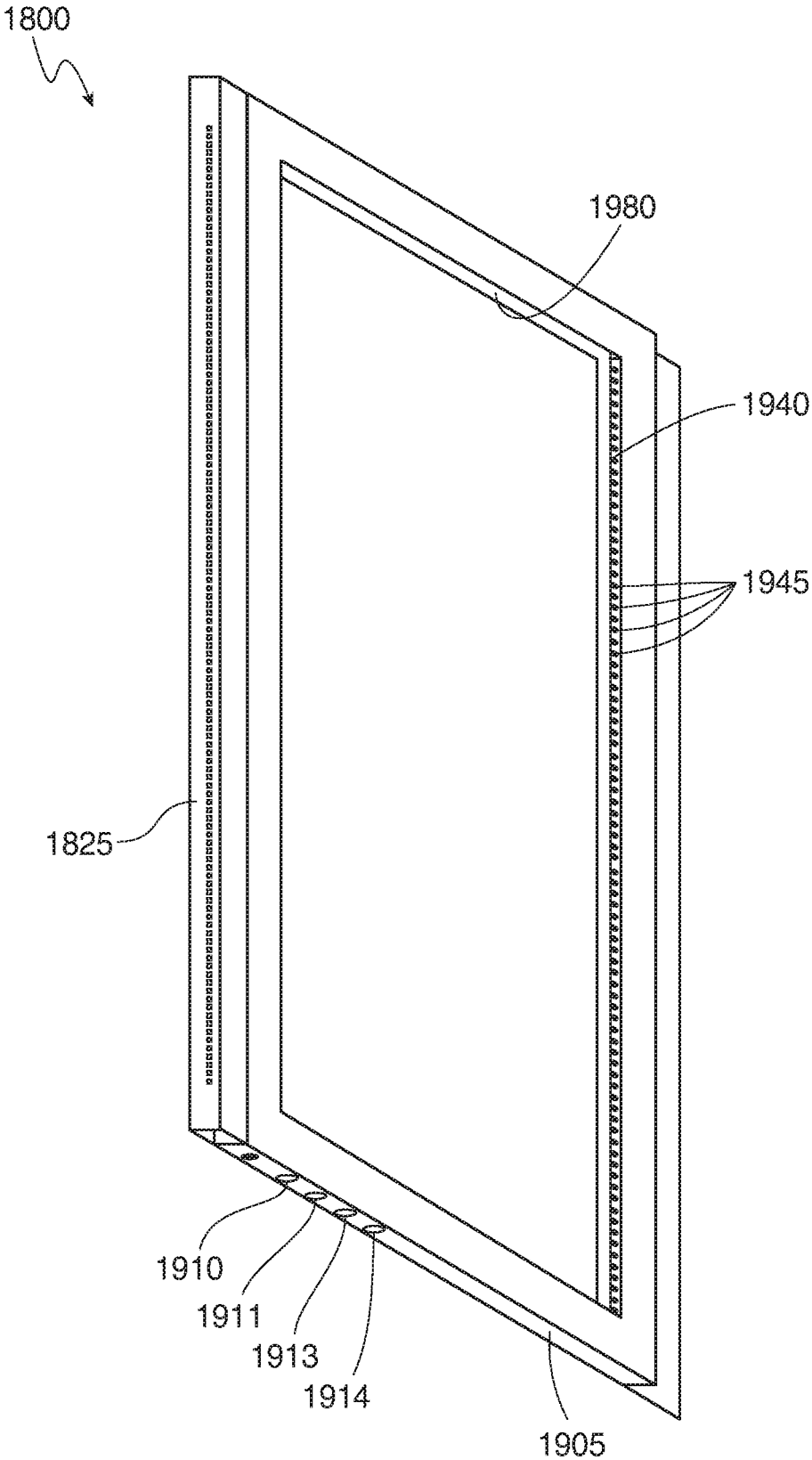
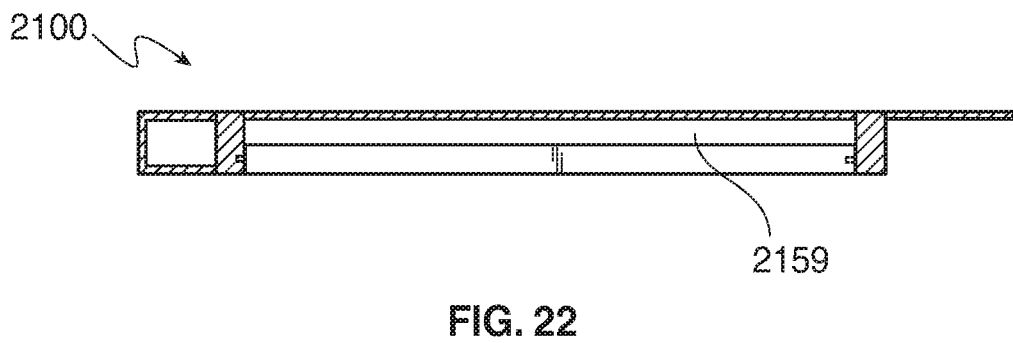
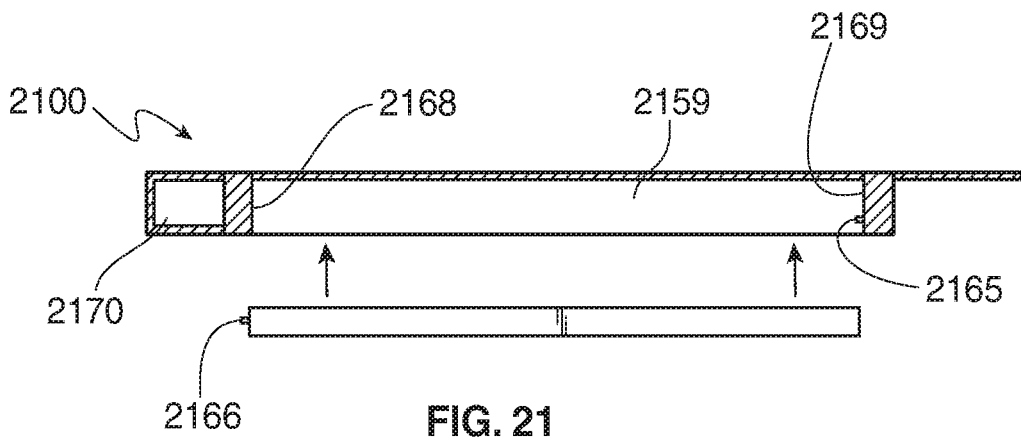
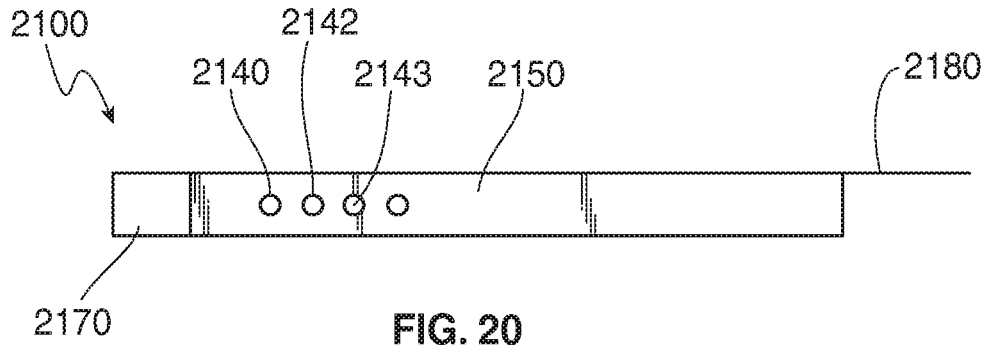


