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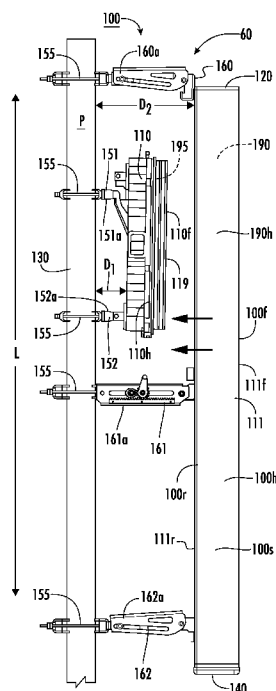


FIG. 3

(57) Abstract: Base station antennas include an externally accessible active antenna module releasably coupled to a target mounting structure behind a rear of a base station antenna housing using active antenna module mounting brackets that attach to the active antenna module, project rearward of the active antenna module and are configured to directly attach to a target mounting structure such as a pole. The base station antenna housing has a passive antenna assembly that cooperates with the active antenna module.

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BASE STATION ANTENNAS HAVING AN ACTIVE ANTENNA MODULE(S) AND RELATED MOUNTING SYSTEMS AND METHODS

Related Application(s)

[0001] The present application claims priority from and the benefit of U.S. Provisional Patent Application Serial No. 63/371,990, filed August 19, 2022, and U.S. Provisional Patent Application Serial No. 63/380,402, filed October 21, 2022, the disclosure of which are hereby incorporated herein in their entireties.

Field

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

Background

[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] FIGS. 1 and 2 illustrate an example of a prior art "active" 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.

[0006] FIG. 2 illustrates that the antenna 10 can include one or more radios 50 that are mounted to the housing 10h. As the radios 50 may generate significant amounts of heat, it may be appropriate to vent heat from the active antenna in order to prevent the radios 50 from overheating. Accordingly, each radio 50 can include a (die cast) heat sink 54 that is mounted on the rear surface of the radio 50. The heat sinks 54 are thermally conductive and include a plurality of fins 54f. Heat generated in the radios 50 passes to the heat sink 54 and spreads to the fins 54f. As shown in FIG. 2, the fins 54f are external to the antenna housing 10h. This allows the heat to pass from the fins 54f to the external environment. Further details of example conventional antennas can be found in co-pending PCT Publication Nos. WO2019/236203 and WO2020/072880, the contents of which are hereby incorporated by reference as if recited in full herein.

Summary

[0007] Embodiments of the present invention are directed to a base station antenna assembly that includes: a housing having a passive antenna assembly and a plurality of mounting brackets coupled directly or indirectly to a rear of the housing and to a mounting structure; and at least one active antenna bracket coupled to the active antenna module and attached directly to the mounting structure whereby the active antenna module is separately attachable to the mounting structure and resides behind the housing of the passive antenna assembly.

[0008] The active antenna module can include a massive multiple input multiple output (mMIMO) antenna array of radiating elements positioned in front of an active reflector.

[0009] The passive reflector in the housing can be electrically coupled to the active reflector to thereby provide a common electrical ground.

[0010] The passive reflector in the housing can be provided as at least one frequency selective surface (FSS).

[0011] The passive reflector in the housing can be provided as first and second FSS' stacked in a front to back direction to be in front of the active antenna module.

[0012] Other aspects are directed to a base station antenna assembly that includes: a housing of a base station antenna with a passive antenna assembly and a passive reflector in the housing; a plurality of passive antenna mounting brackets coupled to the housing and configured to attach to a mounting structure; and an active antenna module having at least one active antenna mounting bracket configured to directly attach to the mounting structure. In an installed position, the active antenna module is behind the housing of the base station antenna.

[0013] The active antenna module can be independently attachable to the mounting structure whereby the active antenna module is directly supported by the mounting structure.

[0014] The at least one active antenna mounting bracket can have at least one mounting arm that extends rearwardly of a rear of the active antenna module to the mounting structure.

[0015] The plurality of passive antenna mounting brackets can include a first passive antenna mounting bracket and a longitudinally spaced apart second passive antenna mounting bracket. The at least one active antenna mounting bracket and the active antenna module can reside between the first and second passive antenna mounting brackets.

[0016] The active antenna module can have a massive multiple input multiple output (mMIMO) antenna array of radiating elements.

[0017] The mMIMO antenna array can be positioned behind a passive reflector in the housing.

[0018] The plurality of passive antenna mounting brackets are configured to be adjustable to provide an adjustable distance between the active antenna module and a rear of the housing.

[0019] The plurality of passive antenna mounting brackets can be configured to provide an adjustable downtilt of the housing.

[0020] The plurality of active antenna mounting brackets can be configured to provide an adjustable downtilt of the active antenna module.

[0021] The plurality of passive antenna mounting brackets can be configured to provide an adjustable downtilt of the housing and the plurality of active antenna mounting brackets can be configured to provide an adjustable downtilt of the active antenna module whereby each set of brackets can be separately/individually adjustable for downtilt.

[0022] The plurality of passive antenna mounting brackets and/or the at least one active antenna bracket can be configured to be adjustable to adjust a distance between a front of the active antenna module and a rear of the housing.

[0023] The plurality of passive antenna mounting brackets can have mounting arms with a first length in a front to back direction and the at least one active antenna mounting bracket can have mounting arms with a second length in a front to back direction. The mounting arms of the at least one active antenna mounting bracket extends rearward of the active antenna module to the mounting structure and the first length can be greater than the second length.

[0024] The active antenna mounting brackets can have pole clamps on respective end portions thereof.

[0025] Other aspect of the present invention are directed to methods of installing an active antenna module to a base station antenna having a passive antenna housing with a passive antenna. The methods include attaching a plurality of passive antenna mounting brackets attached to the passive antenna housing to a target mounting structure; and before or after attaching the plurality of passive antenna brackets to the target mounting structure, attaching the active antenna module directly to the target mounting structure using at least one active antenna mounting bracket that extends rearwardly outward past a rear of the active antenna module.

[0026] The methods can further include adjusting a distance between the passive antenna housing and the active antenna module after the attaching steps to position the passive antenna housing closer to the active antenna module.

[0027] The method can further include moving at least one of the plurality of passive antenna mounting brackets to adjust a downtilt of the passive antenna housing and independently

moving at least one of the at least one active antenna mounting bracket to adjust a downtilt of the active antenna module.

[0028] The passive antenna housing is attached to the target mounting structure before the active antenna module is attached to the target mounting structure.

[0029] The attaching steps are carried out so that a front of the active antenna module and a rear of the passive antenna housing are separated by a first distance and the active antenna module is supported entirely by the target mounting structure.

[0030] The method can further include moving one or both of the active antenna module and/or the passive antenna housing to be closer together while both remain attached to the target mounting structure.

[0031] The active antenna module can provide 5G operation and the passive antenna of the base station antenna can provide 4G operation.

[0032] Still other embodiments are directed to methods of installing an active antenna module to a base station antenna comprising an active antenna module and a passive antenna housing. The methods include: providing a mounting system that includes a plurality of active antenna mounting brackets; attaching the active antenna mounting brackets of the active antenna module directly to a mounting structure to thereby mount the active antenna module to the mounting structure; and mounting passive antenna brackets attached to the passive antenna housing to the mounting structure before or after attaching the active antenna mounting brackets to the target mounting structure, with the passive antenna housing positioned in front of the active antenna; then sliding the passive antenna housing rearward, while attached to the passive antenna brackets to reside closer to the active antenna module to thereby install the active antenna module to the base station antenna.

[0033] The active antenna module can provide 5G operation and the passive antenna of the base station antenna can provide 4G operation.

[0034] Other aspects of the present invention are directed to a base station antenna assembly. The base station antenna assembly includes a housing of a base station antenna comprising an antenna assembly and a plurality of antenna mounting brackets coupled to the housing and configured to attach to a mounting structure. The plurality of antenna mounting brackets include an upper antenna mounting bracket, a middle antenna mounting bracket, and a lower antenna mounting bracket. The middle antenna mounting bracket includes a rack and pinion assembly configured to adjust the housing of the base station antenna a distance from the mounting structure.

[0035] The middle antenna bracket further can include a main body having two opposing sidewalls, each sidewall having an elongated slot. The rack and pinion assembly can be coupled to an outer surface of one of the sidewalls.

