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BASE STATION ANTENNAS HAVING AN EXTERNAL ACCESS PORT FOR RECEIVING INTERCHANGEABLE FREQUENCY SELECTIVE SURFACES**RELATED APPLICATIONS**

[0001] This patent application claims the benefit of and priority to U.S. Provisional Application Serial Number 63/480,039 filed January 16, 2023, the contents of which are hereby incorporated by reference as if recited in full herein.

BACKGROUND

[0002] The present invention generally relates to radio communications and, more particularly, to base station antennas for cellular communications systems.

[0003] Cellular communications systems are well known in the art. In a cellular communications system, a geographic area is divided into a series of regions that are referred to as "cells" which are served by respective base stations. The base station may include one or more antennas that are configured to provide two-way radio frequency ("RF") communications with mobile subscribers that are within the cell served by the base station. In many cases, each cell is divided into "sectors." In one common configuration, a hexagonally shaped cell is divided into three 120° sectors in the azimuth plane, and each sector is served by one or more base station antennas that have an azimuth Half Power Beamwidth (HPBW) of approximately 65°. Typically, the base station antennas are mounted on a tower or other raised structure, with the radiation patterns (also referred to herein as "antenna beams") that are generated by the base station antennas directed outwardly. Base station antennas are often implemented as linear or planar phased arrays of radiating elements.

[0004] In order to accommodate the increasing volume of cellular communications, cellular operators have added cellular service in a variety of new frequency bands. In order to increase capacity without further increasing the number of base station antennas, multi-band base station antennas have been introduced which include multiple linear arrays of radiating elements. Additionally, base station antennas are now being deployed that include "beamforming" arrays of radiating elements that include multiple columns of radiating elements. The radios for these beamforming arrays may be integrated into the antenna so that the antenna may perform active beamforming (i.e., the shapes of the antenna beams generated by the antenna may be adaptively changed to improve the performance of the antenna). These beamforming arrays typically operate in higher frequency bands, such as various portions of the 3.3-5.8 GHz frequency band. Antennas having integrated radios that can adjust the

amplitude and/or phase of the sub-components of an RF signal that are transmitted through individual radiating elements or small groups thereof are referred to as "active antennas." Active antennas can generate narrowed beamwidth, high gain, antenna beams and can steer the generated antenna beams in different directions by changing the amplitudes and/or phases of the sub-components of RF signals that are transmitted through the antenna.

[0005] With the development of wireless communication technology, an integrated base station antenna including a passive module and an active antenna module with an active antenna has emerged. The passive module may include one or more passive arrays of radiating elements that are configured to generate relatively static antenna beams, such as antenna beams that are configured to cover a 120 degree sector (in the azimuth plane) of a base station antenna. The passive arrays may comprise arrays that operate under second generation (2G), third generation (3G) or fourth generation (4G) cellular standards. These passive arrays are not configured to perform active beamforming operations, although they typically have remote electronic tilt (RET) capabilities which allows the shape of the antenna beam to be changed via electromechanical means in order to change the coverage area of the antenna beam. The active antenna module may include one or more arrays of radiating elements that operate under fifth generation (or later) cellular standards. These arrays typically have individual amplitude and phase control over subsets of the radiating elements therein and perform active beamforming.

[0006] **FIG. 1** illustrates an example of a prior art base station antenna **10** that includes a pair of beamforming arrays and associated beamforming radios. The base station antenna **10** is typically mounted with the longitudinal axis **L** of the antenna **10** extending along a vertical axis (e.g., the longitudinal axis **L** may be generally perpendicular to a plane defined by the horizon) when the antenna **10** is mounted for normal operation. The front surface of the antenna **10** is mounted opposite the tower or other mounting structure, pointing toward the coverage area for the antenna **10**. The antenna **10** includes a radome **11** and a top end cap **20**. The antenna **10** also includes a bottom end cap **30** which includes a plurality of connectors **40** mounted therein. As shown, the radome **11**, top cap **20** and bottom cap **30** define an external housing **10h** for the antenna **10**. An antenna assembly is contained within the housing **10h**.

[0007] The antenna **10** can include one or more radios that are mounted to the rear of the housing **10h**. Heat generated in the radio(s) typically passes to a heat sink and spreads to the fins thereof (not shown). Further details of example conventional base station antennas can be found in WO2019/236203 and WO2020/072880, the contents of which are hereby incorporated by reference as if recited in full herein.

SUMMARY

[0008] Embodiments of the present invention are directed to base station antennas with at least one external access port configured to slidably receive a frequency selective surface (FSS) that is configured to allow (high band) radiating elements to propagate electromagnetic waves therethrough and reflect (lower band signal from lower band) radiating elements in front of the FSS.

[0009] The base station antenna can be configured to slidably, serially interchangeably hold different FSS', each having different unit cell configurations or different arrays of unit cell configurations for reflecting, absorbing and/or propagating electromagnetic waves in different target frequency bands.

[00010] The at least one access port can extend about at least 50% of a width of and at a top of the base station antenna.

[00011] The at least one access port can extend about at least 50% of a width of a bottom of the base station antenna.

[00012] The at least one access port can extend a sub-length of and about a side of the base station antenna.

[00013] A cover can reside over the at least one access port.

[00014] The base station antenna can include a passive module and/or a passive antenna assembly and an active antenna module. The active antenna module can be installed at a position corresponding to the frequency selective surface.

[00015] According to embodiments of the present disclosure, the frequency selective surface can be provided as first and second frequency selective surfaces, stacked one in front of the other, and can be configured to allow electromagnetic waves emitted by the active module to pass.

[00016] Embodiments of the present disclosure are directed to a base station antenna that includes: a housing; an external access port provided by the housing; and a frequency selective surface (FSS) configured to be slidably insertable into the external access port.

[00017] The base station antenna can further include a cover that extends over the external access port.

[00018] The external access port can extend laterally across a top of the housing.

[00019] The external access port can extend longitudinally along a sub-length of the base station antenna.

[00020] The external access port can extend laterally across a bottom of the base station antenna.

[00021] The FSS can have a length dimension and a width dimension. The external access port can have a width that is greater than the width dimension or a length that is greater than the length dimension.

[00022] The external access port can be a first external access port and the base station antenna can further include a second external access port that is spaced apart from the first external access port.

[00023] The first and second external access ports can be parallel to each other.

[00024] The base station antenna can have internal mounting structures that releasably couple to the FSS.

[00025] The internal mounting structures can each include a longitudinally extending slot that slidably receives outer edge portions of the FSS.

[00026] The base station antenna can further include a stop feature integral to or coupled to the mounting structures that is configured to prevent the FSS from advancing further into the housing.

[00027] The FSS can be a first FSS with a first configuration of unit cells and the base station antenna can be configured to interchangeably and serially receive a second FSS with a second configuration of unit cells to thereby be used in place of the first FSS.

[00028] The FSS can be a first FSS and the base station antenna can further include a second FSS in front of the first FSS.

[00029] The second FSS can be a sheet metal grid reflector.

[00030] The base station antenna can further include an active antenna unit with a radio behind the housing.

[00031] The second FSS can be stacked in front of the first FSS in a Z direction.

[00032] The base station antenna can further include a first plurality of radiating elements residing in front of the FSS and a second plurality of radiating elements residing behind the FSS.

[00033] The first plurality of radiating elements can operate in a first frequency band and the second plurality of radiating elements can operate in a second frequency band.

[00034] The first plurality of radiating elements can include low band radiating elements that are configured to operate in a first frequency band and the second plurality of radiating elements can include higher band radiating elements that are configured to operate in a second frequency band, the second frequency band encompassing higher frequencies than the first frequency band.

[00035] The first FSS and the second FSS can be configured to allow RF energy in a defined frequency band to propagate therethrough.

[00036] The FSS can have a first subset of the array of unit cells configured for blocking and/or reflecting RF energy in a first frequency band while allowing RF energy in a second frequency band to propagate therethrough and the FSS can have a second subset of the array of unit cells configured for blocking and/or reflecting RF energy in the first frequency band and RF energy in a third frequency band, the third frequency band includes frequencies between the first and second frequency bands.

[00037] The first subset of the array of unit cells can be positioned at an upper portion of the base station antenna and the second subset of the array of unit cells can have unit cells that are to the right side of the first subset of the unit cells and also unit cells that are to the left side of the first subset of the unit cells.

[00038] The first plurality of radiating elements can include high band radiating elements that operate in at least part of a 3.2-4.1 GHz frequency band, and wherein the second plurality of radiating elements can include radiating elements that operate in at least part of a lower frequency band than the high band radiating elements.

[00039] The first FSS and the second FSS can be configured to allow RF energy in at least part of a 3.2-4.1 GHz frequency band to propagate therethrough.

[00040] The second plurality of radiating elements can be provided as a multiple column array in an active antenna module.

[00041] It should be noted that various aspects of the present disclosure described for one embodiment may be included in other different embodiments, even though specific description is not made for the other different embodiments. In other words, all the embodiments and/or features of any embodiment may be combined in any manner and/or combination, as long as they are not contradictory to each other.

BRIEF DESCRIPTION OF THE DRAWINGS

[00042] **FIG. 1** is a perspective view of a prior art base station antenna.

[00043] **FIG. 2A** is a back perspective view of an example base station antenna coupled to an active antenna module according to embodiments of the present invention.

[00044] **FIG. 2B** is a side, back perspective view of another example base station antenna coupled to an active antenna module according to embodiments of the present invention.

[00045] FIG. 3 is a perspective view of an example primary reflector that can be provided in a base station antenna, such as the base station antenna shown in FIG. 2A or FIG. 2B, according to embodiments of the present invention.

[00046] FIG. 4A is a perspective view of a grid reflector coupled to a portion of a primary reflector of a base station antenna according to embodiments of the present invention.

[00047] FIG. 4B is a front view of the grid reflector and portion of the primary reflector shown in FIG. 4A.

[00048] FIG. 5 is a side perspective view of an example base station antenna according to embodiments of the present invention.

[00049] FIG. 6 is an enlarged side perspective view of a top portion of the base station antenna shown in FIG. 5.

[00050] FIG. 7 is an enlarged exploded view of the top portion of the base station antenna shown in FIG. 6.

[00051] FIG. 8 is an enlarged side perspective view of the top end cap of the base station antenna shown in FIG. 7.

[00052] FIG. 9A is a side perspective view of a portion of internal components of the base station antenna shown in FIG. 5 according to embodiments of the present invention.

[00053] FIG. 9B is a schematic front view of a second FSS that is interchangeably held by the base station antenna in place of the first FSS shown in FIG. 9A according to embodiments of the present invention.

[00054] FIG. 10A is a side perspective view of internal rails and the FSS shown in FIG. 9A according to embodiments of the present invention.

[00055] FIG. 10B is an enlarged side perspective view of a portion of one internal rail and corner of the FSS shown in FIG. 10A according to embodiments of the present invention.

[00056] FIG. 11 is a top view of the rails and FSS shown in FIG. 10A.

[00057] FIG. 12 is a side perspective view of another embodiment of a portion of internal components of the base station antenna shown in FIG. 5 according to embodiments of the present invention.

[00058] FIG. 13A is a side perspective view of internal rails and the FSS shown in FIG. 12 according to embodiments of the present invention.

[00059] FIG. 13B is an enlarged side perspective view of a portion of one internal rail and corner of the FSS shown in FIG. 13A according to embodiments of the present invention.

[00060] FIG. 14 is an end view of the rails and FSS shown in FIG. 13A.

[00061] **FIG. 15** is a side perspective view of a portion of internal components of the base station antenna shown in **FIG. 5** according to embodiments of the present invention.

[00062] **FIG. 16A** is a side perspective view of internal rails and the FSS shown in **FIG. 15** according to embodiments of the present invention.

[00063] **FIG. 16B** is an enlarged side perspective view of a portion of one internal rail and corner of the FSS shown in **FIG. 16A** according to embodiments of the present invention.

[00064] **FIG. 17** is an end view of the rails and FSS shown in **FIG. 16A**.

[00065] **FIG. 18** is a side perspective view of another embodiment of a base station antenna according to embodiments of the present invention.

[00066] **FIG. 19** is an enlarged side perspective view of a top portion of the base station antenna shown in **FIG. 18**.

[00067] **FIG. 20** is an exploded view of the top portion of the base station antenna shown in **FIG. 19**.

[00068] **FIG. 21A** is a side perspective view of another embodiment of a base station antenna with a sidewall with the external access port according to embodiments of the present invention.

[00069] **FIG. 21B** is an enlarged side perspective view of a top portion of the base station antenna shown in **FIG. 21A**.

[00070] **FIG. 22** is a schematic illustration of an example internal rail aligned with the sidewall access port and that slidably receives the FSS of **FIG. 23**.

[00071] **FIG. 23** is an exploded view of the top portion of the base station antenna shown in **FIG. 19**.

[00072] **FIG. 24** is a side perspective view of another embodiment of a base station antenna according to embodiments of the present invention.

[00073] **FIG. 25** is an enlarged side perspective view of a top portion of the base station antenna shown in **FIG. 24**.

[00074] **FIG. 26** is an exploded view of the top portion of the base station antenna shown in **FIG. 25**.

[00075] **FIG. 27** is a bottom, side perspective view of another embodiment of a base station antenna according to embodiments of the present invention.

[00076] **FIG. 28** is an enlarged side perspective view of a bottom portion of the base station antenna shown in **FIG. 27**.

[00077] **FIG. 29** is an exploded view of components at the bottom portion of the base station antenna shown in **FIG. 28**.

[00078] **FIGS. 30 and 31** are front views of additional embodiments of FSS' according to embodiments of the present invention.

[00079] **FIG. 32A** is a front, side perspective view of an antenna assembly and example FSS reflector of a base station antenna according to embodiments of the present invention.

[00080] **FIG. 32B** is an enlarged front, side perspective view of a top portion of the antenna assembly and grid reflector shown in **FIG. 32A**.

[00081] **FIGS. 33A and 33B** are simplified lateral section views of example base station antennas and cooperating active antenna modules according to embodiments of the present invention.

DETAILED DESCRIPTION

[00082] **FIG. 2A** illustrates a base station antenna **100** according to certain embodiments of the present invention. In the description that follows, the base station antenna **100** will be described using terms that assume that the base station antenna **100** is mounted for use on a tower, pole or other mounting structure with the longitudinal axis **L** of the base station antenna **100** extending along a vertical axis and the front of the base station antenna **100** mounted opposite the tower, pole or other mounting structure pointing toward the target coverage area for the base station antenna **100** and the rear **100r** of the base station antenna **100** facing the tower or other mounting structure. It will be appreciated that the base station antenna **100** may not always be mounted so that the longitudinal axis **L** thereof extends along a vertical axis. For example, the base station antenna **100** may be tilted slightly (e.g., less than 10°) with respect to the vertical axis so that the resultant antenna beams formed by the base station antenna **100** each have a small mechanical downtilt.

[00083] The base station antenna **100** can couple to or include at least one active antenna module **110**. The term "active antenna module" is used interchangeably with "active antenna unit" and "AAU" and "active antenna" and refers to a cellular communications unit comprising radio circuitry and associated radiating elements. The radio circuitry is capable of electronically adjusting the amplitude and/or phase of the subcomponents of an RF signal that are output to different radiating elements of an array or groups thereof. The active antenna module **110** comprises the radio circuitry and the radiating elements (e.g., a multi-input-multi-output (mMIMO) beamforming antenna array) and may include other components such as filters, a calibration network, an antenna interface signal group (AISG) controller and the like. The active antenna module **110** can be provided as a single integrated unit or provided as a plurality of stackable units, including, for example, first and second sub-units such as a radio

sub-unit (box) with the radio circuitry and an antenna sub-unit (box) with a multi-column array of radiating elements and the first and second sub-units stackably attach together in a front to back direction of the base station antenna **100**, with the radiating elements **1195** of an antenna assembly **1190** (**FIGS. 33A, 33B**) closer to the front radome **111f** of the housing **100h**/radome **111** of the base station antenna **100** than the radio circuitry unit **1120**. In some embodiments, the radiating elements **1195** may comprise a separate sub-unit from the radio circuitry and the radiating element sub-unit may be mounted within the base station antenna **100** instead of being external to the base station antenna **100**.