FIG. 19



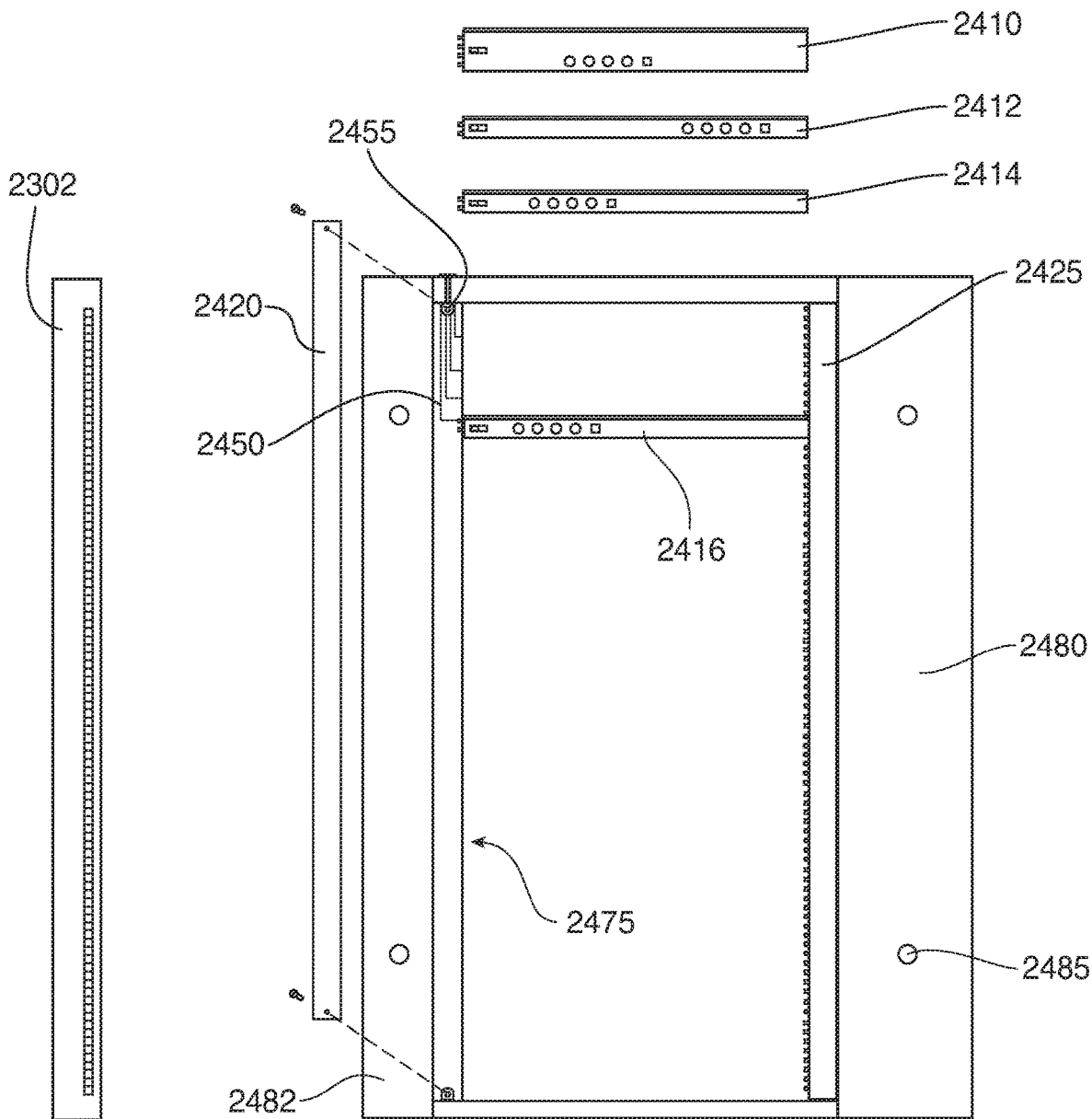


FIG. 23

2400

FIG. 24

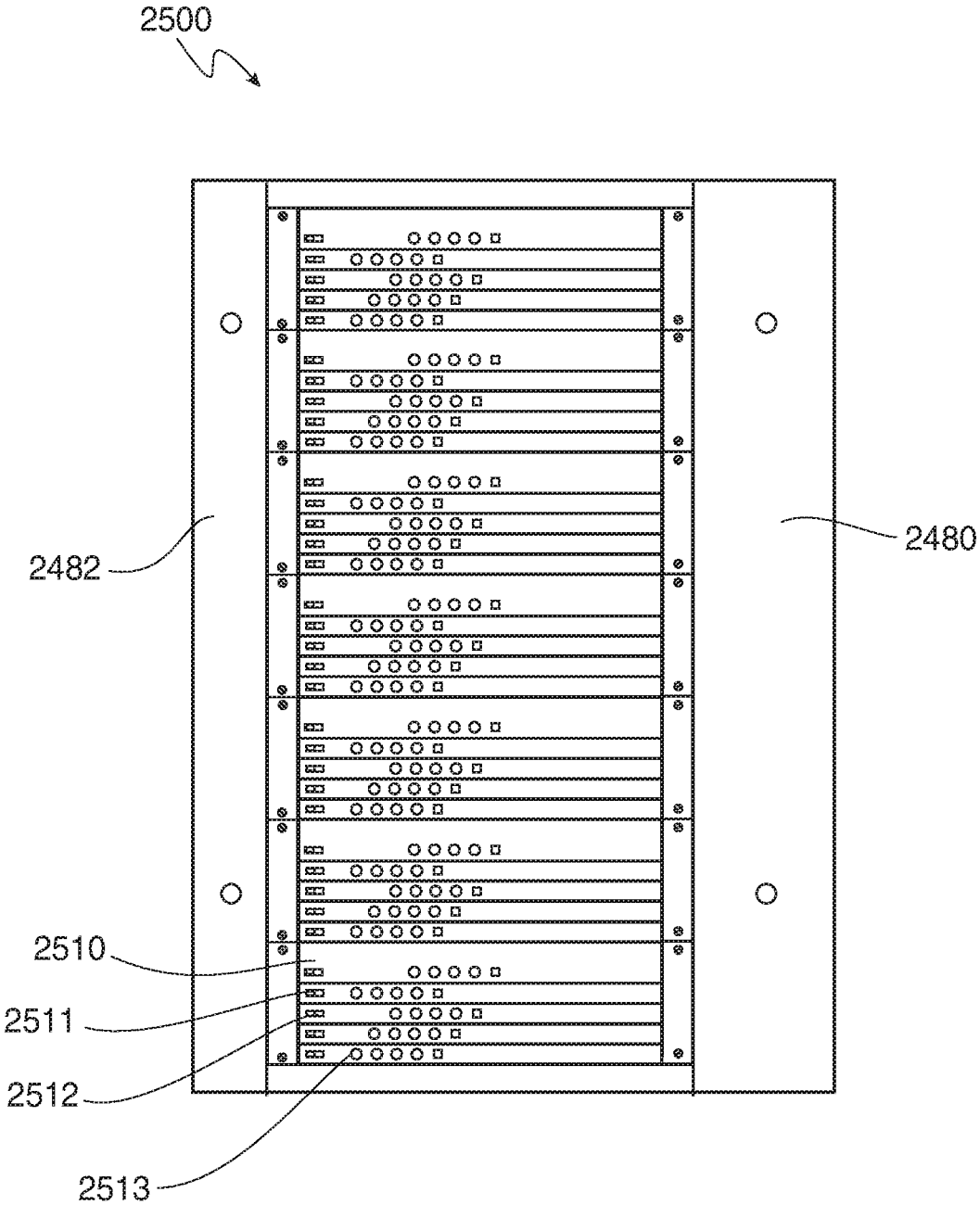


FIG. 25

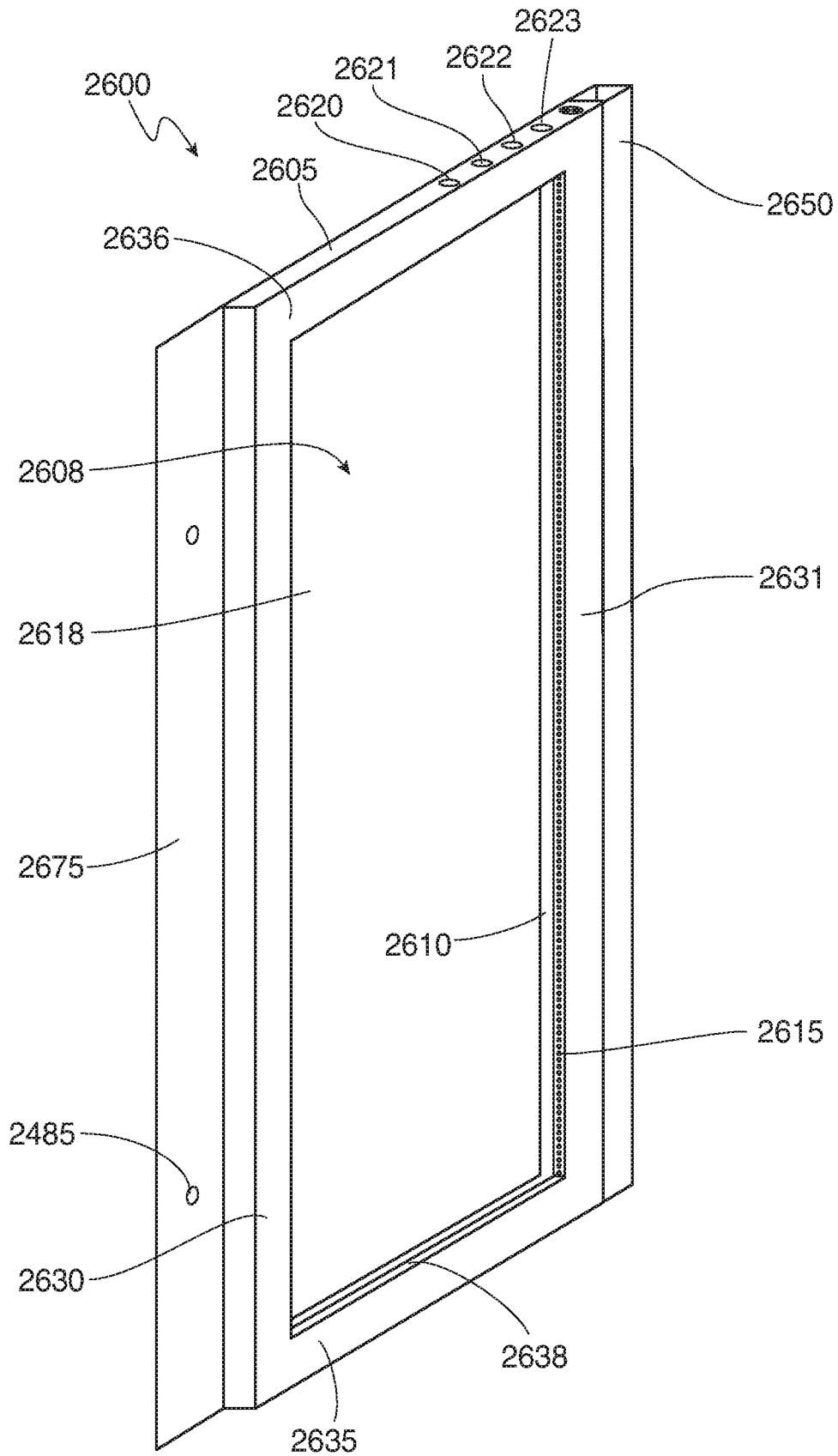


FIG. 26

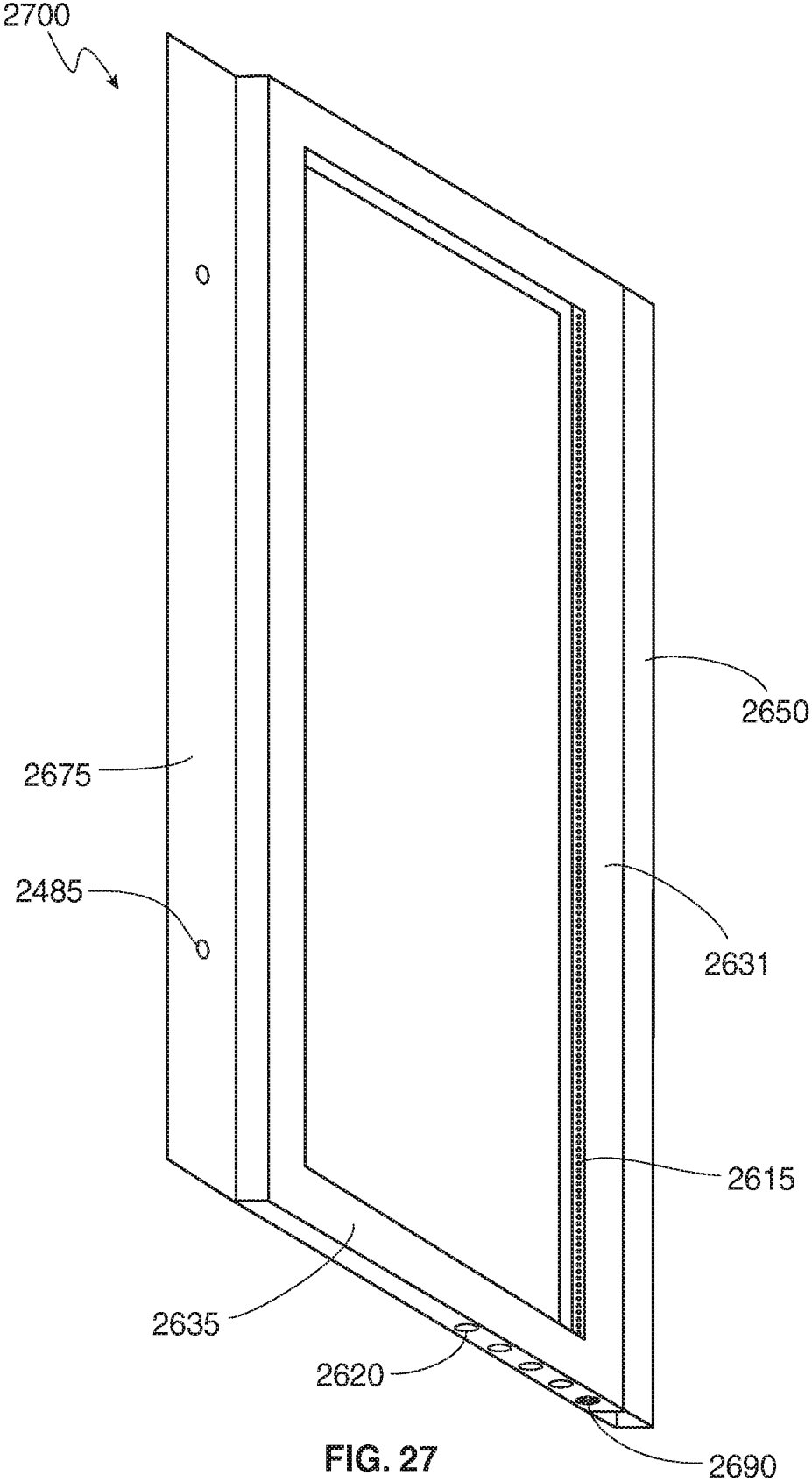


FIG. 27

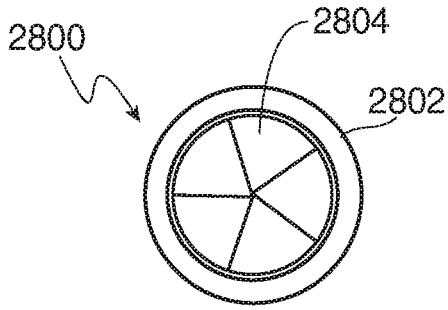


FIG. 28

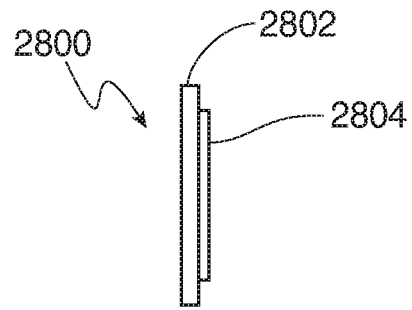


FIG. 29

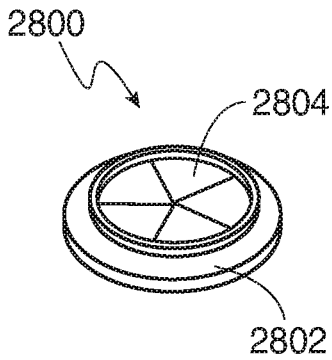


FIG. 30A

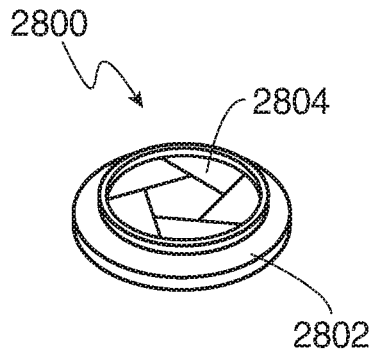


FIG. 30B

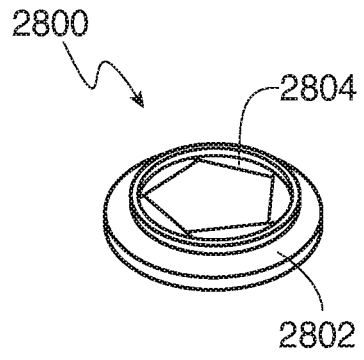
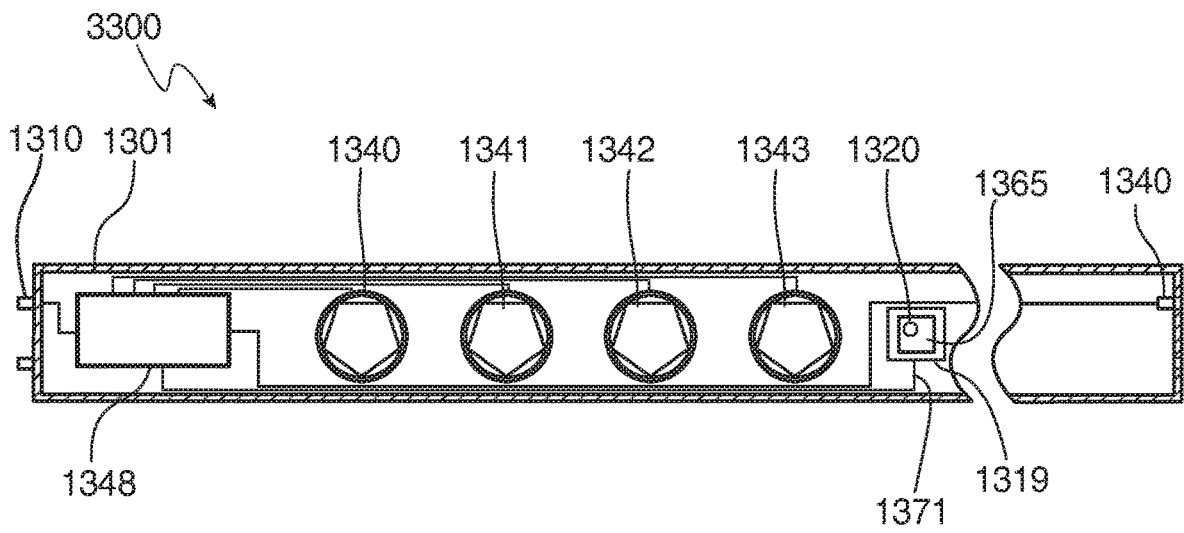
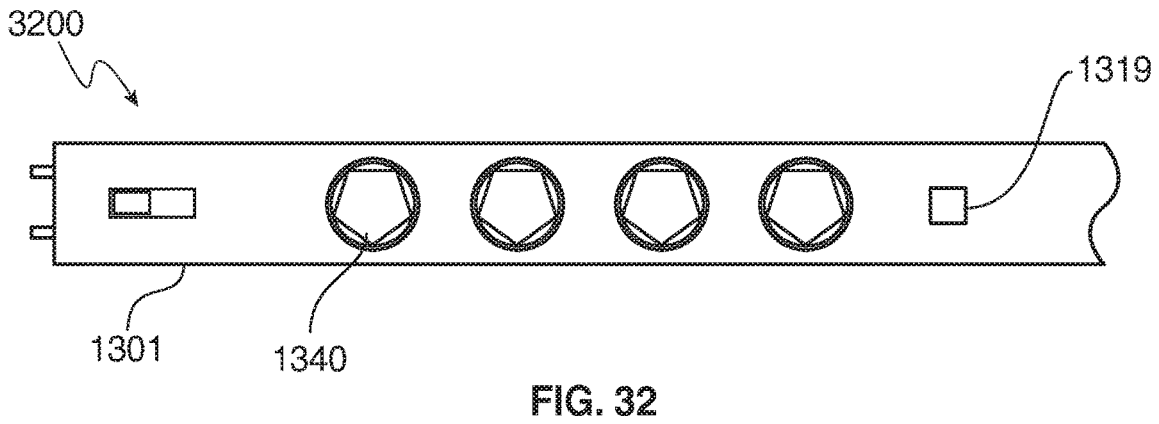
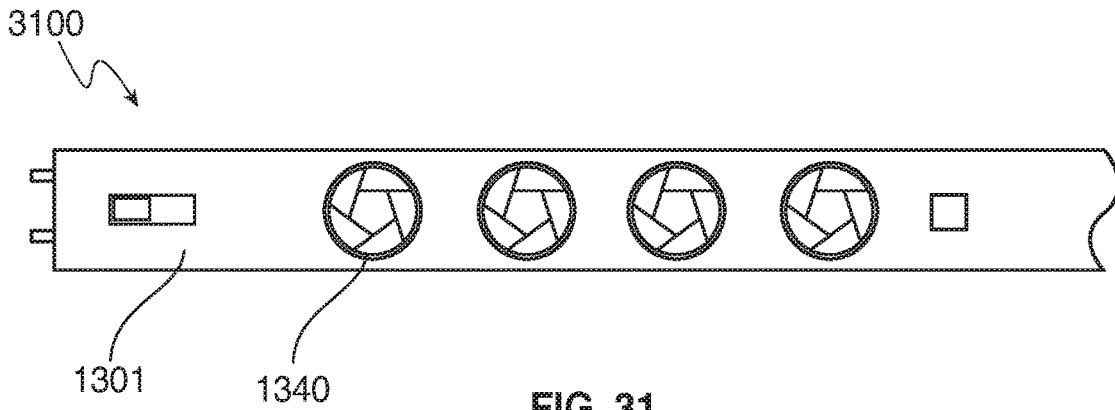


FIG. 30C



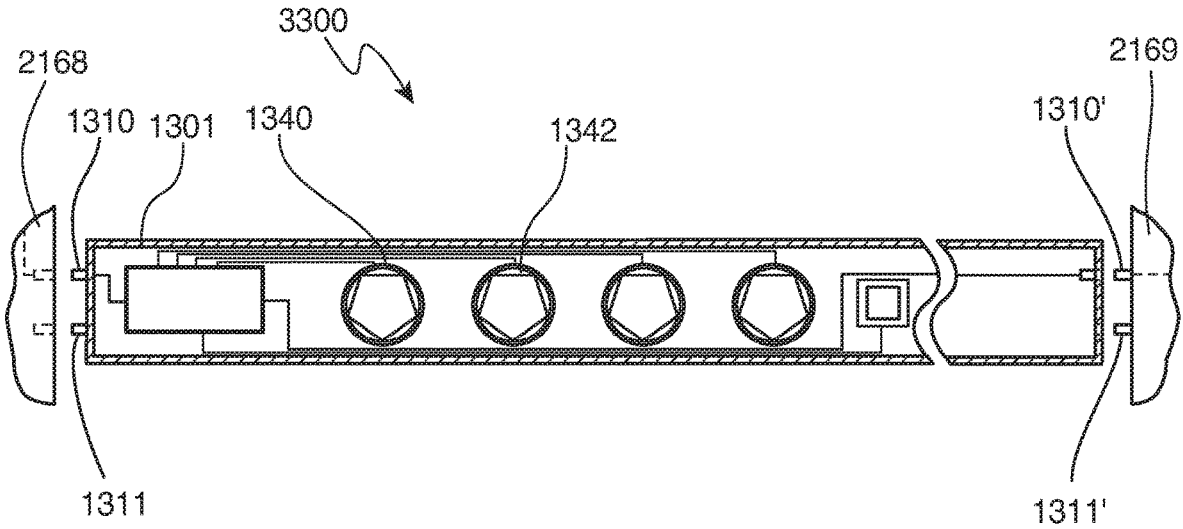


FIG. 34

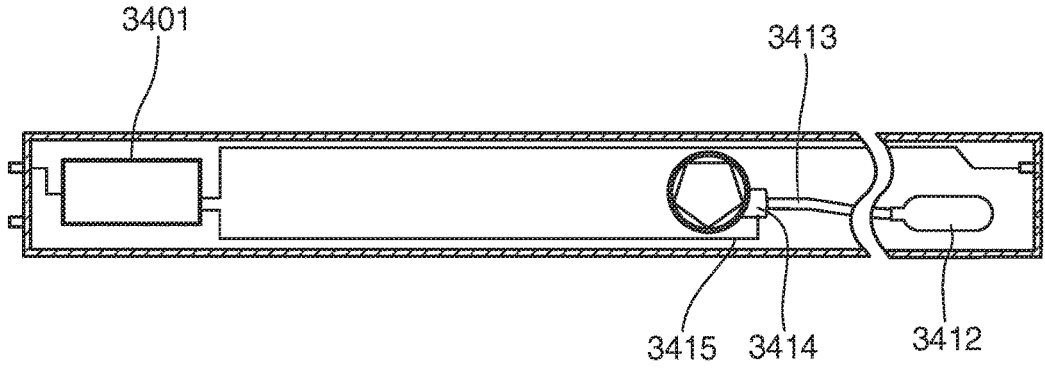
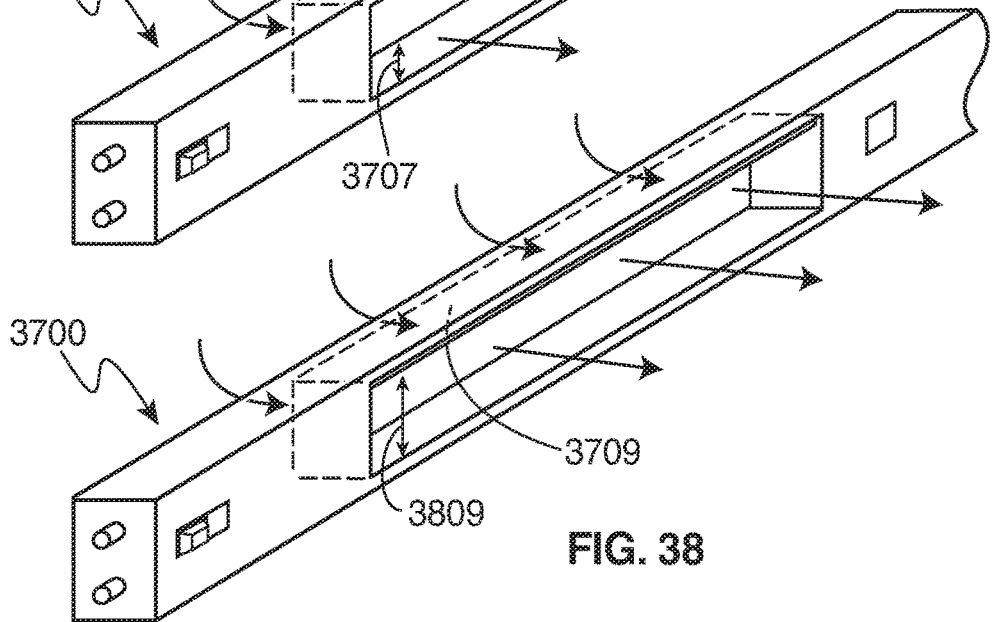
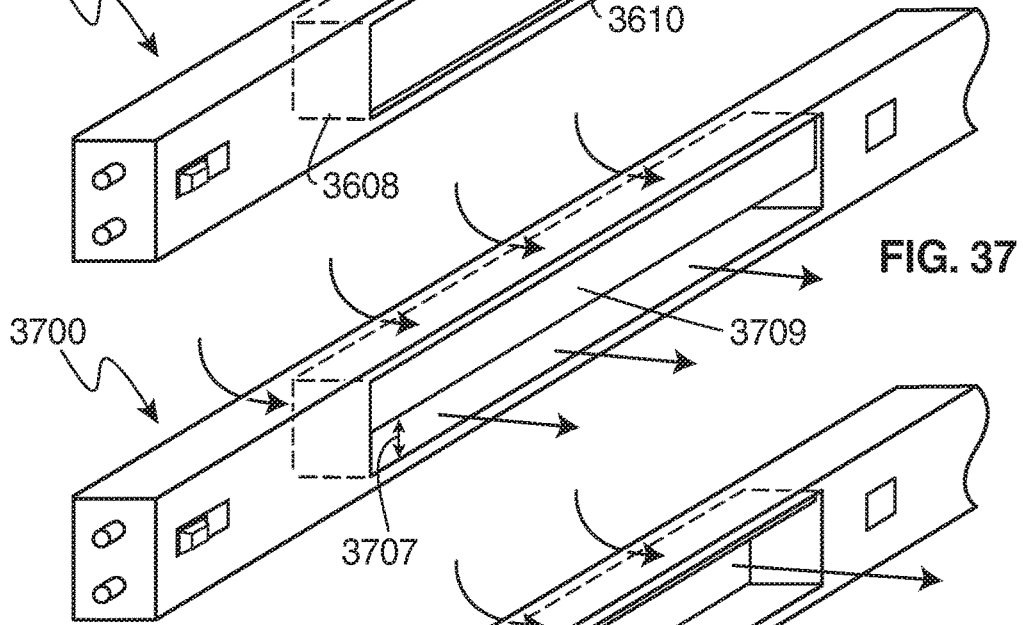
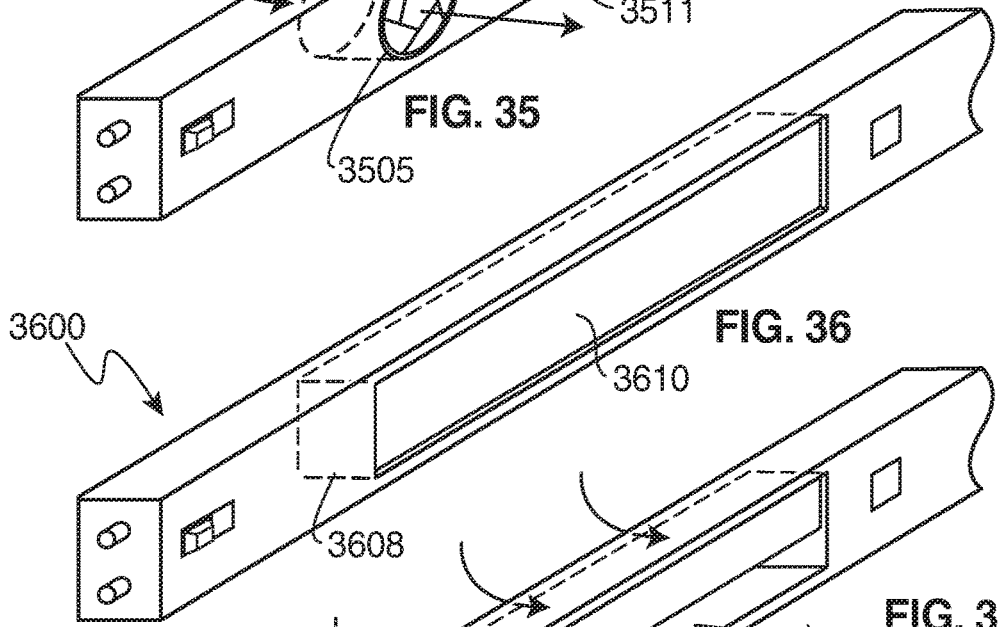
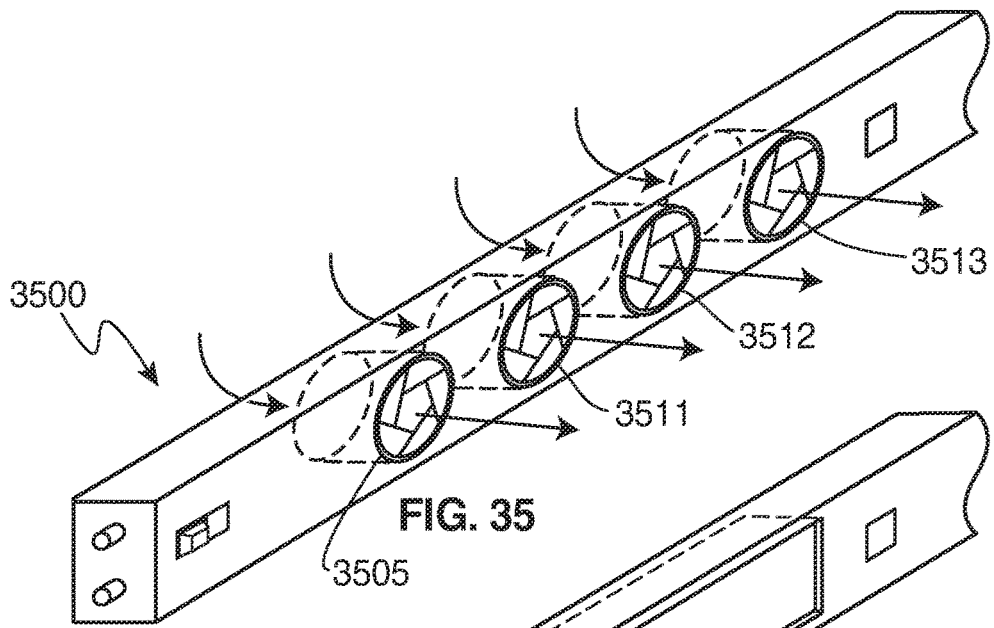
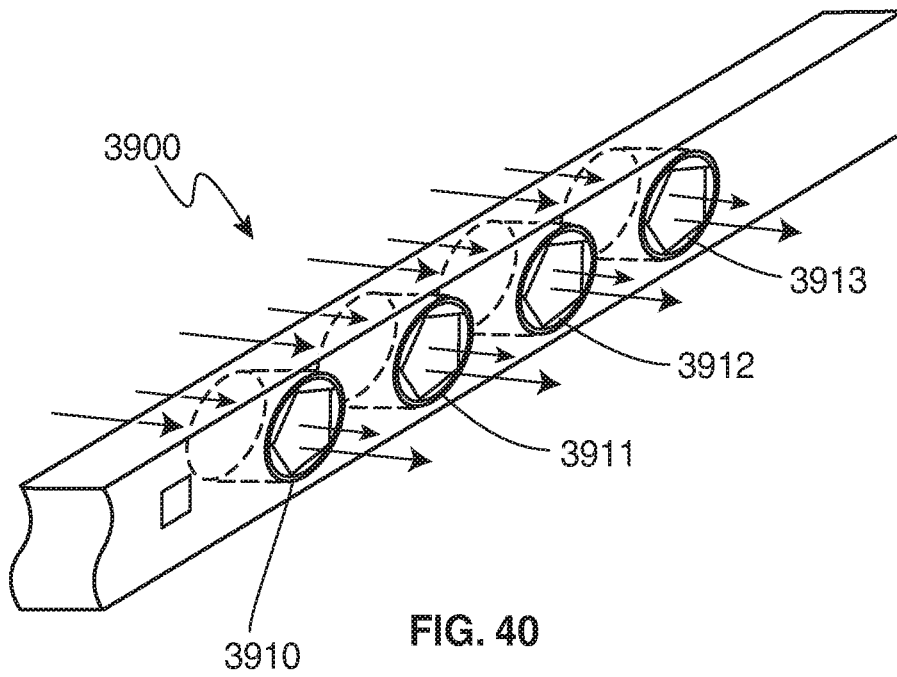
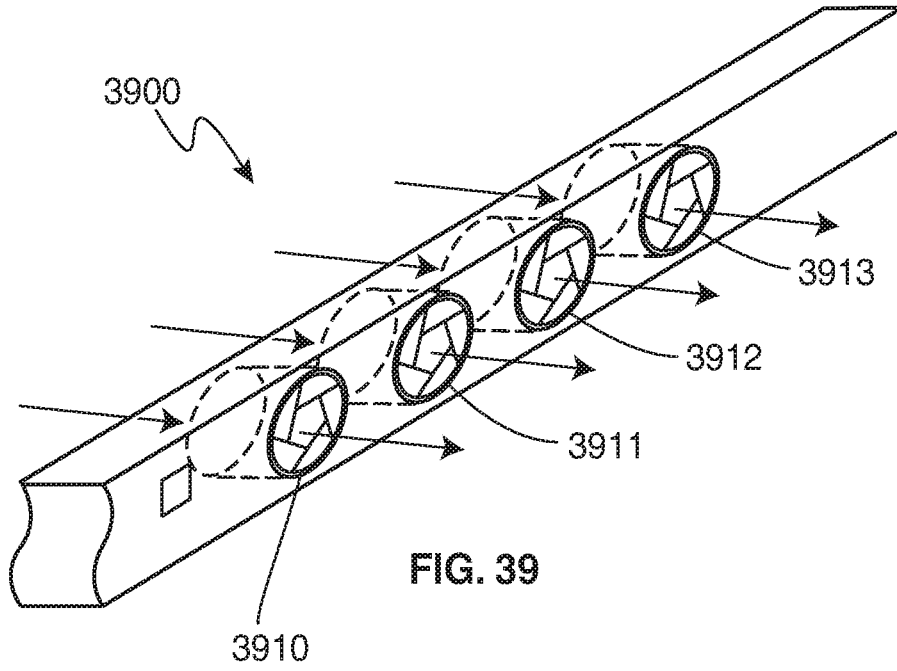


