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(54) **MULTI-RACK IMMERSION COOLING DISTRIBUTION SYSTEM**

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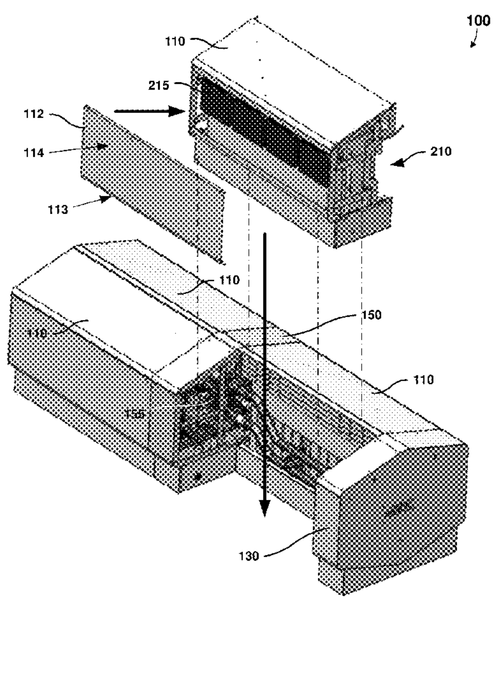
(57) **ABSTRACT**

Various aspects include devices, systems, and methods for multi-tank immersion cooling distribution. The devices and systems may include a coolant distribution unit, a coolant manifold, a supply and return line, and one or more immersion cooling racks. The coolant distribution unit may be configured to adjust a temperature and pump a fluid used as a coolant. The coolant manifold may redistribute the fluid. The immersion cooling racks may be disposed between the coolant distribution unit and the coolant manifold. Each immersion cooling rack may be coupled to the coolant manifold through an inlet duct for receiving the fluid from the coolant manifold and an outlet duct for returning the fluid to the coolant manifold.

12 Claims, 11 Drawing Sheets



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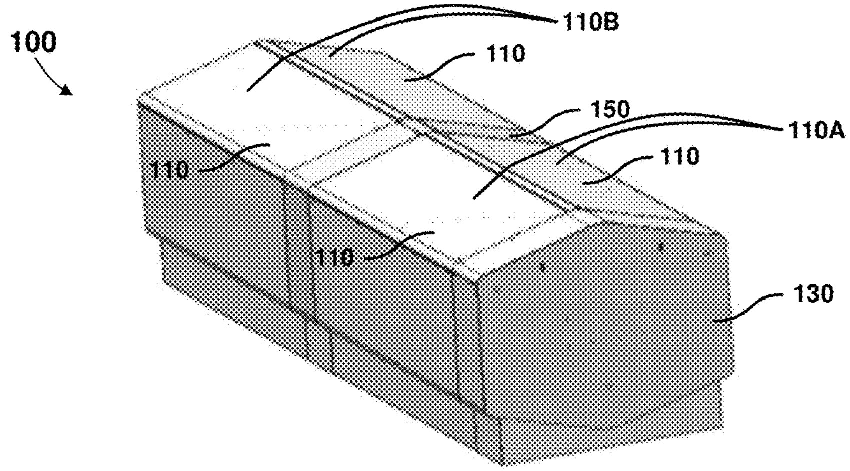
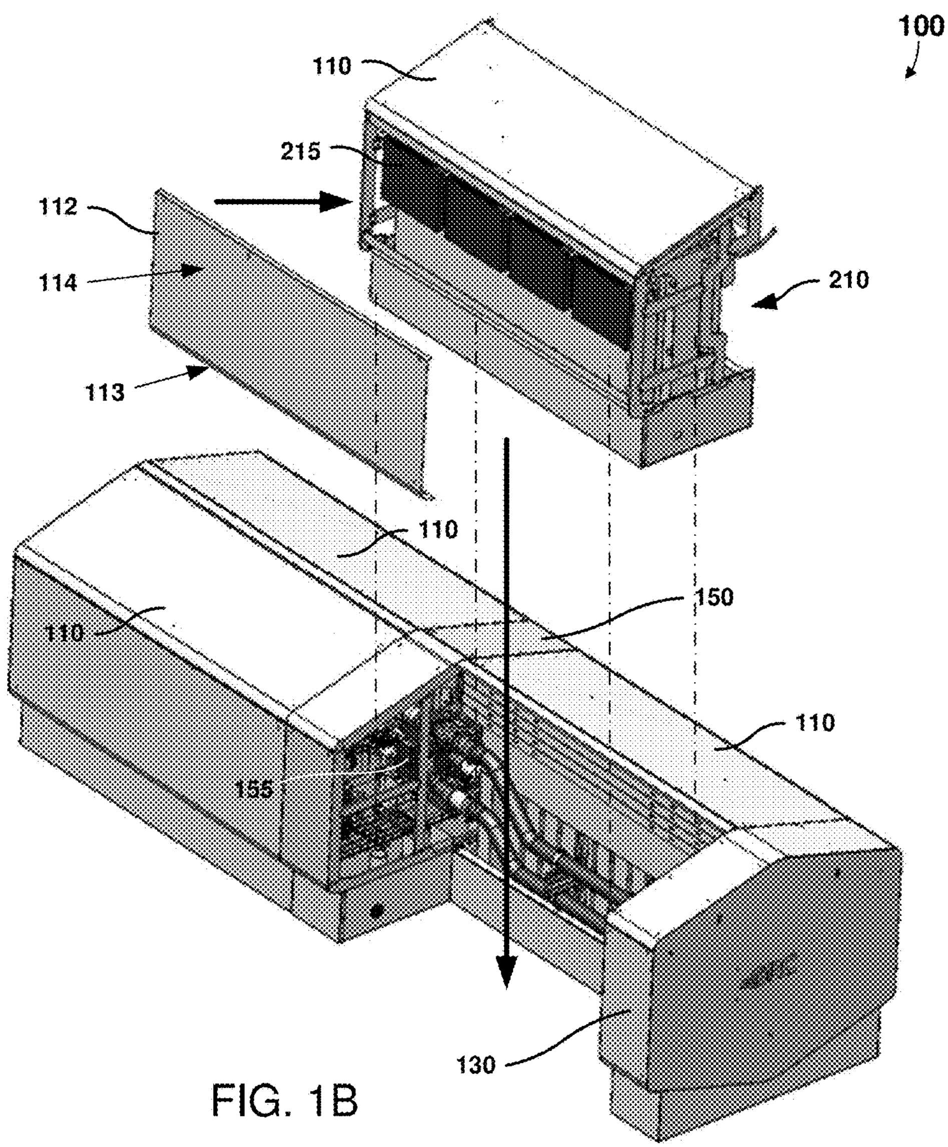

100
110B
110
150
110A
110
110
110
130

FIG. 1A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110
215
112
114
113
210
110
150
110
110
155
130