[0036] The pinion of the rack and pinion assembly can be held against an outer surface of one of the sidewalls by a fastener extending through the elongated slot. The fastener can be configured to allow the pinion to rotate relative to the sidewall such that the pinion can travel back-and-forth along the rack.

[0037] An end of the fastener can be configured to engage a wrench used to rotate the pinion.

[0038] The middle antenna mounting bracket can further include a brake slider configured to engage the pinion of the rack and pinion assembly to lock the pinion in a position along the rack.

[0039] The brake slider can be secured to the middle antenna mounting bracket via a second fastener extending through the same elongated slot in the sidewall of the bracket as the fastener holding the pinion.

[0040] At least a portion of the brake slider can be configured to be received by and slide within the elongated slot of the bracket.

[0041] The brake slider can include an elliptical-shaped aperture through which the second fastener extends and allows the brake slider to slide back-and-forth relative to the fastener to engage or disengage the pinion.

[0042] Other aspects of the present invention are directed to a method of installing an active antenna module to a base station antenna comprising a passive antenna housing with a passive antenna. The method includes providing a mounting system including a plurality of antenna mounting brackets coupled to the housing and configured to attach to a mounting structure. The plurality of antenna mounting brackets includes an upper antenna mounting bracket, a middle antenna mounting bracket, and a lower antenna mounting bracket. The middle antenna mounting bracket includes a rack and pinion assembly configured to adjust the housing of the base station antenna a desired distance from the mounting structure and a brake slider configured to engage the pinion of the rack and pinion assembly. The method further includes sliding the brake slider to disengage from the pinion of the rack and pinion assembly; rotating the pinion to travel a desired direction along the rack of the rack and pinion assembly which simultaneously moves the middle antenna mounting bracket, and passive antenna housing coupled thereto, forwardly or rearwardly relative to the mounting structure; and sliding the brake slider to engage the pinion, thereby locking the housing at the desired distance from the mounting structure.

[0043] The method can further include pivoting the housing about the middle antenna mounting bracket to adjust the base station antenna to a desired angle of downtilt or uptilt.

[0044] The method can further include rotating the pinion in a first direction such that the antenna housing is moved a maximum distance from the mounting structure; mounting an active antenna module to the mounting structure behind the already mounted passive antenna housing; and rotating the pinion in a second opposite direction such that the antenna housing is moved to a minimum distance from the mounting structure, proximate to the active antenna module.

[0045] The method can further include placing a gauge between the active antenna module and the passive antenna housing to prevent the passive antenna housing from contacting the active antenna module.

[0046] Other aspects of the present invention are directed to a mounting gauge kit. The kit includes two gauge plates and two fastening mechanisms. Each gauge plate includes a rectangular main body having one or more apertures and one or more recesses along a bottom edge. Each fastening mechanism is configured to be received through the one or more apertures to secure a respective gauge plate to a clamping member of a pipe clamp for an antenna bracket secured to a passive antenna housing. The gauge plates are configured to define a location along a mounting structure to secure an upper pipe clamp for an active antenna module in relation to the clamping member of the pipe clamp for the antenna bracket.

[0047] The one or more recesses of the gauge plates can be configured to engage a fastener of the upper pipe clamp for the active antenna module.

[0048] The clamping member of the pipe clamp for the antenna bracket can include a pair of flanges extending downwardly therefrom. Each flange can include an open-ended slot extending into an aperture. The open-ended slot and aperture can be configured to receive and secure a respective fastening mechanism.

[0049] The one or more apertures can include a vertically-extending elongated aperture and a series of spaced-apart horizontally-extending elongated apertures. Each horizontally-extending apertures extends outwardly from the vertically-extending elongated aperture such that the horizontally-extending apertures are generally perpendicular to the vertically-extending aperture and generally parallel to each other. Each horizontally-extending aperture can be in fluid communication with the vertically-extending aperture.

[0050] The horizontally-extending apertures can correspond to a defined location for the upper pipe clamp for the active antenna module along the mounting structure in relation to the antenna bracket.

[0051] Each fastening mechanism can have a main body, a transition section extending outwardly from the main body. An end of the transition section can be threaded.

[0052] The main body of each fastening mechanism can have a cylindrical profile with a locking section extending radially outwardly therefrom. The cylindrical main body can be configured to be received through the aperture of a respective flange of the clamping member and the locking section can be configured to be received by the corresponding open-ended slot.

[0053] The main body of each fastening mechanism can have a draft or taper of about 1 degree.

[0054] The transition section of each fastening mechanism can be configured to be received by a horizontally-extending aperture in the gauge plate and configured to traverse and slide therein.

[0055] The threaded end of the transition section can be configured to receive a corresponding nut to lock the respective fastening mechanism in place and secure the gauge plate to the clamping member.

[0056] The threaded end of the transition section of each fastening mechanism can be sized and configured to traverse and slide within the vertically-extending aperture of the gauge plate.

[0057] The mounting gauge kit can be in combination with a base station assembly having a housing of a base station antenna including an antenna assembly. A plurality of antenna mounting brackets can be coupled to the housing and configured to attach to a mounting structure, the plurality of antenna mounting brackets including an upper antenna mounting bracket, a middle antenna mounting bracket, and a lower antenna mounting bracket.

Brief Description of the Drawings

[0058] FIG. 1 is a perspective view of a prior art base station antenna.

[0059] FIG. 2 is a back view of the prior art base station antenna of FIG. 1.

[0060] FIG. 3 is a side view of a mounting system for mounting an active antenna module and a passive antenna housing of a base station antenna to a mounting structure according to embodiments of the present invention.

[0061] FIG. 4 is a lateral section, simplified schematic illustration of an example base station antenna with an active antenna module coupled to a passive antenna housing according to embodiments of the present invention.

[0062] FIG. 5 is a lateral section, simplified schematic illustration of another example base station antenna with an active antenna module coupled to a passive antenna housing according to embodiments of the present invention.

[0063] **FIG. 6** is a front, side perspective view of a portion of a base station antenna, without the radome(s) illustrating example radiating element arrangements according to embodiments of the present invention.

[0064] **FIG. 7** is a rear, side perspective view of the mounting system of **FIG. 3** without the active antenna module according to embodiments of the present invention.

[0065] **FIG. 8A** is an enlarged top perspective view of an upper antenna mounting bracket of the mounting system of **FIG. 7** according to embodiments of the present invention.

[0066] **FIG. 8B** is an enlarged top perspective view of a lower antenna mounting bracket of the mounting system of **FIG. 7** according to embodiments of the present invention.

[0067] **FIG. 9A** is an enlarged side view of a middle antenna mounting bracket of the mounting system of **FIG. 7** according to embodiments of the present invention.

[0068] **FIG. 9B** is an enlarged top perspective view of the middle antenna mounting bracket of **FIG. 9A**.

[0069] **FIG. 10A** is a side perspective view of a brake slider according to embodiments of the present invention.

[0070] **FIG. 10B** is an opposing side perspective view of the brake slider of **FIG. 11A**.

[0071] **FIG. 11A** is a side view of the mounting system of **FIG. 7** positioning the passive antenna at maximum down-tilt (*e.g.*, about -5 degrees).

[0072] **FIG. 11B** is a side view of the mounting system of **FIG. 7** positioning the passive antenna with no tilt (*i.e.*, zero degrees)

[0073] **FIG. 11C** is a side view of the mounting system of **FIG. 7** positioning the passive antenna at maximum up-tilt (*e.g.*, about +5 degrees).

[0074] **FIG. 12A** is a side view of the mounting system of **FIG. 7** illustrating the middle antenna mounting bracket adjusted such that the passive antenna is positioned the farthest possible distance from the mounting pole.

[0075] **FIG. 12B** is a side view of the mounting system of **FIG. 12A** with an active antenna module mounted to the mounting pole.

[0076] **FIG. 12C** is a side view of the mounting system of **FIG. 12B** illustrating the middle antenna mounting bracket adjusted such that the passive antenna is positioned the closest possible distance from the mounting pole.

[0077] **FIGS. 13A-13C** illustrate the adjustment capabilities of the mounting system according to embodiments of the present invention. **FIG. 13A** illustrates distance adjustment of the mounting system with only a passive antenna. **FIG. 13B** illustrates distance adjustment of the mounting system with a passive antenna and an active antenna module. **FIG. 13C**

illustrates tilt adjustment of the mounting system with a passive antenna and an active antenna module.