[00084] As will be discussed further below, the base station antenna **100** includes an antenna assembly **190**, which can be referred to as a “passive antenna assembly”. The term “passive antenna assembly” refers to an antenna assembly having arrays of radiating elements that are coupled to radios that are external to the antenna, typically remote radio heads that are mounted in close proximity to the base station antenna **100**. The arrays of radiating elements included in the passive antenna assembly **190** (**FIG. 32A**) are configured to form static antenna beams (e.g., antenna beams that are each configured to cover a sector of a base station). The passive antenna assembly **190** can comprise a reflector **170, 214** with radiating elements projecting in front of the reflector and the radiating elements can include one or more linear arrays of low band radiating elements that operate in all or part of the 617-960 MHz frequency band and/or one or more linear arrays of mid-band radiating elements that operate in all or part of the 1427-2690 MHz frequency band. The passive antenna assembly **190** is mounted in the housing **100h** of base station antenna **100** and one or more active antenna modules **110** can releasably (detachably) couple (e.g., directly or indirectly attach) to base station antenna **100**.

[00085] The base station antenna **100** has a housing **100h**. The housing **100h** may be substantially rectangular with a flat rectangular cross-section. The housing **100h** may be provided to define at least part of a radome **111** with at least the front side **111f** configured as a dielectric cover that allows RF energy to pass through in certain frequency bands. The housing **100h** may also be configured to that the rear **100r** defines a rear side **111r** radome opposite the front side radome **111f**. Optionally, the housing **100h** and/or the radome **111** can also comprise two (narrow) sidewalls **100s, 111s** facing each other and extending rearwardly between the front side **111f** and the rear side **111r**. Typically, the top **100t** of the housing **100h** may be sealed in a waterproof manner and may comprise an end cap **120** and the bottom **100b** of the housing **100h** may be sealed with a separate end cap **130**. The front **111f**, the sidewalls **111s** and typically at least part of the rear side **111r** of the radome **111** are substantially transparent to radio frequency (RF) energy within the operating frequency bands of the base

station antenna **100** and active antenna module **110**. The radome **111** may be formed of, for example, fiberglass or plastic.

[00086] The base station antenna **100** can comprise at least one external access port **150** configured to slidably receive a frequency selective surface (“FSS”) **170** (FIG. 7, for example).

[00087] Still referring to FIG. 2A, in some embodiments, an active antenna module **110** can reside behind, and may optionally attach to, the base station antenna **100**. The base station antenna **100** can comprise a frame **112** and accessory mounting brackets **113**, **114**. The rear **111r** of the housing **100h** may be a flat surface extending along a common plane over an entire longitudinal extent thereof or along at least a portion of the longitudinal extent thereof.

[00088] FIG. 2B illustrates that the rear surface **100r** can comprise a recessed and/or stepped segment **102** facing the active antenna module **110**. The stepped segment **102** resides closer to a front **100f** of the housing than the back wall that is defined by a primary segment of the rear **100r** of the housing **100h**. The stepped segment **102** can have a lateral and longitudinal extent that is the same or greater than a lateral and longitudinal extent of the active antenna module **110**. The rear surface **100r** can also comprise a pair of spaced apart longitudinally extending rails **118** that engage an adapter mounting bracket **1118** on the active antenna module **110** to attach the active antenna module **110** to the base station antenna housing **100h**. However, other mounting configurations may be used.

[00089] Referring again to FIG. 2A, in another embodiment, the rear surface **100r** can comprise a plurality of longitudinally spaced apart mounting structure brackets, shown as upper, medial, and lower brackets, **115**, **116**, **117**, respectively, that extend rearwardly from the housing **100h**. In some embodiments, the mounting structure brackets **115**, **116**, **117** may be configured to couple to one or more mounting structures such as, for example, a tower, pole or building (not shown). At least two of the mounting structure brackets **115**, **116** can also be configured to attach to the frame **112** of the base station antenna arrangement, where used. The frame **112** may extend over a sub-length of a longitudinal extent L of base station antenna **100**, where the sub-length is shown in FIG. 2A as being at least a major portion thereof (at least 50% of a length thereof). The frame **112** can comprise a top **112t**, a bottom **112b** and two opposing long sides **112s** that extend between the top **112t** and the bottom **112b**. The frame **112** can have an open center space **112c** extending laterally between the sides **112s** and longitudinally between the top **112t** and bottom **112b**.

[00090] The frame **112**, where used, may be configured so that a variety of different active antenna modules **110** can be mounted to the frame **112** using appropriate accessory mounting brackets **113**, **114**. As such, a variety of active antenna modules **110** may be

interchangeably attached to the same base station antenna **100**. While the frame **112** is shown by way of example, other mounting systems may be used.

[00091] In some embodiments, a plurality of active antenna modules **110** may be concurrently attached to the same base station antenna **100** at different longitudinal locations using one or more frames **112**. Such active antenna modules **110** may have different dimensions, for example, different lengths and/or different widths and/or different thicknesses.

[00092] Turning now to **FIG. 3**, an example primary reflector **214** for a base station antenna **100** is shown. As shown, the primary reflector **214** has a first section **214₁** that extends a first longitudinal distance and that merges into a second section **214₂** with spaced apart right and left side segments **214_s** having a lateral extent d_2 that is less than a lateral extent d_1 of the first section **214₁**. An open medial region **14** can extend longitudinally and laterally about the second section **214₂**. The open medial region **14** can have a lateral extent d_3 that is 60-95% of the lateral extent d_1 , in some embodiments. The first section **214₁** can have a longitudinal extent that is greater than the second section **214₂**, typically at least 20% greater, such as 30%-80% greater, in some embodiments.

[00093] **FIGs. 4A** and **4B** illustrate an example FSS **170**. In some embodiments, the FSS **170** can be fixed in position and can extend part of or a full lateral extent of the base station antenna **100** and at least a part of a length of the base station antenna **100**.

[00094] In some embodiments, the FSS **170** can be slidably inserted into the external access port **150** (**FIG. 7**) and into position in the base station antenna **100**, which can allow for field installation, changeout and/or retrofit of a target FSS **170**.

[00095] In some embodiments, the FSS **170** can be electrically and/or mechanically coupled to the primary reflector **214**. In some embodiments, the FSS **170** can be provided as a metal grid reflector **170_g** that can be coplanar with or parallel to the primary reflector **214** and that can be positioned to reside between the right and left sides **214_s** of the primary reflector in the open medial region **14** (**FIG. 3**).

[00096] The FSS **170** can be provided as a non-metallic substrate(s) with metal/metallized patches arranged to define an array **171** of unit cells **171_u** (the “unit cells” can also be interchangeably referred to as “pattern units”) or can be a metal grid **171_g** providing the array **171** of unit cells **171_u**.

[00097] The non-metallic substrate can be provided as a multiple-layer printed circuit board (PCB) which can be rigid, semi-rigid or provided as a flex circuit. The non-metallic

substrate can be a plastic, polymer, co-polymer with a metallized surface(s) providing conductive patches.

[00098] The FSS **170** can be defined by a PCB, such as a PCB having a thickness in a range of about 5 mils to about 30 mils, such as about 5 mil, about 15 mil or about 30 mil.

[00099] The grid reflector FSS **170g** can be provided as a sheet of metal, such as aluminum, with the grid shaped to form the pattern units/unit cells **171u**, e.g., the array **171** of unit cells **171u** can be etched, punched or laser formed through the sheet metal or otherwise formed.

[000100] The FSS **170** provides a frequency selective surface and/or substrate that is configured to allow RF energy (electromagnetic waves) to pass through at one or more first defined frequency range and that is configured to reflect RF energy at a different second frequency band. The FSS **170** of the base station antenna **100**, can reside behind at least some antenna elements (see radiating elements **222**, **FIGS. 9A, 32B**) and can selectively reject some frequency bands and permit other frequency bands to pass therethrough by including the frequency selective surface and/or substrate to operate as a type of “spatial filter”. *See, e.g.,* Ben A. Munk, Frequency Selective Surfaces: Theory and Design, ISBN: 978-0-471-37047-5; DOI:10.1002/0471723770; April 2000, Copyright © 2000 John Wiley & Sons, Inc. the contents of which are hereby incorporated by reference as if recited in full herein.

[000101] The FSS **170** can comprise one or more of a metamaterial, a suitable RF material or even air (although air may require a more complex assembly). The term “metamaterial” refers to composite electromagnetic (EM) materials. Metamaterials may comprise sub-wavelength periodic microstructures.

[000102] The FSS **170** can be provided as one or more FSS structures **170₁, 170₂** (**FIGS. 14, 17**), stacked in a front to back direction of the base station antenna **100**, each having the same or different materials and/or one or more arrays **171** of unit cells **171u** with the same or different unit cell configurations.

[000103] The FSS **170** can include a dielectric substrate that has a dielectric constant in a range of about 2-4, such as about 3.7 and with metal patterns formed on the dielectric substrate. The thickness can vary but thinner materials can provide lower loss.

[000104] In some embodiments, the FSS **170** can be configured to act like a High Pass Filter essentially allowing low band energy to completely reflect (the FSS can act like a sheet of metal) while allowing higher band energy, for example, about 3.5 GHz or greater, to completely pass through. Thus, the frequency selective substrate/surface is transparent or invisible to the higher band energy and a suitable out of band rejection response from the FSS

can be achieved. The FSS **170** may allow a reduction in filters or even eliminate filter requirements for looking back into the radio **1120** (**FIGs. 33A, 33B**).

[000105] In some embodiments, the FSS **170**, for example, may be implemented using a single FSS or two or more closely spaced apart FSS layers **170₁, 170₂** stacked in a Z direction, either one or both of which can be provided as a multi-layer printed circuit board, with the different layers providing a respective frequency selective surface configured such that electromagnetic waves within a predetermined frequency range cannot propagate through the FSS layers **170₁, 170₂**, and one or more other predetermined frequency range is allowed to pass therethrough. Thus, the stacked FSS layers **170₁, 170₂** can be spaced apart in the Z direction and can cooperate to provide at least one rejection band and a (wider) pass band.

[000106] Referring to **FIGS. 4A and 4B**, an FSS **170** according to embodiments of the present disclosure is shown. The FSS **170** can be used in the base station antenna **10** shown in **FIGs. 2A, 2B**, for example. The FSS **170** can be provided as a grid reflector **170g** with a main body **21** and a frequency selective section **22** provided in the main body **21**. At least the main body **21** and/or the primary reflector **214** may be metallic (e.g., formed of aluminum). The frequency selective section **22** may be provided at a position corresponding to the installation position of the active antenna module **110** of the base station antenna **100** and may be configured to allow electromagnetic waves within a predetermined frequency range (for example, high-frequency electromagnetic waves within the range of 2300 to 5000 MHz or a portion thereof, e.g., electromagnetic wave in a 2900-4000 MHz range or 3400-5000 MHz range) to pass. In this way, when the base station antenna **100** is assembled, the high-frequency electromagnetic waves emitted by the active antenna module **110** can pass through the frequency selective reflector **20** via the frequency selective section **22**.

[000107] The FSS **170** may be composed of an array **171** of a plurality of pattern units or unit cells **171u** that are periodically arranged in the transverse and longitudinal directions of the base station antenna. The resonance frequency of the frequency selective section **22** may be configured by selecting or designing the pattern and size of the capacitor structure and the inductor structure of each pattern unit/unit cell **171**, as well as the spacing and arrangement of a plurality of pattern units **171** such that the electromagnetic waves within a predetermined frequency range can pass through the frequency selective section **22**.

[000108] Referring to **FIGS. 5-8**, in some embodiments, the base station antenna **100** can have an external access port **150** on a top portion **100t** of the base station antenna **100**. The external access port **150** can extend in a width dimension/direction “Wb” of the base station antenna **100** and may extend across at least 50% of a width dimension Wb of the base station

antenna **100**, more typically the external access port **150** has a width W_p that extends across 80-95% of the width dimension W_b of the base station antenna. The external access port **150** can have a height dimension “h” that is small relative to the width dimension W_p , typically at least 10 times smaller than the width dimension W_p . The height dimension h corresponds to a Z direction, the width dimensions correspond to an X direction and the longitudinal direction of the base station antenna corresponds to the Y direction. The width dimension W_p can be slightly larger (10% -20% greater) than the width of the FSS **170**.

[000109] The external access port **150** can be formed in the top end cap **120** as shown. A cover **1150** can be positioned over the external access port **150**. The cover **1150** can be configured to pivot to open and close or can be removed to allow access to the external access port **150**. The cover **1150** can sealably engage the end cap **120**. A seal member **1155**, such as an O-ring or gasket, can be positioned about the external access port **150** and the cover **1150** can couple to the end cap **120** and compress against the seal member **1155**. As shown, a plurality of fixation members **1160** can be used to attach the cover **1150** to the end cap **120** over the access port **150**. The fixation members **1160** can be provided as fasteners such as screws, pins, snaps or other suitable components. In some embodiments, the cover **1150** can be configured to frictionally engage the end cap **120** without requiring the fixation members (not shown).

[000110] An end portion **170e** of the FSS **170** can be configured to reside outside the external access port **150** as shown in FIG. 7. The cover **1150** can be configured with an internal chamber **1151** that projects outward and encloses and slidably receives the end portion **170e** of the FSS **170**. The chamber **1151** can be rectangular.

[000111] The exposed end portion **170e** can allow a user to grip the FSS **170** to insert or remove the FSS from the base station antenna **100**.

[000112] In other embodiments, the FSS **170** can be totally enclosed inside the base station antenna and/or external access port **150** and be configured to allow for field installation/replacement. For example, the FSS **170** can be held in the base station antenna **100** and be configured to cooperate with an internal spring-loaded mechanism to have a “push to open” configuration. A user can push the FSS **170** inward and the spring-loaded mechanism can then push the FSS **170** outward in response, to expose the end portion **170e** for release.

[000113] The base station antenna **100** can include internal mounting and guide features that hold and help align the FSS **170** in proper position in the base station antenna **100**.

[000114] Referring to FIGS. 9A, 10A, 10B and 11, the base station antenna **100** can include longitudinally extending (left and right side) mounting structures **1250** with

longitudinally extending slots **1255** that slidably receive the FSS **170**. The mounting structures **1250** can comprise rails **1250r** that slidably receive the FSS **170**.

[000115] A stop feature **1265** can be provided to define a hard stop for proper positioning of the FSS **170**. The stop feature **1265** can be clipped into the slot **1255** or formed into at least one of the mounting structures **1250**. The mounting structures **1250** can be couple to the primary reflector **214**. The slots **1255** can terminate above the primary reflector **214**. Lateral struts **1260** can be coupled to the mounting structures **1250** and can project forwardly of the mounting structures **1250**.

[000116] The mounting structures **1250** can be provided by a closed metal surface or by a metal grid or otherwise configured to provide an isolation surface/wall or an FSS, e.g., metal, metallized, or provided as a frequency selective surface/substrate.

[000117] FIG. 9A illustrates the base station antenna **100** can have a single FSS **170** which can be field installable and/or replaceable with a different FSS **170**.

[000118] FIG. 9A also shows that feed boards **1200** can be provided for the radiating elements **222** and the feed boards **1200** and radiating elements **222** can reside in front of the FSS **170**.

[000119] FIG. 9A illustrates that a first FSS **170a** can be held by the base station antenna **100** and FIG. 9B illustrates a second FSS **170b** that can have a common footprint (about the same width, length and thickness) as the first FSS **170a** but with a different unit cell **171u** configuration for interchangeable replacement of the first FSS **170a** in the base station antenna **100**.

[000120] One of the first and second FSS' **170a**, **170b** can be factory installed and the other can be used to replace the factory installed FSS depending on operational requirements in the field. For example, the first FSS **170a** can be provided in the base station antenna **100** as a "default" configuration that may correspond to a radio, such as a 3.5GHz 5G band (working band of radiating elements provided by an active antenna unit). The second FSS **170b** can be configured to replace the first FSS **170a** to change the working band.

[000121] In other embodiments, the base station antenna **100** can be provided without any FSS **170** and a user can insert a desired one of the first and second FSS' **170a**, **170b** in the field depending on operational requirements, e.g., 2.6 GHz, 3.5 GHz, 3.8 GHz or 4.5 GHz, by way of example. While the drawings show two alternative FSS members **170a**, **170b**, additional FSS members may be provided as interchangeably replaceable and different unit cell/array configurations.

[000122] Turning now to **FIGS. 12-14**, in some embodiments, the base station antenna **100** can have a plurality of FSS members **170**, at least one of which may be releasably held by the base station antenna. As shown, a first internal FSS **170₁**, which may be a grid reflector **170g**, can reside in front of a second FSS **170₂**. The first FSS **170₁** can be fixed in position while the second FSS **170₂** can be releasably held in the base station antenna **100**. A user can either insert the second FSS **170₂** in the field depending on end use requirements of the factory can insert the second FSS **170₂**. The second FSS **170₂** can be interchangeably replaced with a different second FSS **170₂** with a different operational profile, typically with a different array **171** of unit cells **171u**.