FIG. 1B

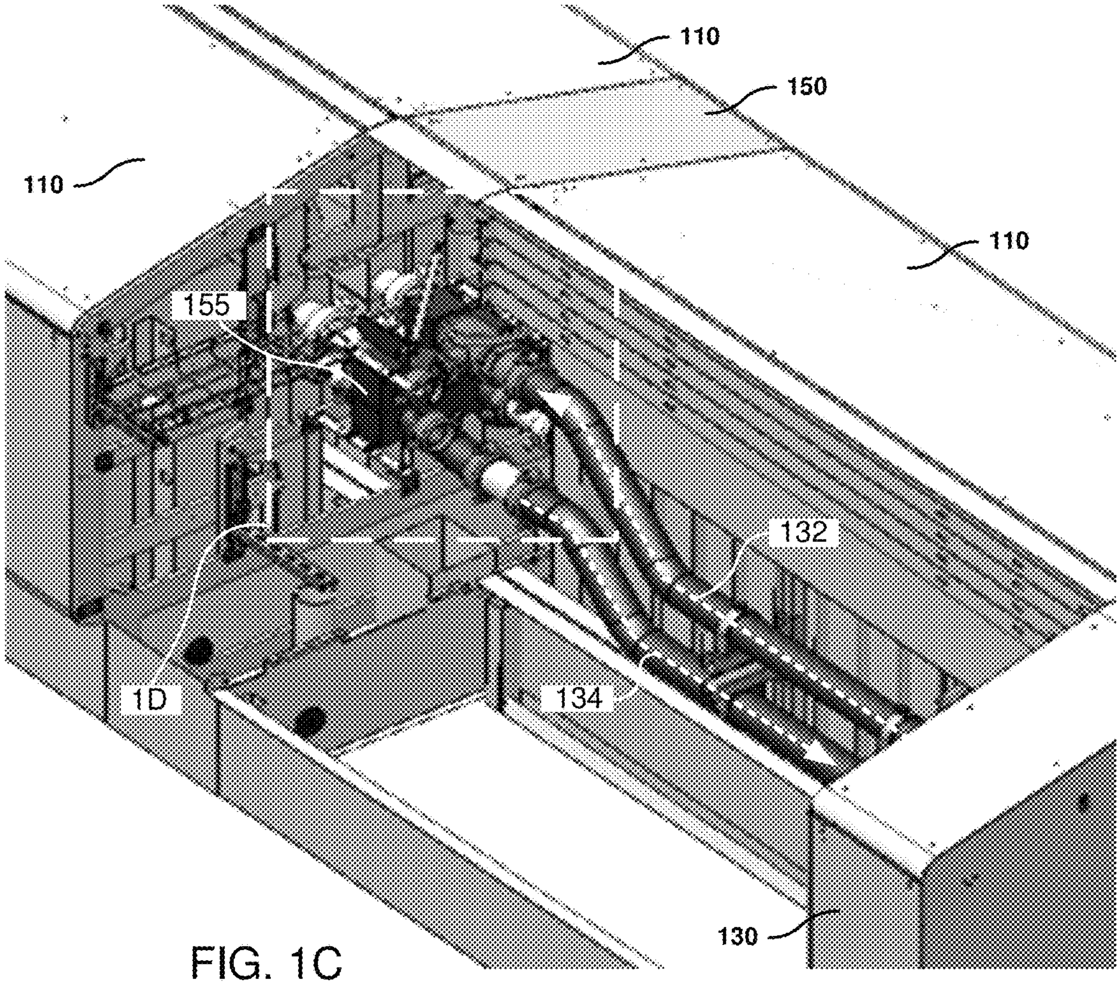

FIG. 1C

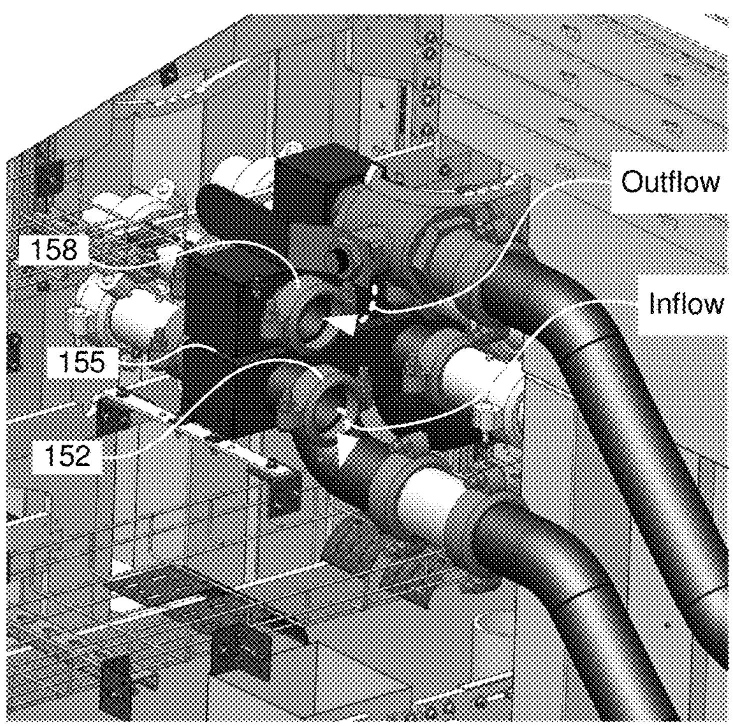

FIG. 1D

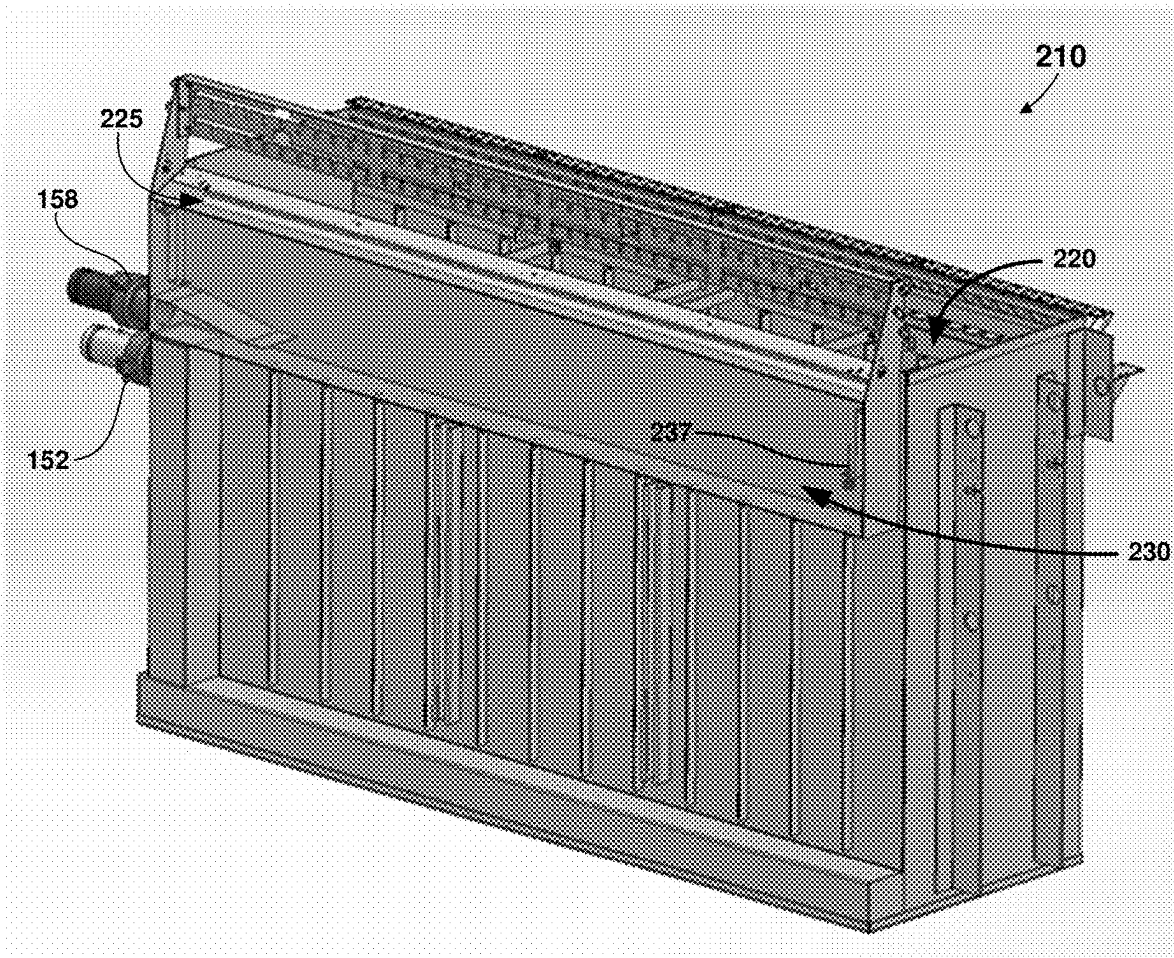

FIG. 2A

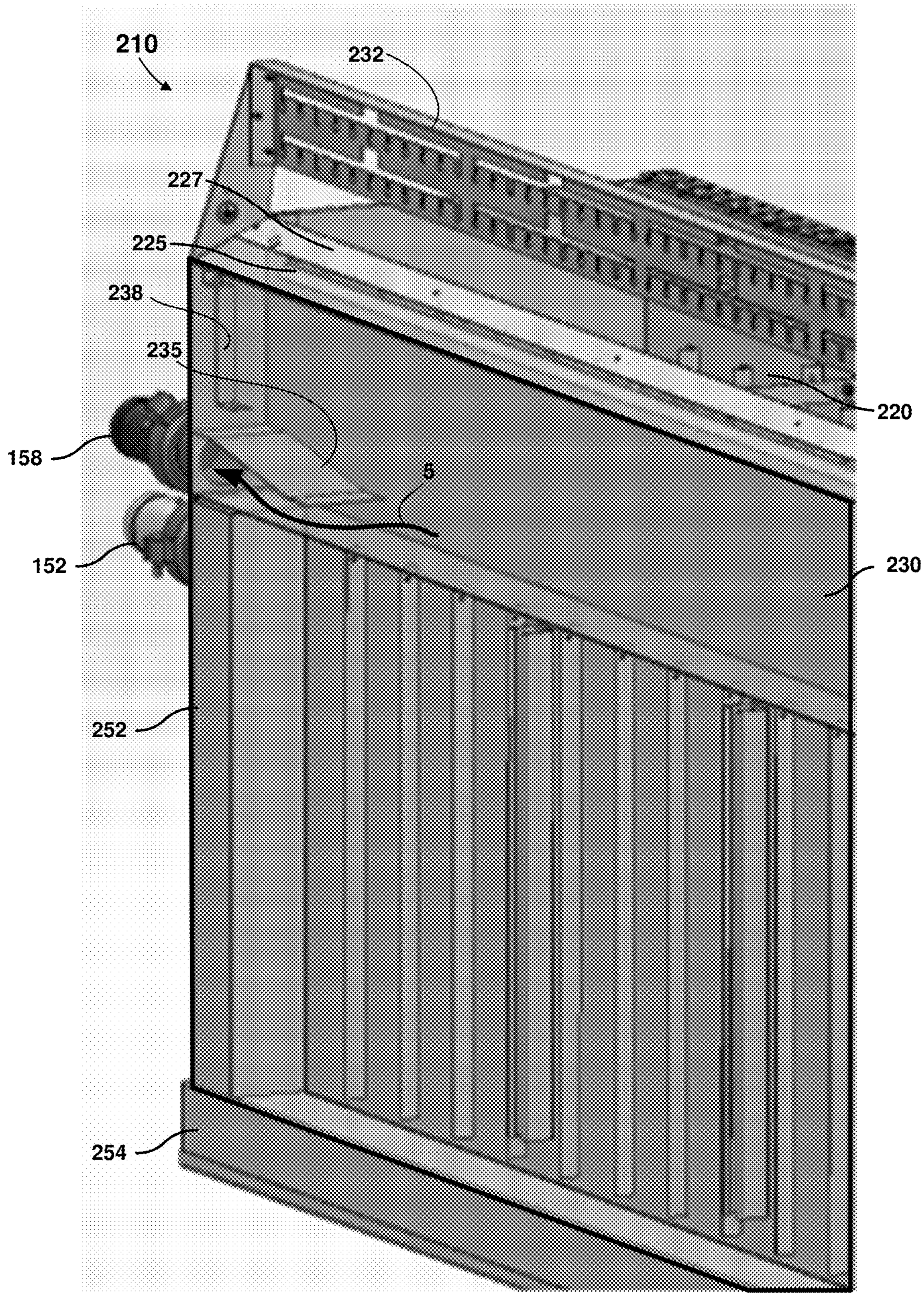

FIG. 2B