[0078] FIG. 14 is an enlarged rear perspective view of the mounting system of FIG. 3 utilizing a mounting gauge kit according to embodiments of the present invention.

[0079] FIG. 15A is a bottom perspective view of the mounting gauge kit shown in FIG. 14.

[0080] FIG. 15B is a bottom perspective view of a modified clamping member for the mounting gauge kit of FIG. 15A.

[0081] FIG. 15C is a rear view of a gauge plate for the mounting gauge kit of FIG. 15A.

[0082] FIG. 15D is a side view of a cap bolt for the mounting gauge kit of FIG. 15A.

[0083] FIG. 15E is a perspective view of the cap bolt of FIG. 15D.

[0084] FIG. 16A is an exploded view of the mounting gauge kit of FIG. 14.

[0085] FIG. 16B illustrates movement of a cap bolt within a gauge plate of the mounting gauge kit of FIG. 14 to define the location of an active antenna module mounting kit.

[0086] FIG. 17A is an enlarged perspective side view of a gauge plate with a respective cap bolt secured thereto.

[0087] FIG. 17B is an enlarged perspective view of the opposing side view of gauge plate and cap bolt of FIG. 17A.

Detailed Description

[0088] In the description that follows, a 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 antenna 100 (FIG. 3) 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 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 or uptilt.

[0089] Referring to FIG. 3, an example mounting system 60 for mounting an active antenna module 110 of a base station antenna 100 behind a passive antenna housing 190h comprising a passive antenna assembly 190. The passive antenna housing 190h can define the primary housing 100h of the base station antenna 100. The term "active antenna module" is used

interchangeably with "active antenna unit," "AAU," "remote radio unit" or "radio" and refers to a cellular communications unit comprising radio circuitry and associated antenna elements that are 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, 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 antenna unit closer to a front **100f** (external radome) of the base station antenna **100** than the radio unit.

[0090] 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** or housing **100h**. The arrays of radiating elements included in the passive antenna assembly **190** are configured to form static antenna beams. The passive antenna assembly **190** can comprise radiating elements such as one or both low-band radiating elements **222** and/or mid-band or high band radiating elements **232** (*see, e.g., FIGS. 4 and 5*). The passive antenna assembly **190** is mounted in the base station antenna housing **100h** and the base station antenna housing **100h** can releasably (detachably) couple (*e.g.*, directly or indirectly attach) to one or more active antenna modules **110** that is/are separate from the passive antenna assembly **190**.

[0091] The arrays of radiating elements included in the passive antenna assembly **190** (*see, e.g., FIGS. 5 and 6*) 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** may comprise a backplane provided by a reflector **170**, with radiating elements **222** projecting in front of the reflector **170** and the radiating elements **222** 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** (**FIG. 3**) 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 a back of the base station antenna housing **100h**.

[0092] Referring to **FIG. 3**, the base station antenna housing **100h** may be substantially rectangular with a flat rectangular cross-section. At least a front side **100f** of the housing **100h** may be implemented as a radome **111** providing a front radome **111f**. A "radome" refers to a dielectric cover that allows RF energy to pass through in certain frequency bands. A rear **100r** of the housing **100h** may also include a rear radome **111r** that is opposite the front radome **111f**. Optionally, the housing **100h** and/or the radome **111** can also comprise two (narrow) sidewalls **100s** providing side radomes **111s** facing each other and extending rearwardly between the front radome **111f** and the rear radome **111r**. The sidewalls **100s**, **111s** can have a width, measured in a front-to-back direction, that is 40%-90% less than a lateral extent of the housing **100h**.

[0093] The top side **100t** of the housing **100h** may be sealed in a waterproof manner and may comprise an end cap **120** and the bottom side **100b** of the housing **100h** may be sealed with a separate end cap **130** with RF ports **140**.

[0094] The front side **100f**, at least part of the sidewalls **100s** and typically at least part of the rear **100r** of the housing **100h** are typically implemented as radomes that are substantially transparent to RF energy within the operating frequency bands of the passive antenna assembly **190** and active antenna module **110**. At least part of the radome **111** may be formed of, for example, fiberglass or plastic.

[0095] Radiation (electromagnetic waves) transmitted by the array of radiating elements **1195** (**FIGS. 4-6**) in the active antenna unit **110** can transmit through a front radome of the active antenna module **110**, enter the housing **100h** from the back **100r** and transmit out the front radome **111f**, thus traveling through at least three radome walls spaced apart in a front-to-back direction. Active antenna modules **110** are often configured to operate using time division duplexing multiple access schemes in which the transmit and receive signals do not overlap in time, but instead the active antenna module **110** transmits RF signals during selected time slots and receives RF signals during other time slots. The passive antenna assembly **190** can operate under frequency division duplexing (FDD) multiple access schemes.

[0096] Turning to **FIG. 3**, the mounting system **60** comprises a plurality of mounting brackets **160**, **161**, **162** that are longitudinally spaced apart and attached to the passive antenna housing **190h** and that are also configured to attach to the target mounting structure **130**, shown as a pole **P**. The brackets **160**, **161**, **162** can be referred to as "passive antenna brackets." Although shown as three brackets, a lesser number of passive antenna brackets such as two brackets (*e.g.*, brackets **160**, **161**) may be used or more than three brackets may be used. The mounting system **60** also includes a plurality of brackets **151**, **152** that are longitudinally spaced

apart and attached to the active antenna module **110** and that are configured to attach directly to the target mounting structure **130**. The brackets **151**, **152** can be referred to as "active antenna brackets." The active antenna module **110** can be separately attached to the target mounting structure **130** (independent of the passive antenna housing **190h**) using the active antenna brackets **151**, **152**.

[0097] The passive antenna brackets **160**, **161**, **162** can have mounting arms **160a**, **161a**, **162a**. The active antenna brackets **151**, **152** can have mounting arms **151a**, **152a**. The active antenna mounting arms **151a**, **152a**, can project rearward a distance D_1 . The passive antenna mounting arms **160a**, **161a**, **162a** can rearward forward a distance D_2 which is greater than D_1 , whereby $D_2 > D_1$. D_2 can be 1.1-10 times greater than D_1 , including 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 8.5, 9, 9.5 and 10 and any number therebetween, or the spacing D_2 can be even greater than 10 times greater than D_1 . Each of the brackets **151**, **152**, **160**, **161**, **162** can have pole clamps **155**. For additional discussion of some brackets for mounting the passive antenna housing **100h**, see PCT Application No. PCT/CN2021/11984, the contents of which are hereby incorporated by reference as if recited in full herein.

[0098] As shown in **FIG. 3**, a first one of the passive antenna brackets **160** resides above the active antenna brackets **151**, **152** of the active antenna module **110** and two lower passive antenna brackets **161**, **162** reside below the active antenna brackets **151**, **152**. The active antenna module **110** can reside between neighbouring passive antenna brackets **160**, **161**. The active antenna module **110** can have a width W_1 in a lateral direction that is the same, less or even greater than a width W_2 of the base station antenna housing **100h**. **FIG. 4** shows the widths W_1 being substantially the same as W_2 . **FIG. 5** shows $W_1 < W_2$ by about 20-80%.

[0099] In some embodiments, D_1 may be a fixed distance and D_2 can be adjustable in a front to back direction so that the passive antenna housing **190h** can have a first installation position that is forward of a final installation position.

[00100] In some embodiments, the passive mounting brackets **160**, **161**, **162** can have a fixed front to back length D_2 and the active antenna brackets **150**, **151** are adjustable to provide an adjustable distance D_1 to allow adjustment in a distance between the active antenna module **110** and the passive antenna housing **100h** to thereby position the active antenna module **110** closer to the passive antenna housing **190h** after preliminary installation.

[00101] In other embodiments, both the active antenna brackets **150**, **151** and the passive antenna brackets **160**, **161**, **162** are adjustable in a front to back direction to adjust D_1 and D_2 and/or the distance between the active antenna module **110** and the passive antenna housing **190h**.