FIG. 34B





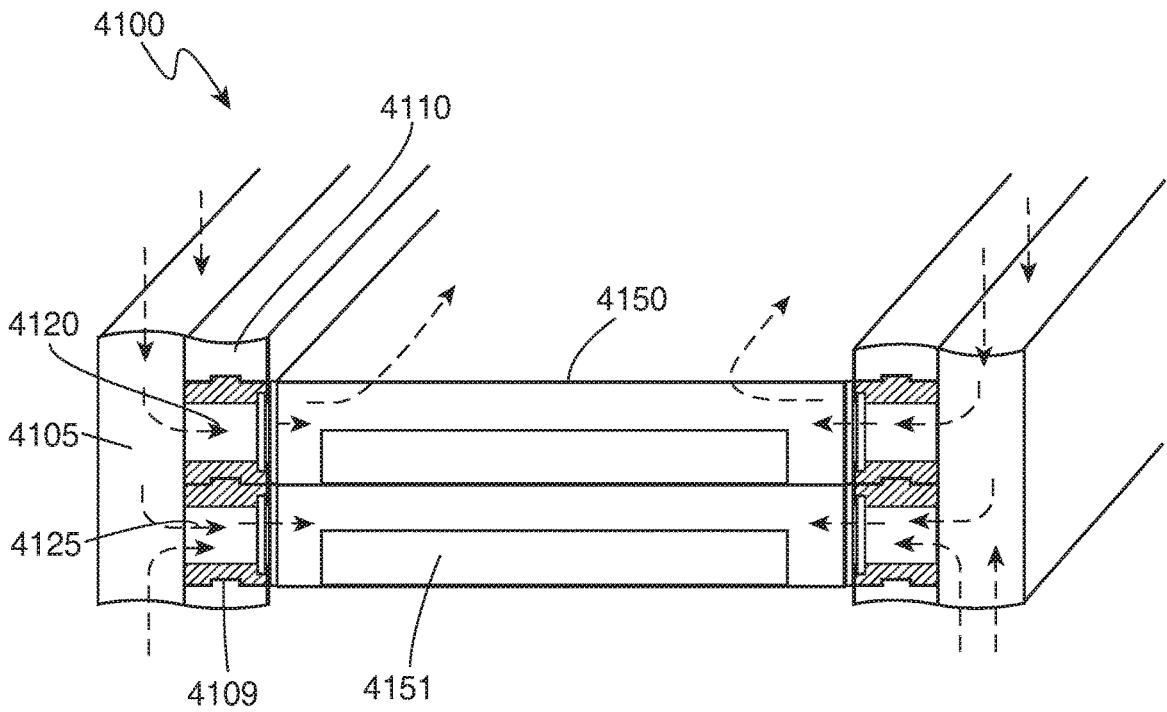


FIG. 41

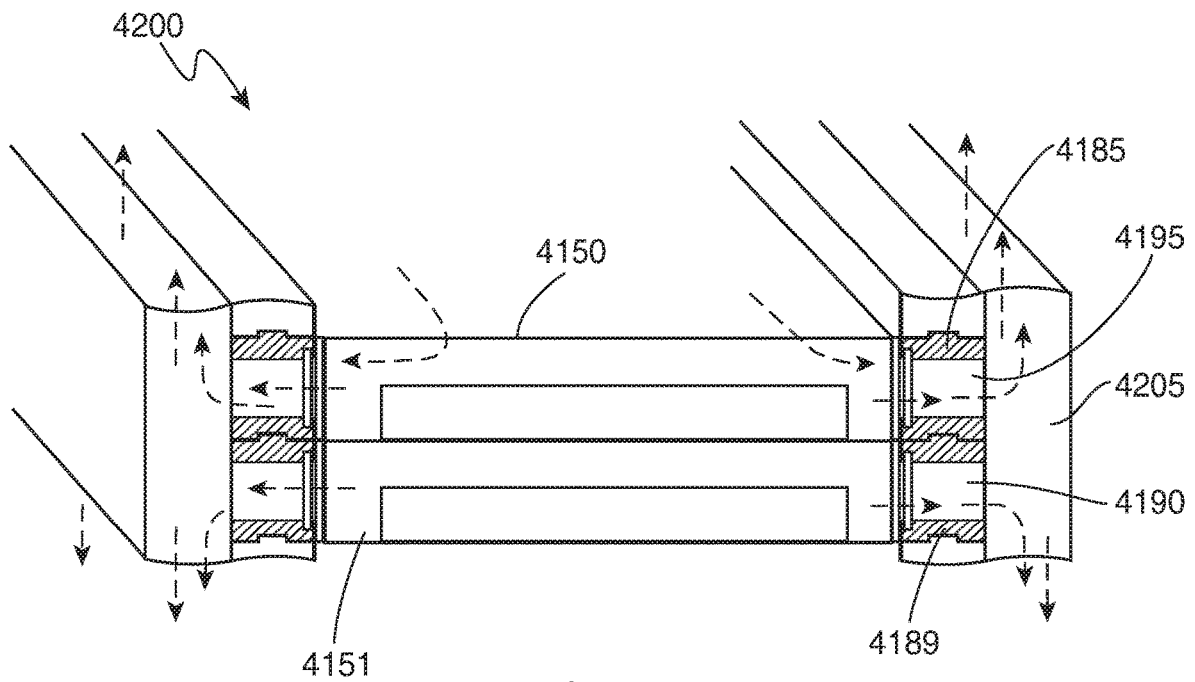
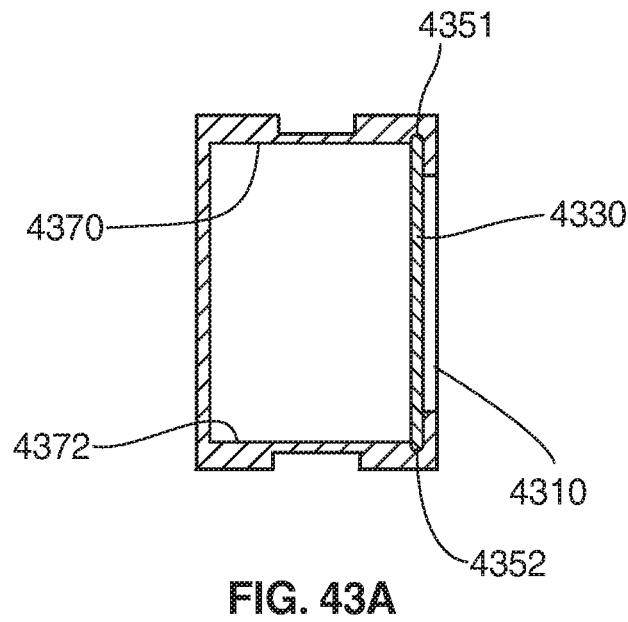
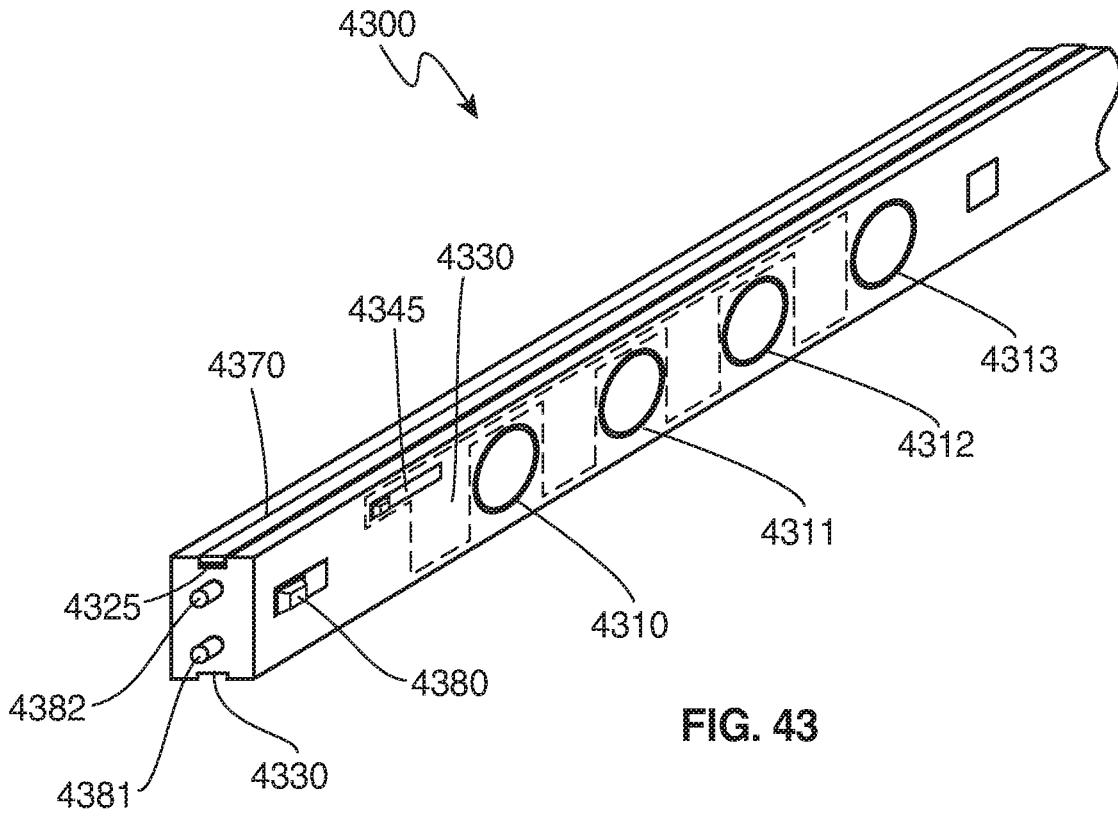