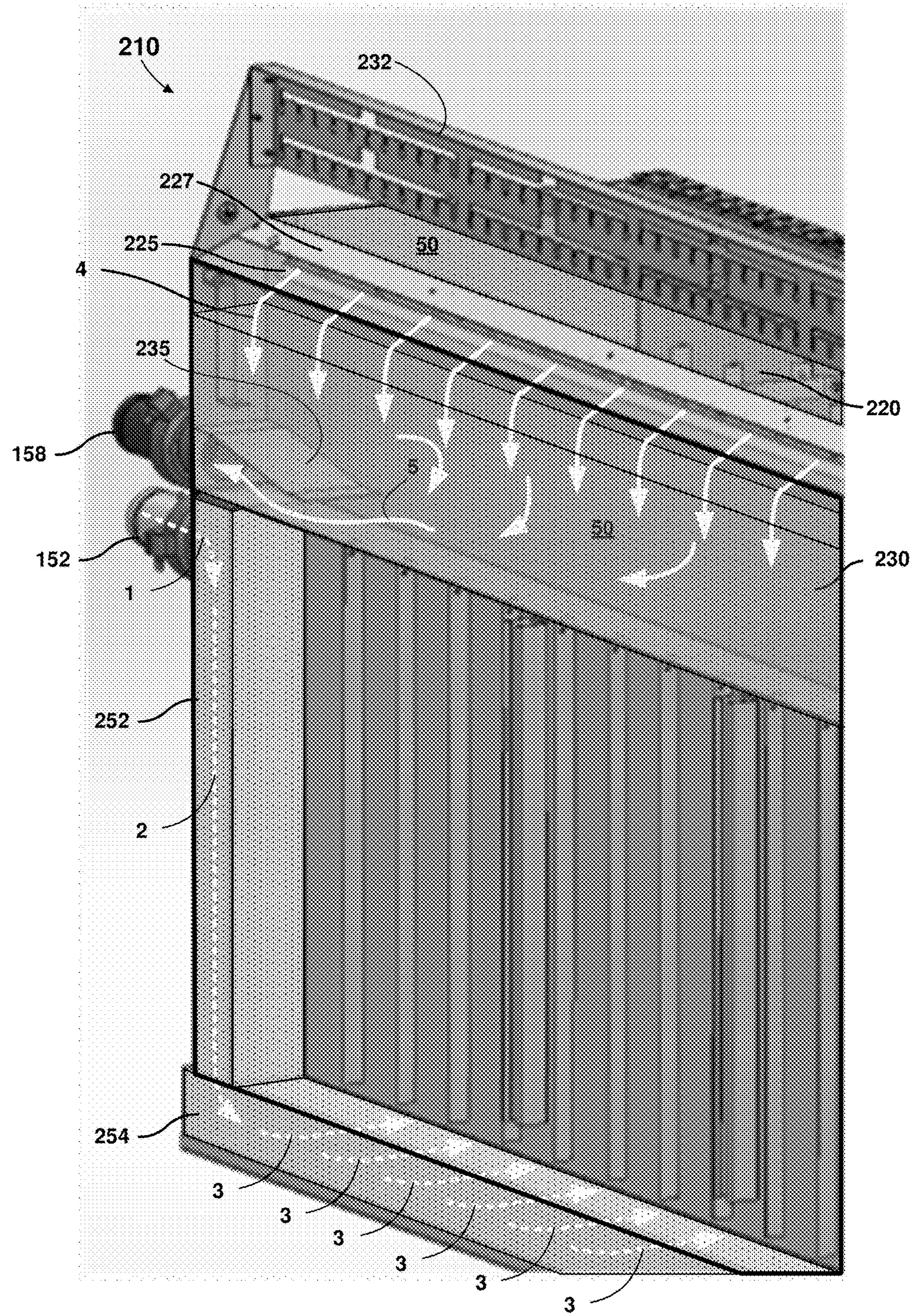

FIG. 2C

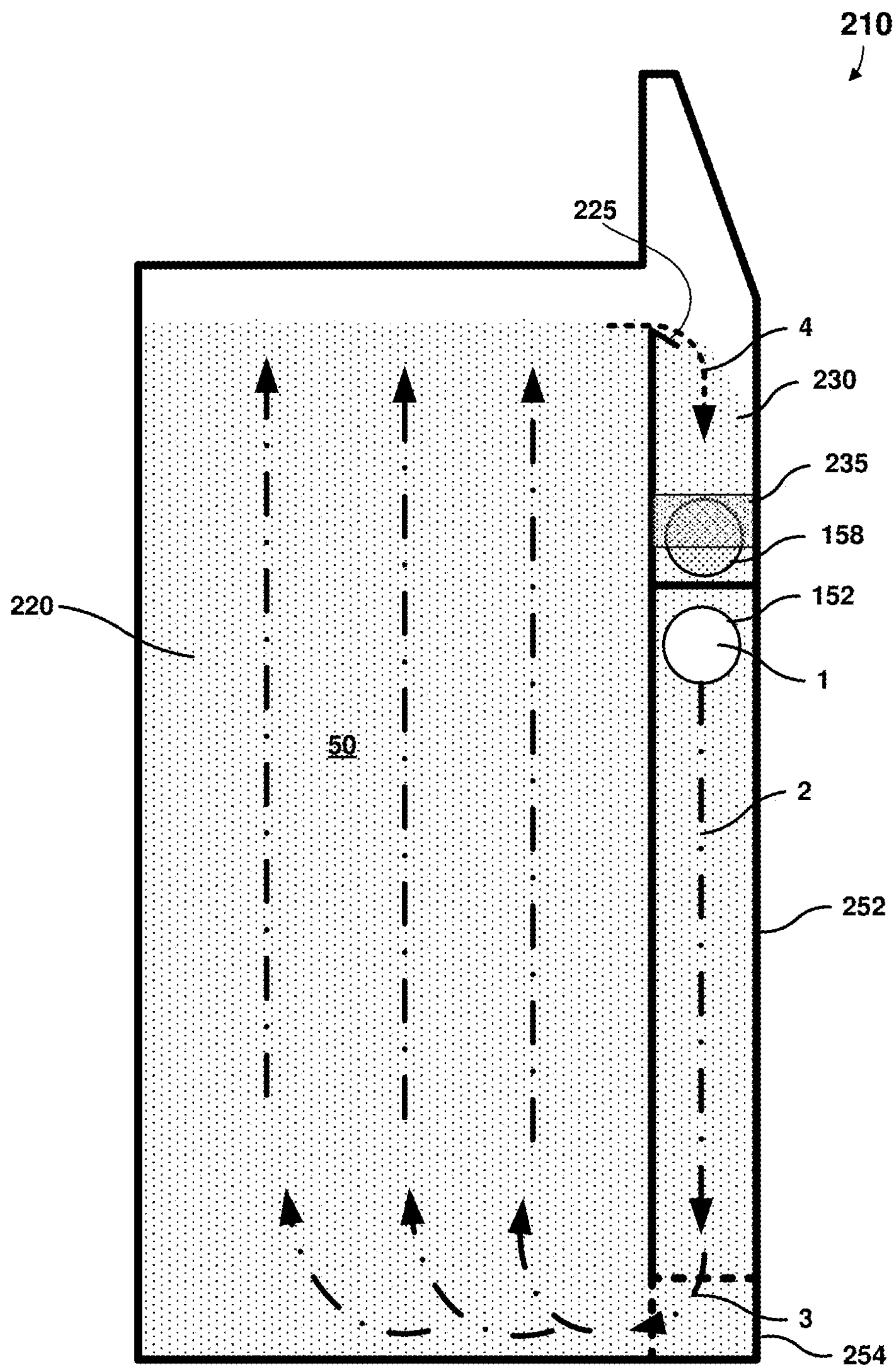

FIG. 3A

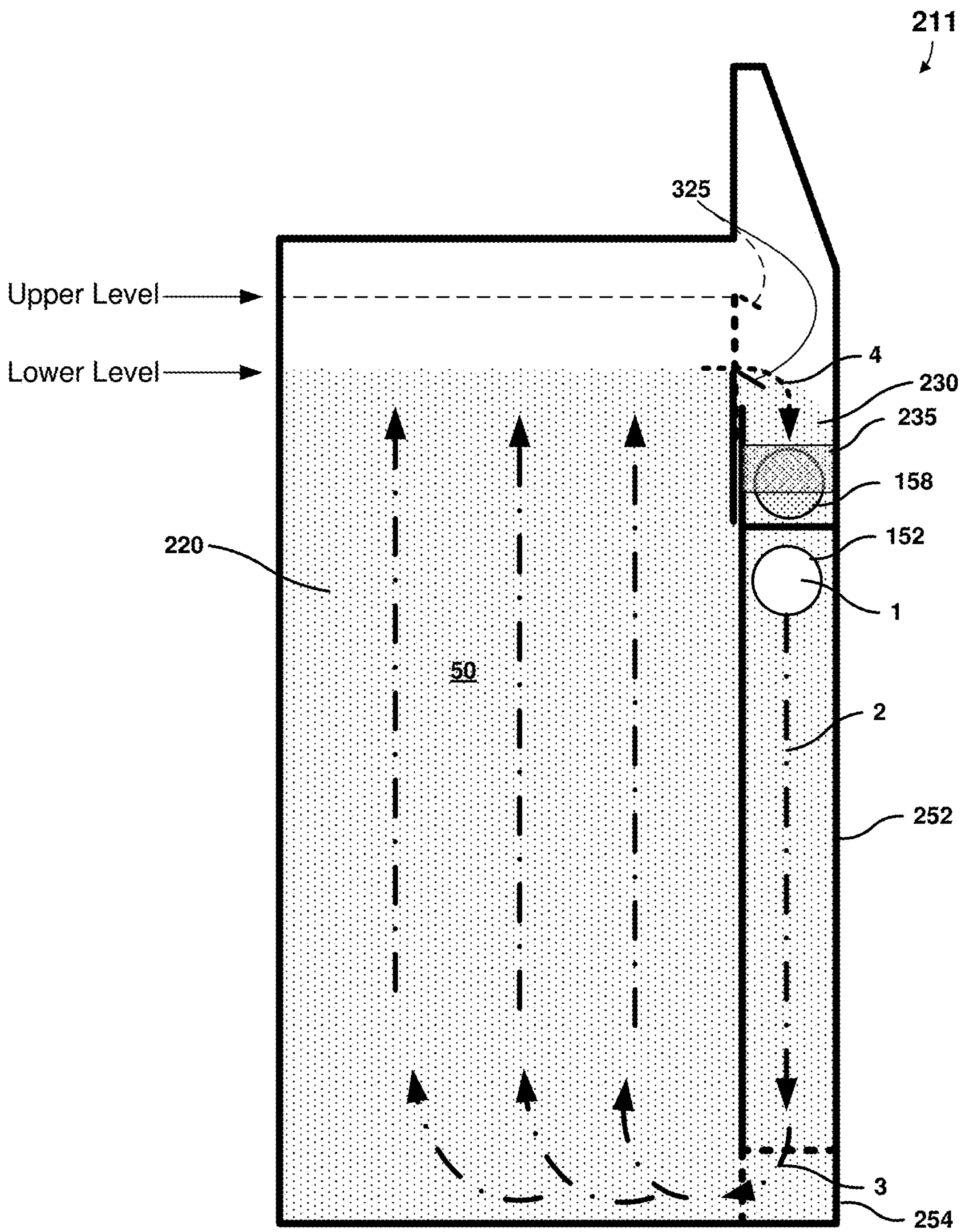
211
325
Upper Level
Lower Level
4
230
235
158
152
220
1
50
2
252
3
254