[00102] In some embodiments, the passive antenna housing **190h** can be moved rearward, while attached to the passive antenna brackets **160-163** and the target mounting structure **130** to reside closer to the front **110f** of the active antenna unit **110**, once attached to the target mounting structure **130**. Thus, the rear **100r** of the passive antenna housing **100h/190h** can abut or be closely spaced apart from the front **110f** of the active antenna module **110**.

[00103] The passive antenna brackets **160**, **161**, **162** can cooperate to provide an adjustable downtilt of the passive antenna housing **190h**. The active antenna brackets **151**, **152** can cooperate to provide an adjustable downtilt of the active antenna module **110**.

[00104] The downtilt of the active antenna module **110** can be adjusted independent of the downtilt of the passive antenna housing **190h**.

[00105] Once in position on the target mounting structure **130**, the active antenna module **110** may optionally be attached to the passive antenna housing **190h**.

[00106] Referring to **FIG. 4**, a passive antenna assembly **190** is shown with a reflector **170** in the housing **100h**. The reflector **170** can have a frequency selective surface (or FSS) **170F**, which can be provided by a printed circuit board/flex circuit or metal grid that extends laterally and longitudinally and can reside in the housing and in front of radiating elements **1195** of the (mMIMO array) of the active antenna module **110** (*see, e.g., FIGS. 3 and 4*). The frequency selective surface **170F** can be provided as first and second frequency selective surfaces **170F₁**, **170F₂**, stacked in a front-to-back direction to reside in front of the antenna array **1195** of the active antenna module. One of the at least one frequency selective surfaces **170F** can reside between longitudinally extending and laterally spaced apart right and left side metal strip reflector segments **170r**, **170l**.

[00107] In some embodiments, the frequency selective surface **170F** can be mounted on a suitable substrate such as, for example, a printed circuit board, PC and/or SMC. In some embodiments, the grid pattern is provided by metallic patches in one or more layers over and/or behind one or more dielectric layers, which may be provided by a multiple layer printed circuit board. The frequency selective surface **170F** can alternatively be configured as a grid reflector with a grid pattern(s) in sheet metal. For additional discussion of example FSS configurations providing at least part of a reflector, *see, e.g.,* co-pending U.S. Patent Application Serial No. 17/787,619 and U.S. Provisional Patent Application Serial No. 63/359,304, the contents of which are hereby incorporated by reference as if recited in full herein.

[00108] The frequency selective surface **170F** can be configured to allow high-band radiating elements, typically located in the active antenna module **110**, to propagate electromagnetic waves therethrough and to reflect lower band RF signals (lower band electromagnetic waves)

from lower band radiating elements **222**, **232** (*see, e.g.*, **FIGS. 4** and **5**) projecting forward of the frequency selective surface **170F**.

[00109] The frequency selective surface **170F** can comprise, in some embodiments, 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.

[00110] The rear **100r** of the housing **100h** may be provided as a closed outer surface, either recessed, or flat as shown in **FIGS. 3** and **4**. In a final installed configuration, the radome **119** and/or front **110f** of the active antenna module **110** can abut or be closely spaced apart from the rear **100r** of the housing **190h/100h**, such as spaced a distance "d" that is in a range of 0-3 inches or even greater (typically less than 12 inches), such as about 0, about 0.5, about 1.0, about 1.5, about 2 inches, about 2.5 inches or about 3 inches or any number therebetween.

[00111] As shown in **FIG. 5**, the rear **100r** of the base station antenna housing **100h** can have an open chamber **195** that receives the radome **119** of the active antenna module **110**.

[00112] Referring to **FIG 4**, the active antenna module **110** can have a reflector and/or ground plane **1172** that resides behind the antenna array **1195** in the active antenna module **110**. The reflector and/or ground plane **1172** can be configured to galvanically or capacitively couple to the reflector **170** in the base station antenna housing **100h**. The reflector **170** in the base station antenna housing **100h** can be called "the passive reflector." The reflector **1172**, where used, in the active antenna module **110** can be called "the active reflector."

[00113] Different active antenna modules **110** may be configured to have different radios, radiating elements or other components whereby the active antenna modules **110** can be different for different cellular service providers and even for the same cellular provider. The active antenna module **110** can be interchangeably replaced with another active antenna module **110** from the original equipment manufacturer (OEM) or from the same cellular communications service provider or from different cellular communications service providers. Thus, a plurality of different active antenna modules **110** that have different configurations, including different internal configurations and different external configurations, can be interchangeably used to cooperate with the base station antenna housing **100h**. The different active antenna modules **110** can each have the same exterior (perimeter) footprint and connectors or may have different exterior footprints and/or connectors. The different active antenna modules **110** can have different depth dimensions (front to back) and/or different width (lateral) dimensions. A respective base station antenna **100** can, for example, accept different active antenna modules **110** from different service providers at a field installation and/or

factory installation site using different adapter members or other mounting configurations that allow the interchangeable field installation/assembly. The base station antenna **100**/passive housing **190h**/antenna housing **100h** can thereby allow different active antenna modules **110** to be interchangeably installed, upgraded, or replaced. The base station antenna **100** can concurrently cooperate with first and second active antenna units **110**, one above the other, behind the housing **100h** and coupled to the mounting structure **130**, in some embodiments.

[00114] Referring to **FIG. 4**, the base station antenna **100** can include a reflector **170** that has right and left side reflector strip segments **170r**, **170l** (the orientation defined when viewed from a front **100f** of the base station antenna **100**) that extend in a longitudinal direction, optionally with an open space across at least part of active antenna module **110** and/or with a frequency selective surface **170F** in front of the radiating elements **1195** of the active antenna module **110**. The reflector **170** can be an extension of or coupled to a primary or main reflector **214** of the passive antenna assembly **190** (**FIG. 6**).

[00115] The base station antenna **100** can include at least one radome positioned between the (passive) reflector **170** and the active antenna module **110**. For example, referring to **FIG. 4**, and as discussed above, the active antenna module **110** can include a radome **119** at a front **110f** thereof, that resides in front of a mMIMO antenna array **1195**. The passive antenna assembly **190** can include a radome **1129** that resides in front of the radome **119** of the active antenna module **110**. The radome **1129** can be defined by a rear wall **100r** of the passive antenna housing **190h** or provided as another layer/wall.

[00116] Thus, in some embodiments, the base station antenna **100** can be configured with a first radome **119** and a second radome **1129**, spaced apart in a front to back direction. The first radome **119** can be the front **110f** part of the active antenna module **110** and be configured to seal the active antenna module **110**. The second radome **1129** can be configured to be a skin or middle/intermediate radome **1129** and can be configured to seal the base station antenna housing **100h** comprising the passive antenna assembly **190**.

[00117] **FIG. 4** also illustrates that (the passive antenna assembly **190** of) the base station antenna **100** can include low-band radiating elements **222** with respective angled feed stalks **222f** projecting forward of the reflector **170**, in front of the active antenna module **110**, and extending laterally inward at an angle that is parallel to or that is between 20-80 degrees from horizontal. Note that the low-band radiating elements **222** may (partially) extend in front of the outer columns of high-band radiating elements **1195** of the active antenna module **110**. Any of the feed stalk designs disclosed in U.S. Patent Publication No. 201/0305718 ("the '718 publication") may be used to implement the angled feed stalks **222f**. The entire content of the

'718 publication is incorporated herein by reference as if set forth in its entirety. However, it is also contemplated that angled feed stalks **222f** are not required and conventional configurations of same may be used.

[00118] The passive antenna assembly **190** of the base station antenna **100** can include low-band radiating elements **222** and/or mid-band radiating elements **232** with one or more of low-band feed stalks **222f** projecting laterally inward from a side segment **170s** of the reflector **170** and forward of the reflector **170**, in front of the active antenna module **110**. Again, note that the low-band radiating elements **222** may (partially) extend in front of the outer columns of high-band (mMIMO) radiating elements **1195** of the active antenna module **110**. This configuration may allow improved spacing and/or alternative configurations of the front of the active antenna module **110**.

[00119] The active antenna module **110** includes radio circuitry. The active antenna module **110** can comprise a radio unit **1120**. The active antenna module **110** can also include a filter and calibration printed circuit board assembly, and may also include phase shifters, which may alternatively be part of the filter and calibration assembly. The radiating elements **1195** can be provided as a massive MIMO array. The radiating elements **1195** can project forward of a multi-layer printed circuit board providing a ground plane **1172** and/or defining a reflector **1172**.