FIG. 42



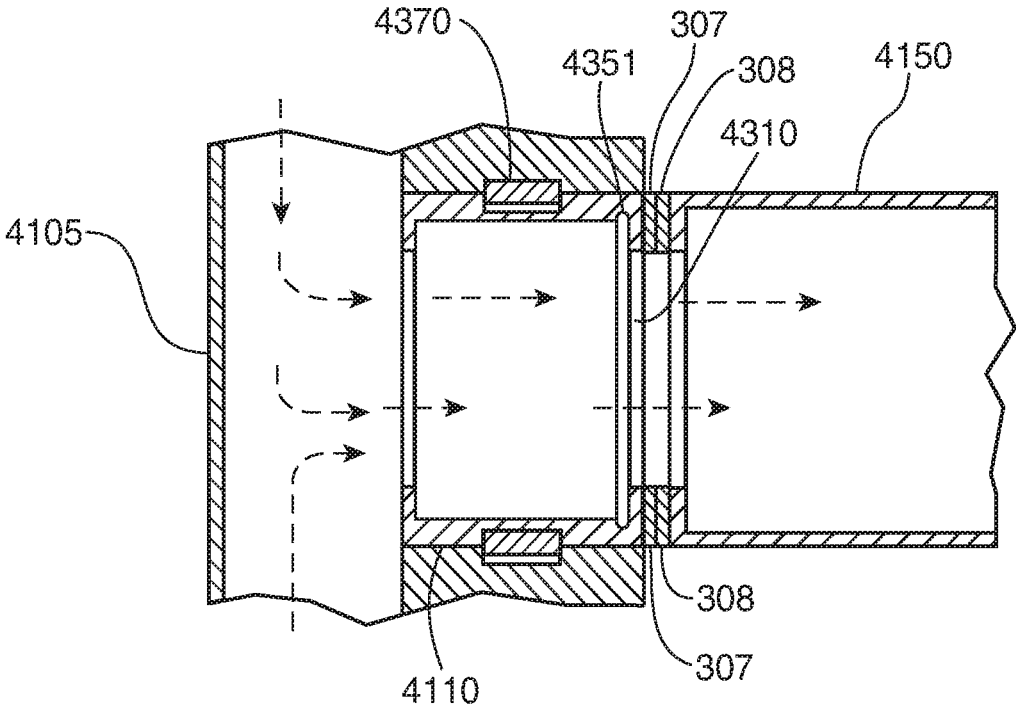


FIG. 43B

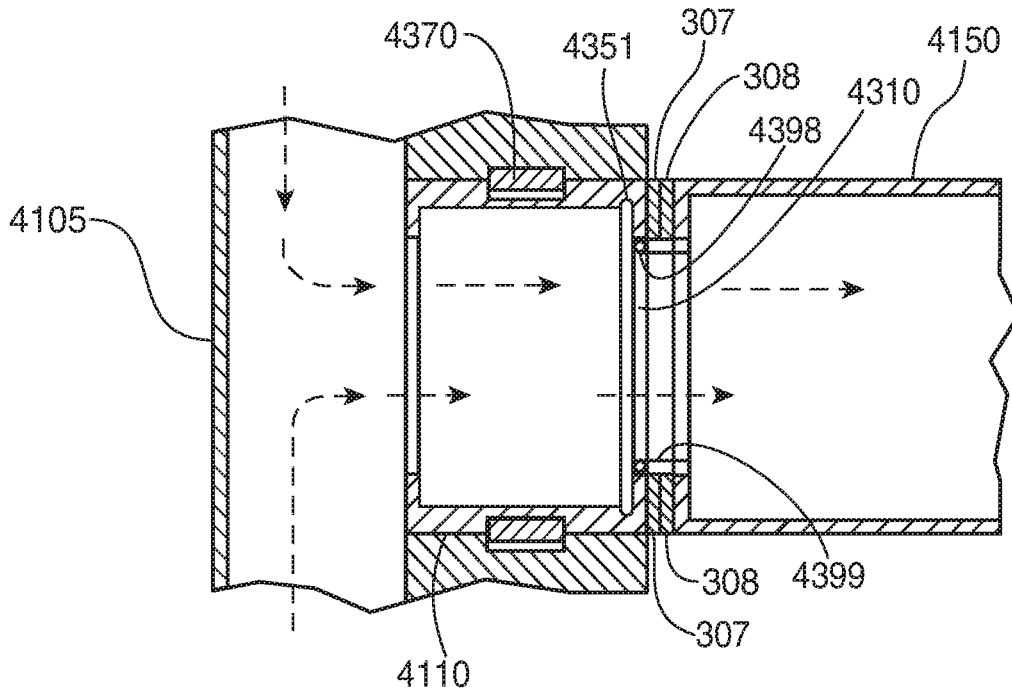


FIG. 43C

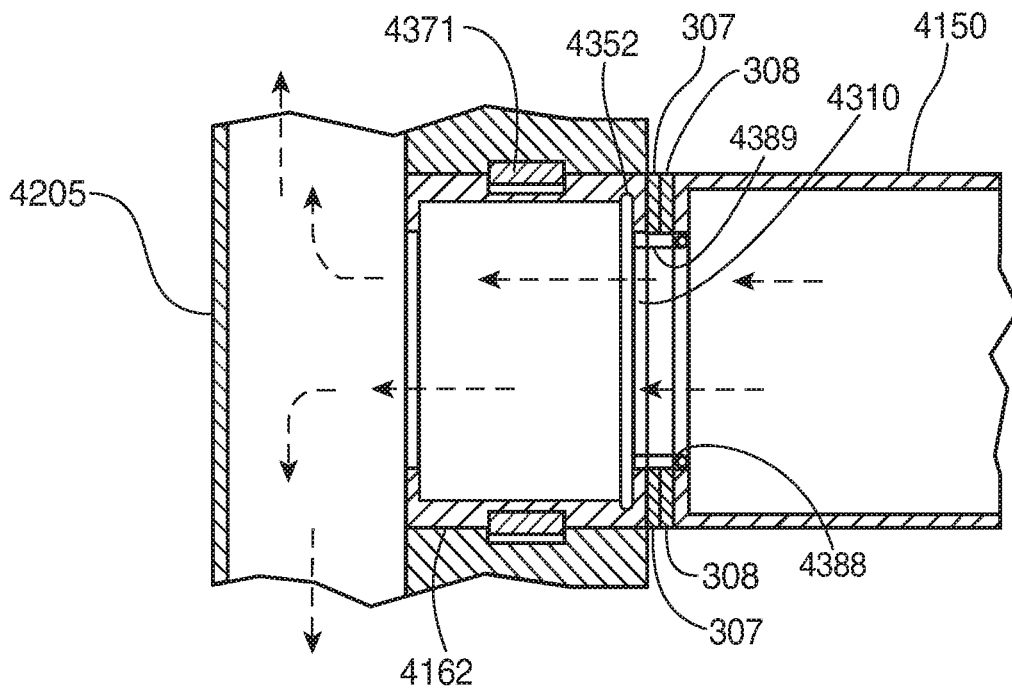


FIG. 43D

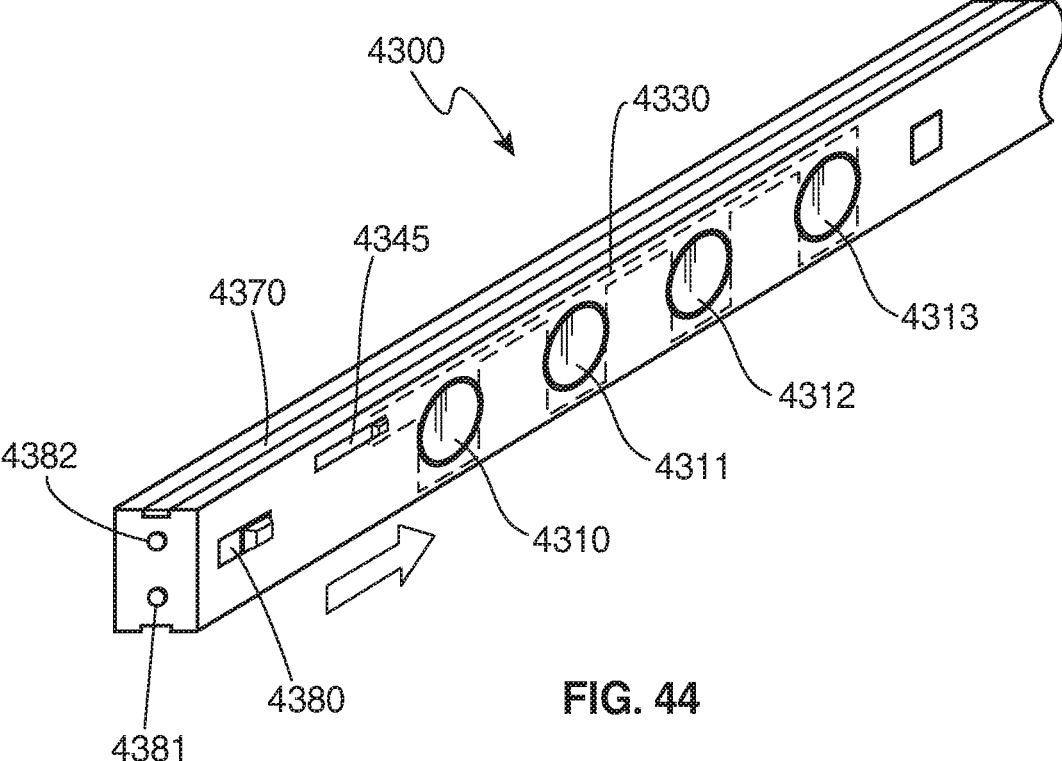


FIG. 44

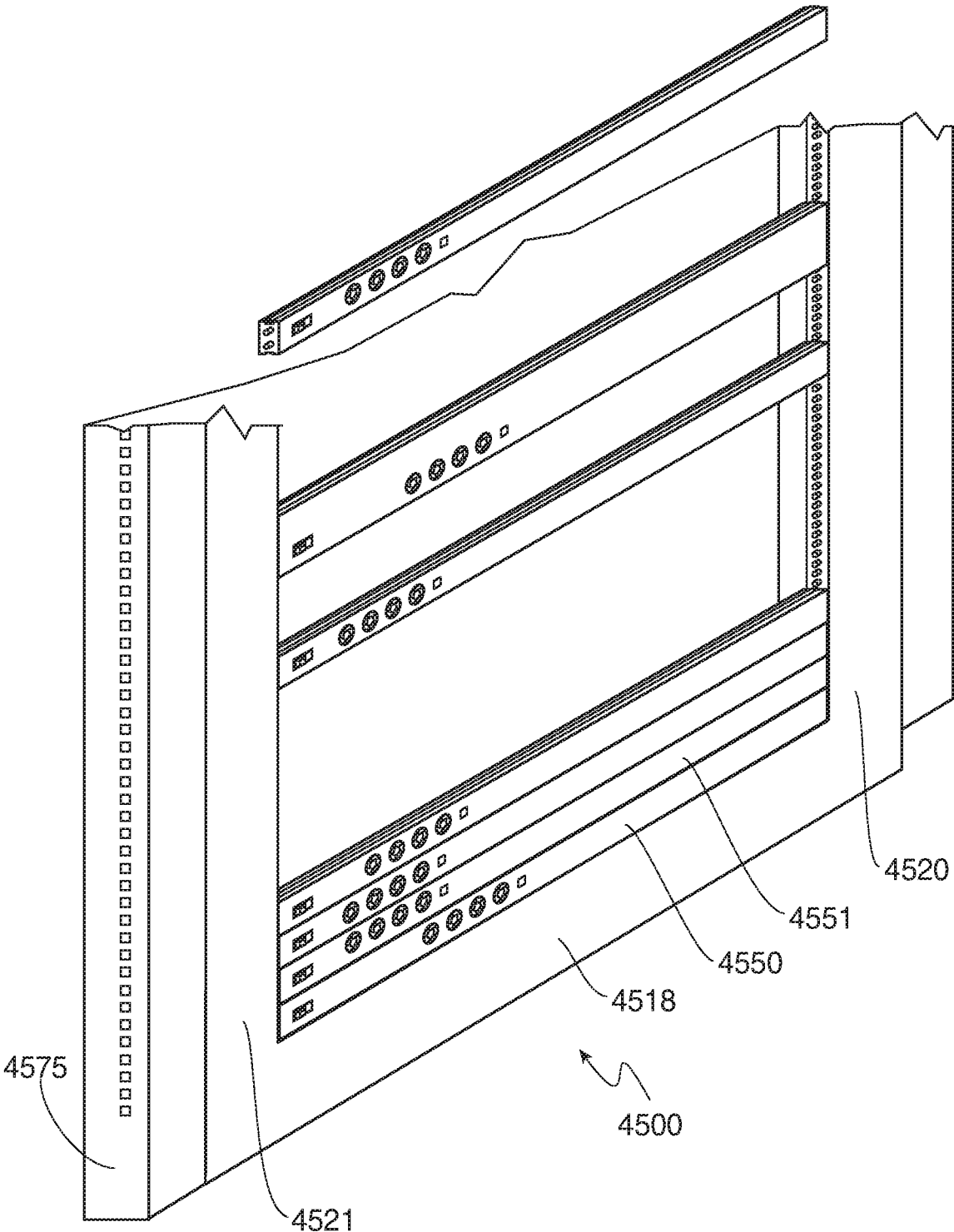


FIG. 45

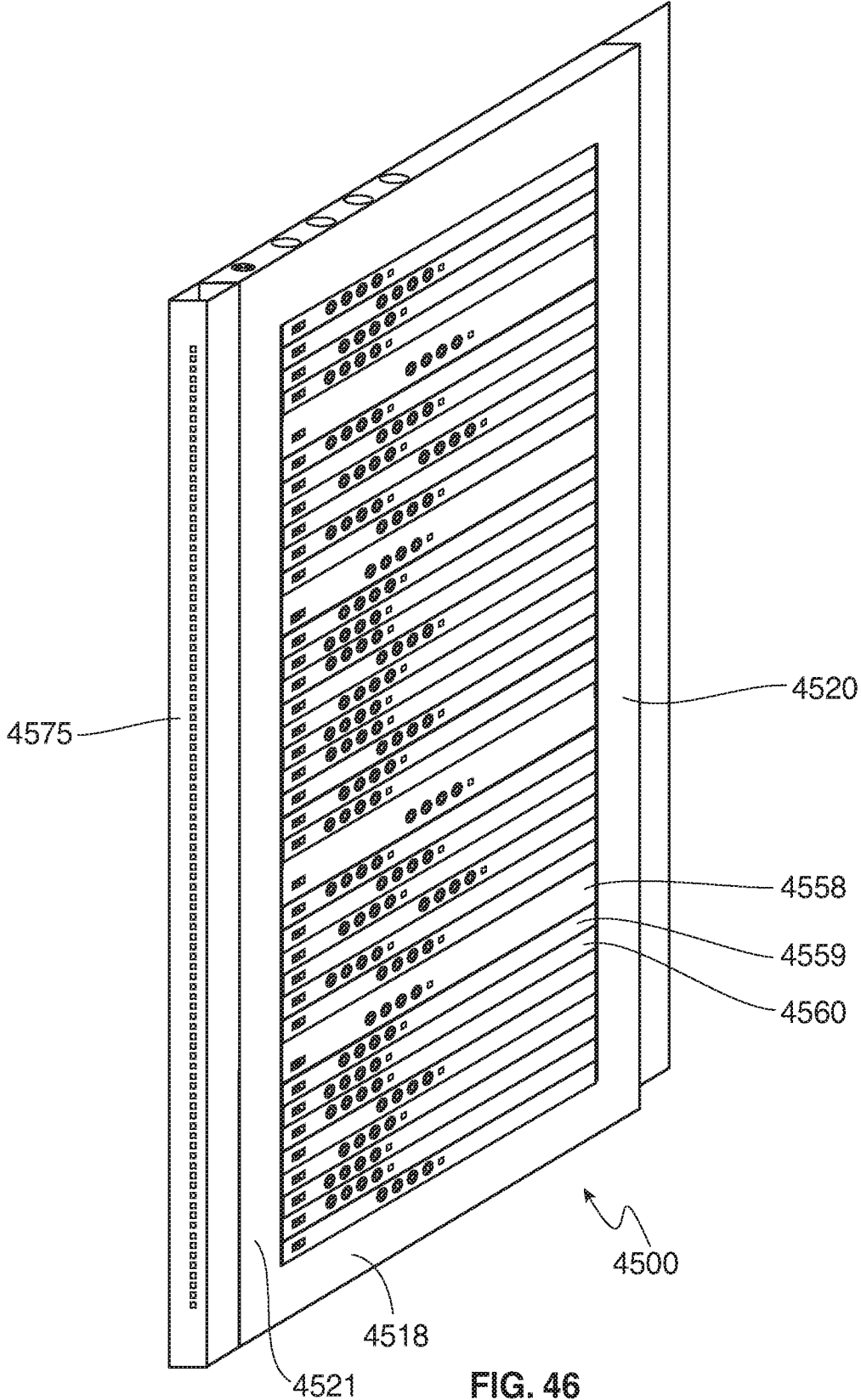


FIG. 46

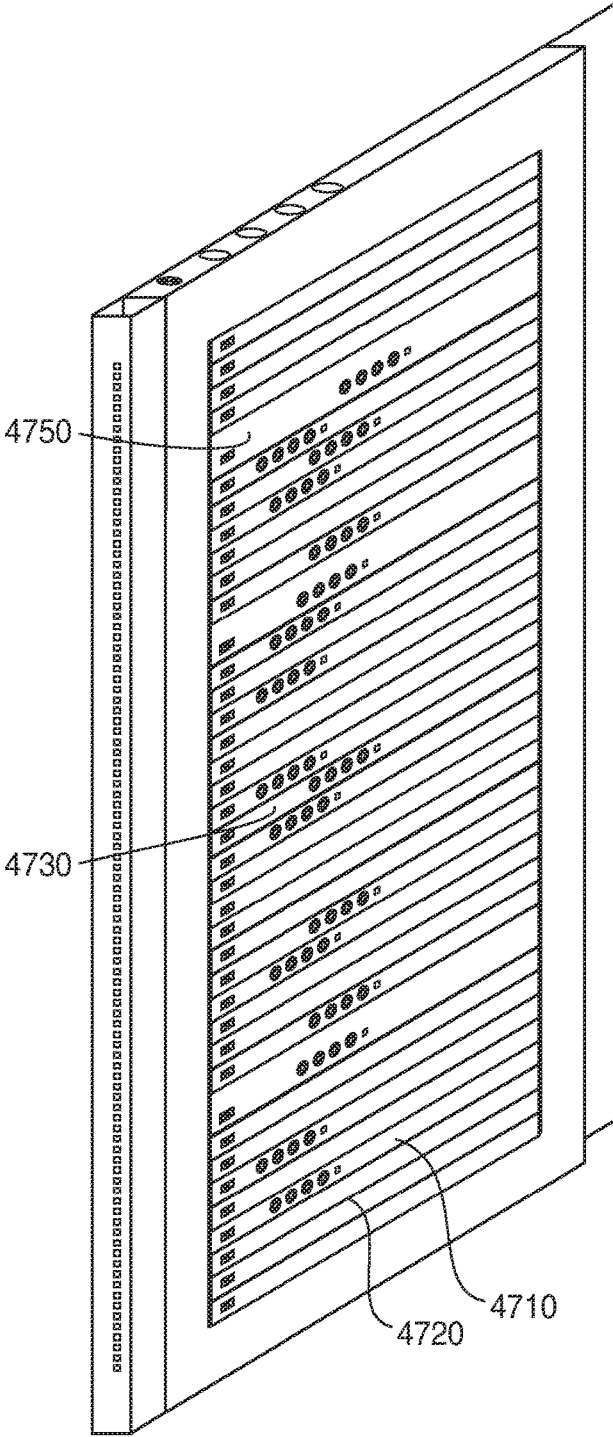


FIG. 47

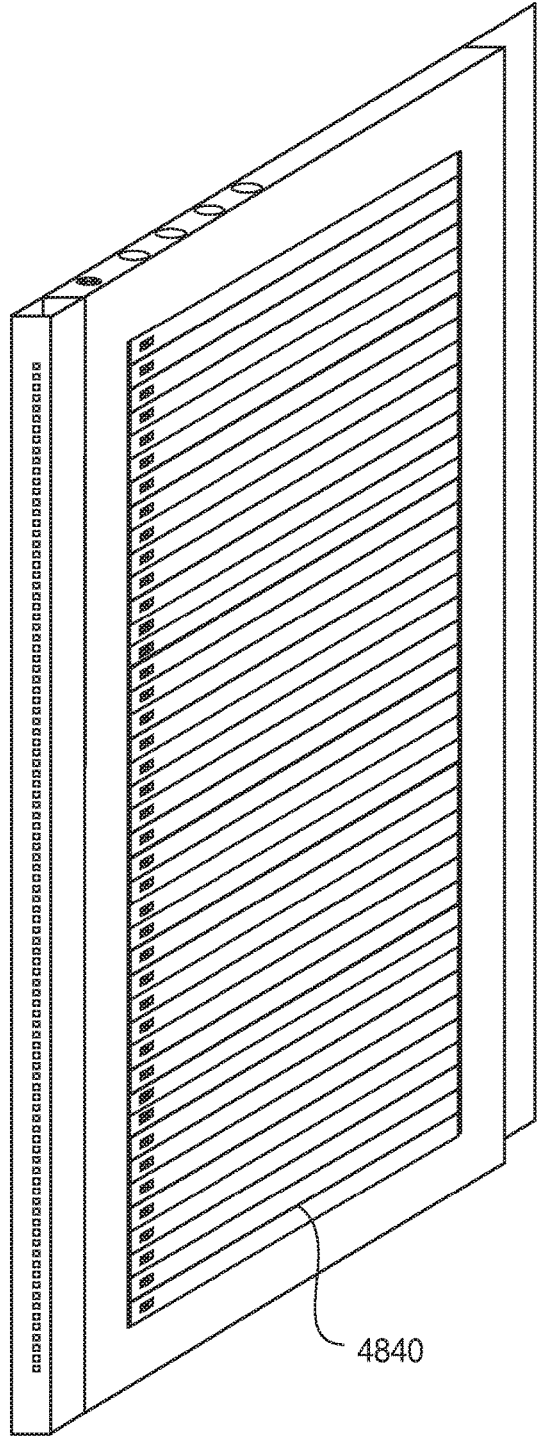


FIG. 48

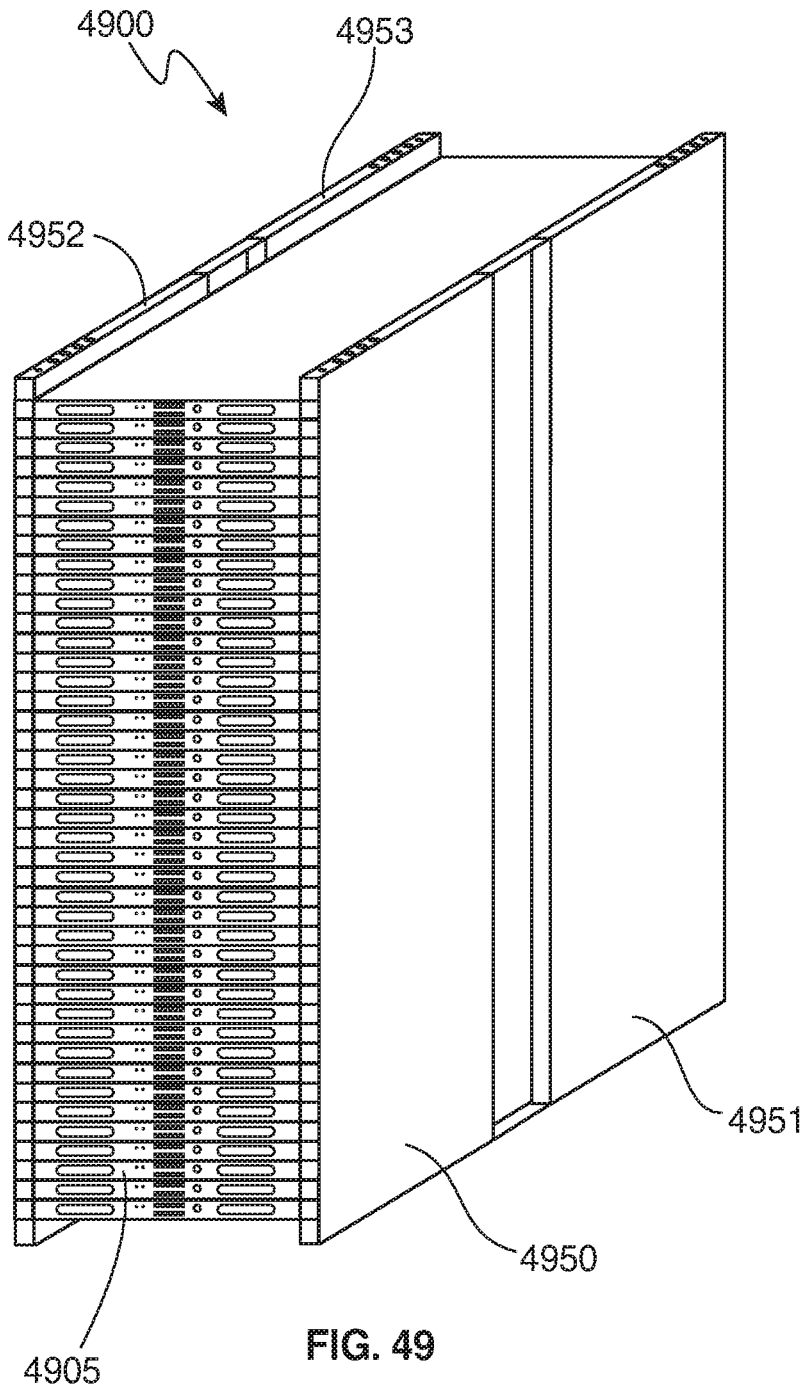


FIG. 49

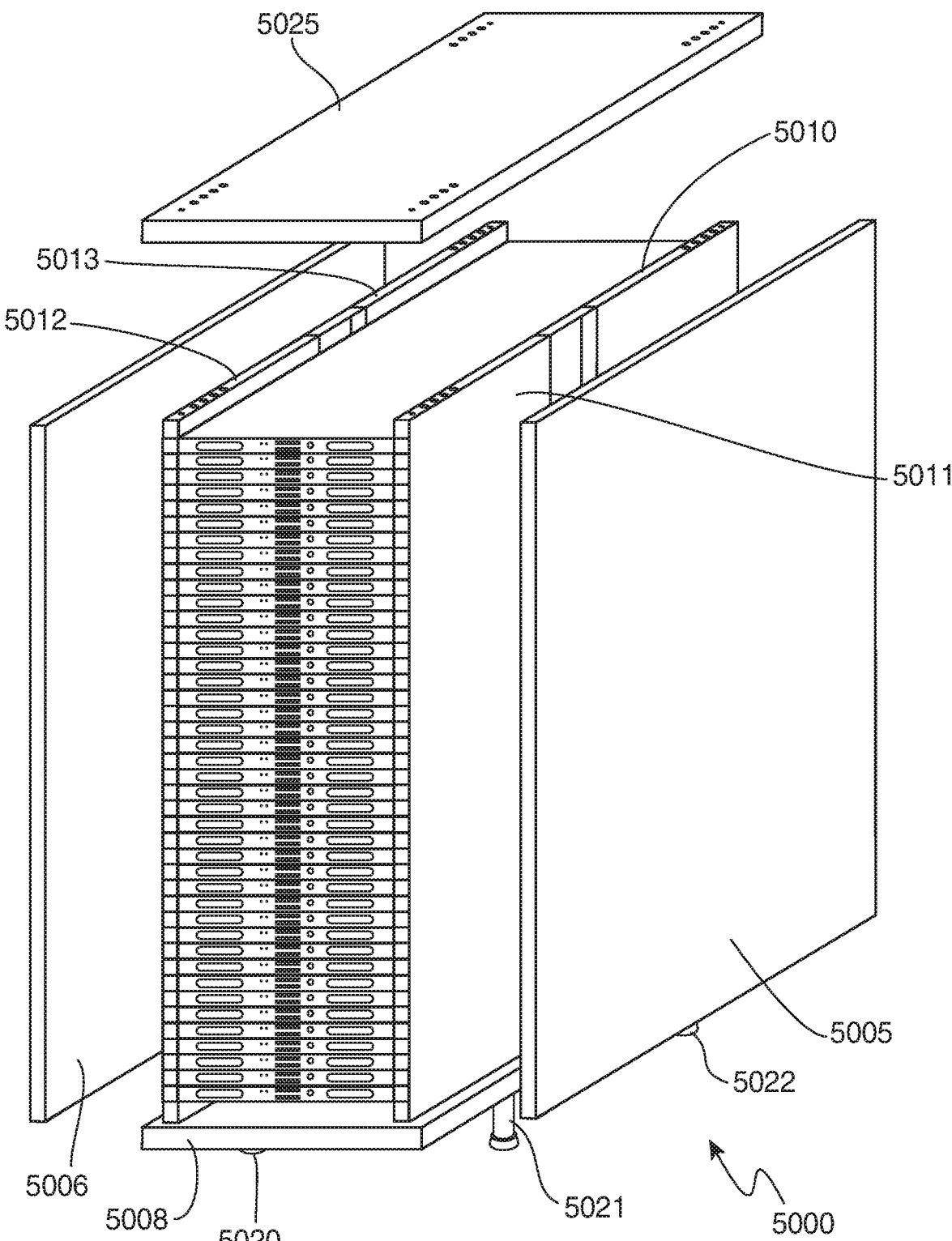


FIG. 50

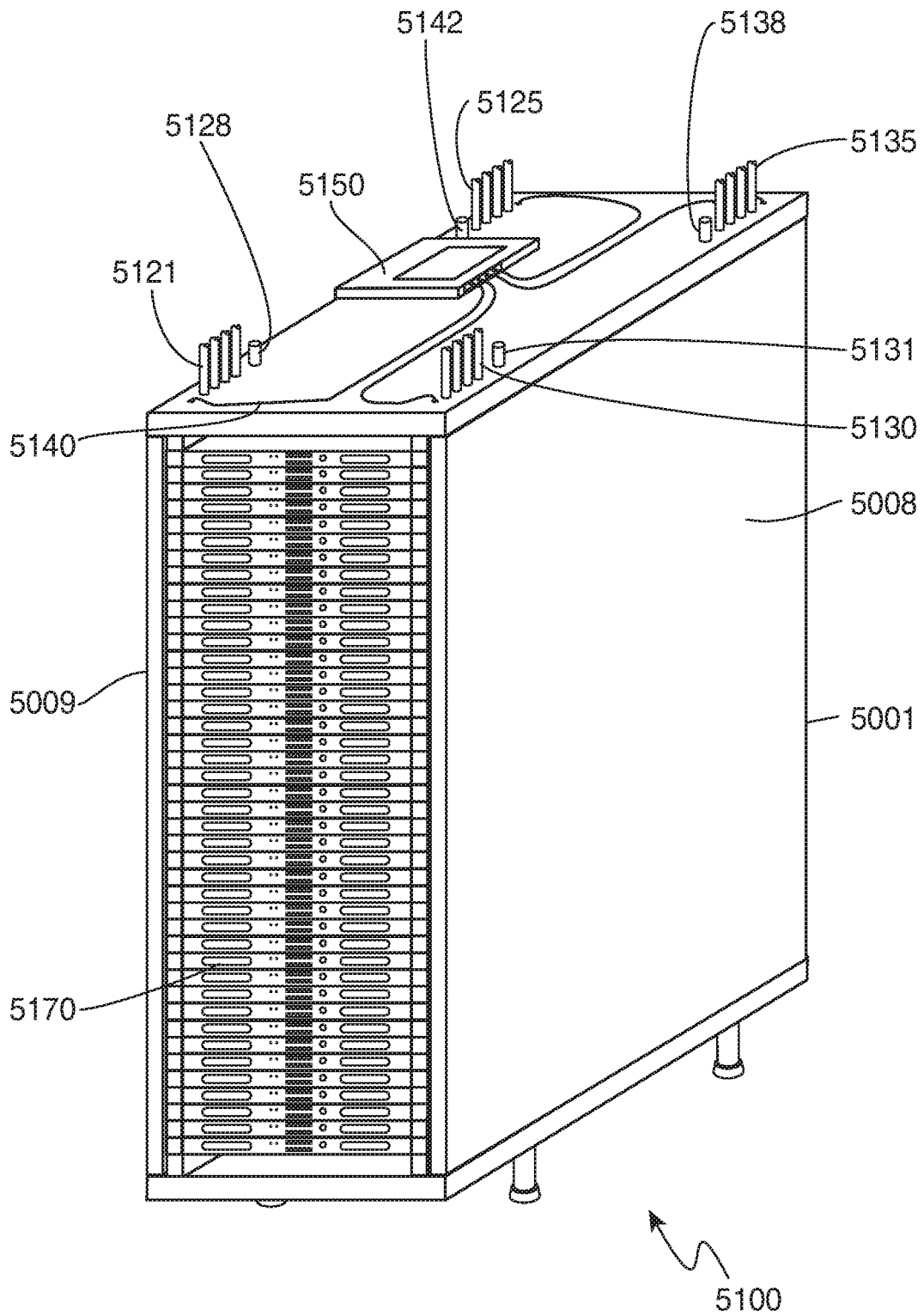


FIG. 51

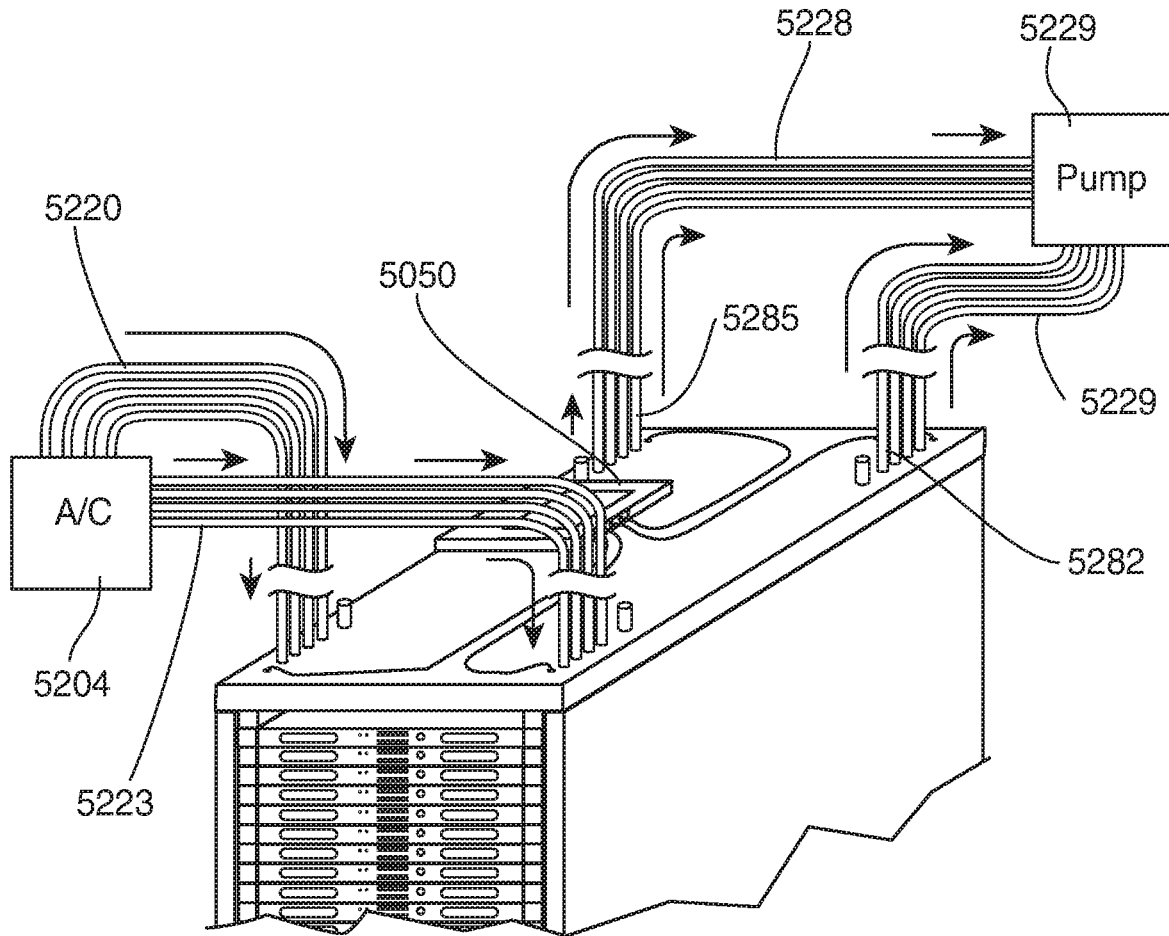


FIG. 52

5200

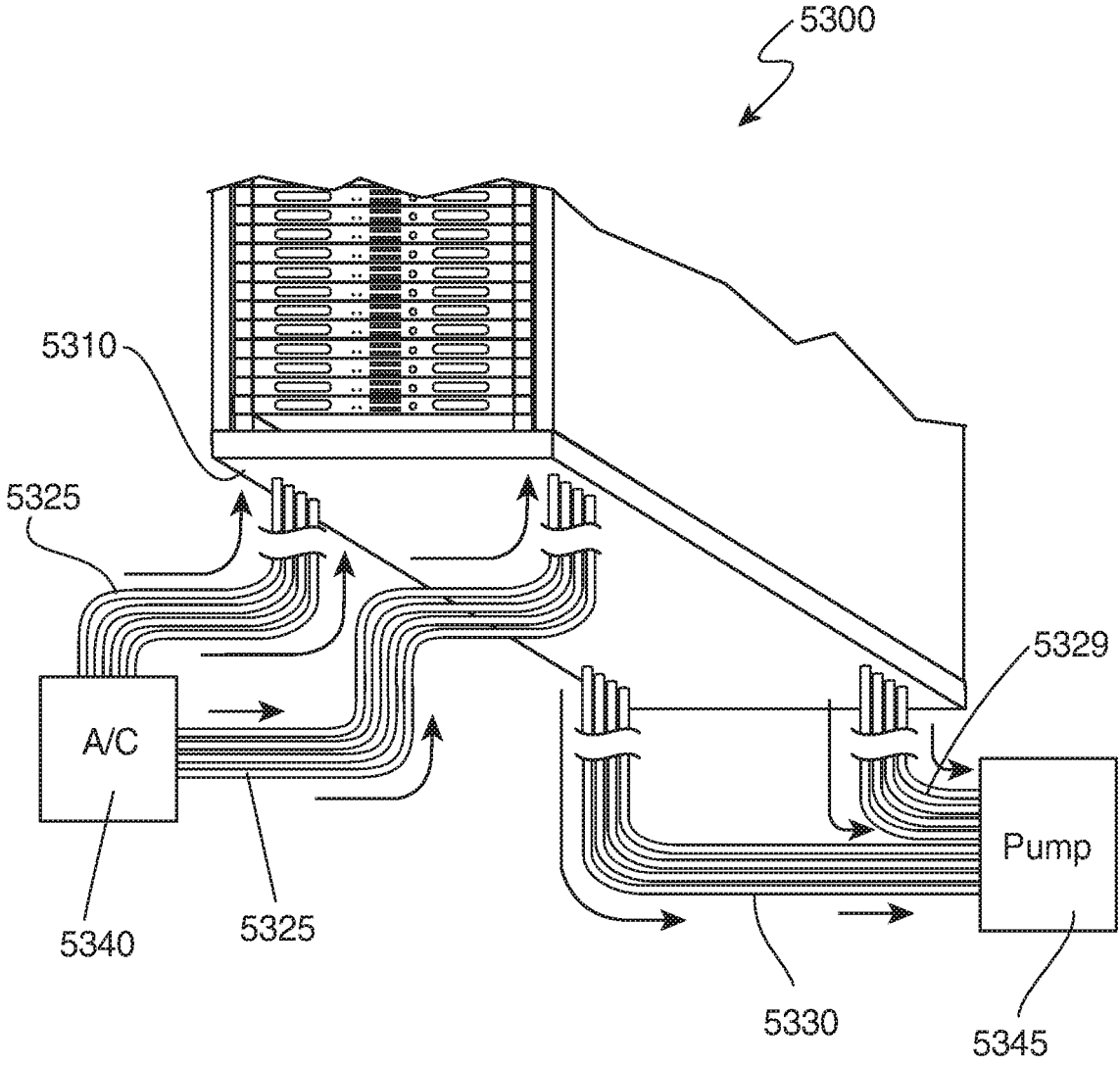


FIG. 53

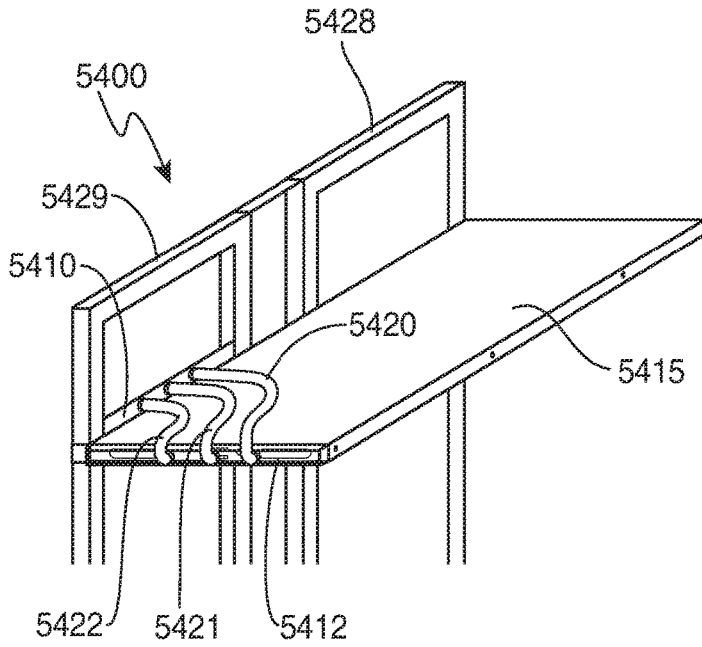


FIG. 54

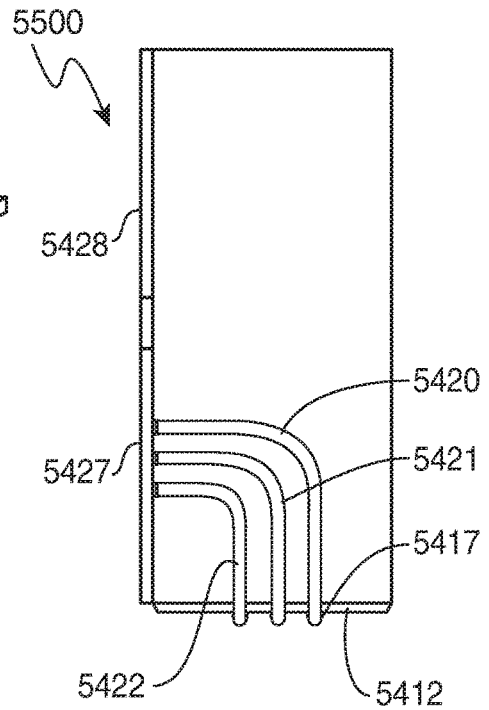


FIG. 55

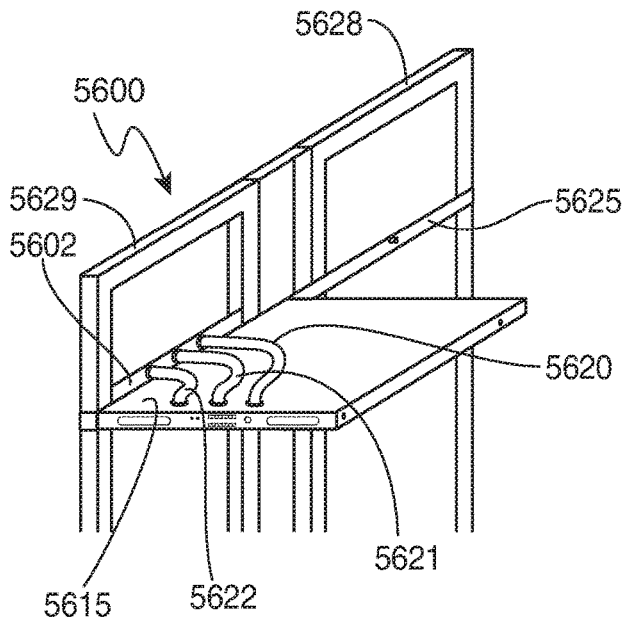


FIG. 56

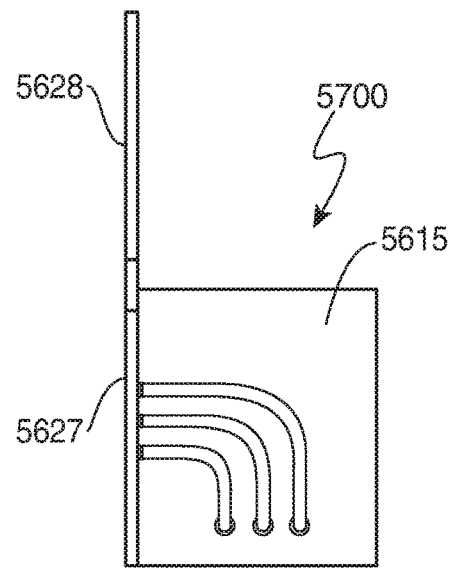


FIG. 57

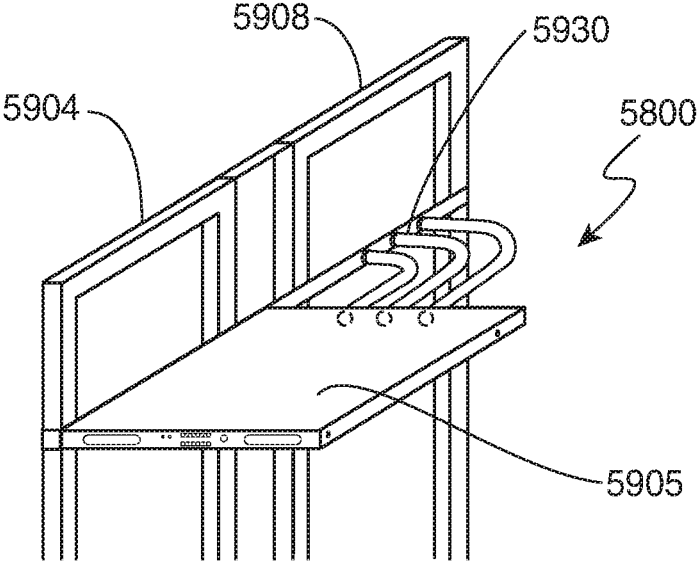


FIG. 58

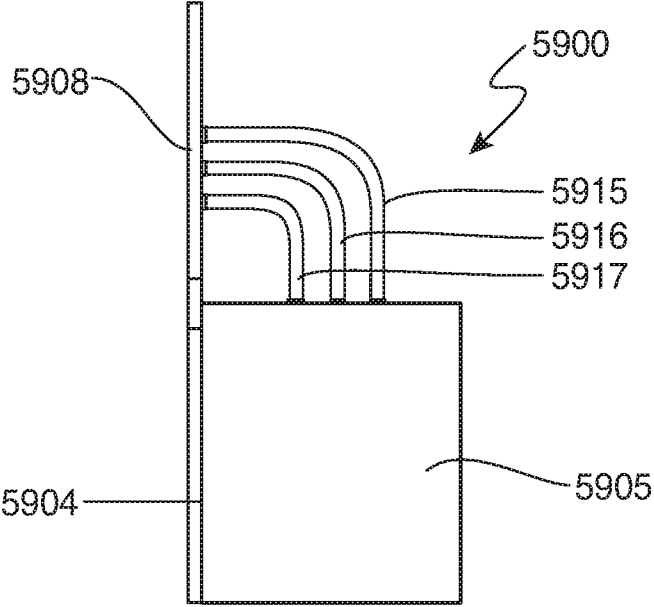