FIG. 3B

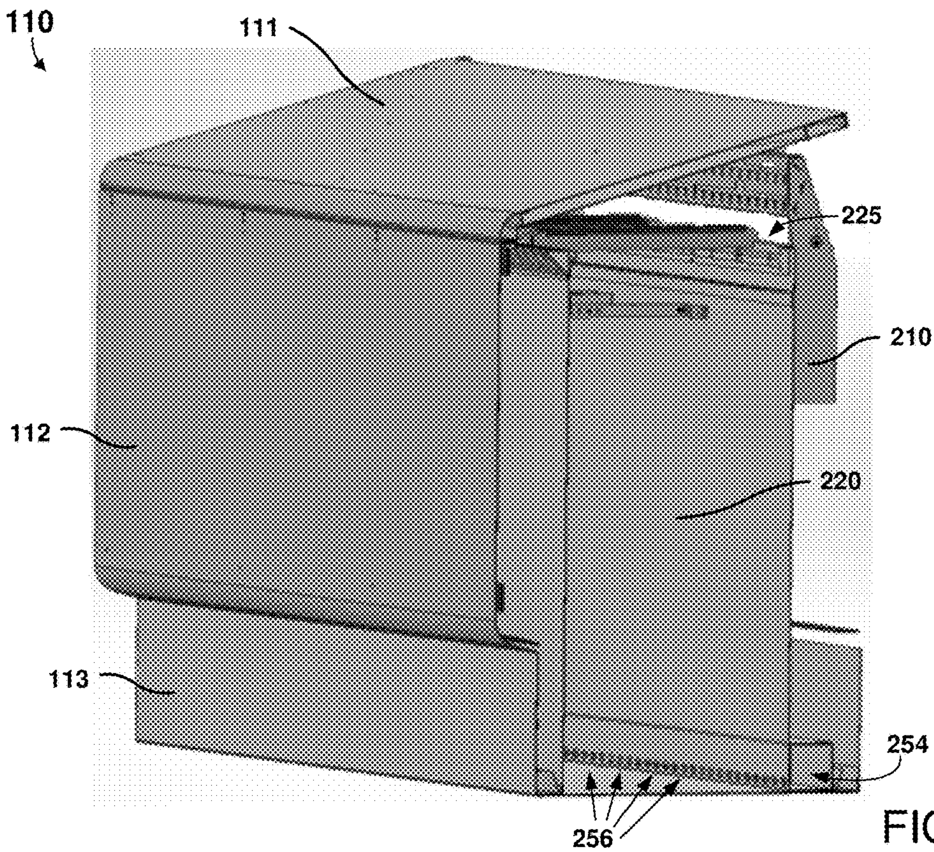

FIG. 4

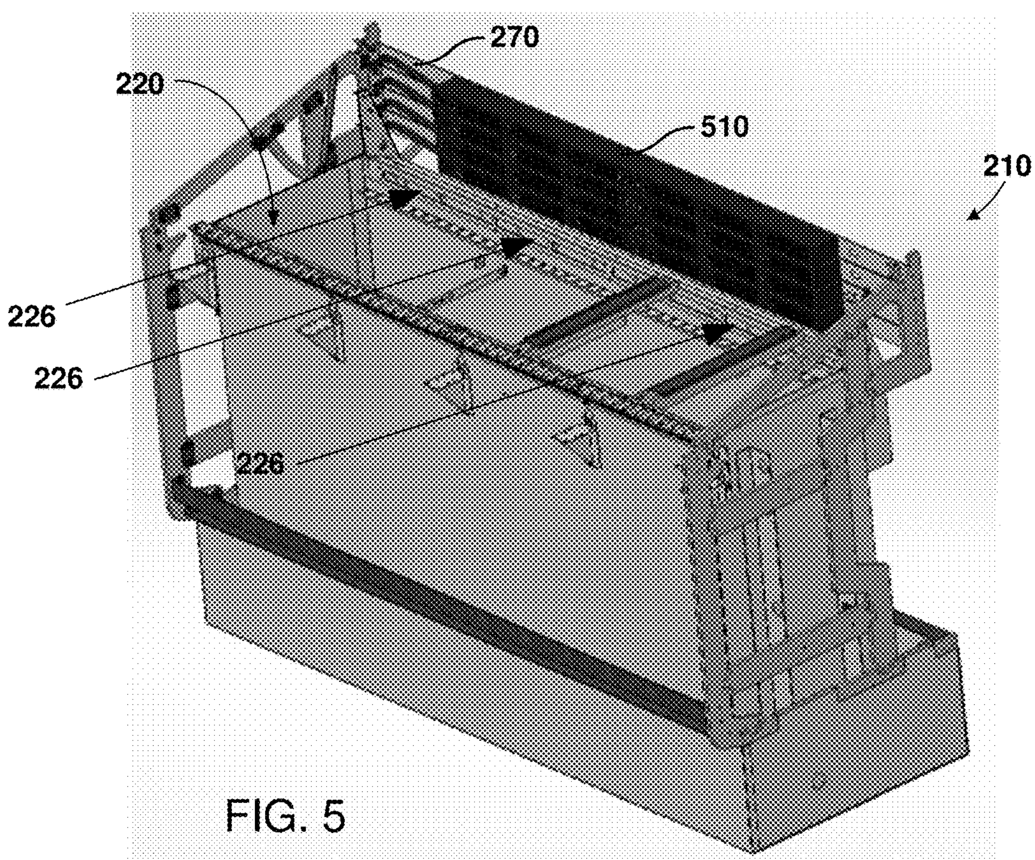

FIG. 5

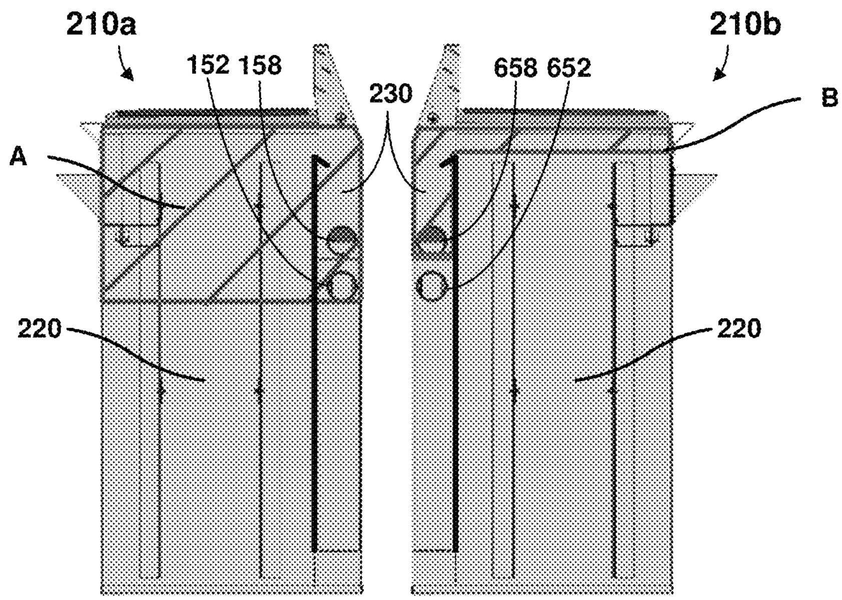
210a
152 158
230
658 652
210b
B
A
220
220

FIG. 6A

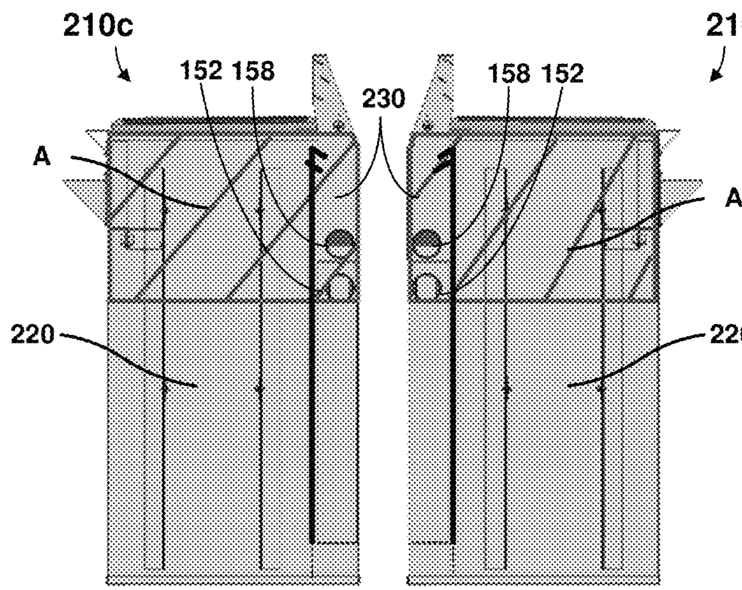
210c
152 158
230
158 152
210d
A
A
220
220