[000123] The first FSS **170₁** and/or second FSS **170₂** can allow electromagnetic waves to propagate therethrough at a first frequency band (working band) and reflect lower band electromagnetic waves. The first FSS **170₁** can be fixed in position or releasably replaceable. The first frequency band can comprise 3.5 GHz because this is the primary 5G band in the world. A user can insert a second FSS **170₂** behind the first FSS **170₁**, to either pull down the work frequency band to band 1 (2.6 GHz) or band 1 and band 2 (in a range that includes at least part of 2.3-4.0 GHz). A user can insert a second FSS **170₂** to pull up the work frequency band to band 3 (4.5 GHz) or band 2 and band 3 (3.3-4.9 GHz) to thereby change the working band or extend the working band.

[000124] In some embodiments, the first FSS **170₁** or **170a** can be provided in the base station antenna **100** as a “default” configuration that may correspond to a 3.5GHz 5G band. The second FSS **170₂** or **170b** can be configured to change the working band or extend the working band.

[000125] Turning now to **FIGS. 15-17**, another example of the mounting structures **1250'** that couple to the second FSS **170₂** is shown. The mounting structures **1250'** can be integral to the grid reflector **170g**. The mounting structures **1250'** can have rails **1250r** that have an inner bend segment **1250b** that merges into a lip **1251**. The lip **1251** is parallel to the first and second FSS' **170₁**, **170₂**, respectively, and holds the second FSS **170₂** behind the first FSS **170₁**. The stop feature **1265** can be provided on the lip **1251**.

[000126] Turning now to **FIGS. 18-20**, in some embodiments, the base station antenna **100** can comprise a plurality of adjacent external access ports **150**, shown as first and second external access ports **150₁**, **150₂** with respective covers **1150**. Also, although shown with two covers **1150**, a single cover can be configured to enclose both external access ports (not shown).

[000127] The single external access port (**FIG. 7**) or the two external access ports **150₁**, **150₂** (**FIG. 19**) can reside closer to the rear **100r** of the base station antenna **100** than the front **100f** with the front radome **111f**.

[000128] Turning now to **FIGS. 21-23**, in some embodiments, the base station antenna **100** can provide the external access port **150** in a sidewall **100s** of the base station antenna housing **100h**. The length dimension *l* can be slightly larger (10% -20% greater) than the length of the FSS **170**. Internal mounting structures **1250''** can include a respective longitudinally extending through-slot **1255'** that slidably receives the FSS **170**. The external access port **150** can be provided as a plurality of external access ports **150**, one above another spaced apart along and residing in a single side **100s** or residing side by side, similar to the side- by-side ports **150** discussed with respect to **FIG. 20**.

[000129] **FIGS. 21-23** show the external access port **150** on/in a right sidewall **100s** while **FIGS. 24-26** show the external access port **150** on/in a left sidewall **100s**. Combinations of right and left side external access ports **150** may also be used whether longitudinally aligned or longitudinally offset (one above the other). If offset, they can be used with different radios/active antenna units **110** concurrently coupled to the base station antenna **100**.

[000130] Turning now to **FIGS. 27-29**, in some embodiments, the external access port **150** can be provided in a bottom **100b** of the base station antenna. The external access port **150** can be arranged behind the RF ports **140**. Combinations of top, bottom and/or right and left side external access ports **150** may also be used for placing different FSS' **170** and such FSS' **170** can be used with different radios/active antenna units **110**.

[000131] The FSS **170** can be positioned about a $\frac{1}{4}$ of an operating wavelength of the high band radiating elements **1195** (**FIGS. 33A, 33B**). The term "operating wavelength" refers to the wavelength corresponding to the center frequency of the operating frequency band of a radiating element, e.g., a low band radiating element **222** or a high band radiating element **1195**.

[000132] Where multiple FSS' are used, the spacing between the FSS', e.g., **170₁** and **170₂**, can be about $\frac{1}{10}$ - $\frac{1}{2}$ (typical $\frac{1}{4}$) of the operating wavelength and is related to the electrical length. For example, placing a higher dielectric constant (DK) material in between will allow a smaller spacing.

[000133] The first FSS **170₁** and the second FSS **170₂** can reside a distance in a range of $\frac{1}{10}$ wavelength to $\frac{1}{2}$ wavelength of an operating wavelength in front of the high band radiating elements **1195**, in some embodiments.

[000134] The FSS **170** can be configured to have a pass band for mMIMO radiating elements **1195** (FIGS. **33A**, **33B**) comprising at least some frequencies in a range of, for example: 3150-5000MHz and 2200-4200MHz and all the sub-band in between, such as 2490-2690MHz, 3400-3980MHz, and 2900-4000MHz.

[000135] Referring to FIGS. **30** and **31**, the FSS **170** can be configured so that there are different densities of unit cells **171** at different locations. In some embodiments, the unit cells **171u** may be asymmetric about one or more axes to, for example, improve cross-polarization performance.

[000136] FIG. **30** illustrates the array of unit cells **171** can be arranged with a greater density of unit cells **171u** at left and right side portions, **170r**, **170l** relative to a medial portion **170m**. FIG. **30** also illustrates that unit cells **171** located at a medial portion **170m** of the grid reflector **170**, can have a larger surface area, height and/or width, shown as a common height dimension and different width dimensions and with larger center spaces **172** than unit cells **171u** located at the left and right side portions **170r**, **170l**.

[000137] FIG. **31** illustrates a greater density of unit cells **171u** at a medial portion **170m** relative to the unit cells **171u** at right and/or left side portions **170r**, **170l**. FIG. **31** also illustrates that unit cells **171** located at right and left side portions **170r**, **170l** can have a larger surface area, height and/or width, shown as a common height and larger width with larger center spaces **172** than unit cells **171** located at the medial portion **170m**.

[000138] Thus, the FSS **170** can have an array of unit cells **171** with a first subset of the unit cells **171u** tuned for blocking and/or reflecting RF energy in a first frequency band while allowing RF energy in a second frequency band to propagate therethrough and a second subset of the unit cells **171u** tuned for blocking and/or reflecting RF energy in the first frequency band and RF energy in a third frequency band. The third frequency band comprises frequencies between the first and second frequency bands.

[000139] The first subset **171a** of the unit cells **171u** can be positioned at an upper portion of the base station antenna **100**. The second subset **171b** of the unit cells **171u** can include unit cells that are below and/or to right and left sides of the first subset **171a** of the unit cells **171u**.

[000140] The first subset **171a** of the unit cells **171** can reside behind low band radiating elements **222** and in front of high band radiating elements **1195** (e.g., a mMIMO array). The second subset **171b** of the unit cells **171** can reside behind mid-band **232** radiating elements. The first frequency band can be low band, the second frequency band can be a high band frequency band, the third frequency band can be mid-band with at least some frequencies between the first and second frequencies.

[000141] The first subset of the unit cells **171u** can be positioned at an upper portion of the base station antenna **100**. The second subset **171b** of the unit cells **171** can include unit cells that are below and/or to right and left sides of the first subset **171a** of the unit cells **171**. Some of the unit cells **171u** in the second subset **171b** of the unit cells **171** can be to the left side and/or right side of the first subset of the unit cells **171a**.

[000142] The first subset **171a** of the unit cells **171** can reside behind low band radiating elements **222** and in front of high band radiating elements **1195** (e.g., a mMIMO array). The second subset **171b** of the unit cells **171** can reside behind mid-band **232** radiating elements.

[000143] The FSS **170** can be configured to merge into or attach to longitudinally extending right and left side **214s** of (substantially solid) surfaces of the primary reflector **214** at one or more locations, such as along longitudinally extending outer sides. As discussed above, the FSS **170** can be configured to have different unit cell configurations and/or sizes at different locations.

[000144] In some embodiments, the first FSS **170₁** can be configured to act like a High Pass Filter essentially allowing low band energy to completely reflect as the grid is formed by a sheet of metal while allowing higher band energy, for example, about 3.5 GHz or greater, to pass through, typically substantially completely pass through.

[000145] The first and second FSS' **170₁**, **170₂** can be transparent or invisible to the higher band energy and can cooperate to provide a suitable out of band rejection response can be achieved.

[000146] Turning now to **FIGS. 32A, 32B**, an example passive antenna assembly **190** is shown. The FSS **170** can merge into the primary reflector **214** that extends longitudinally and laterally. The primary reflector **214** may have a longitudinal length that is greater than a longitudinal length of the FSS **170**. The primary reflector **214** can have a solid reflection surface for antenna elements residing in front of the primary reflector **214** and may reside over operational components **314**, such as filters, tilt adjusters and the like.

[000147] The FSS **170** can reside a distance in a range of $1/8$ wavelength to $1/4$ wavelength of an operating wavelength behind the low band dipoles **222**, in some embodiments. As discussed above, the term "operating wavelength" refers to the wavelength corresponding to the center frequency of the operating frequency band of the radiating element, e.g., a low band radiating element **222**.

[000148] Where used with a second FSS **170₂**, the FSS **170** shown in **FIGs. 32A, 32B** can be the first FSS **170₁** and can reside a distance in a range of $1/10$ wavelength to $1/2$ wavelength of an operating wavelength in front of the high band radiating elements **1195**, in

some embodiments. By way of example, in some particular embodiments, the first FSS **170₁** can reside a physical distance of 0.25 inches and 2 inches from a ground plane or reflector **1172** that is behind a mMIMO array of radiating elements **1195** of an active antenna module **110** (**FIGS. 33A, 33B**). Other placement positions may be used.

[000149] Referring to **FIGS. 33A, 33B**, in some embodiments, the ground plane or reflector **1172** of the active antenna module **110** can be electrically coupled to the grid reflector **170g** and/or primary reflector **214** of the base station antenna **100**, such as galvanically and/or capacitively coupled. In other embodiments, the ground plane or reflector **1172** of the active antenna module **110** is not electrically coupled to the FSS **170** or the grid reflector **170g** and/or primary reflector **214**.

[000150] Referring again to **FIG. 32A**, the FSS **170** can have a longitudinal extent “L” and a lateral extent “W”. The longitudinal extent L can extend a distance that is greater than the lateral extent W. The longitudinal extent L can be less than the lateral extent W. The FSS **170** has a front side **170f** that faces the front side **100f** of the housing **100h**/radome **111**.

[000151] The antenna assembly **190** comprises multiple arrays of radiating elements, typically provided in six columns, with radiating elements that extend forwardly from the front side **170f** of the FSS **170**, with some columns of radiating elements continuing to extend in front of the primary reflector **214**. The arrays of radiating elements of the antenna assembly **190** may comprise radiating elements **222** that are configured to operate in a first frequency band and radiating elements **232** that are configured to operate in a second frequency band. Other arrays of radiating elements may comprise radiating elements that are configured to operate in either the second frequency band or in a third frequency band. The first, second and third frequency bands may be different frequency bands (although potentially overlapping). In some embodiments, low band antenna element **222** with dipole arms can reside in front of the FSS **170**, typically along right and left side portions **170s** of the FSS **170** and/or primary reflector sides **214s**.

[000152] The FSS **170** and the primary reflector **214** can be monolithically formed as a unitary (sheet) metal body in some embodiments. Alternatively, the FSS **170** and the primary reflector **214** can be provided as separate components that are directly or indirectly attached and electrically coupled together to provide a common electrical ground. The FSS **170** and the primary reflector **214** can both be sheet metal of the same or different thicknesses. The FSS **170** can be provided as a printed circuit on a dielectric substrate and the primary reflector **214** can be sheet metal.

[000153] Some of the radiating elements (discussed below) of the antenna **100** may be mounted to extend forwardly from the main reflector **214**, and, if dipole-based radiating elements are used, the dipole radiators of these radiating elements may be mounted approximately $\frac{1}{4}$ of a wavelength of the operating frequency for each radiating element forwardly of the main reflector **214**. The main reflector **214** may serve as a reflector and as a ground plane for the radiating elements of the base station antenna **100** that are mounted thereon.

[000154] Still referring to **FIGS. 32A, 32B**, the passive antenna assembly **190** of the base station antenna **100** can include one or more arrays **220** of low-band radiating elements **222**, one or more arrays **230** of first mid-band radiating elements **232**, one or more arrays **240** of second mid-band radiating elements **242** and optionally one or more arrays **250** of high-band radiating elements **252**. The radiating elements **222, 232, 242, 252, 1195** may each be dual-polarized radiating elements. Further details of radiating elements can be found in WO2019/236203 and WO2020/072880, the contents of which are hereby incorporated by reference as if recited in full herein. Some of the high band radiating elements, such as radiating elements **1195**, can be provided as a mMIMO antenna array and may be provided in the active antenna module **110** rather than in the housing **100h** of the base station antenna **100**.

[000155] The low-band radiating elements **222** can be mounted to extend forwardly from the main or primary reflector **214** and the first FSS **170₁** and can be mounted in two columns to form two linear arrays **220** of low-band radiating elements **222**. Each low-band linear array **220** may extend along substantially the full length of the antenna **100** in some embodiments.

[000156] The low-band radiating elements **222** may be configured to transmit and receive signals in a first frequency band. In some embodiments, the first frequency band may comprise the 617-960 MHz frequency range or a portion thereof (e.g., the 617-896 MHz frequency band, the 696-960 MHz frequency band, etc.). The low-band linear arrays **220** may or may not be used to transmit and receive signals in the same portion of the first frequency band. For example, in one embodiment, the low-band radiating elements **222** in a first linear array **220** may be used to transmit and receive signals in the 700 MHz frequency band and the low-band radiating elements **222** in a second linear array **220** may be used to transmit and receive signals in the 800 MHz frequency band. In other embodiments, the low-band radiating elements **222** in both the first and second linear arrays **220-1, 220-2** may be used to transmit and receive signals in the 700 MHz (or 800 MHz) frequency band.

[000157] The first mid-band radiating elements **232** may likewise be mounted to extend forwardly from the main reflector **214** and/or the first FSS layer **170₁** and may be mounted in

columns to form linear arrays **230** of first mid-band radiating elements **232**. The linear arrays **230** of mid-band radiating elements **232** may extend along the respective side edges of the first FSS layer **170₁** and/or the main reflector **214**. The first mid-band radiating elements **232** may be configured to transmit and receive signals in a second frequency band. In some embodiments, the second frequency band may comprise the 1427-2690 MHz frequency range or a portion thereof (e.g., the 1710-2200 MHz frequency band, the 2300-2690 MHz frequency band, etc.). In the depicted embodiment, the first mid-band radiating elements **232** are configured to transmit and receive signals in the lower portion of the second frequency band (e.g., some or all of the 1427-2200 MHz frequency band). The linear arrays **230** of first mid-band radiating elements **232** may be configured to transmit and receive signals in the same portion of the second frequency band or in different portions of the second frequency band.

[000158] Second mid-band radiating elements **242** can be mounted in columns to form linear arrays of second mid-band radiating elements **242**. The second mid-band radiating elements **242** may be configured to transmit and receive signals in the second frequency band. In the depicted embodiment, the second mid-band radiating elements **242** are configured to transmit and receive signals in an upper portion of the second frequency band (e.g., some, or all, of the 2300-2700 MHz frequency band). In the depicted embodiment, the second mid-band radiating elements **242** may have a different design than the first mid-band radiating elements **232**.

[000159] The high-band radiating elements **252** and/or **1195** can be mounted in columns in the upper medial or center portion of antenna **100** to form a multi-column (e.g., four or eight column) array **250** of high-band radiating elements **252** and/or **1195**. The high-band radiating elements **1195** may be configured to transmit and receive signals in a third frequency band. In some embodiments, the third frequency band may comprise the 3300-4200 MHz frequency range or a portion thereof.

[000160] In the depicted embodiment, the arrays **220** of low-band radiating elements **222**, the arrays **230** of first mid-band radiating elements **232**, and the arrays of second mid-band radiating elements **242** are all part of the passive antenna assembly **190**, while the array **250** of high-band radiating elements **1195** are part of the active antenna module **110**. It will be appreciated that the types of arrays included in the passive antenna assembly **190**, and/or the active antenna module **110** may be varied in other embodiments.

[000161] It will also be appreciated that the number of linear arrays of low-band, mid-band and high-band radiating elements may be varied from what is shown in the figures. For example, the number of linear arrays of each type of radiating elements may be varied from

what is shown, some types of linear arrays may be omitted and/or other types of arrays may be added, the number of radiating elements per array may be varied from what is shown, and/or the arrays may be arranged differently. As one specific example, two linear arrays of second mid-band radiating elements **242** may be replaced with four linear arrays of ultra-high-band radiating elements that transmit and receive signals in a 5 GHz frequency band.