[00120] The radio unit **1120** typically includes radio circuitry that converts base station digital transmission to analog RF signals and vice versa. One or more of the radio units **1120**, the antenna assembly or the filter and calibration assembly can be provided as separate sub-units that are attachable (stackable). The radio unit **1120** and the antenna assembly can be provided as an integrated unit, optionally also including the calibration assembly. 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.

[00121] FIG. 6 is a front view of the passive antenna assembly **190** of base station antenna **100** (with the active antenna module **110** mounted thereon). The active antenna module **110** typically resides entirely behind and external to the rear surface **100r** of the base station antenna **100** but can alternatively project forward into a recess **195** provided by the rear surface **100r**, optionally with at least one frequency selective surface **170F** in front of and over the radiating elements **1195**. As shown, the antenna assembly **190** includes a main backplane **210** that has side walls **212** and a main reflector **214**. The backplane **210** may serve as both a structural component for the antenna assembly **190** and as a ground plane and reflector for the radiating elements mounted thereon. The backplane **210** may also include brackets or

other support structures (not shown) that extend between the side walls **212** along the rear of the backplane **210**. Various mechanical and electronic components of the antenna **100** are mounted between the side walls **212** and the back side of the main reflector **214**, such as phase shifters, remote electronic tilt units, mechanical linkages, controllers, duplexers, and the like as is well known in the art.

[00122] The main backplane **210** defines a main module of the passive antenna assembly **190**. The main reflector **214** may comprise a generally flat metallic surface that extends in the longitudinal direction **L** of the antenna **100**. The main reflector **214** can be the (passive) reflector **170** discussed above or can be an extension of, coupled to or different from the (passive) reflector **170** discussed above. If the main reflector **214** is a separate reflector it is (electrically) coupled to the reflector **170** to provide a common electrical ground.

[00123] 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, for example, 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 antenna **100** that are mounted thereon.

[00124] Still referring to **FIG. 6**, 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 one or more arrays **250** of high-band radiating elements **1195**. The arrays **250** can be provided as high band radiating elements for an active array or a mMIMO array in the active antenna module **110**. The radiating elements **222**, **232**, **242**, **1195** may each be dual-polarized radiating elements. Further details of radiating elements can be found in co-pending PCT Publication Nos. WO2019/236203 and WO2020/072880, the contents of which are hereby incorporated by reference as if recited in full herein.

[00125] The low-band radiating elements **222** are mounted to extend forwardly from the main or primary reflector **214** (and/or the reflector **170**) 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.

[00126] 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.

[00127] The first mid-band radiating elements **232** may likewise be mounted to extend forwardly from the main reflector **214** 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 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 and may extend substantially the full length of the antenna **100** in some embodiments.

[00128] The second mid-band radiating elements **242** can be mounted in columns in the lower medial portion of antenna **100** to form linear arrays **240** 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**.

[00129] The high-band radiating elements **1195** can be mounted in columns in the upper medial or center portion of the active antenna module **110** and/or the base station antenna **100** to form (*e.g.*, four) linear arrays **250** of high-band radiating elements. 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. The high band radiating elements **1195** can reside behind or extend into a recess **155** in the reflector **170** or behind a frequency selective surface that extends across the space depicted by the recess in **FIG. 4**.

[00130] 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 **240** of second mid-band radiating elements **242** are all part of the passive antenna assembly **190**, while the arrays **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.

[00131] 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, the two linear arrays **240** 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.

[00132] The low-band and mid-band radiating elements **222**, **232**, **242** may each be mounted to extend forwardly of and/or from the main reflector **214**.

[00133] 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 **242** 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 **220**, **230**, **240** may be configured to provide service to a sector of a base station. For example, each linear array **220**, **230**, **240** 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**, **1195** are 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.

[00134] Some or all of the radiating elements **222**, **232**, **242**, **1195** may be mounted on feed boards that couple RF signals to and from the individual radiating elements **222**, **232**, **242**, **1195**, with one or more radiating elements **222**, **232**, **242**, **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.

[00135] Referring now to **FIGS. 7-12C**, mounting systems **60**, **600** and their tilt adjustment capabilities according to embodiments of the present invention will now be described in further detail. Properties and/or features of the mounting system **600** may be as described above in reference to the mounting system **60** shown in **FIG. 3** and duplicate discussion thereof may be omitted herein for the purposes of discussing **FIGS. 7-12C**.

[00136] Referring to **FIG. 7**, the mounting system **600** according to embodiments of the present invention is illustrated (*see also, e.g., FIGS. 10A-10C, FIG. 11A, FIG. 12A*). The mounting system **600** is similar to the mounting system **60** described herein, except that an active antenna module (remote radio unit (RRU) or radio) **110** is not included. As shown in **FIG. 7**, the mounting system **600** comprises a plurality of mounting brackets **160**, **161**, **162** that are longitudinally spaced apart and attached to the antenna housing **190h**. The mounting brackets **160**, **161**, **162** are also configured to be attach to a mounting structure **130**, shown as a pole **P**. These brackets **160**, **161**, **162** can be referred to as "antenna brackets" or "passive antenna brackets." As noted herein, although shown as three brackets, a lesser number of antenna brackets such as two brackets (*e.g., brackets 160, 161*) may be used or more than three brackets may be used. These brackets **160**, **161**, **162** will be described in further detail below with reference to **FIGS. 8A-8B** and **FIG. 9A-9B**.

[00137] In some embodiments, as shown in **FIGS. 11B-11C** and **FIGS. 12B-12C**, the mounting system **60** further includes a mounting kit **125** comprising a plurality of brackets **151**, **152** that are longitudinally spaced apart and attached to the active antenna module **110**. These brackets **151**, **152** are also configured to attach directly to the mounting structure **130** (*see also, e.g., FIG. 3*). These brackets **151**, **152** can be referred to as "radio brackets" or "active antenna brackets." The active antenna module **110** can be separately attached to the target mounting structure **130** (independent of the antenna housing **190h**) using the active antenna brackets **151**, **152**. Each of the brackets **151**, **152**, **160**, **161**, **162** can be coupled to a respective pole (or pipe) clamp **155** that mounts and secures the respective brackets **151**, **152**, **160**, **161**, **162** to the mounting structure **130**.

[00138] Referring to **FIG. 8A**, the upper passive antenna bracket **160** according to embodiments of the present invention is illustrated. As shown in **FIG. 8A**, one end of the upper passive antenna bracket **160** is configured to be mounted and secured to the mounting structure **130** (*e.g.*, via a pipe clamp **155**) and the opposing end of the upper passive antenna bracket **160** is configured to be mounted and secured to an upper portion of the passive antenna housing **190h** (*e.g.*, via an upper antenna mount bracket **115**).

[00139] The upper passive antenna bracket **160** includes a main body **620** having two opposing sidewalls **622** that are coupled to and extend downwardly therefrom. In some embodiments, the upper passive antenna bracket **160** further includes an extension member **610** coupled to the opposing sidewalls **622** and secured to a clamping member **156b** of the pipe clamp **155**. Each sidewall **622** comprises an aperture **622a** configured to receive a respective fastener **116** such that the upper passive antenna bracket **160** can be pivotably mounted and secured to the upper antenna mount bracket **115**.

[00140] Each sidewall **622** further comprises an elongated slot **624** configured to receive a respective fastener **116**. In some embodiments, the fastener **116** received through the slot **624** secures the upper passive antenna bracket **160** to the pipe clamp **155** or extension member **610**. As shown in **FIG. 8A**, in some embodiments, the fasteners **116** secure the opposing sidewalls **622** to respective arms **612** of the extension member **610**. As discussed in further detail below, the fasteners **116** are configured to slide within their respective elongated slots **624** as the passive antenna housing **190h** is moved (*e.g.*, pushed or pulled) in relation to the mounting structure **130** (*e.g.*, to adjust the angle of tilt downward or upward).

[00141] Referring to **FIG. 8B**, the lower passive antenna bracket **162** according to embodiments of the present invention is illustrated. The lower passive antenna bracket **162** is the same or similar to the upper passive antenna bracket **160**. As shown in **FIG. 8B**, one end of the lower passive antenna bracket **162** is configured to be mounted and secured to the mounting structure **130** (*e.g.*, via a pipe clamp **155**) and the opposing end of the lower passive antenna bracket **162** is configured to be mounted and secured to a lower portion of the passive antenna housing **190h** (*e.g.*, via a lower antenna mount bracket **117**).