FIG. 6B

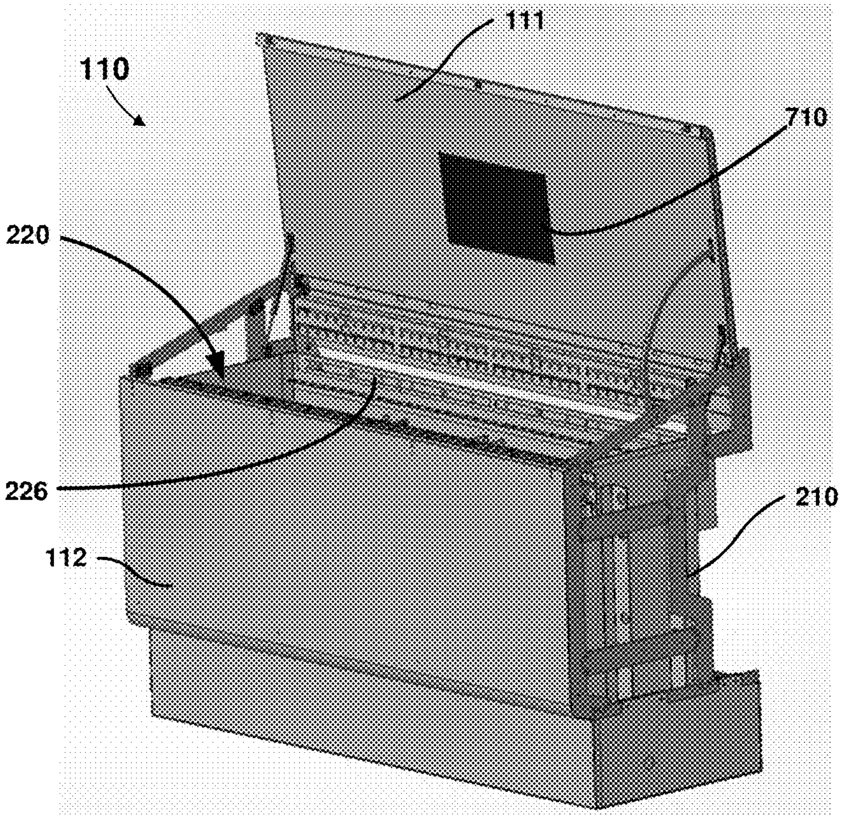

FIG. 7A

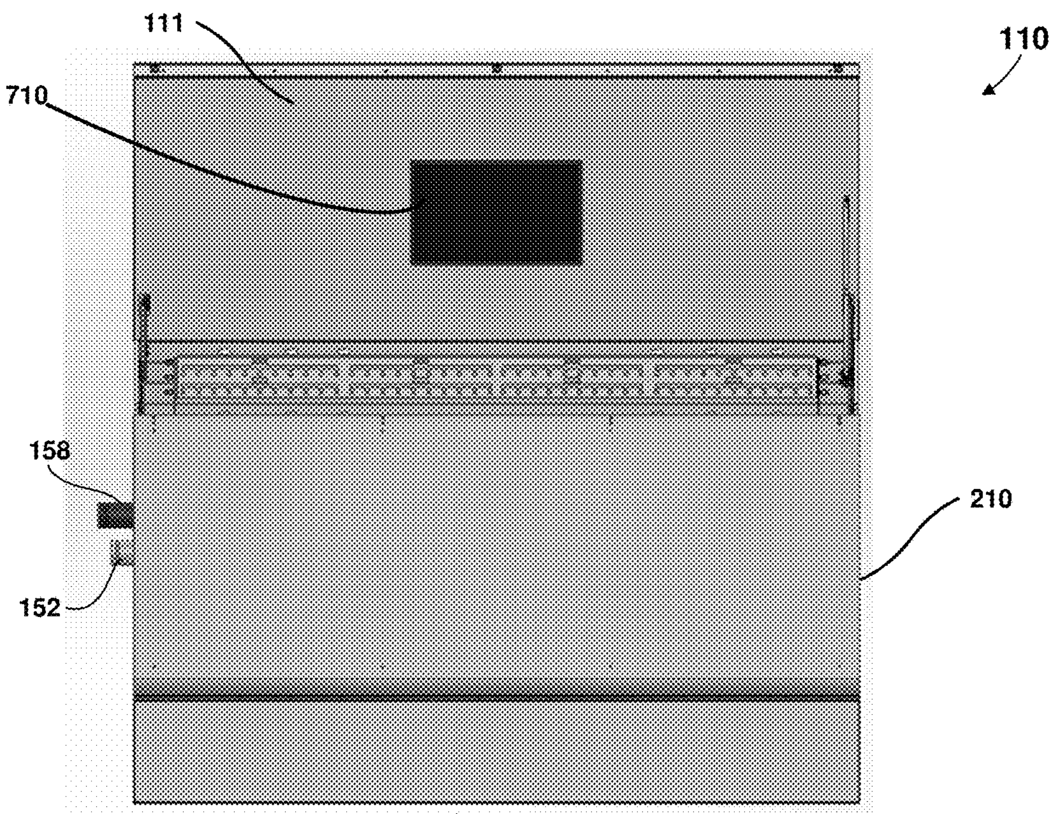

FIG. 7B

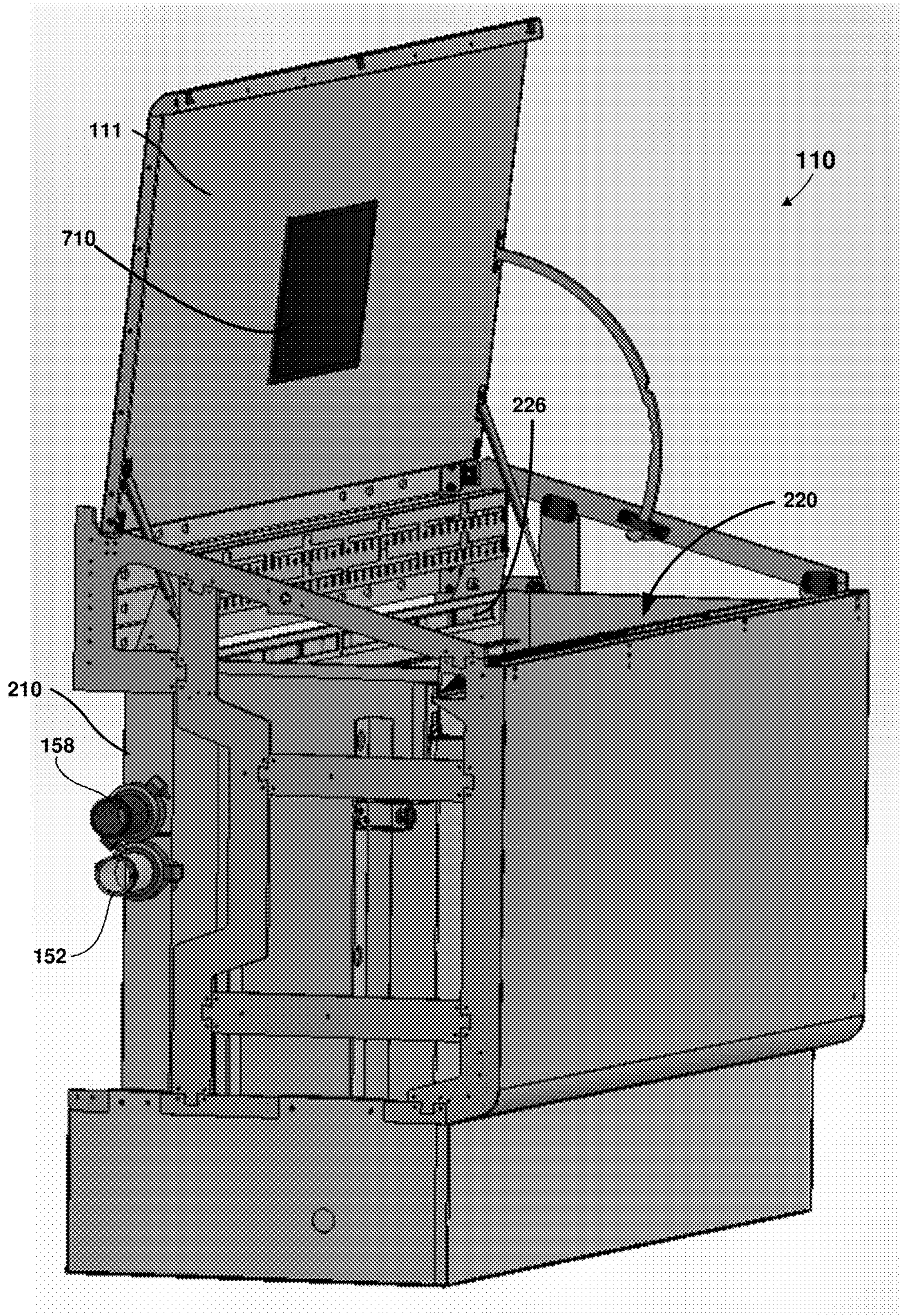

FIG. 7C

MULTI-RACK IMMERSION COOLING DISTRIBUTION SYSTEM

RELATED APPLICATIONS

This application claims the benefit of priority to U.S. Provisional Patent Application No. 63/112,745 entitled "Multi-Rack Immersion Cooling Distribution System" filed Nov. 12, 2020 and U.S. Provisional Patent Application No. 63/119,771 entitled "Multi-Rack Immersion Cooling Distribution System" filed Dec. 1, 2020, the entire contents of both of which are hereby incorporated by reference for all purposes.

BACKGROUND

Immersion cooling systems are often used to cool power distribution components of computer systems, such as commercial computer servers, by submerging those components in a tank filled with a dielectric coolant. Often, computer systems include a large array of components. As a result, oversized or custom racks used to hold those components may be hard to find or expensive. In addition, large cooling racks that include a tank to contain the dielectric coolant may not fit through the narrow hallways or doorways of the buildings in which the computer systems are housed. However, using multiple off-the-shelf smaller racks with tanks may require separate cooling systems for each rack. Although a single pump and heat exchanger may be used to cool multiple racks, a problem arises when those racks need to be cooled at different rates. If minor differences in flow are used to vary the cooling rates of the racks, a difference in coolant levels in the various racks may be introduced, which may be a risk to the other racks if the coolant levels that are cooling the other racks gets too low or too high. In instances in which the coolant level is too high, there may be a risk that the coolant level may overflow the tank containing the rack. In instances in which the coolant level is too low, there may be the risk of exposing parts or all of the computer system to air, which can cause overheating due to insufficient cooling. In addition, in instances in which coolant levels fall to too low a level, there may be the risk of introducing air into the coolant fluid circuit, which can damage pumps that circulate the coolant. While the coolant may be pumped out of the bottom of the tanks to avoid air intake, a subsequent leak or failure at a valve and/or duct located near the bottom of the tank could result in a complete draining of the tank. This in turn may again run the risk of exposing parts or all of the computer system to air, which can cause overheating due to insufficient cooling.

SUMMARY

Various aspects include devices, systems, and methods for cooling multiple immersion cooling tanks with a single coolant distribution system. The devices and systems may include a coolant distribution unit, a coolant manifold, a supply and return line, and one or more immersion cooling racks. The coolant distribution unit may be configured to adjust a temperature and pump a fluid used as a coolant. The coolant manifold may redistribute the fluid. The supply line may be coupled to the coolant distribution unit and the coolant manifold. The supply line may be configured to convey the coolant fluid from the coolant distribution unit to the coolant manifold. The return line may be coupled to the coolant distribution unit and the coolant manifold. The return line may be configured to convey the coolant fluid

from the coolant manifold to the coolant distribution unit. A first pair of immersion cooling racks may be disposed between the coolant distribution unit and the coolant manifold. Each immersion cooling rack of the first pair of immersion cooling racks may be coupled to the coolant manifold through a first inlet duct for receiving the coolant fluid from the coolant manifold and a first outlet duct for returning the coolant fluid to the coolant manifold.

In some aspects, a second pair of immersion cooling racks may be disposed on an opposite side of the coolant manifold relative to the first pair of immersion cooling racks, wherein each immersion cooling rack of the second pair of immersion cooling racks is coupled to the coolant manifold through a second inlet duct for receiving the coolant fluid from the coolant manifold and a second outlet duct for returning the coolant fluid to the coolant manifold.

In some aspects, at least one of the first inlet duct or the first outlet duct in each immersion cooling rack may be an adjustable valve configured to selectively restrict coolant fluid flow between the coolant manifold and the respective immersion cooling rack. Each of the first pair of immersion cooling racks may include a thermal switch that is triggered when a temperature of the coolant fluid drops below a threshold temperature, wherein the triggering of the thermal switch restricts fluid flow through the adjustable valve. At least one of the first inlet duct or the first outlet duct in each immersion cooling rack may be a one-way valve.

In some aspects, a plurality of inlet ports may be located in each of the first pair of immersion cooling racks, wherein the plurality of inlet ports are adjustable to control an orientation of a flow of coolant fluid through each respective immersion cooling rack. Each of the plurality of inlet ports may comprise an adjustable nozzle or jet to control the orientation of the flow of coolant fluid through each respective immersion cooling rack. Each of the plurality of inlet ports may comprise an adjustable coolant fluid valve to control the flow pressure of coolant fluid passing through the respective inlet port, wherein flow pressure controlled by the adjustable coolant fluid valve may constructively or destructively interfere with coolant fluid flow through adjacent inlet ports to control the orientation of the flow of coolant fluid through each respective immersion cooling rack.

Various aspects may include a system for controlling temperature measured in multiple immersion cooling racks with a single coolant distribution system. The system may include a component coolant tank, a buffer coolant tank, and a weir. The component coolant tank may be configured to hold at least one electronic component at least partially submerged in a coolant fluid pumped into the component coolant tank. The weir may extend along an upper edge of a barrier separating the component coolant tank from the buffer coolant tank, wherein the weir is configured to allow excess coolant fluid from the component coolant tank to spill out of the component coolant tank, over the weir, and into the buffer coolant tank.

In some aspects, the coolant fluid may be pumped into the component coolant tank from inlet ports along a bottom of a sidewall of the component coolant tank. Some aspects may include a whirlpool shield mounted inside the buffer coolant tank above an outlet port for the coolant fluid to exit the buffer coolant tank, wherein a first end of the whirlpool shield is attached to a side wall of the buffer coolant tank and the whirlpool shield extends away from the first end toward a second end disposed further from the outlet port than the first end. The whirlpool shield may extend downward at an angle such that the second end of the whirlpool shield is vertically lower than the first end of the whirlpool shield.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated herein and constitute part of this specification, illustrate exemplary embodiments of the claims and together with the general description given above and the detailed description given below, serve to explain the features of the claims.

FIGS. **1**A-**1**D are illustrative examples of various aspects of a multi-rack cooling system in accordance with various embodiments.

FIG. **2**A is a perspective cut-away view of a rear side of an immersion cooling rack, with front and upper walls removed and an outer rear wall shown as transparent to reveal main and buffer coolant tanks, in accordance with various embodiments.

FIG. **2**B is a relief view of one side of the immersion cooling rack of FIG. **2**A, in accordance with various embodiments.

FIG. **2**C is a relief view of one side of the immersion cooling rack of FIGS. **2**A and **2**B with coolant flowing therein, in accordance with various embodiments.

FIG. **3**A is a vertical cross-sectional cut-away view of an immersion cooling rack showing various features of various embodiments.

FIG. **3**B is a vertical cross-sectional cut-away view of an immersion cooling rack with an adjustable height weir, in accordance with various embodiments.

FIG. **4** is a perspective view of an immersion cooling rack with side-walls removed to reveal an inner portion of a main coolant tank, in accordance with various embodiments.

FIG. **5** is a perspective view of a front side of an immersion cooling rack with upper components removed to better show a weir used between the main and buffer coolant tanks and flow of coolant, in accordance with various embodiments.

FIGS. **6**A-**6**B are side cross-sectional views of adjacent pairs of immersion cooling racks with and without one-way valves, in accordance with various embodiments.

FIG. **7**A is a right-side perspective view of an immersion cooling rack assembly with a video monitor.

FIG. **7**B is a front view of an immersion cooling rack assembly with a video monitor.

FIG. **7**C is a left side perspective view of an immersion cooling rack assembly with a video monitor.

DETAILED DESCRIPTION

Various embodiments will be described in detail with reference to the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts. References made to particular examples and implementations are for illustrative purposes and are not intended to limit the scope of the claims.

Various embodiments include devices, systems, and methods for controlling the temperature of multiple immersion cooling racks with a single coolant distribution system. Exemplary implementations may include devices, systems, and methods for cooling multiple immersion cooling tanks with a single coolant distribution system. The devices and systems may include a coolant distribution unit, a coolant manifold, a supply and return line, and one or more immersion cooling racks. The coolant distribution unit may be configured to adjust a temperature and pump a fluid used as a coolant. The coolant manifold may redistribute the fluid. The supply line may be coupled to the coolant distribution unit and the coolant manifold. The supply line may be configured to convey the coolant fluid from the coolant distribution unit to the coolant manifold. The return line may be coupled to the coolant distribution unit and the coolant manifold. The return line may be configured to convey the coolant fluid from the coolant manifold to the coolant distribution unit. A first pair of immersion cooling racks may be disposed between the coolant distribution unit and the coolant manifold. Each immersion cooling rack of the first pair of immersion cooling racks may be coupled to the coolant manifold through a first inlet duct for receiving the coolant fluid from the coolant manifold and a first outlet duct for returning the coolant fluid to the coolant manifold.