[000162] At least some of the low-band and mid-band radiating elements **222**, **232**, **242** may each be mounted to extend forwardly of and/or from the first FSS **170₁** or the main reflector **214**.

[000163] Each array **220** of low-band radiating elements **222** may be used to form a pair of antenna beams, namely an antenna beam for each of the two polarizations at which the dual-polarized radiating elements are designed to transmit and receive RF signals. Likewise, each array **232** of first mid-band radiating elements **232**, and each array of second mid-band radiating elements **242** may be configured to form a pair of antenna beams, namely an antenna beam for each of the two polarizations at which the dual-polarized radiating elements are designed to transmit and receive RF signals. Each linear array may be configured to provide service to a sector of a base station. For example, each linear array **220**, **230**, may be configured to provide coverage to approximately 120° in the azimuth plane so that the base station antenna **100** may act as a sector antenna for a three-sector base station. Of course, it will be appreciated that the linear arrays may be configured to provide coverage over different azimuth beamwidths. While all of the radiating elements **222**, **232**, **242**, **252**, **1195** can be dual-polarized radiating elements in the depicted embodiments, it will be appreciated that in other embodiments some or all of the dual-polarized radiating elements may be replaced with single-polarized radiating elements. It will also be appreciated that while the radiating elements are illustrated as dipole radiating elements in the depicted embodiment, other types of radiating elements such as, for example, patch radiating elements may be used in other embodiments.

[000164] Some or all of the radiating elements **222**, **232**, **242**, **252**, **1195** may be mounted on feed boards that couple RF signals to and from the individual radiating elements **222**, **232**, **242**, **252**, **1195**, with one or more radiating elements **222**, **232**, **242**, **252**, **1195** mounted on each feed board. Cables (not shown) and/or connectors may be used to connect each feed board to other components of the antenna **100** such as diplexers, phase shifters, calibration boards or the like.

[000165] RF connectors or "ports" **140** (**FIGS. 2A, 28**) can be mounted in the bottom end cap **130** that are used to couple RF signals from external remote radio units (not shown) to the arrays of the passive antenna assembly **190**. Two RF ports can be provided for each array

namely a first RF port **140** that couples first polarization RF signals between the remote radio unit and the array and a second RF port **140** that couples second polarization RF signals between the remote radio unit and the array. As the radiating elements **222**, **232**, **242** can be slant cross-dipole radiating elements, the first and second polarizations may be a -45° polarization and a $+45^\circ$ polarization.

[000166] A phase shifter may be connected to a respective one of the RF ports **140**. The phase shifters may be implemented as, for example, wiper arc phase shifters such as the phase shifters disclosed in U.S. Patent No. 7,907,096 to Timofeev, the disclosure of which is hereby incorporated herein in its entirety. A mechanical linkage may be coupled to a RET actuator (not shown). The RET actuator may apply a force to the mechanical linkage which in turn adjusts a moveable element on the phase shifter in order to electronically adjust the downtilt angles of antenna beams that are generated by the one or more of the low-band or mid-band linear arrays.

[000167] It should be noted that a multi-connector RF port (also referred to as a "cluster" connector) can be used as opposed to individual RF ports **140**. Suitable cluster connectors are disclosed in U.S. Patent Application Serial No. 16/375,530, filed April 4, 2019, the entire content of which is incorporated herein by reference.

[000168] The radiating elements **220** can be dipole elements configured to operate in some or all the 617-960 MHz frequency band. A feed circuit comprising a hook balun can be provided on the feed stalk **221** (**FIG. 32B**). Further discussions of example antenna elements including antenna elements comprising feed stalks can be found in U.S. Patent Application Serial Number 17/205,122, the contents of which are hereby incorporated by reference as if recited in full herein.

[000169] Turning now to **FIGS. 33A, 33B**, an example active antenna module **110** is shown. The active antenna module **110** can include an RRU (remote radio unit) unit **1120** with radio circuitry. The active antenna module **110** can also include a filter and calibration printed circuit board assembly (not shown) and an antenna assembly **1190** comprising a reflector or ground plane of a printed circuit board **1172** behind radiating elements **1195**. The antenna assembly **1190** may also include phase shifters (not shown), which may alternatively be part of the filter and calibration assembly. The radiating elements **1195** can be provided as a massive MIMO array. The RRU unit **1120** is a radio unit that typically includes radio circuitry that converts base station digital transmission to analog RF signals and vice versa. One or more of the radio unit or RRU unit **1120**, the antenna assembly **1190** or the filter and calibration assembly can be provided as separate sub-units that are attachable (stackable). The RRU unit

1120 and the antenna assembly **1190** can be provided as an integrated unit, optionally also including the calibration assembly **1180**. Where configured as sub-units, different sub-units can be provided by OEMs or cellular service providers while still using a common base station antenna housing **100h** and passive antenna assembly **190** thereof. In other embodiments, the radio circuitry can be provided with the antenna assembly as a single integrated unit.

[000170] **FIG. 33A** illustrates that the rear **100r** of the base station antenna **100** can have a flat surface and the active antenna assembly **1190** can be configured to face the rear **100r** with the radomes **119**, **100r** therebetween and with the first and second FSS layers **170₁**, **170₂** in front of the radiating elements **1195**. **FIG. 33B** illustrates that the rear **100r** of the base station antenna **100** can have recessed segment **102** and sized to receive the radome **119** of the active antenna unit **110**, again with the radiating elements **1195** behind and facing the FSS layers **170₁**, **170₂**.

[000171] Embodiments of the present invention have been described above with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

[000172] It will be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first element could be termed a second element, and, similarly, a second element could be termed a first element, without departing from the scope of the present invention. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[000173] It will be understood that when an element is referred to as being "on" another element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being "directly on" another element, there are no intervening elements present. It will also be understood that when an element is referred to as being "connected" or "coupled" to another element, it can be directly connected or coupled to the other element or intervening elements may be present. In contrast, when an element is referred to as being "directly connected" or "directly coupled" to another element, there are no intervening elements present. Other words used to describe the relationship between elements should be interpreted in a like fashion (*i.e.*, "between" versus "directly between", "adjacent" versus "directly adjacent", etc.)

[000174] Relative terms such as "below" or "above" or "upper" or "lower" or "horizontal" or "vertical" may be used herein to describe a relationship of one element, layer or region to another element, layer or region as illustrated in the figures. It will be understood that these terms are intended to encompass different orientations of the device in addition to the orientation depicted in the figures.

[000175] The term "about" used with respect to a number refers to a variation of +/- 10%.

[000176] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" "comprising," "includes" and/or "including" when used herein, specify the presence of stated features, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, operations, elements, components, and/or groups thereof.

[000177] Aspects and elements of all of the embodiments disclosed above can be combined in any way and/or combination with aspects or elements of other embodiments to provide a plurality of additional embodiments.

That Which is Claimed is:

1. A base station antenna, comprising:
a housing;
an external access port provided by the housing; and
a frequency selective surface (FSS) configured to be slidably insertable into the external access port.
2. The base station antenna of Claim 1, further comprising a cover that extends over the external access port.
3. The base station antenna of Claim 1, wherein the external access port extends laterally across a top of the housing.
4. The base station antenna of Claim 1, wherein the external access port extends longitudinally along a sub-length of the base station antenna.
5. The base station antenna of Claim 1, wherein the external access port extends laterally across a bottom of the base station antenna.
6. The base station antenna of Claim 1, wherein the FSS has a length dimension and a width dimension, and wherein the external access port has a width that is greater than the width dimension or a length that is greater than the length dimension.
7. The base station antenna of Claim 1, wherein the external access port is a first external access port, and wherein the base station antenna further comprises a second external access port that is spaced apart from the first external access port.
8. The base station antenna of Claim 7, wherein the first and second external access ports are parallel to each other.
9. The base station antenna of Claim 1, further comprising internal mounting structures that releasably couple to the FSS.

10. The base station antenna of Claim 9, wherein the internal mounting structures each comprise a longitudinally extending slot that slidably receives outer edge portions of the FSS.
11. The base station antenna of Claim 9, further comprising a stop feature integral to or coupled to the mounting structures that is configured prevent the FSS from advancing further into the housing.
12. The base station antenna of Claim 1, wherein the FSS is a first FSS with a first configuration of unit cells, wherein the base station antenna is configured to interchangeably and serially receive a second FSS with a second configuration of unit cells to thereby be used in place of the first FSS.
13. The base station antenna of Claim 1, wherein the FSS is a first FSS, and wherein the base station antenna further comprises a second FSS in front of the first FSS.
14. The base station antenna of Claim 13, wherein the second FSS is a sheet metal grid reflector.
15. The base station antenna of Claim 1, further comprising an active antenna unit comprising a radio behind the housing.
16. The base station antenna of Claim 13, wherein the second FSS is stacked in front of the first FSS in a Z direction.
17. The base station antenna of Claim 1, further comprising a first plurality of radiating elements residing in front of the FSS and a second plurality of radiating elements residing behind the FSS.
18. The base station antenna of Claim 17, wherein the first plurality of radiating elements operate in a first frequency band and the second plurality of radiating elements operate in a second frequency band.
19. The base station antenna of Claim 17, wherein the first plurality of radiating elements comprise low band radiating elements that are configured to operate in a first frequency band,

and the second plurality of radiating elements comprise higher band radiating elements that are configured to operate in a second frequency band, the second frequency band encompassing higher frequencies than the first frequency band.

20. The base station antenna of Claim 13, wherein the first FSS and the second FSS are configured to allow RF energy in a defined frequency band to propagate therethrough.

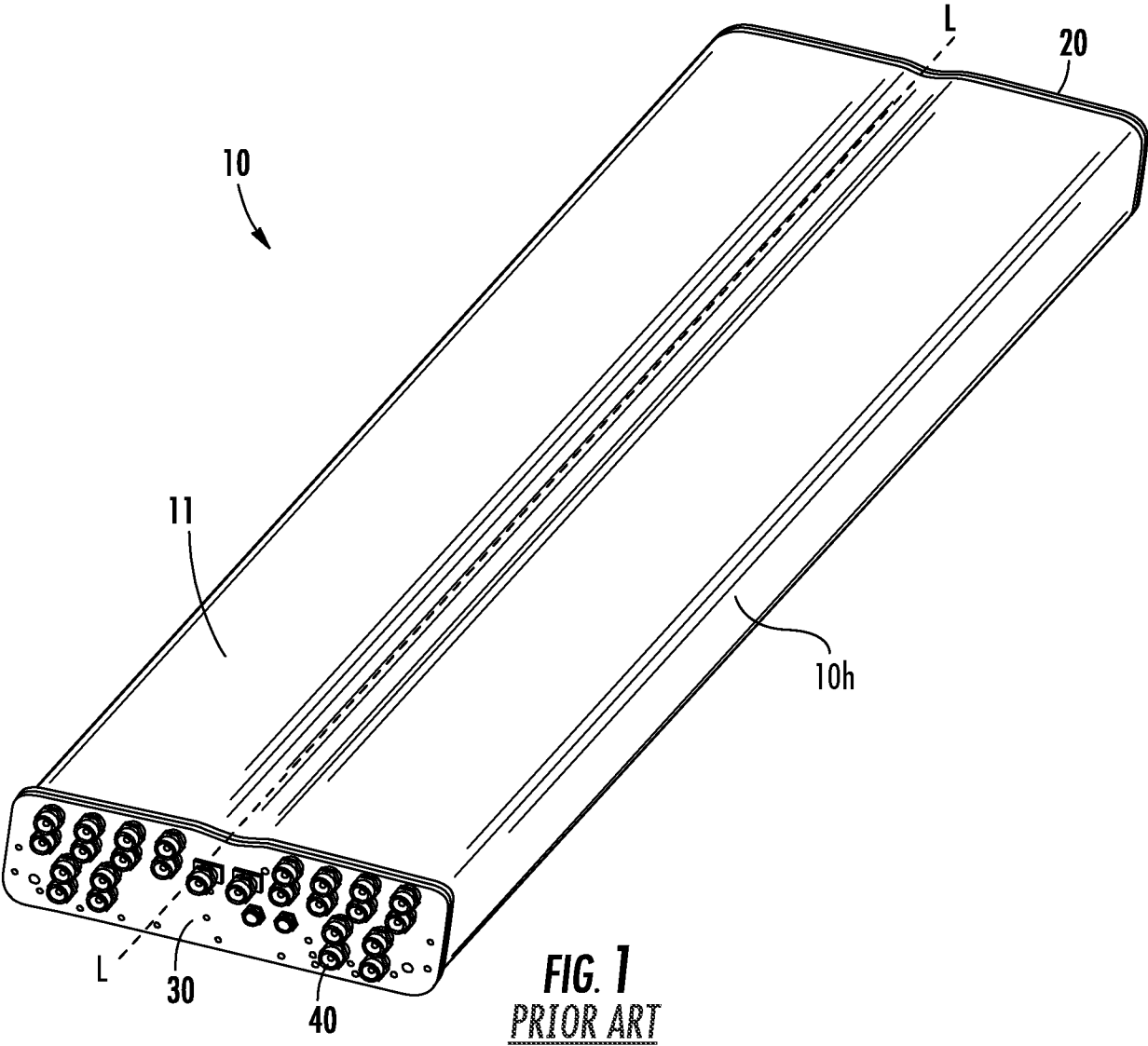
21. The base station antenna of Claim 1, wherein the FSS comprises a first subset of an array of unit cells configured for blocking and/or reflecting RF energy in a first frequency band while allowing RF energy in a second frequency band to propagate therethrough, wherein the FSS comprises a second subset of the array of unit cells configured for blocking and/or reflecting RF energy in the first frequency band and RF energy in a third frequency band, and wherein the third frequency band comprises frequencies between the first and second frequency bands.

22. The base station antenna of Claim 21, wherein the first subset of the array of unit cells are positioned at an upper portion of the base station antenna, and wherein the second subset of the array of unit cells comprise unit cells that are to the right side of the first subset of the unit cells and also comprises unit cells that are to the left side of the first subset of the unit cells.

23. The base station antenna of Claim 17, wherein the first plurality of radiating elements comprise high band radiating elements that operate in at least part of a 3.2-4.1 GHz frequency band, and wherein the second plurality of radiating elements comprise radiating elements that operate in at least part of a lower frequency band than the high band radiating elements.

24. The base station antenna of Claim 13, wherein the first FSS and the second FSS are configured to allow RF energy in at least part of a 3.2-4.1 GHz frequency band to propagate therethrough.

25. The base station antenna of Claim 17, wherein the second plurality of radiating elements are provided as a multiple column array in an active antenna module.