[00142] Like the upper passive antenna bracket **160**, the lower passive antenna bracket **162** includes a main body **820** having two opposing sidewalls **822** that are coupled to and extend downwardly therefrom. In some embodiments, the lower passive antenna bracket **162** further includes an extension member **810** coupled to the opposing sidewalls **822** and secured to a clamping member **156b** of the pipe clamp **155**. Each sidewall **822** comprises an aperture **822a**

configured to receive a respective fastener **116** such that the lower passive antenna bracket **162** can be pivotably mounted and secured to the lower antenna mount bracket **117**.

[00143] Each sidewall **822** further comprises an elongated slot **824** configured to receive a respective fastener **116**. In some embodiments, the fastener **116** received through the slot **824** secures the lower passive antenna bracket **162** to the pipe clamp **155** or extension member **810**. As shown in **FIG. 8B**, in some embodiments, the fasteners **116** secure the opposing sidewalls **822** to respective arms **812** of the extension member **810**. The fasteners **116** are configured to slide within their respective elongated slots **824** as the passive antenna housing **190h** is moved (*e.g.*, pushed or pulled) in relation to the mounting structure **130** (*e.g.*, to adjust the angle of tilt downward or upward).

[00144] Referring now to **FIGS. 9A-9B**, the middle passive antenna bracket **161** according to embodiments of the present invention is illustrated. As shown in **FIGS. 9A-9B**, the middle passive antenna bracket **161** includes a main body **720** having two opposing sidewalls **722** that are coupled to and extend downwardly therefrom. Each sidewall **722** comprises an elongated slot **724**. In some embodiments, the middle passive antenna bracket **161** further includes an extension member **710** coupled to the opposing sidewalls **722** and secured to a clamping member **156b** of the pipe clamp **155**. In some embodiments, the extension member **710** comprises opposing arm members **712** extending outwardly therefrom. As shown in **FIG. 9B**, in some embodiments, each sidewalls **722** of the middle passive antenna bracket **161** may be coupled and/or secured to a respective arm member **712** of the extension member **710**.

[00145] Still referring to **FIGS. 9A-9B**, the middle passive antenna bracket **161** further comprises a rack and pinion assembly **735** (*i.e.*, rack **728** and pinion **726**). The rack **728** is coupled to an outer surface of one of the sidewalls **722**. The pinion **726** has a plurality of teeth **726a** configured to engage the rack **728** and is secured the bracket **161** via a fastener **729**. In some embodiments, the fastener **729** extends through the elongated slot **724** in the corresponding sidewall **202** and may be secured to the extension member **710** or clamping member **156b**. The fastener **729** holds the pinion **726** against an outer surface of the sidewall **722** and is configured to allow the pinion **726** to rotate relative to the sidewall **722** such that the pinion **726** can travel back-and-forth along the rack **728**. As described in further detail below, the rack and pinion assembly **735** is used to adjust the antenna housing **190h** to a desired distance (**D₃**) from the mounting structure **130** (*see, e.g.*, **FIG. 7**).

[00146] In some embodiments, an end **727a** of the fastener **727** may be configured to engage a wrench **740** which may be used by a technician to rotate the pinion **726** to adjust the

distance (**D₃**) between the mounting structure **130** and the passive antenna housing **190h**. For example, the end **209a** of the fastener **209** may be keyed to engage a hex wrench.

[00147] In some embodiments, the middle passive antenna bracket **161** may further comprise a brake slider **730** (*see also, e.g., FIGS. 10A-10B*). The brake slider **730** is configured to engage the pinion **726** to lock the pinion **726** in position (*e.g., when the antenna housing 190h has been moved a desired distance (D₃) in relation to the mounting structure 130*). In some embodiments, the brake slider **730** may be secured to the extension member an arm member **712** of the extension member **710** via a respective fastener **116**. The fastener **116** for the brake slider **730** extends through the same elongated slot **724** in the sidewall **722** of the bracket **161** as the fastener **727** holding the pinion **726**.

[00148] As shown in **FIGS. 10A-10B**, in some embodiments, the brake slider **730** has a main body **732** having opposing sides **732a**, **732b**. An oval-shaped aperture **734** extends through the main body **732**. An edge of the brake slider **730** has a plurality of protrusions **736** and recesses **738** (*e.g., teeth*). The teeth of the brake slider **730** are configured to engage the teeth **726a** of the pinion **726**. In some embodiments, one side **732a** of the main body **732** of the brake slider **730** may be substantially planar (*e.g., flat*). In some embodiments, the opposing side **732b** may have a protruding section **733** that extends outwardly therefrom. In some embodiments, the protruding section **733** has a shoulder **731**.

[00149] In some embodiments, the protruding section **733** of the brake slider **730** is configured to be received by the elongated slot **724** of the bracket **161**. An outer surface **735** of the protruding section **733** is configured to slide against an inner surface of the elongated slot **724**. The shoulder **731** of the protruding section **733** contacts an outer surface of the sidewall **722** of the bracket **161** creating a gap between the main body **732** of the brake slider **730** and the sidewall **722** of the bracket **161**. In some embodiments, the gap helps align the "teeth" of the brake slider **730** (*i.e., protrusions 736 and recesses 738*) with the teeth **726a** of the pinion **726**.

[00150] The elliptical-shaped aperture **734** allows the brake slider **730** to slide back-and-forth relative to the fastener **116**. This movement allows the brake slider **730** to engage or disengage the pinion **726**. When the brake slider **730** is disengaged from the pinion **726**, the pinion **726** is able to rotate relative to the sidewall **722** of the bracket **161** (*i.e., the brake slider 730 is in an "unlocked" position*). When the brake slider **730** is engaged with the pinion **726**, the pinion **726** is prevented from rotating relative to the sidewall **722** of the bracket **161** (*i.e., the brake slider 730 is in a "locked" position*).

[00151] Referring back to **FIGS. 9A-9B**, each sidewall **722** of the bracket **161** further comprises a plurality of apertures **722a** that are configured to receive respective fasteners **116**.

As shown in **FIGS. 9A-9B**, at least two of the apertures **722a** are configured to receive a respective fastener **116** for pivotably mounting and securing a middle antenna mounting bracket **114** (and antenna housing **190h** attached thereto) to the middle antenna bracket **161**.

[00152] In operation, and shown in **FIGS. 11A-11C**, the mounting system **600** may be configured to tilt the base station antenna **100** upwardly or downwardly to a desired angle of tilt (α). **FIG. 11A** shows the mounting system **600** providing a downward tilt to the base station antenna **100** (e.g., a downward angle of tilt (α) at about 5 degrees). **FIG. 11B** shows the mounting system **600** providing zero tilt to the base station antenna **100**. **FIG. 11C** shows the mounting system **600** providing an upward tilt to the base station antenna **100** (e.g., an upward angle of tilt (α) at about 5 degrees). The arrows in **FIG. 11B** show that the base station antenna **100** is configured to move (e.g., pivot) relative to the respective passive antenna brackets **160**, **161**, **162** (e.g., pivot about the fasteners securing the antenna mounting brackets **114**, **115**, **117**) to adjust the base station antenna **100** to a desired angle of tilt (α).

[00153] To adjust the angle of tilt (α), a technician engages a wrench **740** (or other similar device) with the rack and pinion assembly **735** of the middle passive antenna bracket **161** (e.g., engages the wrench **740** with the end **727a** of a fastener **727** of the pinion **726**) (see, e.g., **FIGS. 9A-9B**). The technician then moves/slides the brake slider **730** to disengage the pinion **726**, thereby allowing the pinion **726** to rotate relative to the sidewall **722** of the bracket **161** and travel back-and-forth along the rack **728**. The technician rotates the pinion **726** to travel a desired direction along the rack **728** which simultaneously moves the bracket **161** forwardly or rearwardly relative to the pipe clamp **155** (and extension member **710** coupled thereto) and mounting structure **130** (see also, e.g., **FIGS. 12A-12C** and **FIGS. 13A-13C**).