Some embodiments may include a system for controlling temperature measured in multiple immersion cooling racks with a single coolant distribution system. The system may include a component coolant tank, a buffer coolant tank, and a weir. The component coolant tank may be configured to hold at least one electronic component at least partially submerged in a coolant fluid pumped into the component coolant tank. The weir may extend along an upper edge of a barrier separating the component coolant tank from the buffer coolant tank, wherein the weir is configured to allow excess coolant fluid from the component coolant tank to spill out of the component coolant tank, over the weir, and into the buffer coolant tank.

Immersion cooling racks, in accordance with various embodiments provide a bath of fluid in a tank. The fluid may be circulated such that heat can be rejected from the fluid to the atmosphere (typically via an external cooling device such an evaporative cooling tower) and cool fluid may then be delivered to the heat-generating electronic components that would otherwise overheat. Various embodiment may take advantage of natural methods of circulating/delivering fluids due to density changes as fluid is heated (hot coolant is less dense, which tends to rise to the top of the tank). Another method of circulating/delivering fluid may use a pump, such as from a manifold into the bottom of one or more fluid tanks.

Various embodiments disclosed herein provide for multiple racks coupled together to increase the number and volume of computer system components that may be cooled. By dividing the total number and volume of computer system components to be cooled into multiple racks, the overall cooling system may consist of smaller individual racks that allow for easier movement and placement in a location. The various embodiments provide for a singular coolant distribution unit (sometimes referred to as a CDU) that cools the coolant fluid that is passed through multiple individual racks. Such embodiments may improve efficiency by allowing for a single coolant distribution system to service a plurality of racks.

Computer system components, such as information technology (IT) equipment, may have a depth/width such that passive recirculation (such as depending on the variations in temperature and densities) does not guarantee that the cooler fluid may be delivered evenly throughout the IT equipment. To optimize cooling across all IT equipment, a solution consisting of a pump and jets may be implemented. The jets may be located at the bottom of the tank and may be oriented such that cool fluid is distributed across the bottom of the tank. The orientation of the jet flow shall be flexible enough to suit the need of the product design. In some embodiments, the orientation of the jet flow may be adjustable to control and manipulate the flow of coolant fluid over particular locations and components in the tank. Such adjustment of jet flow orientation may be through the physical manipulation of nozzles or jets. In other embodiments, the adjustment of jet flow orientation may be through the manipulation of flow rates to cause constructive and destructive wave interference. Angled jets (not horizontal) could be implemented for immersion solutions that have IT equipment with shorter chassis.

FIGS. **1A**-**1D** illustrate various aspects of a multi-rack cooling system in accordance with various embodiments. The various embodiments are described herein with regard to a system for controlling the temperature of multiple immersion cooling racks.

FIG. **1A** illustrates a multi-rack cooling system **100** in accordance with various embodiments. The embodiment multi-rack cooling system **100** illustrated in FIGS. **1A**-**1D** includes four immersion cooling rack assemblies **110** set up in rows, a coolant distribution unit **130**, and a coolant manifold unit **150**. In other embodiment multi-rack cooling system (not shown) additional immersion cooling rack assemblies **110** may be included in conjunction with the coolant distribution unit **130**, and a coolant manifold unit **150**. For example, other embodiment multi-rack cooling systems may include 2, 4, 6, 8, etc. immersion cooling rack assemblies **110** in conjunction with the coolant distribution unit **130**, and a coolant manifold unit **150**. The coolant distribution unit **130** may be configured to adjust a temperature (e.g., cool down) and pump a fluid used as a coolant into each of the plurality of immersion cooling rack assemblies **110**. The fluid may be a liquid dielectric, which is a thermally conductive fluid configured to prevent or rapidly quench electric discharges. The coolant manifold unit **150** may be configured to redistribute the fluid between the coolant distribution unit **130** and the plurality of immersion cooling rack assemblies **110**. Each of the immersion cooling rack assemblies **110** may include a component cooling tank configured to hold at least one electronic component fully, or at least partially, submerged in a fluid pumped into the component coolant tank.

Pairs of the immersion cooling rack assemblies **110** may be arranged side-by-side in the multi-rack cooling system **100**. For example, a first pair of immersion cooling rack assemblies **110**A may be disposed between the coolant distribution unit **130** and the coolant manifold unit **150**. Also, a second pair of immersion cooling rack assemblies **110**B disposed on an opposite side of the coolant manifold unit **150** relative to the first pair of immersion cooling rack assemblies **110**A.

Various embodiments may use multiple immersion cooling rack assemblies **110** in parallel to reduce the cost per space of cooling. For example: four immersion cooling rack assemblies **110** of approximately 50 U may be connected to a single pump. While some datacenters employ the same information technology load in each area or immersion cooling rack assembly **110**, some collocation facilities may have significantly different loads from one immersion cooling rack to another. Customer may only require a single rack of space, which needs far fewer resources than a customer using multiple racks.

Various embodiments may provide equal cooling across the plurality of immersion cooling racks, even without any flow regulation between the plurality of immersion cooling rack assemblies **110**. The cooling flow may be scaled to handle the hottest of the plurality of immersion cooling rack assemblies **110**, which enables the pumping system to work as hard as if the most power dense rack was the average heat generating rack.

Various embodiments may include flow regulation that adjusts and varies the flow of coolant fluid to each of the plurality of immersion cooling rack assemblies **110**. This adjustability may allow for reduced power usage of a pump while maintaining the most dense immersion cooling rack assembly **110** by diverting flow to the dense immersion cooling rack assembly **110** rather than increasing flow to all immersion cooling rack assemblies **110**. The maximum capacity of the coolant distribution unit **130** may become the sum of the immersion cooling racks power, rather than four times (4×) the peak power rack, which may enable higher density racks.

For example, if a coolant distribution unit **130** has a capacity of 100 kW, the immersion cooling racks may have the following loads.

- 25, 25, 25, 25 (i.e., even loading, no capacity or efficiency is wasted); or
- 25, 25, 15, 15 (i.e., uneven loading, associated with wasted efficiency.

If adjustable valves are included for balancing fluid level, the following loads may be possible:

- 25, 25, 15, 15 (i.e., flow diverted from 15 kW racks to improve efficiency); or
- 35, 35, 15, 15 (i.e., divert flow from 15 kW to boost capacity of racks over max/4.

Heat loads may be dynamic, so the methods of various embodiments may divert flow automatically, which may be achieved by controlling inlet and outlet temperatures. A temperature sensor on the exhaust may be used to control the amount of fluid flowing through the rack. The fluid entering each rack may act like fluid cooled by the heat exchanger directly. Heat load may be proportional to the flowrate, which may be measured by the difference between inlet and exhaust temperatures (dT). If an immersion cooling rack has a low difference between temperatures, that rack's flow may be constricted, essentially maintaining a constant dT. The main pump may be controlled by those temperatures or by providing a constant pressure. With a constant pressure method, when valves close, the pump may slow down and maintain flow to the least restricted immersion cooling rack.

FIG. **1B** illustrates a partially exploded view of the multi-rack cooling system **100** in FIG. **1A**. In FIG. **1B**, one immersion cooling rack assembly **110** has been removed from its station in the multi-rack cooling system **100**. An outside panel **112** of the removed immersion cooling rack assembly **110** is pulled away to reveal electronic components **215** attached to an outer side of a frame **210** forming the immersion cooling rack assembly **110**. The electronic components **215** may be switches, batteries, transformers, or other components of the immersion cooling rack assembly **110** that may not need to be submerged in coolant. The outside panel **112** at its base **113** may be configured to lie closer to the frame **210** than an upper portion **114**, which makes room for the electronic components **215** while forming a toe-kick area at the base **113**. The toe-kick area at the base **113** allows technicians to stand more comfortably close to the sides of the multi-rack cooling system **100** while servicing and maintaining the multi-rack cooling system **100**.

In addition, in FIG. **1B** a lid and side panel of one side of the coolant manifold unit **150** are removed to reveal the coolant manifold **155** located therein. The coolant manifold **155** receives cooled coolant fluid from the coolant distribution unit **130** via plumbing (supply line **132** and return line **134**) and redistributes the cooled coolant fluid to each of the individual immersion cooling rack assembly **110**. The compartment inside the coolant manifold unit **150** may include sensors for checking temperature, leaks of coolant fluid, and/or the accumulation of water from condensation or other sources.

FIG. 1C is a relief view of the partially exploded view of the multi-rack cooling system **100** in FIG. 1B. FIG. 1C illustrates the manner in which a supply line **132** may couple the coolant distribution unit **130** and the coolant manifold **155**. In particular, the supply line **132** may be configured to convey the fluid from the coolant distribution unit **130** to the coolant manifold **155**. In addition, FIG. 1C illustrates the manner in which a return line **134** may couple the coolant distribution unit **130** and the coolant manifold **155**. In particular, the return line **134** may be configured to convey the coolant fluid, that has been heated due to its contact with the various computer components housed in each of the immersion cooling racks, from the coolant manifold **155** to the coolant distribution unit **130**. In this way, the supply line **132** may deliver to the coolant manifold **155** cooled coolant fluid from the coolant distribution unit **130** and return heated coolant fluid to the coolant distribution unit **130**.

FIG. 1D is a further relief view of the multi-rack cooling system **100** in FIG. 1C. FIG. 1D shows how the coolant manifold **155** may include inlet ducts (i.e., inflow) and outlet ducts (i.e., outflow) configured to be coupled to an immersion cooling rack assembly **110**. For example, an immersion cooling rack assembly **110** of the first pair of immersion cooling rack assemblies **110**A may be coupled to the coolant manifold **155** through a first inlet duct **152** for receiving the fluid selectively from the coolant manifold **155**. Using the first inlet duct **152**, the coolant manifold **155** may supply the attached immersion cooling rack assembly **110** an inflow of coolant fluid. Also, the immersion cooling rack assembly **110** of the first pair of immersion cooling rack assemblies **110**A may be coupled to the coolant manifold **155** through a first outlet duct **158** for returning the heated coolant fluid to the coolant manifold **155** (and back to coolant distribution unit **130**). Using the first outlet duct **158**, the coolant manifold **155** may receive an outflow of coolant fluid from the attached immersion cooling rack assembly **110**. In embodiments that include four immersion coolant rack assemblies **110** (as shown in FIGS. 1A-1D), the coolant manifold **155** may have four sets of inlet and outlet ducts, each coupled to a different one of the immersion cooling rack assemblies **110**. In embodiments in which the number of immersion coolant racks varies, the number of pairs of inlet and outlet ducts will also vary. Thus, a second immersion cooling rack assembly **110** of the first pair of immersion cooling rack assemblies **110**B may be coupled to the coolant manifold **155** through a second inlet duct **152** for receiving the fluid selectively from the coolant manifold **155** and so on. Also, the second immersion cooling rack assembly **110** of the second pair of immersion cooling rack assemblies **110**B may be coupled to the coolant manifold **155** through a second outlet duct **158** for returning the heated coolant fluid to the coolant manifold **155** (and back to coolant distribution unit **130**). In some embodiments, the ducts **152**, **158** may include a valve or other flow control element and/or device.

In accordance with various embodiments, a partial solution to the potential coolant level imbalance that may occur when multiple immersion cooling rack assemblies **110** with component cooling tanks are being supported by a single pump and heat exchanger (i.e., coolant distribution unit **130**) may be to include a weir between a main coolant tank **220** and buffer coolant tank **230** both included in each immersion cooling rack (**110**, **210**).