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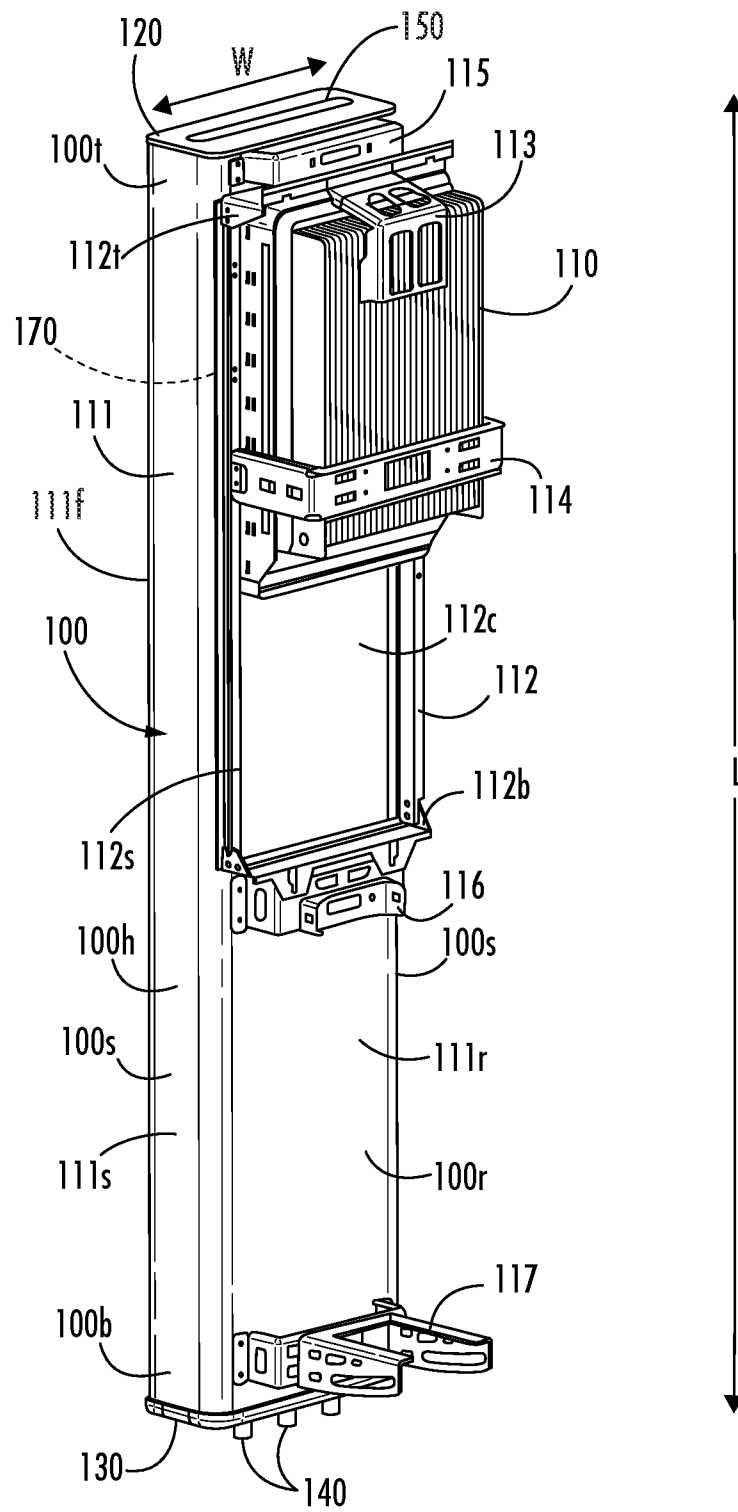
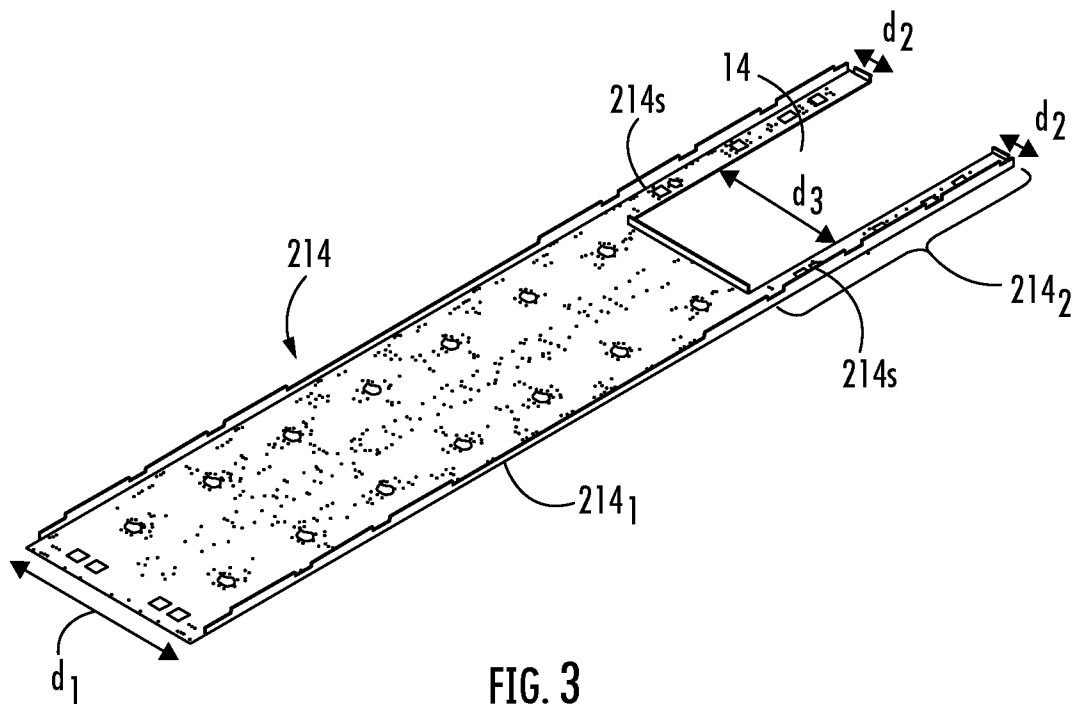
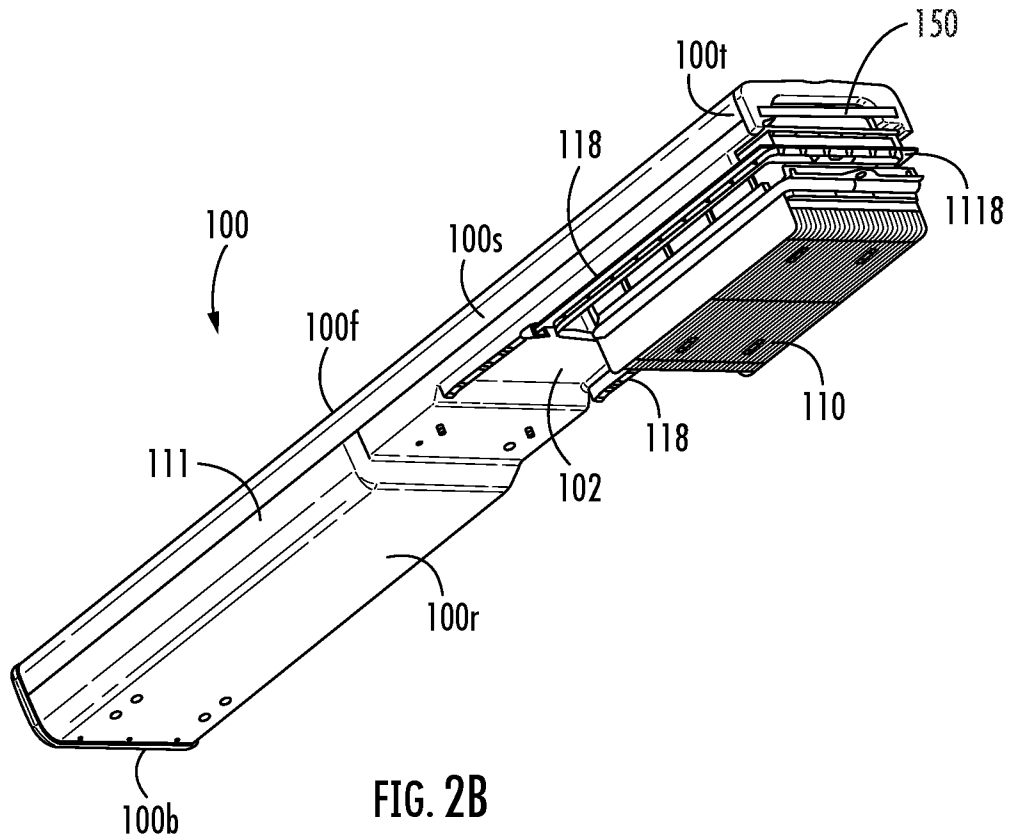
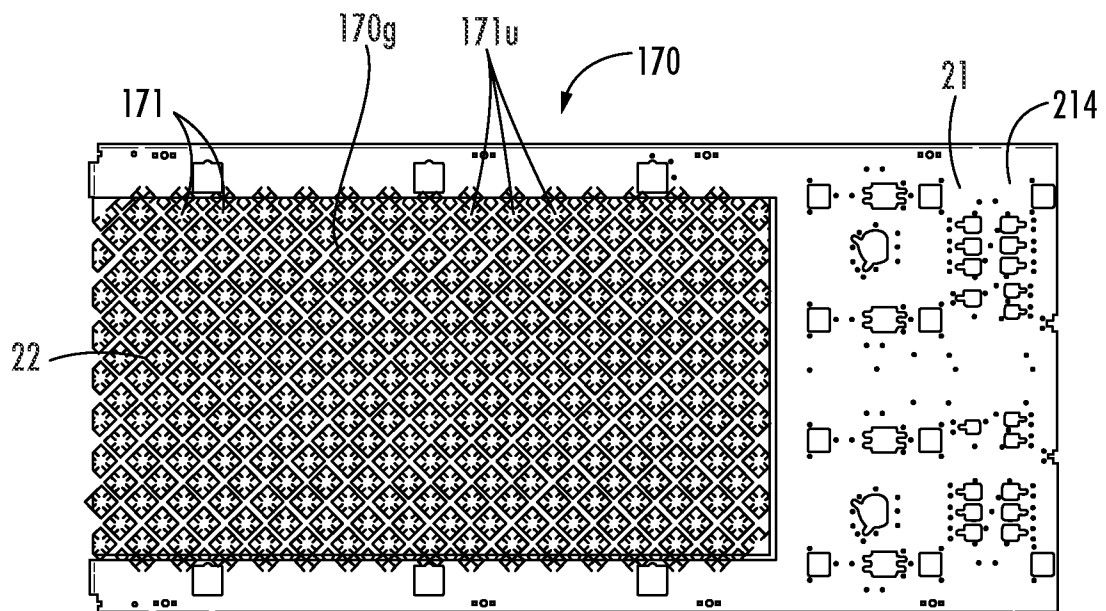
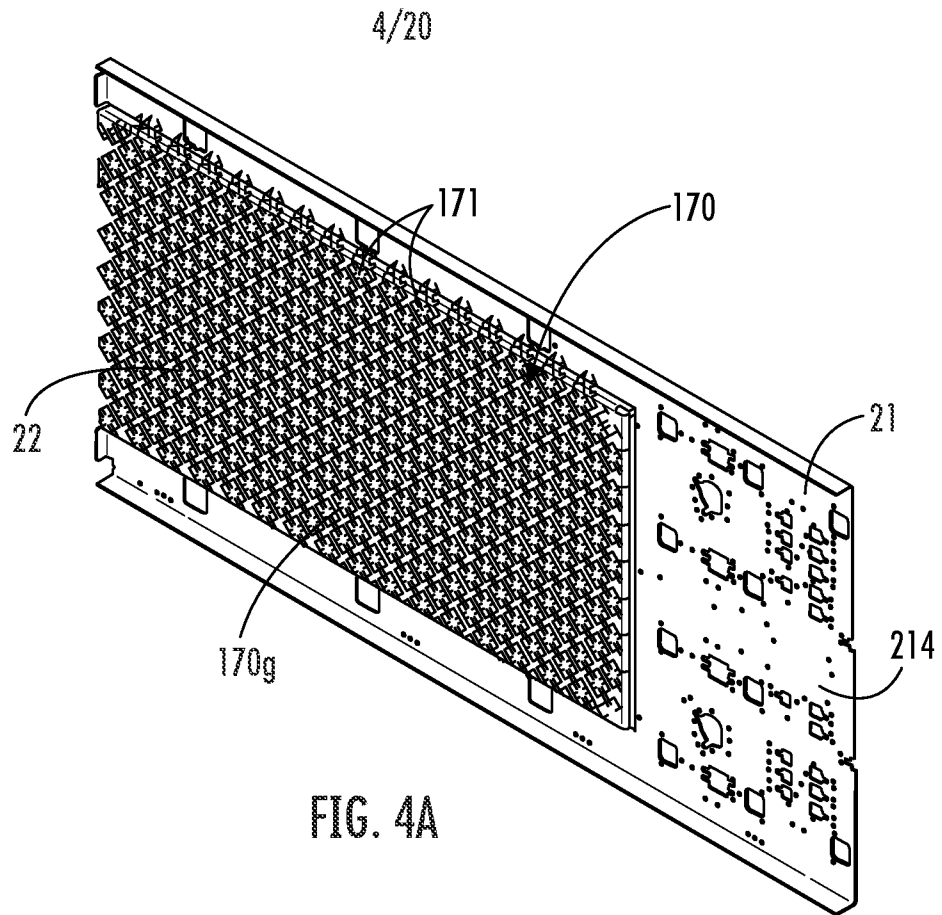
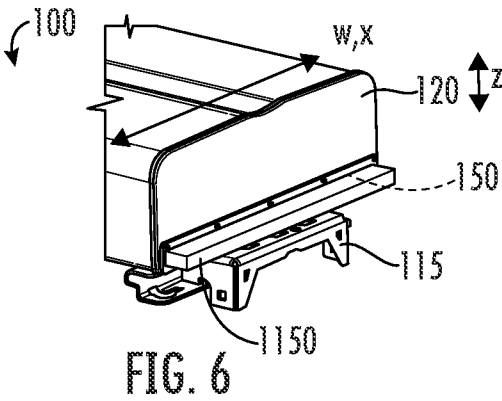
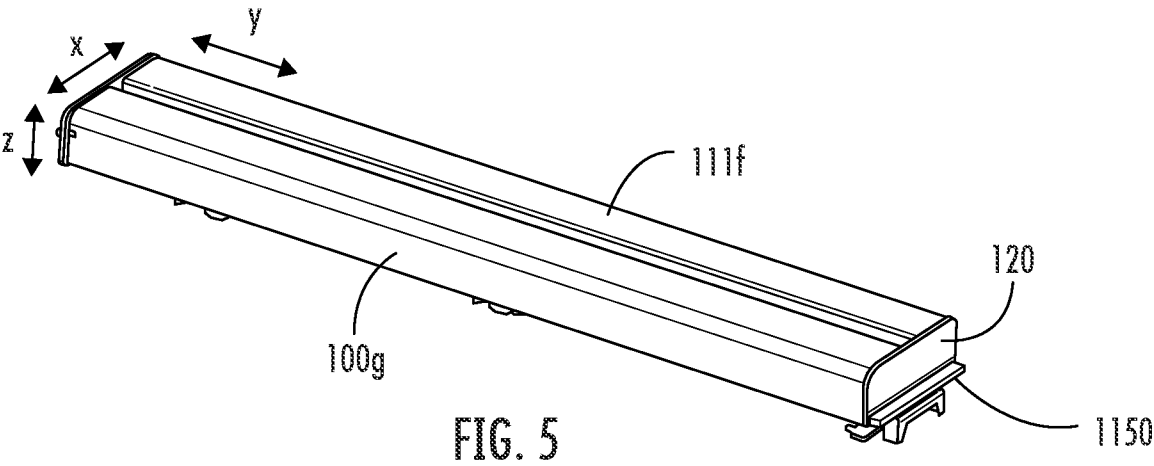


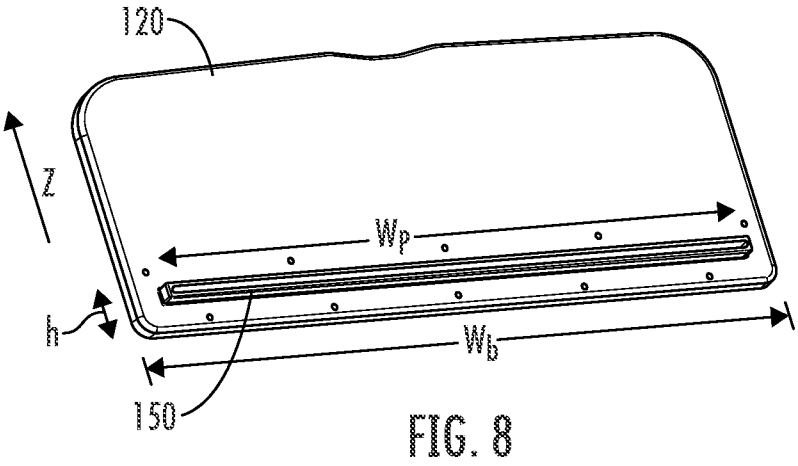
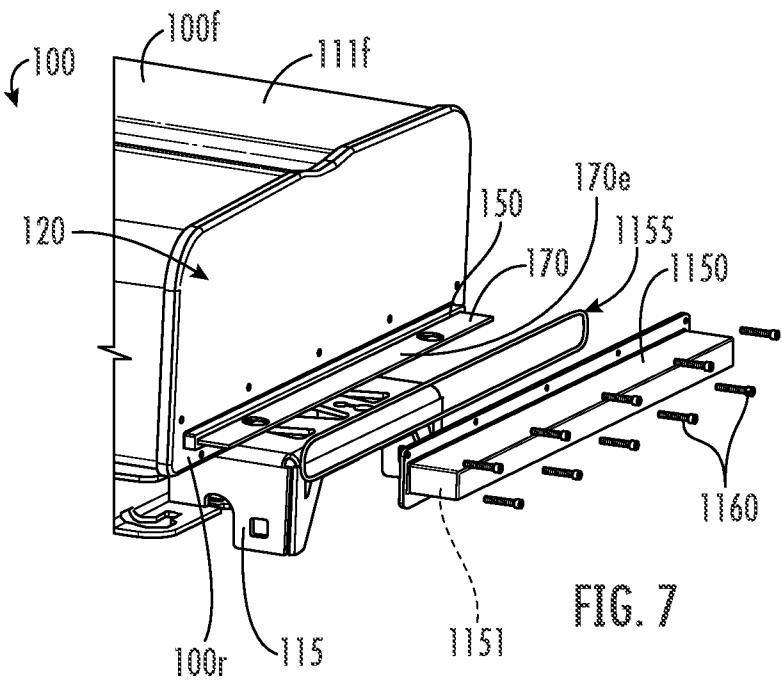
FIG. 2A