FIG. 59

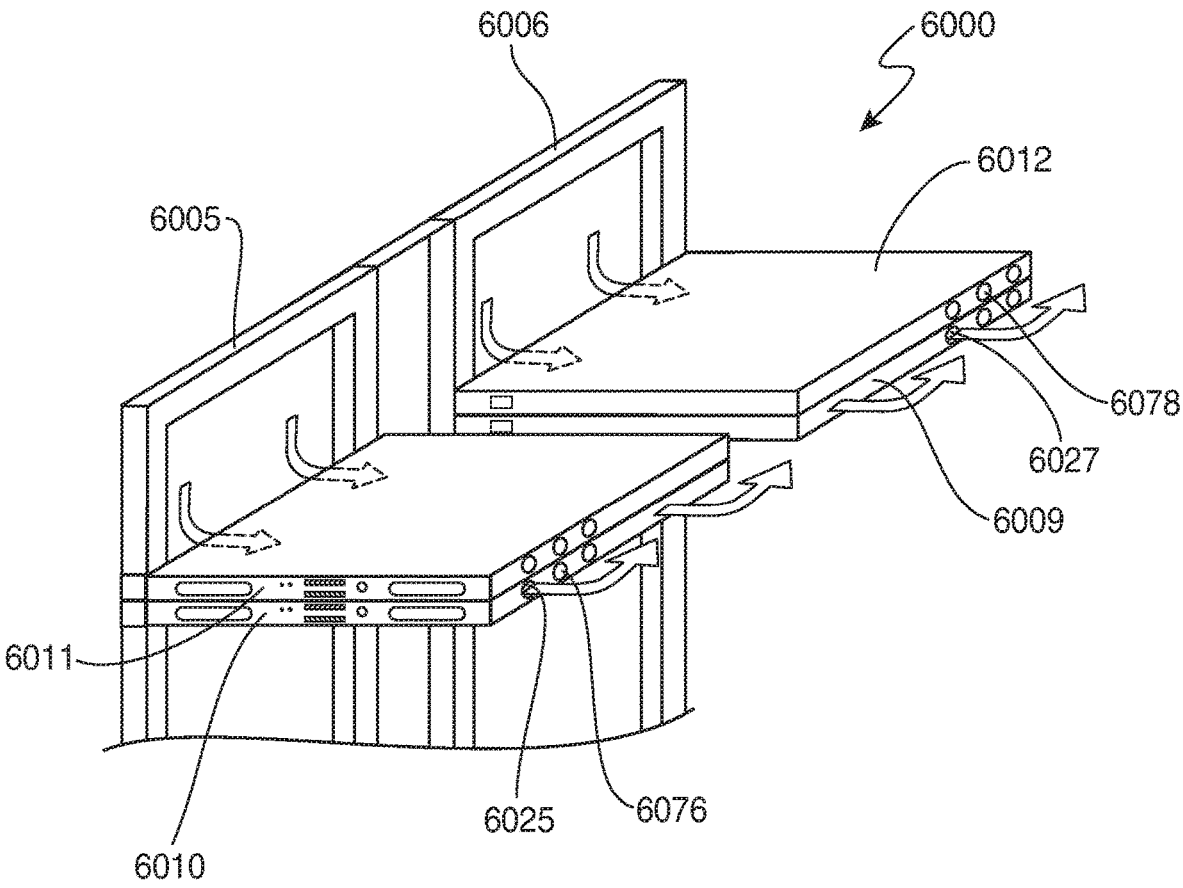


FIG. 60

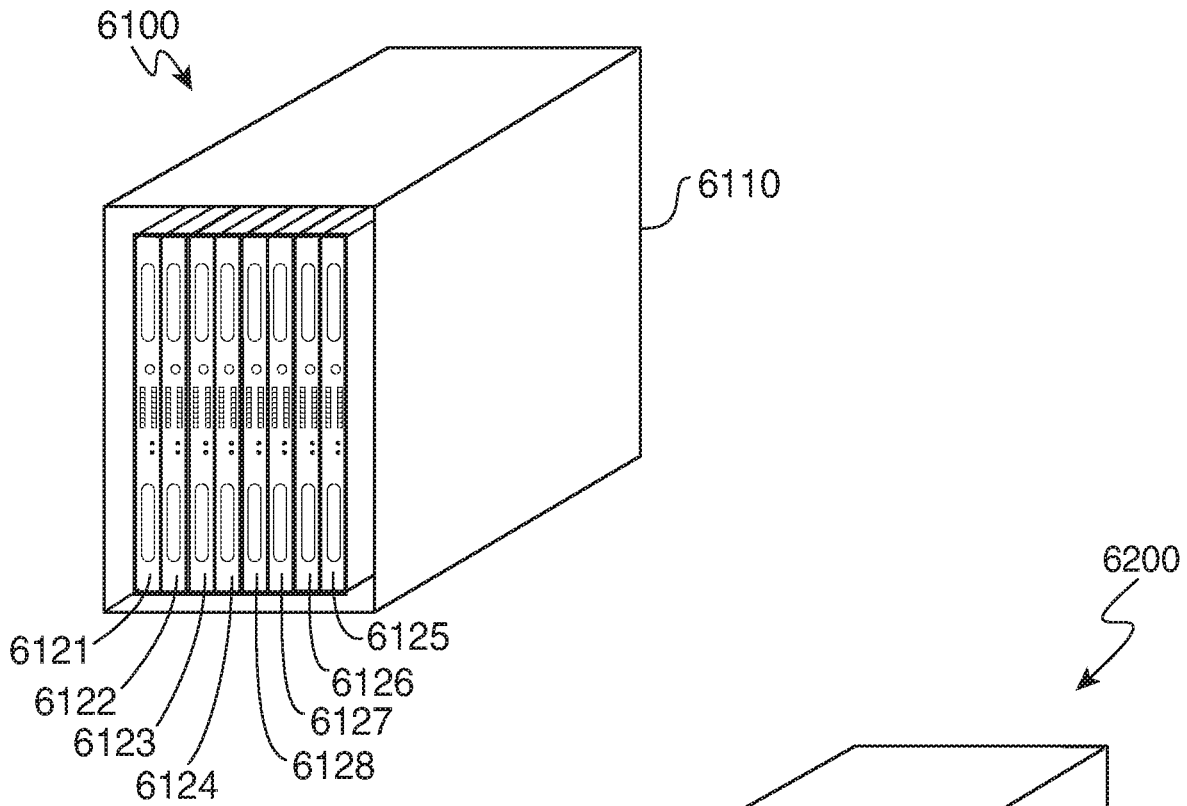


FIG. 61
PRIOR ART

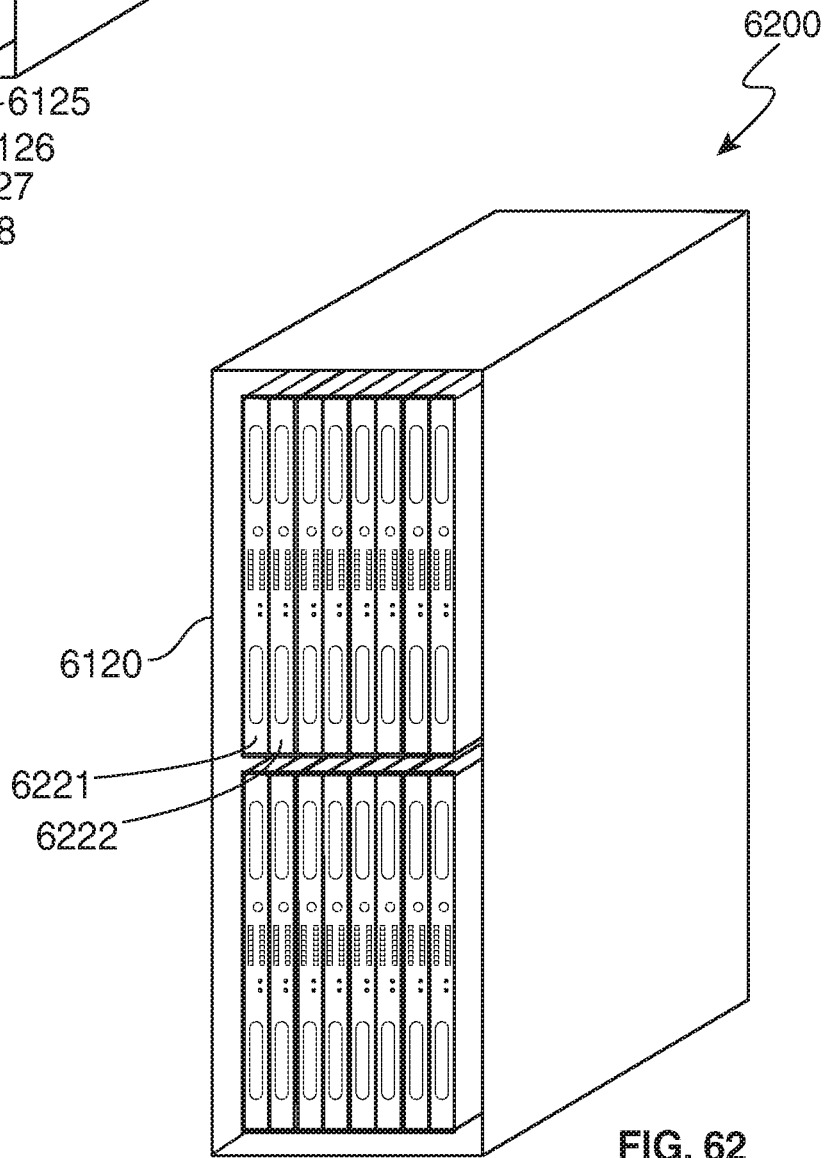


FIG. 62
PRIOR ART

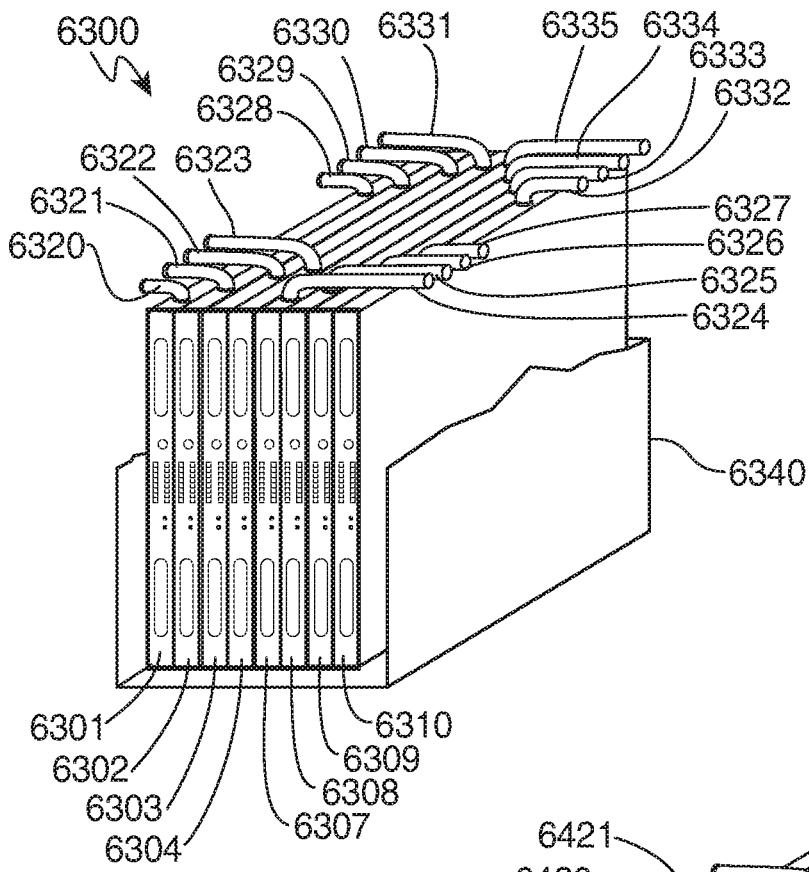


FIG. 63

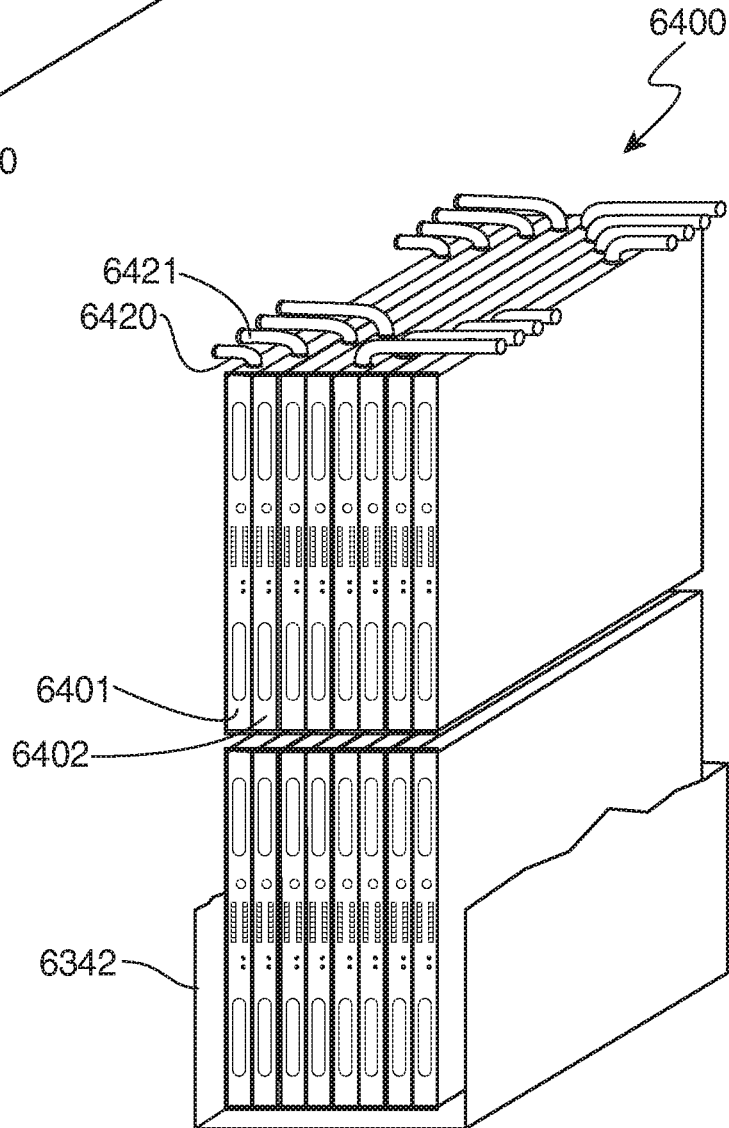


FIG. 64

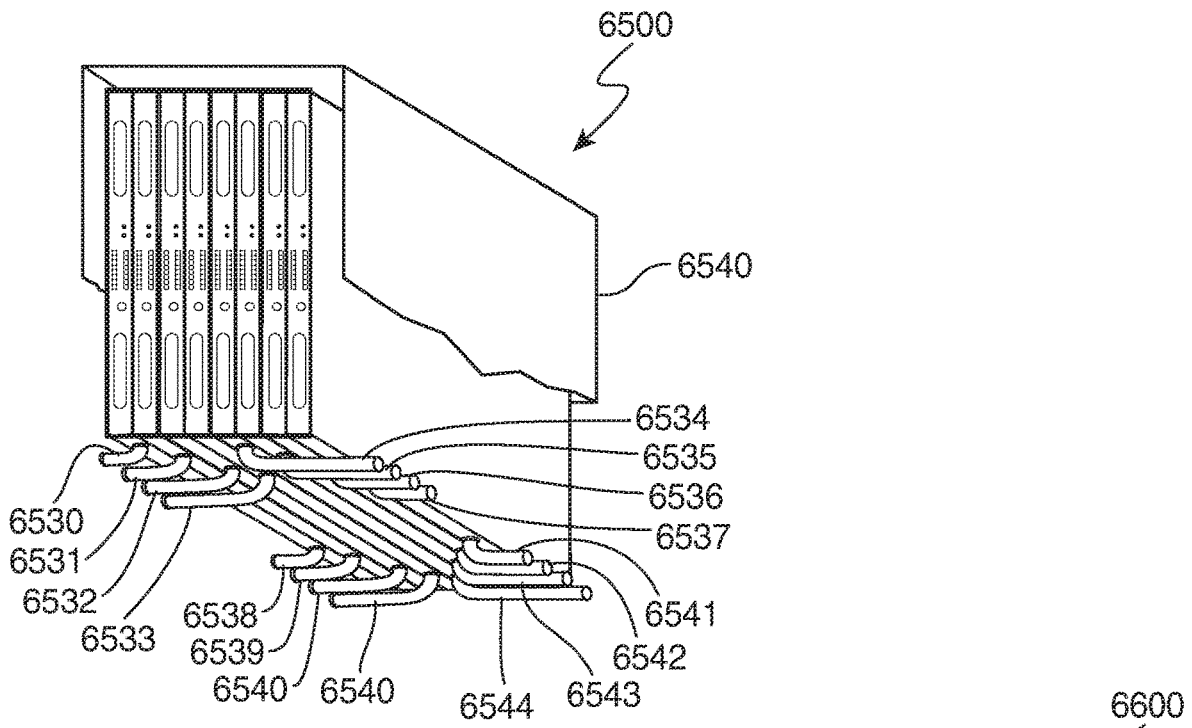


FIG. 65

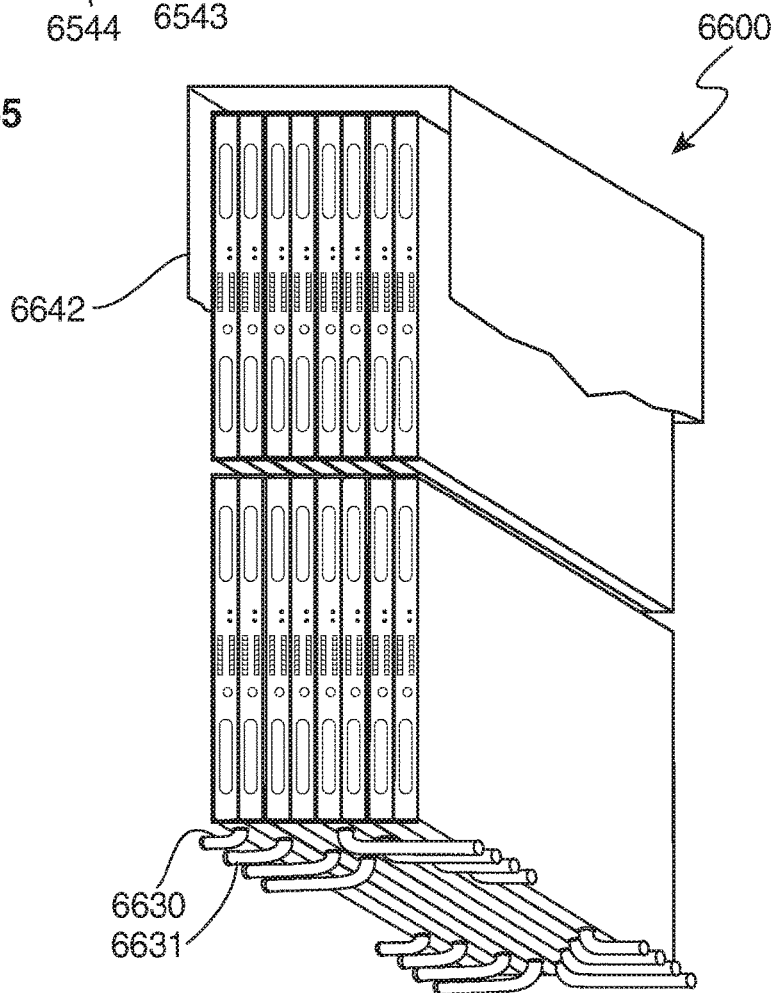


FIG. 66

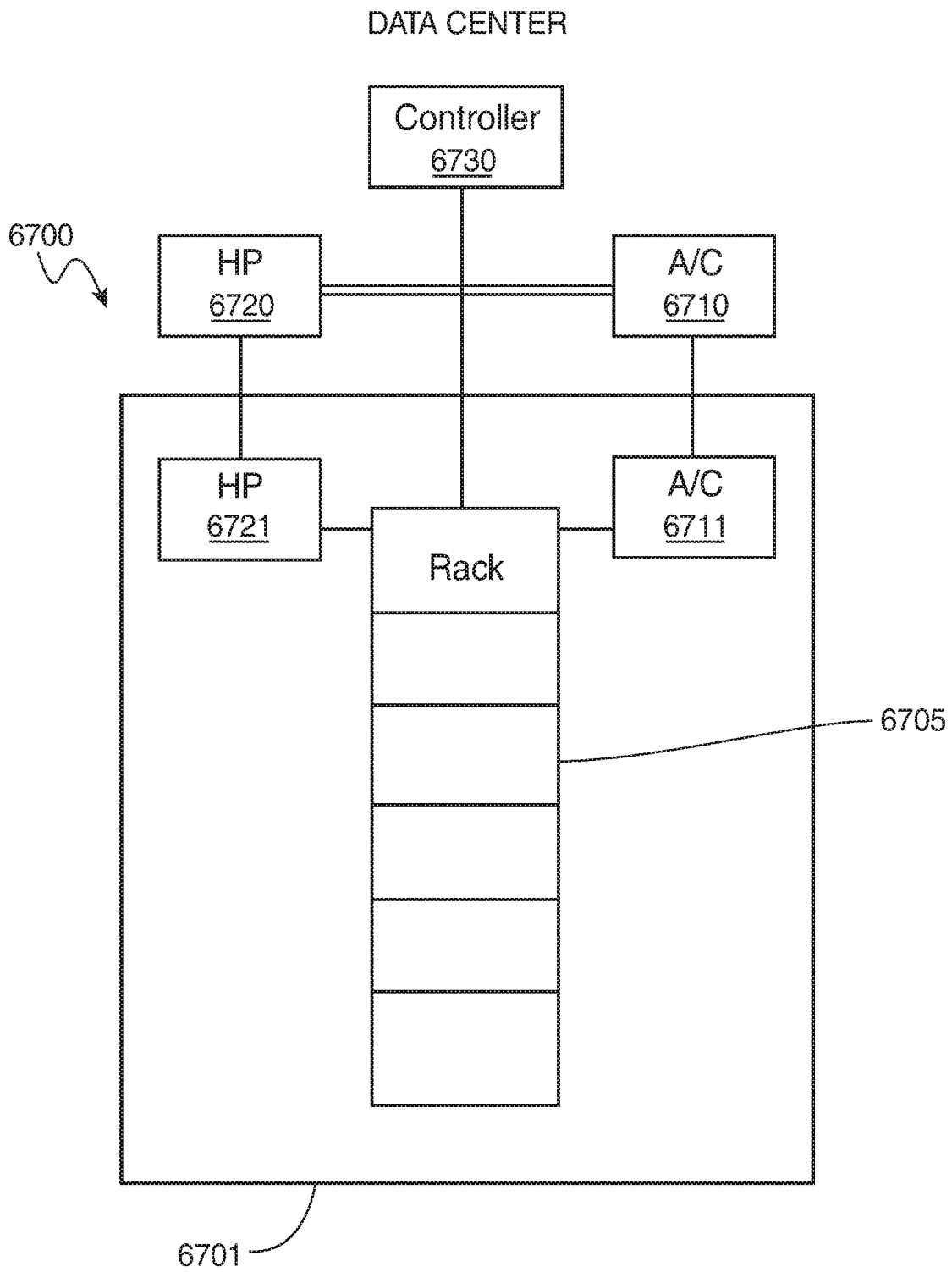


FIG. 67

COMPUTER SERVER HEAT REGULATION UTILIZING INTEGRATED PRECISION AIR FLOW

RELATED APPLICATIONS

[0001] This application claims priority under 35 U.S.C. § 120 from U.S. non-provisional patent application Ser. No. 16/577,886 titled Server Rack with Integrated Precision Air Flow filed on Sep. 20, 2019 from U.S. non-provisional patent application Ser. No. 15/792,663 titled Server Rack with Integrated Precision Air Flow filed on Oct. 24, 2017, which in turn claims priority under U.S. 35 U.S.C. § 120 from U.S. non-provisional patent application Ser. No. 15/144,788 titled Server Rack with Integrated Precision Air Flow filed on May 2, 2016, which in turn claims priority under 35 U.S.C. § 120 from U.S. provisional patent application 62/158,529 titled Server Rack with Integrated Precision Air Flow filed on May 7, 2015.

FIELD OF THE INVENTION

[0002] The present disclosure relates to a computer server rack and more particularly, a computer server rack system that can be used to efficiently direct air flow to electric equipment such as servers and other network devices for dissipation of heat.

BACKGROUND

[0003] Existing rack-mount server systems include a server rack and a plurality of server units received in the server rack. Typically each of the server units is mounted to the server rack with a pair of mounting brackets or rails respectively fixed to the inside surface of opposite sidewalls of a server rack. There have been numerous efforts to direct air and other fluids to electronic equipment to aid in heat dissipation.