[00154] As the bracket **161** moves in response to the rotation of the pinion **726**, the passive antenna housing **190h** moves forwardly or rearwardly (i.e., toward or away from the mounting structure **130**). For example, in some embodiments, rotation of the pinion **726** in a clockwise direction may move the bracket **161** (and passive antenna housing **190h**) rearwardly relative to the mounting structure **130** (i.e., toward the mounting structure **130**) (see, e.g., **FIG. 12C**). In some embodiments, rotation of the pinion **726** in a counterclockwise direction may move the bracket **161** (and passive antenna housing **190h**) forwardly relative to the mounting structure **130** (i.e., away from the mounting structure **130**) (see, e.g., **FIG. 12B**). The brake slider **730** may then be moved or slid to engage the pinion **726**, thereby locking the mounting system **600** and base station antenna **100** (i.e., passive antenna housing **190h**) at the desired distance (**D₃**) from the mounting structure **130** (see, e.g., **FIG. 7**).

[00155] Once positioned at the desired distance (D_3) from the mounting structure 130, the base station antenna 100 can be adjusted to the desired angle of tilt (α). As noted above, the passive antenna housing 190h (and base station antenna 100) is pivotably mounted to the middle passive antenna bracket 161 (*i.e.*, pivots about the fasteners 116 securing the middle antenna mounting bracket 114 to the middle passive antenna bracket 161) which allows the base station antenna 100 to be adjusted to desired angle of tilt (α).

[00156] As shown in FIG. 11A, to provide downtilt to the base station antenna 100, the upper passive antenna bracket 160 allows the upper portion of passive antenna housing 190h to move in a direction away from the mounting structure 130 (*i.e.*, via the fastener 116 sliding within the elongated slot 624 and pivoting about the fastener 116 securing the upper passive antenna bracket 160 to the upper antenna mounting bracket 115). In response, the lower passive antenna bracket 162 allows the lower portion of the passive antenna housing 190h to move in a direction toward the mounting structure 130 (*i.e.*, via the fastener 116 sliding within the elongated slot 824 and pivoting about the fastener 116 securing the lower passive antenna bracket 162 to the lower antenna mounting bracket 117). The passive antenna housing 190h pivots about the middle passive antenna bracket 161 as the upper and lower portions of the passive antenna housing 190h move in opposite directions until a desired downtilt of the base station antenna 100 has been achieved.

[00157] As shown in FIG. 11C, to provide uptilt to the base station antenna 100, the upper portion of passive antenna housing 190h is moved in a direction toward the mounting structure 130. In response, the lower passive antenna bracket 162 allows the lower portion of the passive antenna housing 190h to move in a direction away the mounting structure 130. The passive antenna housing 190h pivots about the middle passive antenna bracket 161 as the upper and lower portions of the passive antenna housing 190h move in opposite directions until a desired uptilt of the base station antenna 100 has been achieved.

[00158] FIGS. 12A-12C and FIGS. 13A-13C illustrate how the mounting system 60, 600 is configured to adjust the distance (D_3) that base station antenna 100 (antenna housing 190h) is from the mounting structure 130 in order to accommodate the mounting of an active antenna module (radio) 110 to the mounting structure (FIGS. 12A-12C) as well as also being configured such that the angle of tilt (α) of the base station antenna 100 may be adjusted after the active antenna module 110 has been mounted to the mounting structure 130 behind the base station antenna 100 (*i.e.*, the antenna housing 190h) (FIGS. 13A-13C).

[00159] As discussed above, FIG. 12A further illustrates how the middle passive antenna bracket 161 is configured to move the base station antenna 100 (*i.e.*, the passive antenna

housing **190h**) back-and-forth a distance (D_3) relative to the mounting structure **130** (via the rack and pinion assembly **735**).

[00160] As shown in **FIG. 12B**, to install (mount) an active antenna module **110** to the mounting structure **130** behind the already-mounted passive antenna housing **190h**, first the mounting system **60, 600** (*i.e.*, the middle passive antenna bracket **161**) moves the passive antenna housing **190h** a maximum distance (D_{3MAX}) from the mounting structure **130**. This provides additional space between the mounting structure **130** and the passive antenna housing **190h** which allows a technician to more easily mount the active antenna module **110** to the mounting structure **130** (via mounting kit **125** including mounting brackets **151, 152**) behind the passive antenna housing **190h**. As shown in **FIG. 12C**, after the active antenna module **110** has been secured to the mounting structure **130**, the mounting system **60, 600** (*i.e.*, the middle passive antenna bracket **161**) moves the passive antenna housing **190h** a minimum distance (D_{3MIN}) from the mounting structure **130** which is proximate to the active antenna module **110**. In some embodiments, a gauge **180** may be placed between the active antenna module **110** and the passive antenna housing **190h** to prevent the passive antenna housing **190h** from contacting the mounted active antenna module **110**) (*see, e.g.*, **FIG. 13C**).

[00161] In some embodiments, as shown in **FIGS. 13A-13C**, the active antenna module **110** may be secured to the mounting structure **130** via an alternative mounting kit **125'** that is configured to provide downtilt to the active antenna module **110**. After the active antenna module **110** is mounted to the mounting structure **130** by mounting kit **125'**, the mounting system **60** is configured move both the passive antenna housing **190h** (and base station antenna **100**) relative to the mounting structure **130** and configured to tilt the passive antenna housing **190h** (and base station antenna **100**) to accommodate the tilt of the active antenna module **110**, as previously described herein.

[00162] Referring now to **FIGS. 14-16B**, a mounting gauge kit **900** according to embodiments of the present invention is illustrated. As shown in **FIG. 14**, the mounting gauge kit **900** may be used with the mounting systems **60, 600** described herein. The mounting gauge kit **900** is configured to define a relative location for the mounting system **60, 600** and the active antenna module (radio) **110**. Specifically, the mounting gauge kit **900** is configured to define the location of an upper pipe clamp **155** for the active antenna module (radio) **110** along the mounting structure **130** in relation to the upper passive antenna bracket **160** of the mounting system **60, 600**.

[00163] The mounting gauge kit **900** is also illustrated in **FIG. 15A**. As shown in **FIG. 14** and **FIG. 15A**, the mounting gauge kit **900** comprises two gauge plates **930** (*see also*

FIG. 15C). As described in further detail below, according to embodiments of the present invention, each gauge plate **930** is configured to be secured to a modified clamping member **920** of the pipe clamp **155** coupled to the upper passive antenna bracket **160**. In addition, a bottom end **932b** of each gauge plate **930** is configured to engage a respective rod or bolt **118a** of the upper pipe clamp **155** coupled to the active antenna module **110**.

[00164] The modified clamping member **920** is illustrated in **FIG. 15B**. The modified clamping member **920** has a main body **922** having a pair of recesses **923**. The modified clamping member **920** is configured to be coupled to an opposing clamping member **156b** via a pair of fasteners **118** (*see, e.g., FIG. 14 and FIG. 15A*). The opposing clamping member **156b** is coupled to the upper passive antenna bracket **160**, as described herein (*see, e.g., FIG. 8A, FIG. 14, and FIG. 15A*). One of the fasteners **118** is configured to be received through an aperture **922a** in the main body **922** of the modified clamping member **920**. In some embodiments, the main body **922** further comprises an open-ended slot **924** configured to receive the second fastener **118**. In some embodiments, the main body **922** may comprise a second aperture **922a** in place of the open-ended slot **924**. As the fasteners **118** are tightened, the clamping members **156b, 920** are pulled together to secure the mounting structure **130** therebetween. The recesses **923** of the clamping member **920** are configured to receive at least a portion of the mounting structure **130** to help further secure the mounting structure **130** therebetween.

[00165] The modified clamping member **920** further comprises a pair of flanges **925** extending downwardly from the main body **922**. Each flange **925** is configured to affix a respective gauge plate **930** to the clamping member **920**. As shown in **FIG. 15B**, in some embodiments, each flange **925** comprises an open-ended slot **925b** extending into an aperture **925a**. As discussed in further detail below, the apertures **925a** and slots **925b** are configured to receive and secure a respective cap bolt **940** therein.