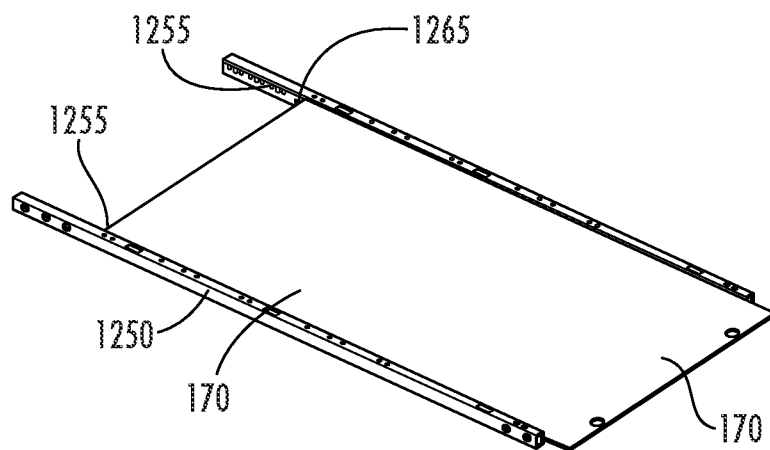
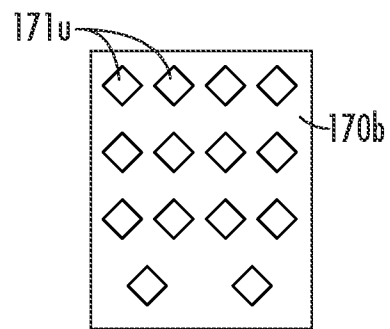
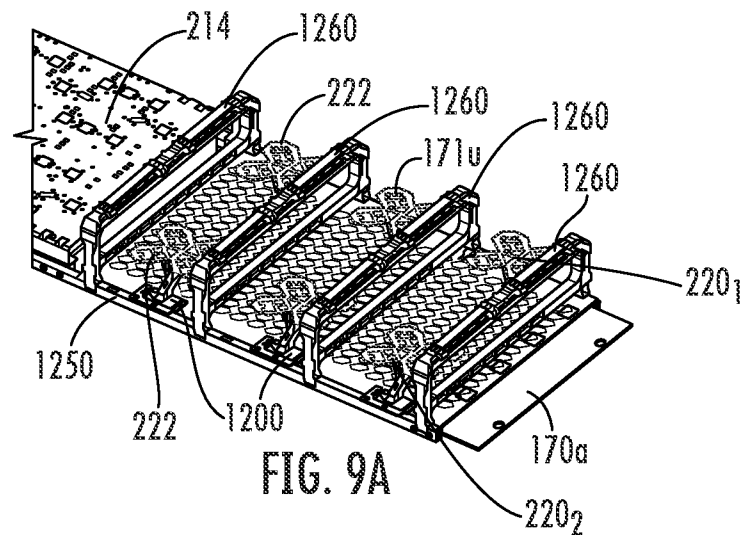


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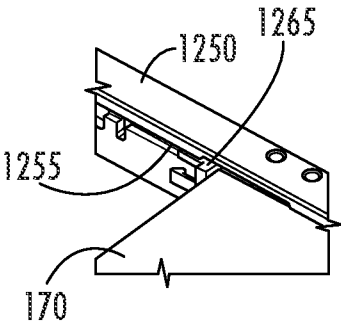


FIG. 10B

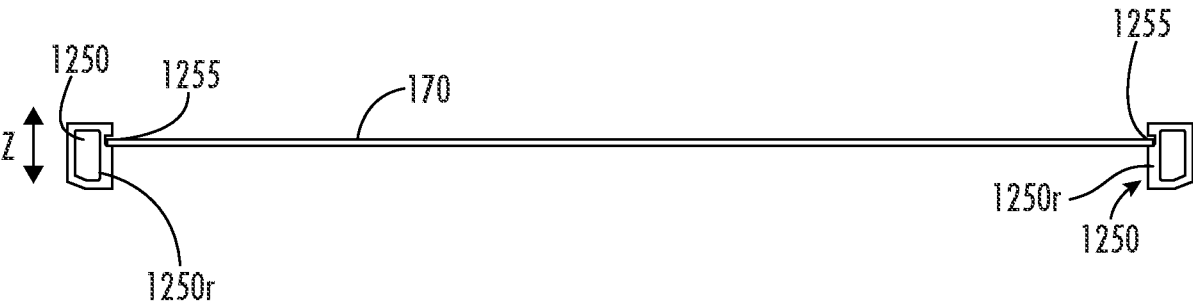


FIG. 11

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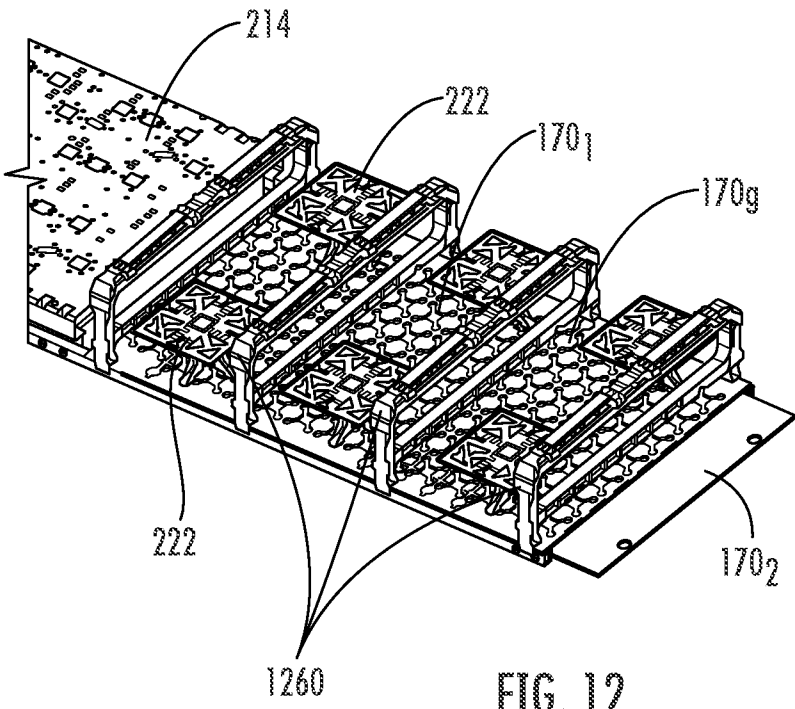


FIG. 12

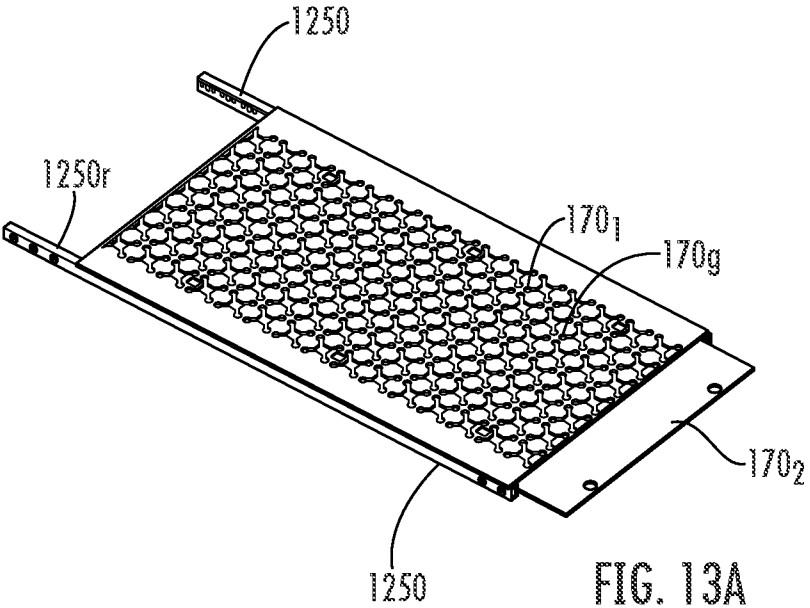


FIG. 13A

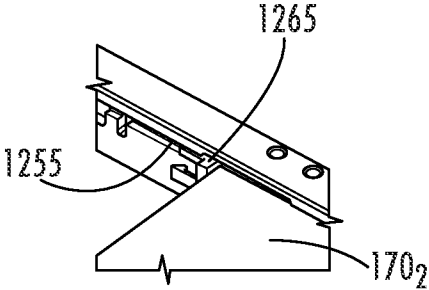


FIG. 13B

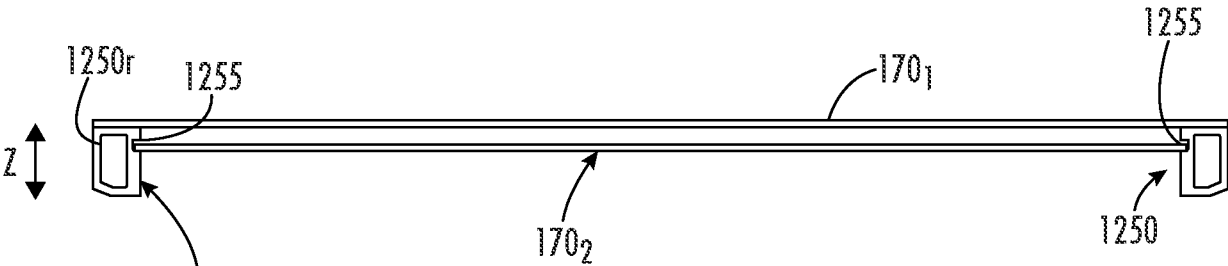
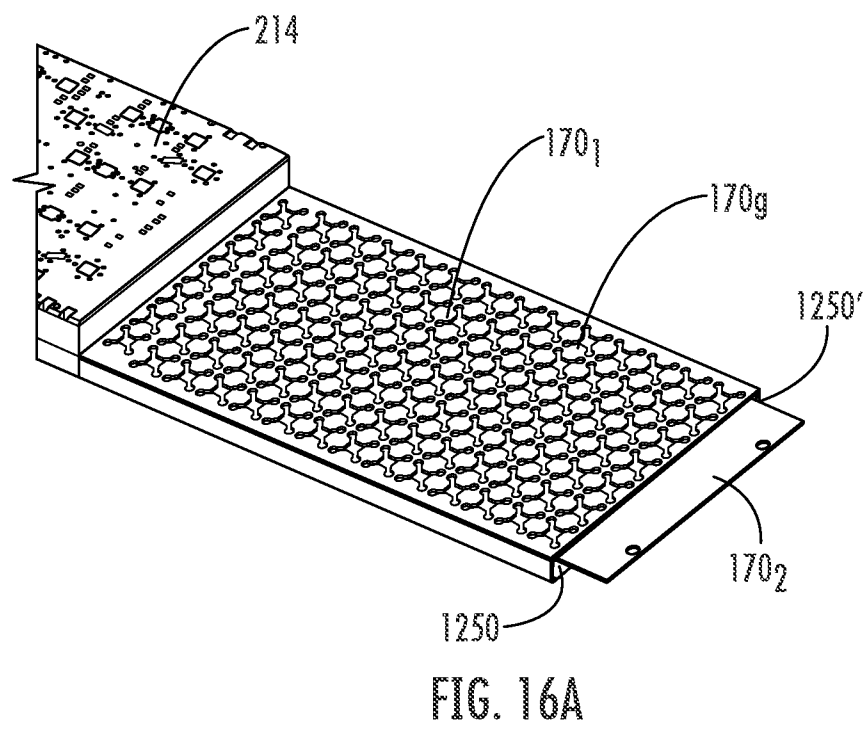
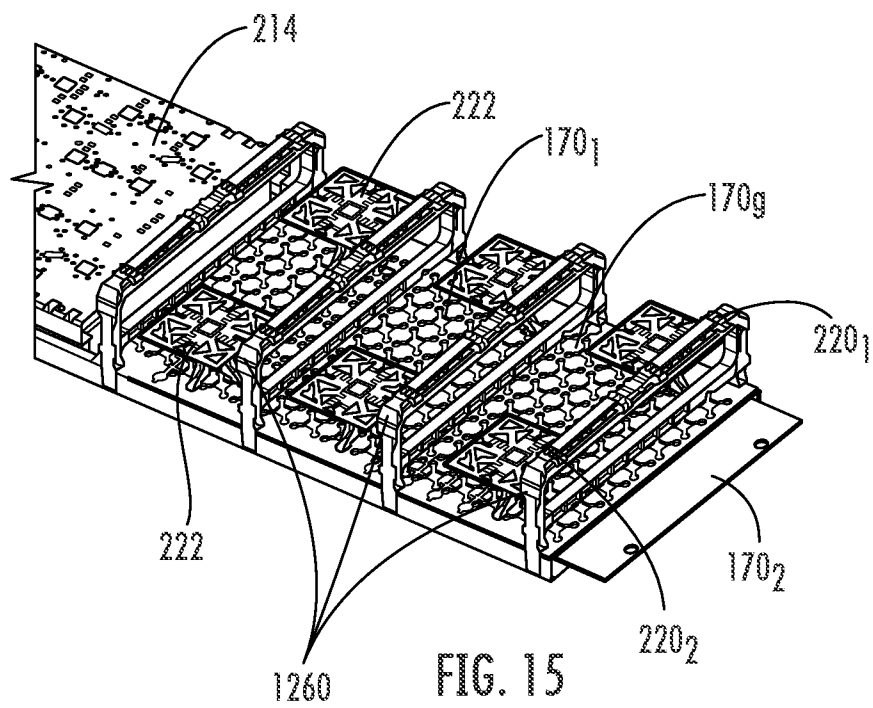


FIG. 14



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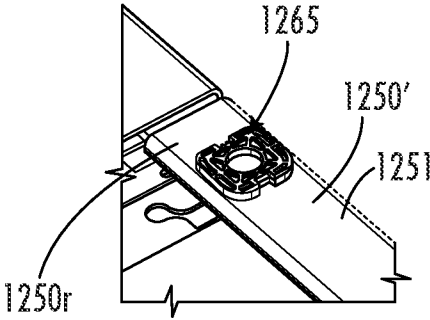