SUMMARY

[0004] The server rack according to the invention includes a frame that includes hollow tubular support posts on the front sides and rear sides of the device. Between the front and rear posts are forward side panels and rearward side panels. The panels receive a complement of cartridges that have valve members to control the flow of air from a rear cavity through passages in the cartridges, through the rail and into servers. A plurality of side rails for receiving servers are attached to the front and rear posts. The rails have passages through the sidewalls that correspond with passages provided on the sidewalls of the servers.

[0005] In a preferred embodiment, air conditioned air is introduced to forward side panels through passages provided on the upper and lower surfaces. Next, air travels from the forward panel, through one or more passages that is provided through a cartridge member, and then, into a front section of a server through a passage that is provided on the lateral sidewall of the server. Air travels through the server from the front section of the server to a rear section and then exits through a passage in the lateral sidewall to a cartridge that is provided in a rear panel. Next the air is returned to the air conditioner unit for recirculation.

[0006] In an embodiment the server rack is approximately 6 feet tall and designed to accommodate forty-two server units in 4.445 cm (1.75 inch) increments. Rail members are provided at each unit segment on the side panels and support

a server. In embodiments further discussed below, passages through the cartridges have at least one valve member that can be individually electromechanically or manually controlled. When no server is provided in a specific rack unit, or when the temperature is otherwise adequately controlled in a particular server unit, the aperture may be closed, in embodiments, a controller automatically opens or closes valve members provide in cartridges in response to a signal from a thermometer.

[0007] As such, it should be appreciated that the valves or passages can be opened and closed variably for each server depending on the cooling needs for the server. Further, as discussed herein, the degree of air flow through the aperture can be controlled using a damper or weir arrangement. Therefore, in embodiments, a local controller is provided and can receive input information from thermometers reading the temperatures of the servers and can adjust the opening and closing valves aperture accordingly. Alternatively the dampers may be manually adjusted. In yet further embodiments a central controller receives signals from a plurality of server racks.

[0008] Each of the openings on the post is provided with a releasable seal to block flow depending on the particular configuration of servers. In embodiments, flexible manifolds extend from the posts to direct the fluid to and from access areas provided on the servers. While the preferred embodiment contemplates the use of air flow, in embodiments the frame is configured to receive a liquid and the posts and manifold direct fluid to heat exchange elements that engaged the respective servers.

[0009] In yet further embodiments the rack is configured to allow both liquid flow and air flow.

[0010] These aspects of the invention are not meant to be exclusive. Furthermore, some features may apply to certain versions of the invention, but not others. Other features, aspects, and advantages of the present invention will be readily apparent to those of ordinary skill in the art when read in conjunction with the following description, and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a perspective view of a prior art server rack and side panel.

[0012] FIG. 2a is a perspective view of a partial rack assembly according to an embodiment of the invention.

[0013] FIG. 2b is a perspective view of two side panels of a partial rack assembly according to an embodiment of the invention.

[0014] FIG. 3 is a perspective exploded view of a first rail assembly, a server and a second rail assembly according to an embodiment of the invention.

[0015] FIG. 4A is a top exploded view of a first rail assembly, a server and a second rail assembly according to an embodiment of the invention.

[0016] FIG. 4B is a top view of a first rail assembly, a server and a second rail assembly attached together according to an embodiment of the invention. FIG. 5 is a perspective exploded view of a side panel and server in alignment before assembly according to an embodiment of the invention.

[0017] FIG. 6 is a perspective view of a side panel and server attached to one another. FIG. 7 is a perspective exploded view of side panel rails, a server and a second panel according to an embodiment of the invention.

[0018] FIG. 8 is a perspective view of side panel rails, a server and a second panel according to embodiment of FIG. 7 that has been assembled.

[0019] FIG. 9 is a perspective view of a rack assembly including side panels, rails, and a server that schematically illustrates a server sliding into the assembly.

[0020] FIG. 10 is a perspective view of a side panel, rails, a server and a second panel that further includes cartridges received in the forward and rearward side panels that illustrate a server sliding into the assembly.

[0021] FIG. 11 is a perspective view of the embodiment depicted in FIG. 10 with a server secured within the device.

[0022] FIG. 12 is a perspective illustration of an embodiment of the invention that includes a schematic representation of the direction of air flow from the forward panels to a server.

[0023] FIG. 13 is a perspective illustration of an embodiment of the invention that includes a schematic representation of the direction of air flow from a server through rearward side panels.

[0024] FIG. 14 is a perspective view of a rail assembly that is used connection with an embodiment of the invention.

[0025] FIG. 15 is a top view of the rail assembly that is shown in FIG. 14.

[0026] FIG. 16 is a perspective view in elevation of the rail assembly with the front section extended from the rear section that is shown in FIG. 14.

[0027] FIG. 17 is a top view of the rail assembly with the front section extended from the rear section.

[0028] FIG. 18 is a perspective view of a forward side panel and forward post according to an embodiment of the invention depicting the top surface of the panel.

[0029] FIG. 19 is a perspective view of a forward side panel and forward post shown in FIG. 18 depicting the bottom surface of the panel.

[0030] FIG. 20 is a top view of the forward side panel and forward post shown in FIG. 18.

[0031] FIG. 21 is a top sectional view of the forward side panel and forward post shown in FIG. 18 also depicting a cartridge and the manner in which it is received in the panel.

[0032] FIG. 22 is a top sectional view of the forward side panel and forward post shown in FIG. 18 with a cartridge retained in the panel.

[0033] FIG. 23 is a front view in elevation of a post member used in connection with the invention.

[0034] FIG. 24 is a fragmented view in elevation of a forward side panel, a series of cartridges, a cover plate and a forward post according to an embodiment of the invention.

[0035] FIG. 25 is a front view in elevation of a forward panel having a complete complement of cartridges.

[0036] FIG. 26 is a perspective view of a rearward side panel depicting the top surface. FIG. 27 is a perspective view of a rearward side panel depicting the lower surface.

[0037] FIG. 28 is a top view of an iris air flow control valve used in a cartridge according to an embodiment of the invention.

[0038] FIG. 29 is a side view of an iris valve used in a cartridge according to an embodiment of the invention.

[0039] FIG. 30a is a perspective view of an iris valve used in a cartridge according to an embodiment of the invention in a closed position.

[0040] FIG. 30b is a perspective view of an iris valve used in a cartridge according to an embodiment of the invention in a partial opened position.

[0041] FIG. 30c is a perspective view of an iris valve used in a cartridge according to an embodiment of the invention in a fully opened position.

[0042] FIG. 31 is a side fractional view in elevation of a cartridge assembly with the valves partially opened.

[0043] FIG. 32 is a side fractional view in elevation of a cartridge assembly with the valves fully opened.

[0044] FIG. 33 is a side sectional fractional view in elevation of a cartridge assembly. FIG. 34 is side sectional fractional view of a cartridge according to an embodiment of the invention.

[0045] FIG. 34B is side sectional fractional view of a cartridge according to a further embodiment of the invention.

[0046] FIG. 35 is a perspective partial view of a cartridge according to an embodiment of the invention.

[0047] FIG. 36 is a perspective partial view of a cartridge according to an embodiment of the invention depicting a central channel impeded by a block member.

[0048] FIG. 37 is a perspective partial view of a cartridge according to a further embodiment of the invention with a central channel that is partially impeded by an adjustable shutter and that schematically depicts air flow through the device. FIG. 38 is perspective partial view of a cartridge according to the embodiment depicted in FIG. 36 that schematically depicts air flow through the device.

[0049] FIG. 39 is a perspective partial view of an alternative cartridge according to a further embodiment of the invention with iris valves in partially open position that schematically depicts air flow through the device.

[0050] FIG. 40 is a perspective partial view of a cartridge according to the embodiment depicted in FIG. 39 with iris valves in fully open position and that schematically depicts air flow through the device.

[0051] FIG. 41 is a perspective fractional front view of side panel members and servers that schematically depicts air flow through the device.

[0052] FIG. 42 is a perspective fractional rear view of side panel members and servers that schematically depicts air flow through the device.

[0053] FIG. 43 is a perspective partial view of a cartridge according to a further embodiment of the invention with a series of circular passages.

[0054] FIG. 43A is a side sectional view of the cartridge embodiment depicted in FIG. 43 without the top seal member.

[0055] FIG. 43B is a sectional view of a forward panel, a cartridge rail and server that illustrates the direction of airflow through the elements.

[0056] FIG. 43C is a sectional view of a forward panel, a cartridge, a rail and server that illustrates the direction of airflow through the elements according to a further embodiment of the invention.

[0057] FIG. 43D is a sectional view of a rearward panel, a cartridge, a rail and server that illustrates the direction of airflow through the elements according to an embodiment of the invention.

[0058] FIG. 44 is a perspective partial view of a cartridge according to the embodiment of 43 with the passages obstructed.

[0059] FIG. 45 is a perspective fractional view of a forward side panel depicting a plurality of different cartridges.

[0060] FIG. 46 is a perspective view of a forward side panel depicting a plurality of different cartridges.

[0061] FIG. 47 is a perspective view of a forward side panel in an alternative embodiment depicting a plurality of different cartridges.

[0062] FIG. 48 is a perspective view of a forward side panel depicting a plurality of different cartridges that are all devoid of passages.

[0063] FIG. 49 is a perspective view of an embodiment of the rack according to the invention with a full complement of servers.

[0064] FIG. 50 is a perspective exploded view of an embodiment of the rack of the invention and depicting external paneling.

[0065] FIG. 51 is a perspective view of an embodiment of the invention depicting a controller and external paneling.

[0066] FIG. 52 is a perspective fractional top view of an embodiment of the invention with an air conditioner and air pump system with a schematic representation of an air flow system.

[0067] FIG. 53 is a perspective fractional bottom view of an embodiment of the invention with a schematic representation of an air flow system with an air conditioner and air pump system.

[0068] FIG. 54 is a perspective fractional front view of an embodiment of the invention wherein air is delivered from the side panel cartridge to the front of a server using a flexible hose.

[0069] FIG. 55 is a top view of the embodiment depicted in FIG. 54.

[0070] FIG. 56 is a perspective fractional front view of an embodiment of the invention wherein air is delivered from the side panel cartridge to an opening in the top of a server using a flexible hose.

[0071] FIG. 57 is a top view of the embodiment depicted in FIG. 54.

[0072] FIG. 58 is a perspective fractional front view of an embodiment of the invention wherein air is delivered from the rear of a server to a rear cartridge using a flexible hose.

[0073] FIG. 59 is a top view of the embodiment depicted in FIG. 58

[0074] FIG. 60 is a perspective view of a further embodiment that uses two servers in a single rack unit and an alternative air flow configuration.

[0075] FIG. 61 is a perspective view of a plurality of blade servers according to prior art.

[0076] FIG. 62 is a perspective view of an alternative arrangement of blade servers according to the prior art.

[0077] FIG. 63 is a front perspective fractional view of a chassis containing a number of blade servers according to an embodiment of the invention.

[0078] FIG. 64 is a front perspective fractional view of a chassis containing a number of blade servers in multiple rows.

[0079] FIG. 65 is a front fractional view of a chassis containing a number of blade servers according to an embodiment of the invention.

[0080] FIG. 66 is a front perspective fractional view of a chassis containing a number of blade servers in multiple rows according to an embodiment of the invention.

[0081] FIG. 67 is a schematic illustration of a system used according in connection with a data center.

DETAILED DESCRIPTION

[0082] The forgoing description, including the accompanying drawings, is illustrated by way of example and is not to be construed as limitations with respect to the invention. Now referring to FIG. 1, a prior art rack system is depicted that includes upright members and side members and is configured to receive a plurality of servers.

[0083] FIGS. 2A and FIG. 2B depicts aspects of an embodiment of the invention 200 including forward side panel 204 and 202 and rearward side panels 201 and 203. As best seen in FIG. 2B the side panels have respective cavities 210 and 212 on their inner sides. The opposite side panels may be attached together by a rear member or rear panel or other transverse members that spans the opposite sidewalls of the device.

[0084] Now referring to FIG. 3, a further feature of embodiments of the invention includes use of a rail member 307 which is configured to be attached to server 305. On the opposite side of the server is rail 309 which includes passages 315 and 322 which correspond with adjacent passages such as passages 310 and 320 that are located on the lateral sidewall 312 of the server 305. FIG. 4a is a top view of the invention illustrates how rails 307 and 309 engage server 305 using fasteners 410, 411 and 412 on one side and 414, 415 and 416 on the opposite side. FIG. 4b depicts the rails attached to the server 305.

[0085] FIG. 5 shows a plurality of rails 307, 308 and 309 that are secured to lateral panels 505. These rails are configured to engage server 305. FIG. 6 depicts the side panel 505 wherein server 305 is engaged with the panel at the top rail.

[0086] FIG. 7 depicts an exploded view of the assembly of rack assembly components including side panel 505, rails 307 and 309 and opposite side panel 702.

[0087] FIG. 8 is an embodiment of the invention holding server 305 between panels 505 and 702. Server 305 slides along rails 307 and 309 which are affixed to the side panel sections 505 and 702.

[0088] FIG. 9 depicts how the server 305 slides in to the rack system from the front along the opposite rails 307 and 309 attached to panels 505 and 702 in an embodiment of the invention.

[0089] FIG. 10 depicts assembly 1000 that includes a depiction of the air passages 1010, 1011, 1015, and 1020 in the lateral side panels. In this embodiment there are plurality of cartridges provided in the side panels such as cartridges 1028 and 1025 and 1030. A server is received in the rack member by sliding it in the direction illustrated along the opposite rails.

[0090] FIG. 11 depicts the rack invention including server 305 in engagement with the rails in position. The panel depicts a series of cartridges attached and connected to the panel wherein the cartridges are designed to control the flow of air from the panel to the servers.

[0091] FIG. 12 illustrates the airflow though the rack of the invention. Airflow enters the left and right side panels through passages that are provided on the top and bottom surface and passes from the front of the panel, through cartridges, through side and into a server. As best seen in FIG. 13, air from the servers passes rearward and out passages in the sidewall back to a rear panel section. Air passes from the through passages provided on the top and bottom of the panels.

[0092] Now referring to FIG. 14, a two part rail member is depicted that includes passages 1450 and 1451 to allow for air flow and are located at the front of rail member 1400 and passages 1460 and 1461 near the opposite end. The two parts of the rail slide along one another to allow the rail to extend, such as that used in a conventional drawer. In embodiments the rails may include bearing and roller elements. Each end of rail 1400 has attachment sections 1480 and 1481 that are oriented perpendicular to the length of the rail element and includes fastening means to engage the upright members. The rail includes fastener elements 1420, 1421, and 1422 that engage the server. FIG. 15, a top view of the rail 1400, depicts the fastening members 1420, 1421 and 1422. As seen in FIG. 16, the passages 1450, 1451, 1460, & 1461 allow air flow through the rail. FIG. 17 depicts a rail with the forward member fully extended.

[0093] FIG. 18 depicts panel 1800 that includes a front hollow upright member 1825 and rear upright member 1850 that frame panel 1828. Panel 1800 includes passages 1830 that allows airflow into the panel member. Along the inside surface of panel are a series of electrical contact pins 1840 that are designed to receive the cartridge members. FIG. 19 depicts panel 1800 illustrating the bottom surface 1905 that includes a services of passages such as passages 1910, 1911, 1913, and 1914 that allow air flow into the panel. In embodiments, interior horizontal surface 1980 of the panel is provided with an elastomeric material on the surface which can engage opposite surfaces of the cartridge and establish an air tight seal. Vertical surface 1940 has a series of contact pins 1945 that can establish an electrical connection with the cartridge members. Like surface 1980, in embodiments, the surface 1940 panel is provided with an elastomeric material on the surface which can engage opposite surfaces of the cartridge and establish an air tight seal.

[0094] FIG. 20 is a top view of panel member 2100 showing openings 2140, 2142, and 2143 through top surface 2150. The openings provide an entrance for air flow to a section of the panel member.

[0095] FIGS. 21 and 22 are top sectional view of panel 2100 that shows how cartridge is received in the panel. In this regard, the cartridge is retained in place by pins 2165 and 2166 which engage upright members 2168 and 2169 located in the lateral panel. The assembly creates a void 2159 behind the cartridge. FIG. 22 depicts a top section view of the engagement of the cartridge with a side panel member 2100.

[0096] FIG. 24 includes a side view of a series of different cartridges 2410, 2412, 2414, and 2416 that have passages through their respective lateral sides that are at different locations. The cartridges are designed to complement different servers that may be used in the rack system. Cartridge 2416 is depicted in engagement with side panel member 2400. It is in electrical connection to a central bus 2455 by control wire 2450 that is routed through a cavity in the side portion of panel 2400. The cavity within the side panel is covered by plate 2420 or plate 2425. FIG. 23 is a front view of member 2482 and surface 2302 depicts holes provided for attachment of the rails members. Flange section 2480 is provided for attachment to the supporting frame for the rack system.

[0097] FIG. 25 depicts a side view of an exemplary panel containing a plurality of cartridges, such as cartridges 2510, 2511, 2512, and 2513. In addition, FIG. 25 depicts an alternative configuration of cover plates to 2420 or 2425.

[0098] FIG. 26 depicts a rearward side panel 2600 designed to be used in the rack system of the invention. Like the front panel, rearward panel includes a series of vertical passages 2620, 2621, 2622, and 2623 through top surface 2605 of panel 2600. The passages terminate in the recess region 2608 defined by upright members 2630 and 2631 and horizontal members 2635 and 2636 and rear flat section 2618. The panel 2600 is attached to the supporting frame for the rack using flange member 2675. At the rear of the section, upright post member 2650 provides additional structural support for the panel. As shown in FIG. 27, panel 2600 also includes passages through the lower member 2635 such as passage 2620. A series of connector pins 2615 is provided on upright member 2631 for engagement to the cartridges.

[0099] Now referring to FIGS. 28-30 an exemplary iris control valve is shown. The valve includes movable panel 2804 that can be opened and closed to define different sized openings that are retained by an annular ring 2802.

[0100] FIG. 31 depicts cartridge assembly 3100 that includes a control switch 1301 which can be used to slide the pin members into or out of the panel to lock the cartridges into place. In embodiments, a control valve is manually manipulated to selectively open and close the valves 1340, 1341, 1342 and 1343. In further contemplated embodiments, valves may be opened and closed using a sliding planar sheet that covers the passage. In yet further embodiment the cartridge may use a motorized screw gear that may be controlled by a rotating handle at the top of the panel attached to an extended threaded rod and the rotational movement of the rod is translated to rectilinear motion. In yet a further embodiment the cartridge may use a servomotor that may be connected to the iris valve selector arm by a connecting rod. In embodiments, on the ends of the cartridge are spring biased contact pins such as pin 1310 that is designed to engage the lateral interior side surfaces of forward or rearward panel members. As seen in FIG. 33, sensor 1391 is designed to detect the presence of an adjacent server. In an embodiment, the sensor includes is an infrared light 1320 and photo detector 1356 wherein light is reflected from a reflective surface provided on the server can be detected. When the server is present opposite the detector infrared light is reflected off of a surface on the server and impinges on the photo detector. The photo detector then sends a signal via wire 1371 to controller 1348 which in turn can provide a signal to open the valves, such as valve 1340, on the cartridge opposite the sever and allow air to flow.

[0101] In yet further contemplated embodiments the sensor can communicate with the server transmitted by the server, such as a signal containing information relating to the internal temperature of the server components. This signal is transmitted to the controller and may be further related to the processor associated with a server rack. The server rack processor received data from the various servers and the status of the valves that are associated with the cartridges. As discussed below the processor may be configured to communicate with a remote computer that may include a display that allows for remote monitoring and control by an administrator and alerts that provide information that relates to the status of the respective servers. Such communication may employ an Ethernet connection, USB connection, other cabling, or using wireless technology.

[0102] As best seen in FIG. 33, pin 1310 is also connected to the controller 1348 which can bring power and control

signals from an external source. Contact member 1340 is on the opposite end of the cartridge 3300 from pin 1310. Contact member 1340 engages its adjacent side panel in order to complete a power circuit. The contact surfaces along the side surface and top interior surfaces are made of an elastomeric material and, when the cartridges are in an engaged position with the panel, an air tight seal is established wherein a cavity formed in the panel behind the cartridges can be pressurized.

[0103] Controller 1348 is attached to valves 1340, 1341, 1342, and 1343. In an embodiment, sensor 1319 includes an infrared light source and photo detector and will send a signal to the controlled reflecting the presence of absence of a server opposite the sensor. If a server is present, the valves will be opened. If no server is detected opposite the sensor, the valves remain closed.

[0104] Now referring to FIG. 34, cartridge 3300 is shown opposite side members 2168 and 2169.

[0105] FIG. 34B depicts a further embodiment wherein the cartridge includes a reservoir 3412 (not shown to scale) which contains an inert gas under pressure that can be used for fire suppression. Reservoir 3412 is connected to a valve 3414 by tubular passage 3413. Valve 3414 controls the regulation of the inert gas into one of the passageways through cartridge 3400. Valve 3414 is controlled by controller 3401 and, in embodiments, a temperature control sensor in communication with the central controller can send a signal indicative of temperature. The central controller is programmed to send a signal to local controller 3401 over wire 3415 when the temperature within a server has rapidly increased thereby reflecting a possible fire event.