FIGS. 2A-2C illustrate perspective cut-away views of a rear side of an immersion cooling rack **210**, with front and upper walls removed and an outer rear wall shown as transparent to reveal component and buffer coolant tanks **230**, in accordance with various embodiments. FIG. 2A illustrates the entire immersion cooling rack **210**, while FIGS. 2B and 2C are relief views of one side thereof that includes inlet and outlet ports. FIGS. 2A and 2B illustrate the immersion cooling rack **210** with no coolant fluid, while FIG. 2C illustrates a coolant fluid **50** in various parts of the immersion cooling rack **210**. FIG. 3A is a side schematic view of the immersion cooling rack **210** showing and exemplary coolant fluid flow, in accordance with various embodiments. The immersion cooling rack **210** includes a component coolant tank **220**, a buffer coolant tank **230**, and a weir **225**. The component coolant tank **220** is configured to contain at least one electronic component (not shown) at least partially submerged in a volume of coolant fluid pumped into the component coolant tank **220**. The coolant fluid **50** in the coolant tank **220** should keep the electronic equipment disposed therein from overheating. Thus, in order to ensure the coolant fluid **50** maintains a proper temperature, the coolant tank **220** may include at least one temperature sensor. For example, a thermal switch may be included that is triggered when a temperature of the coolant fluid **50** drops below or rises above a threshold temperature. Triggering of the thermal switch may restrict or increase the fluid flow through an adjustable valve in the coolant manifold **155** or other parts of the coolant fluid flow path. In addition, the coolant tank **220** may include a level sensor to monitor the coolant fluid levels. Still further the coolant tank **220** may include a water sensor that may detect the presence of water that may have spilled or condensed into the coolant fluid **50**. The density of the coolant fluid **50** may prevent water from easily mixing into solution with the coolant fluid **50**. As water may damage the computer components placed in the rack, the detection of water may be critical to safe and effective operation.

The buffer coolant tank **230** may be a separate tank from the component coolant tank **220**. The buffer coolant tank **230** is configured to receive overflow coolant fluid from the component coolant tank **220**. The weir **225** may extend along a lower edge of an aperture (see **226** in FIG. **5**) near the top of a barrier (i.e., a wall of the component coolant tank **220**) separating the component coolant tank **220** from the buffer coolant tank **230**. Alternatively, an upper extent of the barrier separating the component coolant tank **220** from the buffer coolant tank **230** may be lower than the other walls of the component coolant tank **220**. The weir **225** may be formed as a flat horizontal strip, configured to allow excess coolant fluid **50** to spill out from the component coolant tank **220**, over the weir **225**, and into the buffer coolant tank **230**. In various embodiments, the weir **225** may extend from one side of the component coolant tank **220** to the other. In other embodiments, the weir **225** may only extend across a portion of the component coolant tank **220**. In other embodiments, more than one weir **225** may be provided, each extending across different portions of the component coolant tank **220**. In this manner, a weir **225** may be disposed on any and all edges of the component coolant tank **220** so that the component coolant tank **220** has a buffer tank around some or all of its perimeter.

As shown in FIGS. 2B, 3A and 3B, at a first stage ("1") of fluid flow into the immersion cooling rack **210**, coolant fluid **50** may enter from the inlet duct **152** through an inlet port. The inlet duct **152** may be coupled to an inlet port (e.g., an aperture) that is open to the inside of a hollow vertical column **252** configured to direct the coolant fluid **50** through a second stage ("2") of fluid flow toward the bottom of the immersion cooling rack **210**. From the hollow vertical column **252**, the coolant fluid **50** is directed through a third stage ("3") of coolant fluid flow through a horizontally extending channel **254**. An innermost wall of the horizontally extending channel **254** includes a series of apertures (see inlet ports **256** in FIG. **4**) that extend from the horizontally extending channel **254** into a lower region of the component coolant tank **220**. Once the coolant fluid **50** fills the component coolant tank **220**, rather than spilling out of the immersion cooling rack **210**, the weir **225** may direct overflow of the coolant fluid **50** to a fourth stage ("4") of coolant fluid flow, which spills over the weir **225** and into the buffer coolant tank **230**. In this way, the fourth stage ("4") includes coolant fluid flow through an opening in an upper portion of wall of the component coolant tank **220**, which extends from the weir **225** to a weir cover **227** that is vertically spaced away from the weir **225**. The weir cover **227** may be removable for service access to the weir **225**. The opening in the upper portion of wall of the component coolant tank may be covered with a mesh screen or be formed from a wall portion that includes one or more apertures therein. The vertical height of a highest part of the weir **225** is lower than other upper edges of the component coolant tank **220** that are not intended to retain (i.e., hold back) fluid, to provide a release of overflow coolant fluid **50** in to the buffer coolant tank **230**. Once the coolant fluid **50** is in the buffer coolant tank **230**, a fifth stage ("5") of coolant fluid **50** flow may exit the immersion cooling rack **210** under a whirlpool shield **235** and out the outlet duct **158**. A cable management bar **232** may be provided, extending from one end of the immersion cooling rack **210** to the other, parallel to the weir **225**. The cable management bar **232** may be used to attach and/or hold up cables that need to run across the assembly or hold other equipment that needs to be stay out of the coolant fluid **50**.

The weir **225** provides a flow mechanism that may maintain a constant level of coolant fluid **50** in the component coolant tank **220**, which is upstream of the weir **225**. Maintaining a constant level of coolant fluid **50** avoids unintentionally exposing the computer components in the component coolant tank **220** to air, which could occur with variable coolant fluid **50** levels. In addition, the weir **225** may facilitate removal of the hottest coolant fluid **50** from the component coolant tank **220**, since the hottest coolant fluid **50** tends to collect toward the top of the volume of coolant fluid **50** due to the relative density of the hotter coolant fluid **50** as compared to the density of the cooler coolant fluid **50**. The area immediately downstream of the weir **225**, but upstream of the outlet duct **158** may act as a fluid collection zone. The volume of coolant fluid **50** held back by the weir **225** may occasionally run low due to imbalances across the multi-rack cooling system (e.g., **100**), but increasing the coolant fluid **50** flow may remedy such low coolant fluid **50** levels. Overflow of coolant fluid **50** over the weir **225** may be recirculated back to the coolant distribution unit **130**.

FIG. **3**B is a side schematic view of an immersion cooling rack **211** showing and exemplary coolant fluid flow, in accordance with various embodiments. The immersion cooling rack **211** includes the component coolant tank **220**, the buffer coolant tank **230**, and an adjustable weir **325**. When using a weir for level control of the immersion cooling rack **211** or multiple racks, the level of the fluid is set by the height of the adjustable weir **325**. As shown, the weir may adjust between an upper level and a lower level. The adjustable weir **325** may be a sliding plate structure that may be raised and lowered. The adjustable weir **325** may have at least two positions (e.g., upper level and lower level), may have one or more incremental positions there between, or may be variably adjustable to any position there between. A servo-mechanism (not shown) may be included that raises or lowers the adjustable weir **325** as needed. Alternatively, the adjustable weir **325** may be formed as a vertical plate that is configured to pivot from a pivot point at the lower level, thereby pivoting the uppermost part thereof down into the component coolant tank **220**.

The buffer coolant tank **230** may be formed as large as possible to allow the greatest variance. Constraints on the size of the buffer tank may be linked to an ideal product size, which is generally as small as possible to use the minimum floor space in valuable data center real estate. The immersion cooling racks **210** may be positioned back-to-back with inlets and outlet ducts **152**, **158** disposed in the same vertical plane.

Alternatively, the component coolant tank **220** may have more than one buffer tank on different sides thereof. Thus, one or more weirs **225** may be provided between the component coolant tank **220** and each of the sides having a buffer tank. As a further alternative embodiment, the component coolant tank **220** may be surrounded by buffer tanks, allowing overflow in any direction.

Although it may be advantageous to provide the inlet ducts **152** at the lowest portion of the immersion cooling rack **210**, design considerations may prevent such inlet ducts **152** position. For example, in instances in which the fittings, gaskets or components of the inlet ducts **152** fails, a low inlet port position could result in the draining of all or most of the coolant fluid **50** in the immersion cooling rack **210**. Thus, it may be advantageous to position the inlet ducts **152** as high as possible to reduce lost fluid in the event of a leak. There is a method of determining required fluid containment volume by regulation that the containment volume must catch the probable volume. It is far more likely that a fitting connection would leak than a sealed welded vessel. Thus, raising the inlet height may reduce the probable leak volume and hence the required infrastructure to catch leaks.

It may be advantageous to position the outlet duct **158** as low as possible to maximize variance volume. Variance volume may be defined by the difference in volume of fluid in the collection zone between max and min levels. The max fluid level in the collection zone may be considered almost to the edge of the weir **225**, the lowest when air enters the pump suction.

The whirlpool shield **235** may ensure only coolant fluid **50**, and not air, is suctioned through the outlet duct **158**. The intake or suctioning of air into the outlet duct **158** may damage a pump (not shown) that is used to circulate the coolant fluid **50**. The whirlpool shield **235** may be mounted inside the buffer coolant tank **230** above the outlet **158** for the coolant fluid **50** to exit the buffer coolant tank **230**. A first end of the whirlpool shield **235** may be attached to a side wall of the buffer coolant tank **230**. The whirlpool shield **235** may extend away from the first end toward a second end disposed further from the outlet duct than the first end. Also, the whirlpool shield **235** may extend downward at an angle (i.e., with a slope) such that the second end of the whirlpool shield **235** is vertically lower than the first end of the whirlpool shield **235**. Alternatively, the whirlpool shield **235** may be formed to have an L-shape, extending away from the outlet **158**, toward the central part of the buffer coolant tank **230**, and then bending downward at a remote end thereof. Including the whirlpool shield **235** may lower the minimum fluid level needed to be maintained in the buffer coolant tank **230** before air gets sucked into the outlet duct **158**. In addition, the whirlpool shield **235** may prevent air bubbles caused by coolant fluid **50** flowing over the weir **225** into the buffer coolant tank **230** from entering the outlet duct **158**. In other words, the whirlpool shield **235** may ensure only fluid is expelled from the bottom of the collection zone. Also, the whirlpool shield **235** may prevent whirlpool flows inside the buffer coolant tank **230**, particularly right next to the outlet duct **158**. For example, with the whirlpool shield **235** mounted immediately above a 2.5" diameter outlet duct aperture, the minimum fluid height may be lowered by inches, such as ½" from the bottom of the buffer coolant tank **230**. The fluid **50** in the buffer coolant tank **230** will be forced under the second end of the whirlpool shield **235**.

The buffer coolant tank **230** may also include one or more sensors, such as the fluid level sensor **237** (see FIG. **2**A), which may be used to detect when a level of the coolant fluid **50** is getting low. If the level of the coolant fluid **50** gets too low, the outlet duct **158** may start taking in air, which may not be desirable. The fluid level sensor **237** may be a float sensor that rises and falls with the level of coolant **50**. Additionally, a temperature sensor may be included, which may be mounted inside the buffer coolant tank as well, such as on a sensor bracket **238** (see FIG. **2**B).