FIG. 16B

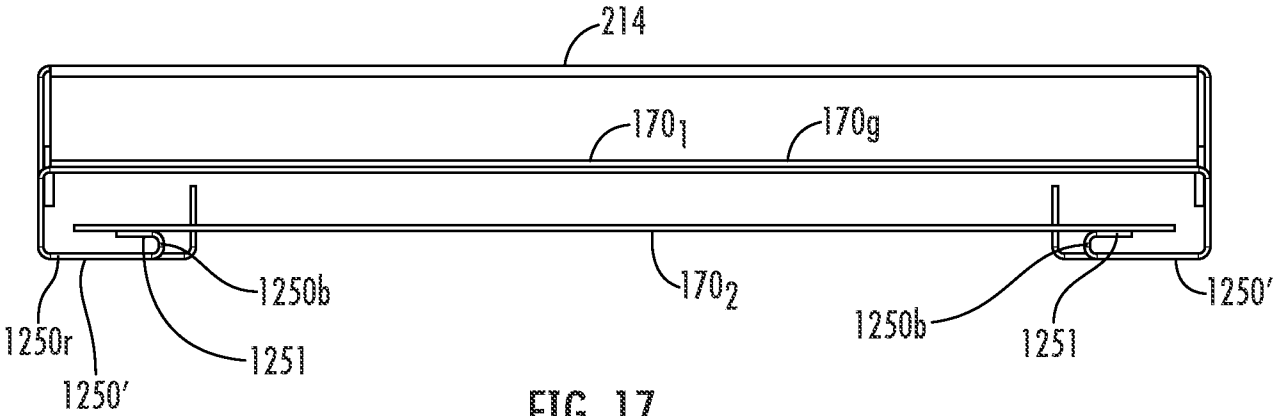


FIG. 17

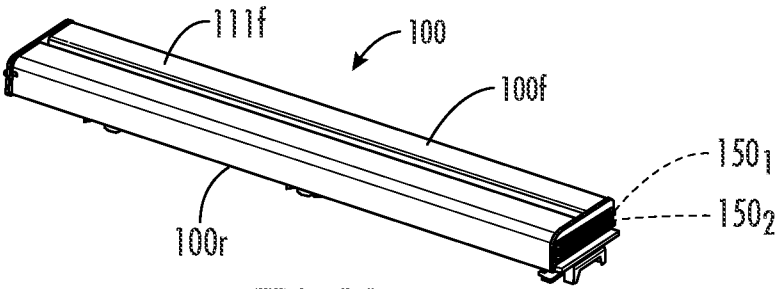


FIG. 18

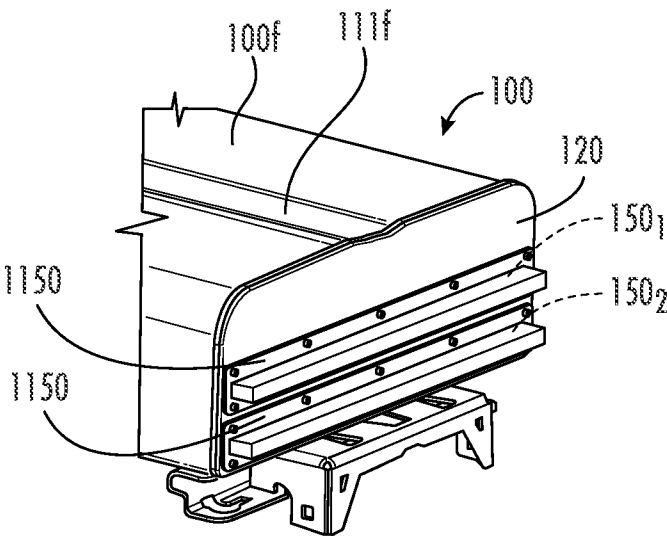


FIG. 19

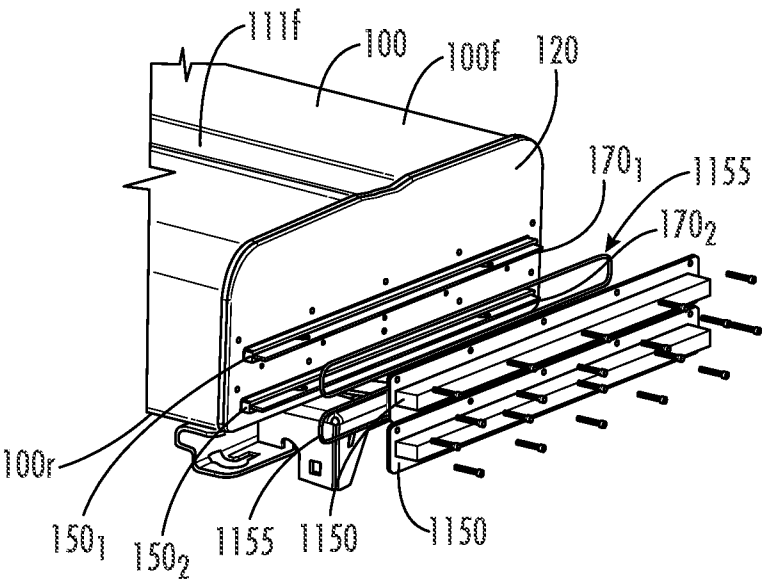


FIG. 20

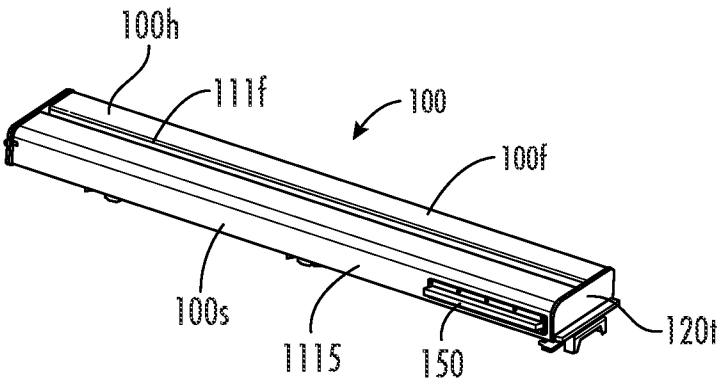


FIG. 21A

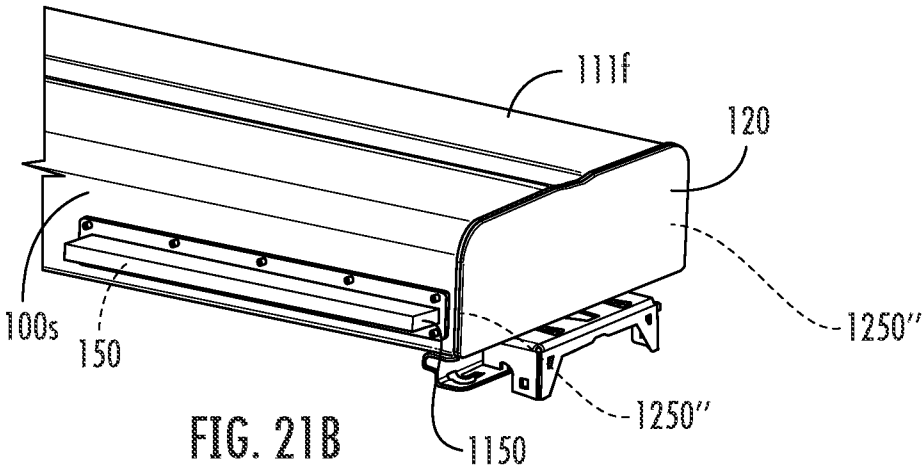


FIG. 21B

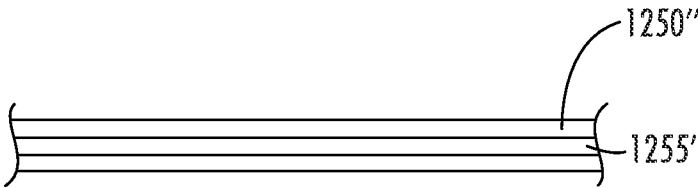
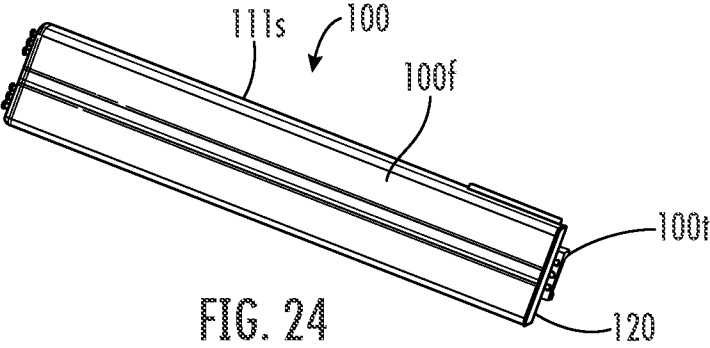
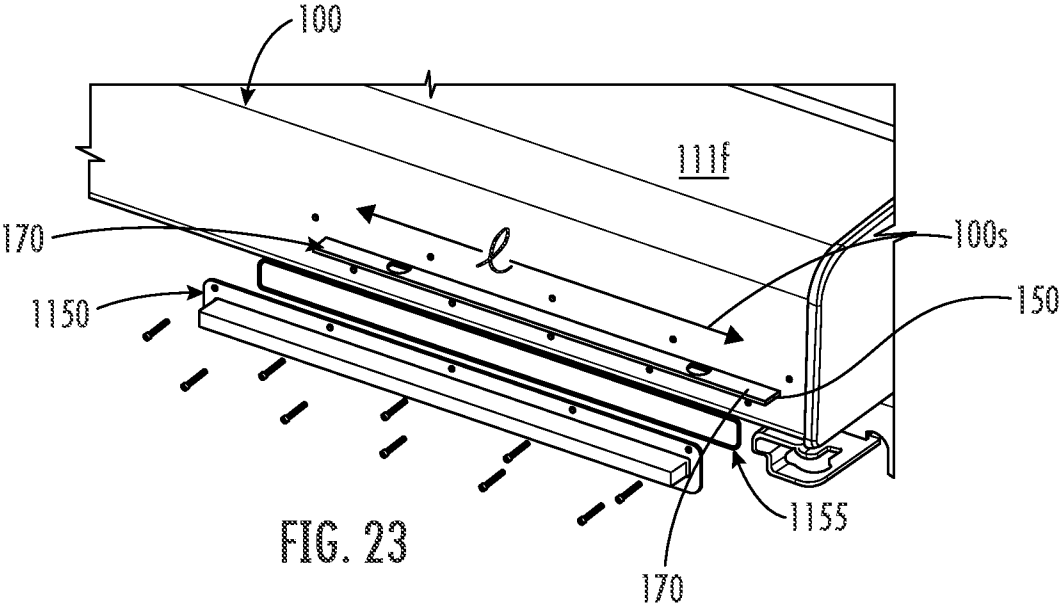


FIG. 22



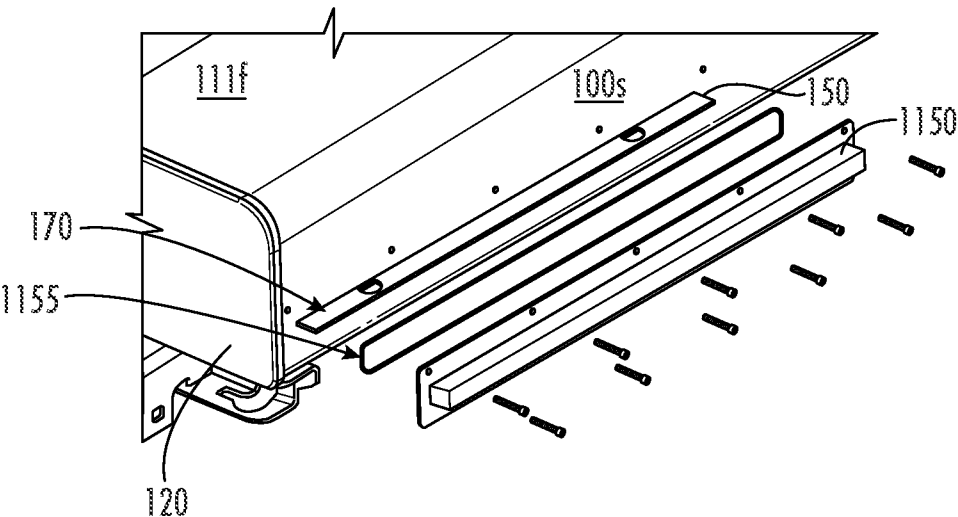
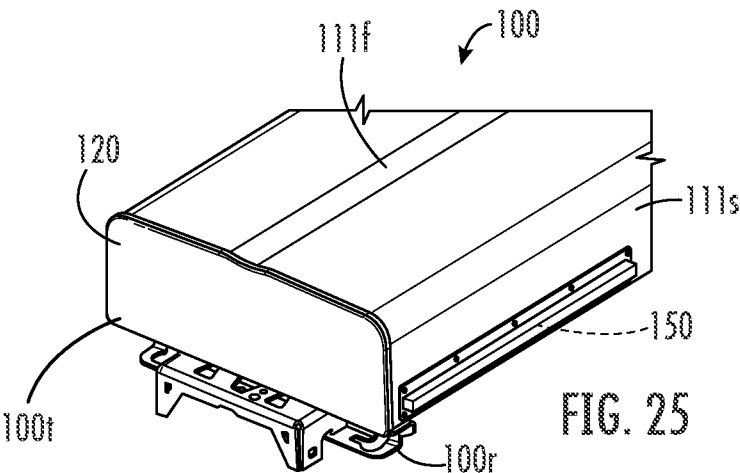
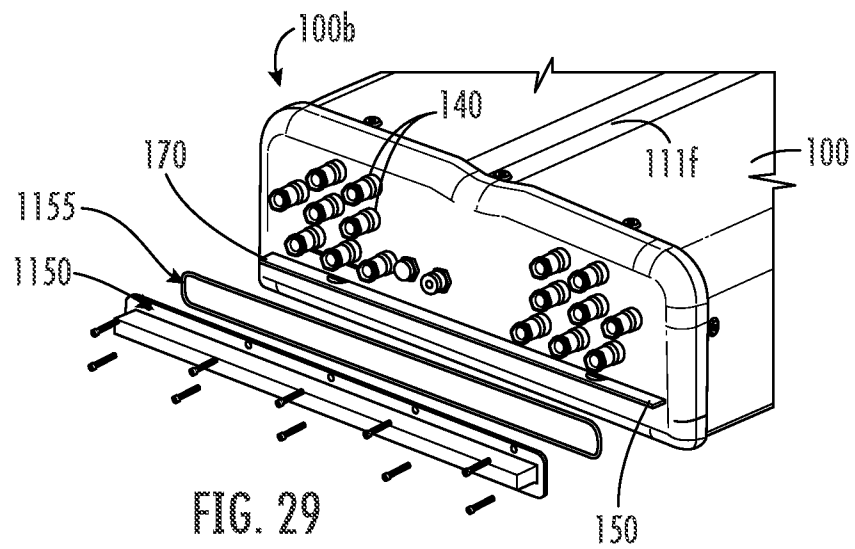
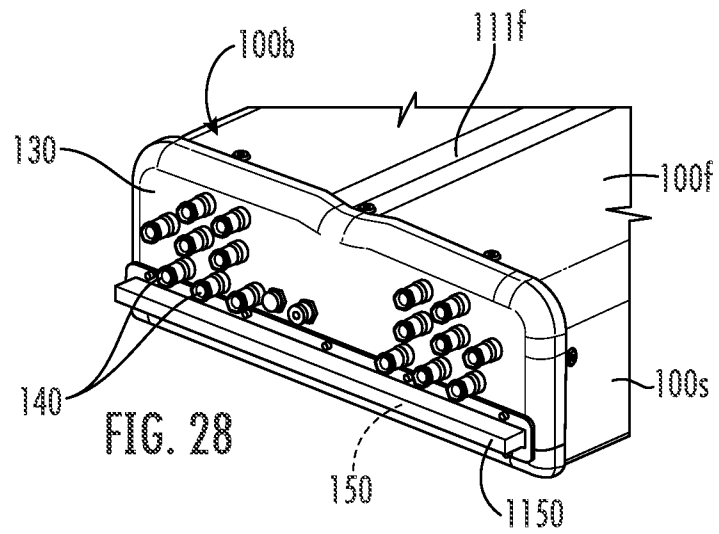
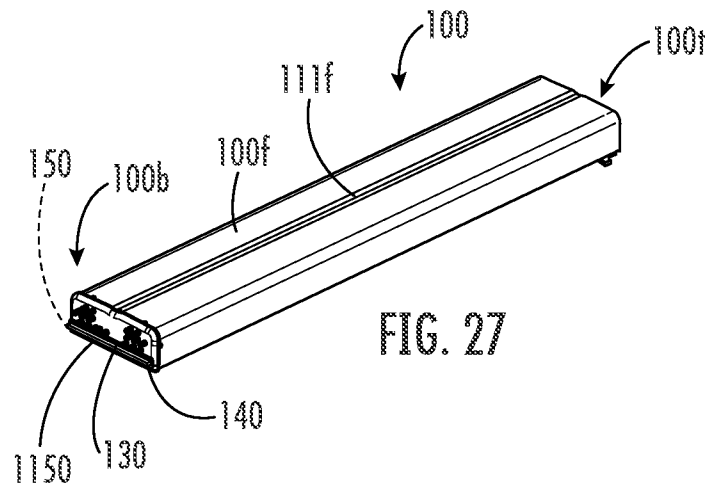
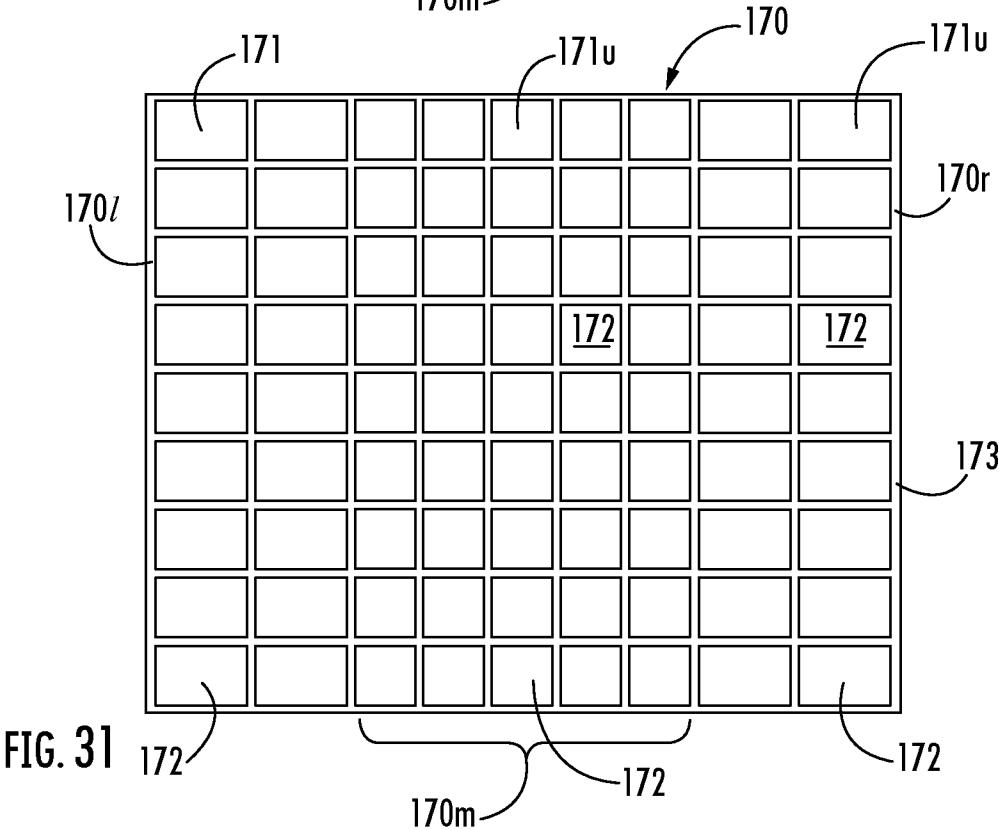
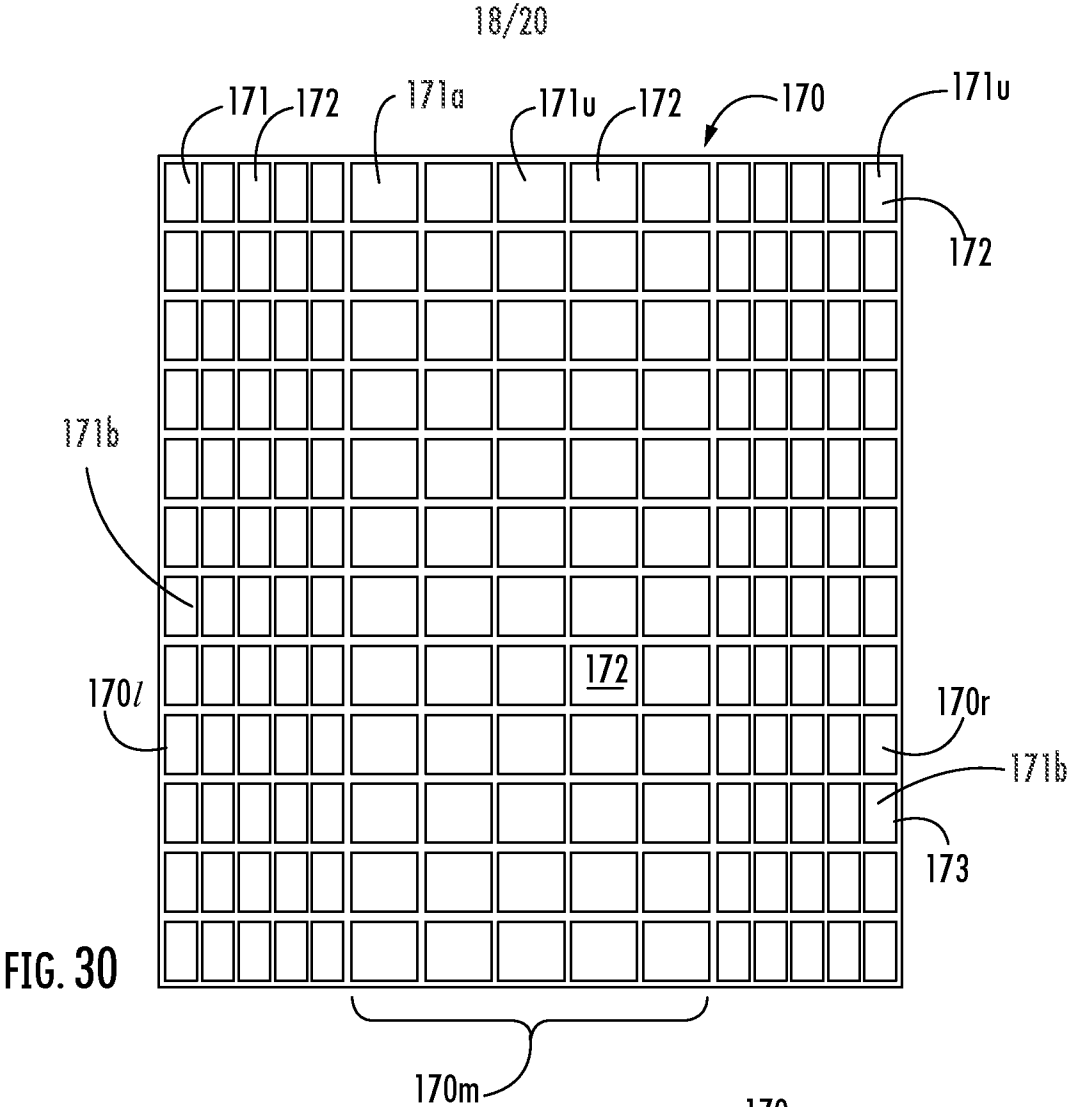