[0106] FIG. 35 depicts air flow through an exemplary cartridge 3500 that includes valves 3505, 3511, 3512, and 3513 in a partially-opened position. As shown in FIG. 36 an alternative embodiment of the cartridge 3600 depicts cavity 3608 that may receive removable insert 3610 that functions to block airflow through the cartridge. In a further embodiment, depicted in FIG. 37 and cartridge 3700, a movable flap 3709 is provided to regulate air flow. As depicted the shutter 3709 or shutter is mounted for pivotal movement and only allows flow through gap 3707. In embodiments shutter is 3709 is incrementally opened using a stepper motor that can incrementally adjust the position of the shutter and correspondingly incrementally adjust the size of the opening. In other embodiments the shutter can be manually adjusted. It is contemplated that this cartridge design may be used with a server that has corresponding rectangular passages on the lateral sidewall (not shown). Referring to FIG. 38, the shutter is depicted in a fully opened position and the gap or opening is defined by space 3809. In this position the air flow through the cartridge is maximized.

[0107] FIG. 39 illustrates a fractional view of a cartridge 3900 having a series of valves 3910, 3911, 3912, and 3913 in a partially open position and depicts the direction of airflow through the valves. FIG. 40 depicts valves 3910, 3911, 3912, and 3913 in a fully open position wherein the air flow is increased.

[0108] FIG. 41 is a sectional view of a front section of a rack system and server depicting air flow first into the received cavity section 4105 of panel 4100 from both the lower and upper directions. Air flows into passage 4120, through a rail section (not shown) and into server 4150. Another flow path that is illustrated travels from the panel cavity 4105 through passage 4125 that is provided through

cartridge 4109. Air introduced in the front of servers 4150 and 4151 cools components within the servers and flows rearward. As shown in FIG. 42, air flows from the front of server 4150 passes through passage 4195 that is provided through cartridge 4185 and into panel cavity section 4205. From the rear cavity 4205 the air flows either upwardly or downwardly to the passages in the top and bottom of the rearward side panel section.

[0109] FIG. 43 depicts an embodiment of a cartridge member 4300 having a plurality of passages 4310, 4311, 4312, and 4313 depicted in an open position. In this embodiment there is a sealing member 4370 received in a groove 4325 provided along the top surface of the cartridge member 4300. Sealing member 4370 designed to engage the bottom surface of an adjacent cartridge or a top horizontal member of a panel and form an air tight seal. Sealing member 4370 can be raised and lowered via a mechanical connection with member 4380. When member 4380 is in the retracted position, pins 4381 and 4382 will be retracted along with seal 4370 being lowered. When member 4380 is in the engaged position, pins 4381 and 4382 will be moved forward and seal 4370 will be in the raised position. The bottom of the cartridge is also provided with a lower groove 4330 that can be received the top of a cartridge positioned under cartridge 4300. In this embodiment a flat blocking member 4330 is provided within the cartridge 4300 which can be controlled by engagement of member 4345 to laterally slide the member to block the passages and thereby impede the flow of air through the cartridge. In this embodiment pin 4381 and pin 4382 are spring biased and can be retracted by sliding control lever 4380 in a lateral direction. Upon release of the lever, the pins may be received in opposite openings provided on the side panel members to retain the cartridge members in place. In FIG. 43A, blocking member 4330 is depicted retained within opposite grooves 4351 and 4352 provided in the interior top surface 4370 and bottom interior surface 4372 of the cartridge 4300 and engaged to allow for movement within the grooves.

[0110] FIG. 43B depicts a sectional view of an assembly that includes the planar sheet member 4105 that defines a void region through which air flows into the rear of a cartridge 4110. The cartridge includes a top sealing member 4370 that is comprised of a resilient material which is provided to assist with forming a seal with an adjacent cartridge. The air flow is interfered by member 4351 which will slide to open and close a passage 4310 that allows air flow to server 4150. The rail member is depicted as two part member 307 and 308 through which is provided with a passage to allow for air flow from cartridge 4110 to server 4150.

[0111] FIG. 43C depicts a further embodiment that include annular seal ring member 4398. In this embodiment an annular fabric shroud will axially extend from the annular ring 4399 provided at the junction of air passages and, in response to air flow, shroud 4399 is radially displaced to seal the junction between the components. As such when air flows, the shroud fills the gap between the cartridge, rail, and server.

[0112] FIG. 43D schematically depicts air flow from server 4150 to a rear panel. Like the embodiment depicted in FIG. 43C, the embodiment includes annular seal member 3488 and shroud member 4389 that, in response to air flow

is displaced to minimize the air loss through the interface between server **4150**, rail members **307** and **308** and cartridge **4162**.

[0113] FIG. **44** depicts cartridge **4300** wherein the blocking member **4330** has been moved to close the passages **4310**, **4311**, **4312**, and **4313** and the pins **4381** and **4382** are depicted in a retracted position. In embodiments, the seal is mechanically lifted by rotation of a cam member that alternatively lowers and raises a seal member such as seal member **4370**. In yet alternative embodiments, the resilient member is spring biased and can be displaced downwardly upon assembly. In yet further embodiments, a mechanical switch is provided that lifts and mechanically locks the resilient member by lateral movement of a switch extension that is accessible through an

[0114] L shaped opening. FIG. **45** illustrates a side panel assembly **4500** including a plurality of cartridges such as cartridges **4550** and **4551** that span upright member **4521** and upright member **4520**. The rear surface of the cartridges define a front surface of an internal cavity of the panel. Adjacent to upright member **4521** is an upright front post member **4575** that is provided to support the servers and rails of the device.

[0115] FIG. **46** depicts a completely assembled forward panel including upright front post member **4575**, section and cartridges such as **4558**, **4559**, **4560**. FIG. **47** depicts an alternative assembly that includes a number of cartridges that are devoid of valves and passages. FIG. **48** depicts a further alternative assembly where the cartridges that were selected include no valves or passages. Thus FIGS. **47** and **48** illustrate alternative configurations of cartridges that may be used with the invention. As best seen in FIG. **47**, the cartridges may have different vertical dimensions to conform the vertical dimension of a server. In addition, in embodiments cartridges may have different lateral placement of the iris valves and passages to conform to the needs of differing servers and network equipment.

[0116] FIG. **49** depicts a server assembly with a full complement of single rack unit servers.

[0117] As shown in FIG. **50**, the server rack assembly and servers are optionally enclosed in a cabinet **5000** that includes side exterior panels **5005** and **5006**, top exterior panel **5025** and bottom exterior panel **5008**. All of the quarter panels are attached to an intermediate frame to be fully supported. The entire rack is elevated from a support surface by legs **5020** or **5021** or, alternatively, on casters. The top panel is provided with passages that allow air to flow to the forward panel **5012** and rearward panel **5010** that is contained within exterior panels. Additional passages, not pictured, may be added to **5008** and **5025** for power, network cables, and other cabling.

[0118] Referring now to FIG. **51**, an assembled rack system **5100** includes exterior side panels **5008** and **5009** that contain the side forward panels and rearward side panels.

[0119] In embodiments, there are front and rear doors provided that can be used to close and lock the whole rack. In further embodiments, the panels used are insulated. Again referring to FIG. **51**, the top of the device includes front top passages **5121** and **5130** that communicate with the forward lateral side panels. Next to the inlet passages **5121** and **5130** are pressure relief valves **5128** and **5131**. When the pressure in the system exceeds a predetermined pressure, the valves will release air to the atmosphere and prevent damage to

components of the system. Similar pressure relief valves **5138** and **5142** are located in the rear panel. On the top of the panel is a controller **5150** that is in communication with the cartridges via wires **5140**.

[0120] A top view of a rack device **5200** is depicted in FIG. **52** that includes an air conditioner **5204** that provides cool air to top inlet passages in forward panels through conduits **5220** and **5223**. Air, after it has passed through a server, flows to the rearward panels and may exit through top passages **5282** and **5285**. Air exiting the panels is then directed through conduits **5228** and **5229** to pump **5229** that maintains negative pressure in the exhaust system and moves the air from the forward panels, through the servers and out to the rearward panels. Air from the pump may be transferred back to the air conditioner through passages (not shown) for recirculation through the system.

[0121] As shown in FIG. **53** the bottom surface **5310** of a rack system **5300** receives cool air from air conditioner **5340** from conduits **5325**. Air is vented from the system through conduits **5329** and **5330**. A pump **5345** is provided that creates and maintains negative pressure in the exhaust air flow system and may transfer air back through passages (not shown) to the air conditioner.

[0122] In embodiments, the system includes a controller and servo motor that can adjust the flow parameters depending on the temperature of the server or group of servers. In further embodiments, the system includes a control board that includes a small circuit board with an Ethernet communications port for communication with the servers, a valve controller, air conditioner, heat pump, and a remote central monitoring and control location.

[0123] Referring now to FIG. **54**, in a further embodiment **5400** air is directed from a cartridge member **5410** to openings provided in the front panel **5412** of server **5415** using flexible tubular members **5420**, **5421**, and **5422**. The depiction includes panels **5428** and **5429** that receive the cartridges that are described herein, FIG. **55** depicts a top view of the system described above and includes the flexible tubes **5420**, **5421**, and **5422** that are depicted extending past the front edge of the server **5417**.

[0124] In another embodiment of the invention that is depicted in FIG. **56**, air is distributed from cartridge member **5602** through flexible tubular members **5620**, **5621**, and **5622** to openings on the top of a server **5615**. In this embodiment, server **5615** only extends one half the distance of the server rack. FIG. **57**, a top view of the embodiment depicted in FIG. **56**, shows conduits that extend from the lateral panel **5627** to the top of server **5615**. Now referring to FIG. **58**, a further aspect of the invention is depicted wherein air is removed or vented from the rear of server **5905** using flexible hoses or tubular members to cartridge **5930** in rear panel **5908**. As seen in FIG. **59**, the air is directed from server **5905** to the rear panel section **5908** using tubular members **5917**, **5916** and **5915**.

[0125] FIG. **60** depicts a schematic representation of an alternative air flow arrangement in a further embodiment of the invention. In this embodiment servers **6011** and **6012** are attached to the same vertical location that is in turn attached to the front side panel **6005** and rear side panel **6006**. Also shown are servers **6010** and **6009** that are also attached to the front side panel opposite **6005** and rear side panel opposite **6006** using conventional a rack mount hardware. Air from cartridges provided in the front panel **6005** and rear panel **6006** flows laterally into the servers **6009**, **6010**, **6011**, and

6012 and exits the servers through openings such as openings 6025, 6076, 6027 and 6078. The openings are on the opposite sides of the servers and passages on cartridges (not shown) provided on lateral panels (not shown) that are opposite panels 6005 and 6006 and which receive from the servers and distribute the air out of the panels.

[0126] FIG. 61 is a depiction of prior art blade server system 6100 wherein a plurality of server blades 6121, 6122, 6123, 6124, 6125, 6126, 6127 and 6128 are oriented in a vertical direction and contained in an external housing 6110. External hosing 6110 is designed to be received in server rack. FIG. 62 depicts a further alternative wherein an external housing 6120 encloses a plurality of servers such as 6221 and 6222. Blade server system 6200 includes two rows of vertically oriented servers. FIG. 63 depicts an embodiment of the invention adapted to provide cool air to and remove air from vertically oriented blade servers. Here, conduit 6320 is connected to a cartridge according to one of the embodiments of the invention discussed above and direct air to an opening provided on the top surface of server 6301. Air is removed from server 6301 using hollow tubular conduit 6328 which is directed air to a cartridge provided in rearward lateral panel as described above. FIG. 63 therefore depicts a server device in which each of the servers 6301, 6302, 6303, 6304, 6307, 6308, 6309 and 6310 are provided with air flow to and from the server. These conduits pass through the external casing 6340 that retains the servers and then direct the air laterally.

[0127] FIG. 64 depicts a further embodiment 6400 wherein hollow tubular cooling conduits such as 6420 and 6421 provide airflow into servers 6401 and 6402. Air is removed from the servers in a similar manner as described with respect to the embodiment 6300 depicted herein.

[0128] FIG. 65 depicts a blade server arrangement 6500 wherein air is distributed to servers through openings on their bottom surfaces through tubular conduits 6530, 6531, 6532, 6533, 6534, 6535, 6536 and 6537. Air is removed from the servers using tubular conduits 6538, 6539, 6540, 6541, 6542, 6543 and 6544 and is directed laterally wherein it can be received by cartridge members as described herein provided on lateral panels. In a further embodiment 6600 depicted in FIG. 66, a row of blade servers includes multiple rows of servers oriented vertically. Air is provided to servers on a lower row using through tubular conduits such as 6630 and 6631. These conduits provide air flow from lateral sides of the device 6600 and deliver the air to the bottom surface of servers. Air is removed from the servers using similar conduits and directed laterally.

[0129] In further embodiments (not shown), fans are provided in the cartridges to assist with air flow to the servers and to assist with the removal of air from the servers. In yet other embodiments the fans may be provided in connection with the intake openings and exhaust opening in the panels, or along the conduits that provide for air handling to and from the panels.

[0130] FIG. 67 is a schematic view of an embodiment wherein a plurality of racks 6705 are positioned in a building structure 6701 to constitute a server facility or data center. The data center includes a central controller 6730 that may be in proximity to the data center or in remote communication. The system optionally includes an air conditioner system that includes conventional exterior components 6710 such as a compressor, condenser element and a fan and interior components 6711 that include fans, evaporator coils,

and an expansion device for the coolant used in the system. The system may also include heat pump technology including interior components 6721 (not shown) which may include a blower, an expansion device, and an exterior coil and conventional exterior components 6720 including a compressor, check valves, an expansion device, exterior coils and a fan.

[0131] In yet further embodiments, a variety of rails members are provided in connection with the rack systems to receive different server models, wherein the rails have different designs with different passages to complement the passages in different servers.

[0132] It is to be understood, however, that even though numerous characteristics and advantages of the embodiment have been set forth in the foregoing description, together with details of the structure and function of the embodiment, the disclosure is illustrative only, and changes may be made in detail, especially in the matters of shape, size, and arrangement of parts within the principles of the present disclosure to the full extent indicated by the broad general meaning of the terms in which the appended claims are expressed.

[0133] Although the present invention has been described in considerable detail with reference to certain preferred versions thereof, other versions would be readily apparent to those of ordinary skill in the art. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.

INDUSTRIAL APPLICABILITY

[0134] The present invention permits the efficient cooling of computer equipment, particularly aggregated computer equipment confined to enclosed spaces. The power use of server farms, co-location facilities, and other data centers that specialize in providing computation and storage availability are using a sizeable percentage of available electricity. Much of this power use is related, not only to operating the computer equipment, but also cooling the computer equipment. The present invention represents a substantial advance in the effectiveness of cooling this equipment in way that does not require the substantial modifications to facilities, and allows a modular and upgradable solution.

What is claimed is:

1. A processor-readable medium comprising instructions to cause a processor to:
 - receive a signal indicative of a measurement of a sensor;
 - select an action based on the measurement of the sensor;
 - and
 - send, to a valve, a signal indicative of the action to cause the valve, in response to the signal, to be in a position to define an airflow through the valve,
 - the valve having a range of motion between an opened position and a closed position, the valve in the opened position defining an airflow inlet opening having a size and a shape substantially corresponding to a size and a shape, respectively, of an airflow inlet opening of a case of a server when the server is disposed with the sensor.
2. The processor-readable medium of claim 1, wherein:
 - the position is a second position,
 - the sensor is a temperature sensor,
 - the measurement is a temperature associated with an interior of the case of the server, and

the signal indicative of the action causes the valve to change from a first position to the second position based on the temperature associated with the interior of the case of the server.

3. The processor-readable medium of claim 1, wherein: the position is a second position, the sensor is a photodetector,

the signal indicative of the action causes the valve to change from a first position to the second position based on the photodetector not detecting light, indicating the server has been added, and

the first position corresponds to the closed position, the second position is not the closed position.

4. The processor-readable medium of claim 1, wherein the sensor is a temperature sensor, the measurement is a rate of temperature change associated with an interior of the case of the server, the processor-readable medium further comprising instructions to cause a processor to:

detect a possible fire event within an interior of the case of the server when the rate of temperature change exceeds a threshold; and

send an alarm signal in response to the possible fire event being detected.

5. The processor-readable medium of claim 1, wherein the sensor is a temperature sensor, the measurement is a rate of temperature change associated with an interior of the case of the server, the processor-readable medium further comprising instructions to cause a processor to:

detect a possible fire event within an interior of the case of the server when the rate of temperature change exceeds a threshold; and

send, in response to the possible fire event being detected, a control signal to cause a fire suppressant to be released into the interior of the case.

6. The processor-readable medium of claim 1, wherein: the position is the closed position, the sensor is a photodetector, and

the signal indicative of the action causes the valve to maintain the closed position based on the photodetector detecting light, indicating the server is not present.

7. The processor-readable medium of claim 1, wherein the sensor is a first sensor, the server is a first server, the valve is a first server, the action is a first action, the processor-readable medium further comprising instructions to cause the processor to:

receive a signal indicative of a measurement of a second sensor;

select a second action based on the measurement of the second sensor; and

send, to a second valve, a signal indicative of the second action to cause the second valve, in response to the signal indicative of the second action, to be in a position to define an airflow through the second valve, the second valve having a range of motion between an opened position and a closed position, the second valve in its opened position defining an airflow inlet opening having a size and a shape substantially corresponding to a size and a shape, respectively, of an airflow inlet opening of a case of a second server when the second server is disposed with the second sensor.

8. The processor-readable medium of claim 7, wherein the first server, the second server and the processor-readable medium are located with a common rack.

9. The processor-readable medium of claim 7, wherein: the first server is located with a first rack, the second server is located with a second rack, and the processor-readable medium is located at neither the first rack or the second rack.

10. The processor-readable medium of claim 1, the processor-readable medium further comprising instructions to cause a processor to:

send, to a computer remote from the processor-readable medium, a signal indicating the measurement and the position of the valve; and

receive, from the computer remote from the processor-readable medium, a control signal associated with at least one of the processor-readable medium or the valve.

11. A processor-readable medium comprising instructions to cause a processor to:

receive a plurality of signals from a plurality of temperature sensors, each temperature sensor from the plurality of temperature sensors being located with a unique server from a plurality of servers, each signal from the plurality of signals indicating a temperature of a unique server from the plurality of servers;

select an action based on the plurality of signals; and

send, to a valve from a plurality of valves, a signal indicative of the action to cause the valve, in response to the signal, to change from a first position to a second position to define an airflow through the valve,

each valve from the plurality of valves being positioned with a unique server from the plurality of servers, each valve from the plurality of valves having a range of motion between an opened position and a closed position, each valve from the plurality of valves in the opened position defining an airflow inlet opening having a size and a shape substantially corresponding to a size and a shape, respectively, of an airflow inlet opening of a case of the server uniquely associated with that valve and from the plurality of servers.

12. The processor-readable medium of claim 11, wherein the plurality of servers and the processor-readable medium are located with a common rack.

13. The processor-readable medium of claim 11, wherein: a first subset of servers from the plurality of servers is located with a first rack,

a second subset of servers from the plurality of servers is mutually exclusive from the first subset of servers and located with a second rack, and

the processor-readable medium is located at neither the first rack or the second rack.

14. The processor-readable medium of claim 11, further comprising instructions to cause a processor to:

send, to a computer remote from the processor-readable medium, a signal indicating the temperature of each server from the plurality of servers and indicating a position of each valve from the plurality of valves; and receive, from the computer remote from the processor-readable medium, a control signal associated with at least one of the processor-readable medium or a valve from the plurality of valves.

15. A processor-readable medium comprising instructions to cause a processor to:

receive a plurality of signals from a plurality of photodetectors, each photodetector from the plurality of photodetectors being located with a unique server slot

from a plurality of server slots within at least one rack, each signal from the plurality of signals indicating whether a light is detected at a photodetector from the plurality of photodetectors and uniquely associated with a server slot from the plurality of server slots; select an action based on the plurality of signals; and send, to a valve from a plurality of valves, a signal indicative of the action to cause the valve, in response to the signal, to be in a position to define an airflow through the valve,

each valve from the plurality of valves being positioned with a unique server slot from the plurality of server slots, each valve from the plurality of valves having a range of motion between an opened position and a closed position, each valve from the plurality of valves in the opened position defining an airflow inlet opening having a size and a shape substantially corresponding to a size and a shape, respectively, of an airflow inlet opening of a case of the server uniquely associated with that valve and from the plurality servers when that server is disposed in the server slot from the plurality of server slots and for that server.

16. The processor-readable medium of claim **15**, wherein: each light source from a plurality of light sources is located with a unique server slot from the plurality of server slots, and

each photodetector from the plurality of photodetectors detects a light output from the light source from the plurality of light sources and is uniquely associated with the server slot for that photodetector, when a server from the plurality of servers is not present in that server slot.

17. The processor-readable medium of claim **15**, wherein: each light source from a plurality of light sources is located with a unique server slot from the plurality of server slots, and

each photodetector from the plurality of photodetectors not detecting a light output from the light source from the plurality of light sources and uniquely associated with the server slot for that photodetector when a server from the plurality of servers is present in that server slot.

18. The processor-readable medium of claim **15**, wherein the plurality of server slots and the processor-readable medium are located with a common rack.

19. The processor-readable medium of claim **15**, wherein: a first subset of server slots from the plurality of server slots is located with a first rack,

a second subset of server slots from the plurality of server slots is mutually exclusive from the first subset of servers and located with a second rack, and

the processor-readable medium is located at neither the first rack or the second rack.

20. The processor-readable medium of claim **15**, further comprising instructions to cause a processor to:

send, to a computer remote from the processor-readable medium, a signal indicating the temperature of each server from the plurality of servers and indicating a position of each valve from the plurality of valves; and receive, from the computer remote from the processor-readable medium, a control signal associated with at least one of the processor-readable medium or the plurality of valves.

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