FIG. **4** is a perspective view of an immersion cooling rack with side-walls removed to reveal an inner portion of a main coolant tank, in accordance with various embodiments. In particular, FIG. **4** illustrates how the immersion cooling rack **210** may include a component coolant tank **220** that includes a series of inlet ports **256** along a bottom of a sidewall of the component coolant tank **220**. Coolant fluid **50** flowing in the horizontally extending channel **254** will flow through the inlet ports **256** to fill the component coolant tank **220**, eventually flowing over the weir **225** once the coolant fluid **50** level gets high enough. The inlet ports **256** may include nozzles or jets (not shown). The nozzles or jets may be adjusted to direct the orientation of the coolant fluid **50** to flow over a particular location or direction within the component coolant tank **220**. For example, in instances where a computer component placed in the immersion cooling rack **210** is known to operate at a higher temperature, multiple inlet ports **256** may be adjusted to direct more coolant fluid **50** to flow over that hotter computer component. In other embodiments, the flow pressure from each inlet port **256** may be adjusted such that the coolant fluid **50** flow may be manipulated due to constructive and/or destructive wave interference of the coolant fluid **50** flow being directed through the inlet ports **256**. Additionally, or alternatively, one or more of the inlet ports **256** may be fully constricted (i.e., closed), forcing the coolant fluid **50** to flow through the other inlet ports **256** that remain open, which may increase the pressure of the coolant fluid **50** passing through those open inlet ports **256**.

In various embodiments, the immersion cooling rack **210** may include an outside panel **111** that is removable to provide access to electronic components, such as those mounted outside the component coolant tanks (e.g., see **215** in FIG. **1**B).

FIG. **5** is a perspective view of a front side of the immersion cooling rack **210** with upper components removed to better show the weir **225** used between the component buffer tank **220** and the buffer coolant tank, in accordance with various embodiments. As shown, the immersion cooling rack **210** may also include additional component supports **270** configured to hold additional electronic components **510**, which remain outside the coolant fluid **50** of either of the component coolant tank **220** and/or buffer coolant tank **230**.

FIGS. **6**A-**6**B are side cross-sectional views of adjacent pairs of electronic cooling racks with and without one-way valves, in accordance with various embodiments. FIG. **6**A illustrates a first pair of immersion cooling racks **210***a*, **210***b*, one with unregulated ducts two-way valves **152**, **158** and one with one-way valves **652**, **658**, such as check valves. In contrast, FIG. **6**B illustrates a second pair of immersion cooling racks **210***c*, **210***d* both with ducts **152**, **158**.

The one-way valves **652**, **658** may prevent coolant fluid **50** drainage from the immersion cooling racks **210***a*, **210***b*, particularly while being serviced. Including one-way valves **652**, **658** may enable the ability to service the immersion cooling racks without losing coolant fluid **50** or requiring the coolant fluid **50** to be pumped from immersion cooling racks **210***a*, **210***b* below the level of the inlet/outlet ducts (**152**, **158**) or valves (**652**, **658**), which may minimize downtown resulting from having to resupply lost coolant fluid **50** or re-balancing available coolant fluid **50** across all the immersion cooling racks **210***a*, **210***b*. In particular, by using check valves for injection ports, drainage may be prevented. If a leak occurs in piping outside the immersion cooling racks **210***a*, **210***b*, the amount of coolant fluid **50** that will drain may be decreased significantly. The first cross-hatched area A represents the amount of coolant fluid **50** that would be lost, across immersion cooling racks **210***a*, **210***b*, if one of the ducts or connection thereto leaked or was disconnected. In contrast, the second cross-hatched area B shows a far smaller amount of fluid lost in the event of a leak or disconnection. The benefit of the one-way valve is that it makes integrated containment within a small space achievable since spill containment capacity needs to support the most common spill event and most common spill capacity, which will be minimized by the installed check valve.

FIGS. **7**A-**7**C are right side perspective, front, and left side perspective views of an immersion cooling rack assembly with a video monitor. The immersion cooling rack assembly **110** may include an upper panel **111** and an outside panel configured to enclose and/or cover the immersion cooling rack **210**. The upper panel **111** may be configured to pivot from a closed position (see FIGS. **11**C) to an open position (see FIGS. **7**A-**7**C). In the open position, the upper panel **111** allows access to the main coolant tank **220**.

In accordance with various embodiments, the upper panel **111** may include a video monitor **710**. The video monitor **710** may be configured to provide a visual display of an operating status and/or conditions of the immersion cooling rack assembly. For example, the video monitor **710** may display readouts of conditions (e.g., fluid levels and/or temperatures) in the main coolant tank **220**. Additionally, or alternatively, the video monitor **710** may be coupled to the electronic components inside and/or outside the main coolant tanks, for displaying an operating status and/or conditions thereof. The video monitor **710** may be helpful to technicians charged with maintaining the immersion cooling rack assembly **110**, components therein, and/or the overall multi-rack cooling system **100**.

The multi-rack cooling system **100** may include a control unit with one or more processor, memory, and software for controlling the multi-rack cooling system **100** or parts thereof. The control unit may include redundant power sources and a programmable logic controller (PLC). When a preferred power supply for the PLC is lost, a secondary power supply may be activated and/or the PLC may perform a restart of the control unit. When the preferred power supply resumes functioning, the PLC may experience a seamless transition back to the preferred power supply.

The control unit may determine when to transition to a secondary coolant circulating system, such as due to higher than desired coolant temperatures or primary coolant circulating system failure or errors. The PLC may have the ability to determine if/when the secondary coolant circulating system is functioning properly and take action to bring the primary coolant circulating system back on-line, if there is an issue with the secondary coolant circulating system, thus ensuring that the best possible function for the coolant circulatory system is achieved.

The PLC may also have the ability to detect issues with the primary coolant circulating system and switch to the secondary coolant circulating system during normal operation. Issues with the primary pump, a variable frequency drive (VFD) or primary power supply can be detected by analyzing the data returned to the PLC from the VFD along with other sensor data from the CDU, when certain VFD errors, combinations of VFD errors, sensor data, combinations of sensor data or a combination of VFD errors and sensor data occurs the PLC can transition to the secondary coolant circulating system to ensure that the best possible function for the coolant circulatory system is achieved. The VFD may be a motor drive used to vary the frequency and/or voltage of power going to an AC motor for the purposes of changing speed and torque.

When the control unit determines, for any reason, that a high temperature threshold has been reached (e.g., a thermostat reaches a trigger temperature) or that a secondary coolant circulating system is activated by breaking and making contacts using a relay. While the relay may make a connection to turn on the secondary pump it also may break a connection to a water valve, which may cause the water valve to open fully. This way of activating the secondary coolant system may reliably resolve some error states involving the water valve control and water valve actuator in the water circulation system. In addition, these systems may provide cross control between the two circulating systems, coolant, and water, all by the control unit, which may ensure that, regardless of the situation, both circulatory systems are functioning under either the primary or secondary control unit at any given time.

In various embodiments, multi-rack cooling lighting and/or logo backlighting may be utilized to deliver flash codes, alerts, or warnings to technicians by controlling the power thereto through the PLC.

The control unit may have security and access monitoring devices integrated into both the immersion cooling rack assemblies and/or the central distribution unit (e.g., **130**). This may provide alerts regarding access, lock out tag out (LOTO), technician workflow tracking, security level access limitations, and limits customer/technician access to specific units in a collaborative environment, along with other capabilities yet to be specified.

The foregoing descriptions of systems, devices, and methods are provided merely as illustrative examples and are not intended to require or imply that the steps of the various embodiments must be performed in the order presented. As will be appreciated by one of skill in the art the order of steps in the foregoing embodiments may be performed in any order. Words such as "thereafter," "then," "next," etc. are not intended to limit the order of the steps; these words are used to guide the reader through the description of the methods. Further, any reference to claim elements in the singular, for example, using the articles "a," "an" or "the" is not to be construed as limiting the element to the singular.

The preceding description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the invention. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the following claims and the principles and novel features disclosed herein.

What is claimed is:

1. A system for controlling temperature measured in multiple immersion cooling racks, comprising:
- a coolant distribution unit configured to adjust a temperature and pump a coolant fluid;
- a coolant manifold unit housing a coolant manifold for redistributing the coolant fluid;
- a supply line coupled to the coolant distribution unit and the coolant manifold, wherein the supply line is configured to convey the coolant fluid from the coolant distribution unit to the coolant manifold;
- a return line coupled to the coolant distribution unit and the coolant manifold, wherein the return line is configured to convey the coolant fluid from the coolant manifold to the coolant distribution unit;
- a first pair of immersion cooling racks interposed between the coolant distribution unit and the coolant manifold unit, wherein each immersion cooling rack of the first pair of immersion cooling racks is coupled to the coolant manifold through a first inlet duct for receiving the coolant fluid from the coolant manifold and a first outlet duct for returning the coolant fluid to the coolant manifold; and
- a second pair of immersion cooling racks disposed on an opposite side of the coolant manifold unit relative to the first pair of immersion cooling racks such that the coolant manifold unit is interposed between the first pair of immersion cooling racks and the second pair of immersion cooling racks, wherein each immersion cooling rack of the second pair of immersion cooling racks is coupled to the coolant manifold through a second inlet duct for receiving the coolant fluid from the coolant manifold and a second outlet duct for returning the coolant fluid to the coolant manifold.

2. The system of claim **1**, wherein at least one of the first inlet duct or the first outlet duct in each immersion cooling rack is an adjustable valve configured to selectively restrict coolant fluid flow between the coolant manifold and the respective immersion cooling rack.

3. The system of claim **2**, wherein each of the first pair of immersion cooling racks includes a thermal switch that is triggered when a temperature of the coolant fluid drops below a threshold temperature, wherein the triggering of the thermal switch restricts fluid flow through the adjustable valve.

4. The system of claim **1**, wherein at least one of the first inlet duct or the first outlet duct in each immersion cooling rack is a one-way valve.

5. The system of claim **1**, further comprising a plurality of inlet ports located in each of the first pair of immersion cooling racks, wherein the plurality of inlet ports are adjustable to control an orientation of a flow of coolant fluid through each respective immersion cooling rack.

6. The system of claim **5**, wherein each of the plurality of inlet ports comprises an adjustable nozzle or jet to control the orientation of the flow of coolant fluid through each respective immersion cooling rack.

7. The system of claim **5**, wherein each of the plurality of inlet ports comprises an adjustable coolant fluid valve to control the flow pressure of coolant fluid passing through the respective inlet port, wherein flow pressure controlled by the adjustable coolant fluid valve may constructively or destructively interfere with coolant fluid flow through adjacent inlet ports to control the orientation of the flow of coolant fluid through each respective immersion cooling rack.

8. The system of claim **1**, wherein each of the first pair of immersion cooling racks comprises:

a component coolant tank configured to hold at least one electronic component at least partially submerged in a coolant fluid pumped into the component coolant tank;

a buffer coolant tank; and

a weir extending along an upper edge of a barrier separating the component coolant tank from the buffer coolant tank, wherein the weir is configured to allow excess coolant fluid from the component coolant tank to spill out of the component coolant tank, over the weir, and into the buffer coolant tank.

9. The system of claim **8**, wherein the coolant fluid is pumped into the component coolant tank from inlet ports along a bottom of a sidewall of the component coolant tank.

10. The system of claim **8**, further comprising:

a whirlpool shield mounted inside the buffer coolant tank above an outlet port for the coolant fluid to exit the buffer coolant tank, wherein a first end of the whirlpool shield is attached to a side wall of the buffer coolant tank and the whirlpool shield extends away from the first end toward a second end disposed further from the outlet port than the first end.

11. The system of claim **10**, wherein the whirlpool shield extends downward at an angle such that the second end of the whirlpool shield is vertically lower than the first end of the whirlpool shield.

12. The system of claim **1**, wherein at least one set of the first and second inlet ducts and the first and second outlet ducts are interposed between the first pair of immersion cooling racks and the second pair of immersion cooling racks.

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