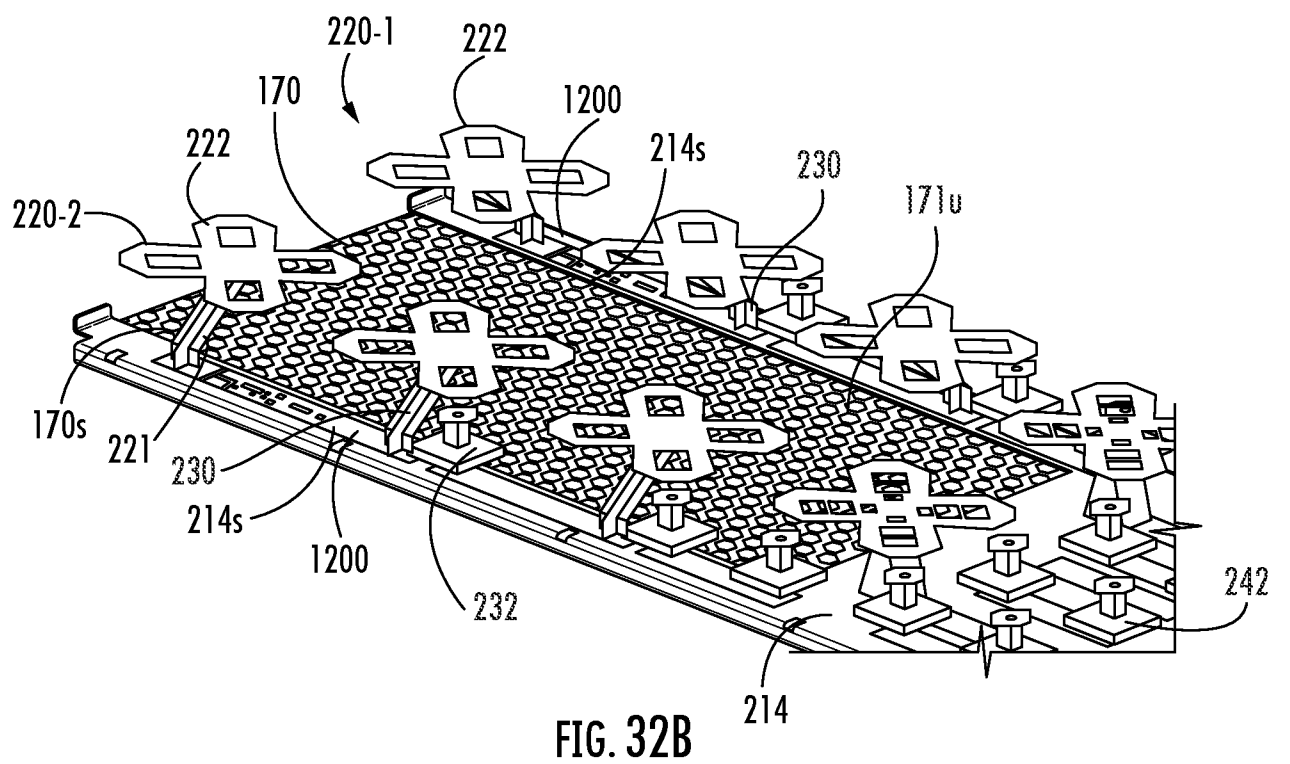
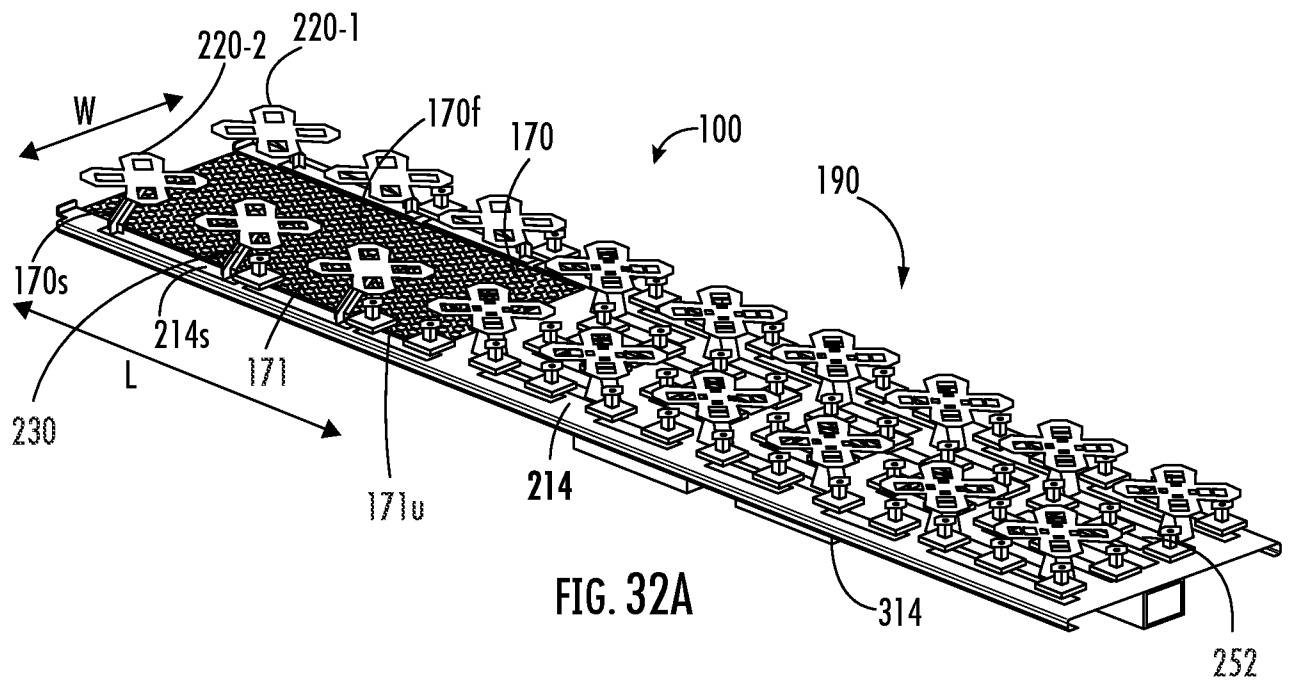
FIG. 26

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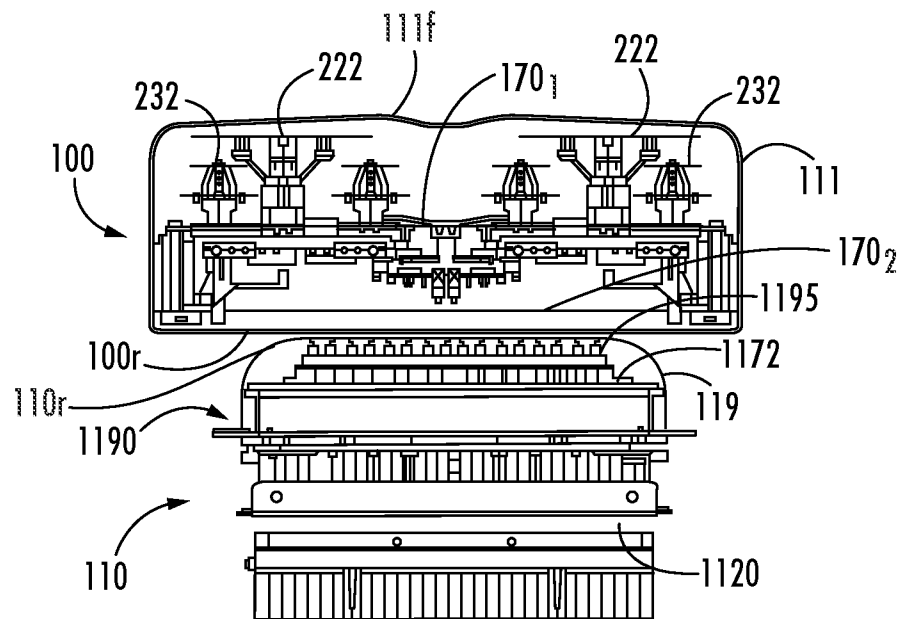


FIG. 33A

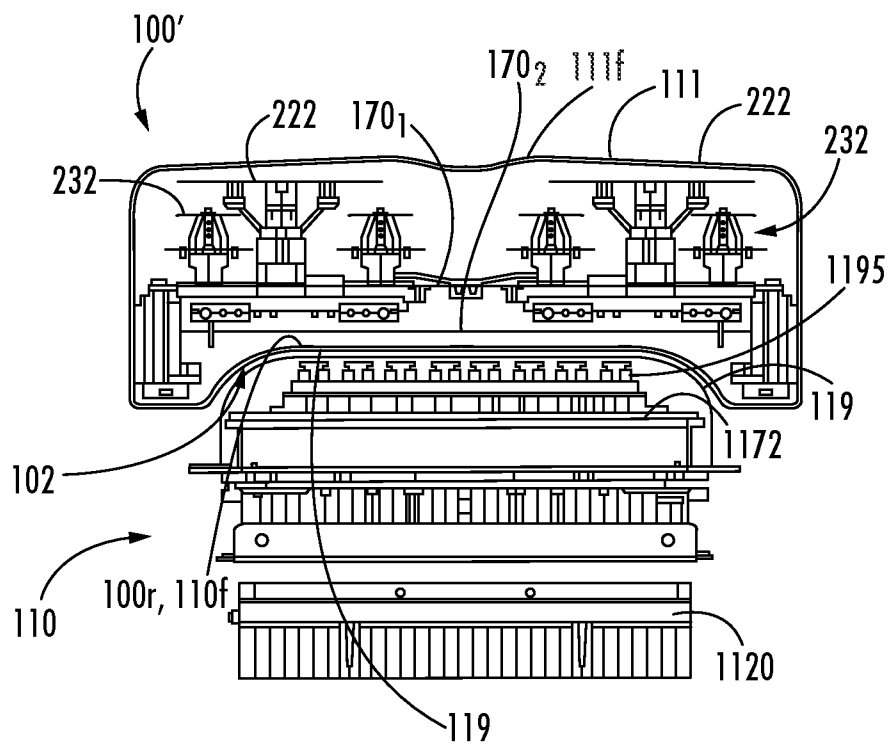


FIG. 33B

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 24/10969

A. CLASSIFICATION OF SUBJECT MATTER

IPC - INV. H01Q 15/00, H04B 7/0413 (2024.01)

ADD. H01Q 1/12 (2024.01)

CPC - INV. H01Q 15/0013, H04B 7/0413

ADD. H01Q 1/12

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

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

See Search History document

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

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2021/0305684 A1 (CommScope Technologies LLC) 30 September 2021 (30.09.2021), entire document, especially: para [0308], [0366], [0417]	1-25
A	US 2022/0037768 A1 (CommScope Technologies LLC) 03 February 2022 (03.02.2022), entire document, especially: para [0049], [0051]	1-25
A	US 2021/0320400 A1 (DISH Wireless LLC) 14 October 2021 (14.10.2021), entire document	1-25
A	US 2022/0195687 A1 (CommScope Technologies LLC) 23 June 2022 (23.06.2022), entire document	1-25
A	US 2022/0278462 A1 (CommScope Technologies LLC) 01 September 2022 (01.09.2022), entire document	1-25

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

* Special categories of cited documents:

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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

"&" document member of the same patent family

Date of the actual completion of the international search

20 March 2024

Date of mailing of the international search report

APR 19 2024

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Authorized officer

Kari Rodriguez

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