[00166] Referring to **FIG. 15C**, one of the gauge plates **930** is illustrated. Each gauge plate **930** is identical, and thus, any details of one gauge plate **930** described herein are applicable to both gauge plates **930**. As shown in **FIG. 15C**, the gauge plate **930** comprises a generally rectangular main body **932**. A lower edge **932b** of the main body **932** comprises one or more recesses **936**. The recesses **936** are configured to receive a respective rod or bolt **118a** of the upper pipe clamp **155** that is coupled to the active antenna module **110** (*see FIG. 15A*). Having more than one recess **936** in the gauge plate **930** allows the gauge plate **930** to be used on mounting structures **130** (*e.g., mounting pipes P*) having different diameters (*i.e., different distances between the fasteners 118a*).

[00167] The main body **932** of the gauge plate **930** further comprises one or more apertures **934**. As shown in **FIG. 15C**, in some embodiments, the one or more apertures **934** include a vertically-extending elongated aperture **934a** and a series of horizontally-extending apertures **934b**. Each of the horizontally-extending apertures **934b** extend outwardly from the vertically-extending elongated aperture **934a** such that the horizontally-extending apertures **934b** are generally perpendicular to the vertically-extending aperture **934a** and generally parallel to each other. In some embodiments, the horizontally-extending apertures are spaced apart a distance (**D₄**) in a range of about 6 mm to about 12 mm, and typically about 9 mm. The distance between the active antenna module **110** and the upper passive antenna bracket **160** will vary depending on the size of the active antenna module **110** and/or passive antenna housing **190h**. As discussed in further detail below, each horizontally-extending aperture **934b** is in fluid communication with the vertically-extending aperture **934a** such that at least a portion of a cap bolt **940** can traverse within one of the horizontally-extending apertures **934b** into the vertically-extending aperture **934a**, and then back into a different horizontally-extending apertures **934b** without having to be removed from the gauge plate **930**. The horizontally-extending apertures **934b** correspond to a defined location to secure the active antenna module **110** mounting kit (*i.e.*, a location for the upper pipe clamp **155** for the active antenna module (remote radio unit) **110** along the mounting structure **130** in relation to the upper passive antenna bracket **160** of the mounting system **60, 600**).

[00168] The mounting kit **900** further comprises two fastening mechanisms. In some embodiments, the fastening mechanism comprise a cap bolt **940** and corresponding nut **950**. One of the cap bolts **940** is illustrated in **FIGS. 15D-15E**. As noted above, each cap bolt **940** is configured to be received through a respective aperture **925a** in the modified clamping member **920**. At least a portion of each cap bolt **940** is also configured to be received through the apertures **934** of a respective gauge plate **930** (*see also* **FIGS. 17A-17B**).

[00169] As shown in **FIGS. 15D-15E**, each cap bolt **940** has a main body **942**, a transition section **946**, and a threaded end **948**. In some embodiments, the main body **942** has a generally cylindrical profile with a locking section **944** extending radially outwardly therefrom. The cylindrical main body **942** is configured to be received through the aperture **925a** of a respective flange **925** of the modified clamping member **920** and the locking section **944** is configured to be received by the corresponding open-ended slot **925b** (*see also*, **FIG. 17A**). In some embodiments, a top edge **942e** of the main body **942** has a slight draft or taper. For example, in some embodiments, the top edge **942e** of the main body **942** has a draft of about 1 degree. The draft degree of the cap bolt **940** may help a technician more easily fix the gauge

plate **930** to the clamping member **920**. In some embodiments, one end of the main body **942** may also comprise a recess **942a** for weight reduction.

[00170] The transition section **946** is integral with or coupled to the main body **942** and extends outwardly from one end of the main body **942** (*i.e.*, extending outwardly from the opposing end having the recess **942a**) and defines a shoulder **942s** between the main body **942** and the transition section **946**. The transition section **946** is sized and configured to be received by the horizontally-extending apertures **934b** in the gauge plate **930** (*see also*, **FIGS. 16A-16B** and **FIG. 17B**). When the transition section **946** is received within a respective aperture **934b** the transition section **946** is configured to traverse and slide within the apertures **934b**. When a technician inserts the cap bolt **940** into an aperture **934b** of the gauge plate **930**, the shoulder **942s** provides a stop point which prevents the technician from inserting the cap bolt **940** completely through the respective aperture **934b** in the gauge plate **930**. In some embodiments, the transition section **946** may have an elliptical cross-sectional shape. In other embodiments, the transition section **946** may have a circular cross-sectional shape.

[00171] The cap bolt **940** further comprises a threaded end **948**. The threaded end **948** resides at the end of the transition section **946** opposite the main body **942**. The threaded end **948** is configured to receive a corresponding nut **950** to lock the cap bolt **940** in place and secure the gauge plate **930** to the clamping member **920**. The threaded end **948** is also sized and configured to traverse and slide within the vertically-extending aperture **934a** in the gauge plate **930** (*see also* **FIGS. 16A-16B**).

[00172] As noted above, the mounting gauge kit **900** may be used to define a mounting location for the active antenna module (radio) **110** on a mounting structure **130** relative to the mounting system **60** described herein. In use, a technician first secures the upper passive antenna bracket **160** to a mounting structure **130** (*e.g.*, mounting pole **P**) via a pipe clamp **155** having at least one modified clamping member **920**. Next, as shown in **FIG. 16A**, the cap bolt **940** is secured to the gauge plate **930** by inserting the threaded end **948** and transition section **946** of the cap bolt **940** through one of the horizontally-extending apertures **934b** corresponding to the desired location along the mounting structure **130** that the upper pipe clamp **155** for the active antenna module (radio) **110** should be secured (*i.e.*, in relation to the upper passive antenna bracket **160** of the mounting system **60**, **600**). A nut **950** is then loosely threaded onto the threaded end **948** of the cap bolt **940** to secure the cap bolt **940** to the gauge plate **930**, but also allow the cap bolt **940** to traverse and slide within the selected horizontally-extending aperture **934b** of the gauge plate **930**. As shown in **FIG. 16B**, if the upper pipe clamp **155** for the active antenna module **110** needs to be secured at a different location along

the mounting structure **130** (*i.e.*, in relation to the upper passive antenna bracket **160** of the mounting system **60, 600**), the cap bolt **940** is capable to also traverse and slide within the vertically-extending aperture **934a**, for example, to move the cap bolt **940** to a different horizontally-extending aperture **934b** that corresponds to the desired location along the mounting structure **130** that the upper pipe clamp **155** for the active antenna module (radio) **110**. The nut **950** can then be tightened, thereby securing the cap bolt **940** in the desired location on the gauge plate **930**.

[00173] As shown in **FIGS. 17A-17B**, after the cap bolt **940** is secured to the gauge plate **930**, the gauge plate **930** is then mounted to the modified clamping member **920** by inserting the main body **942** and locking section **944** of the cap bolt **940** through the aperture **925a** and corresponding slot **925b**, respectively, in the flange **925**. Using the gauge plate **930** as a guide, a technician can then mount the upper pipe clamp **155** for the active antenna module **110** to the mounting structure **130**. As shown in **FIG. 15A**, by aligning the rods or bolts **118a** of the pipe clamp **155** within one of the recesses **936** in the lower edge **932b** of the gauge plates **130**, the technician can secure the upper pipe clamp **155** at the desired location along the mounting structure **130**.

[00174] In some embodiments, the base station antennas **100** may be designed so that a variety of different active antenna modules **110** can be used on/in a given antenna **100**. The active antenna module **110** can be manufactured by any original equipment manufacturer and/or cellular service provider and mounted on the back of the antenna. This allows cellular operators to purchase the base station antennas and the radios mounted thereon separately, providing greater flexibility to the cellular operators to select antennas and radios that meet operating needs, price constraints and other considerations.

[00175] The antennas **100** may have a number of advantages over conventional antennas. As cellular operators upgrade their networks to support fifth generation ("5G") service, the base station antennas that are being deployed are becoming increasingly complex. It is desirable to minimize antenna size and/or integrate increased number of antenna or antenna elements inside a single bases station antenna/external radome. For example, due to space constraints and/or allowable antenna counts on antenna towers of existing base stations, it may not be possible to simply add new antennas to support 5G service. Accordingly, cellular operators are opting to deploy antennas that support multiple generations of cellular service by including linear arrays of radiating elements that operate in a variety of different frequency bands in a single antenna. Thus, for example, it is common now for cellular operators to request a single base station antenna that supports service in three, four or even five or more different frequency bands.

Moreover, in order to support 5G service, these antennas may include multi-column arrays of radiating elements that support active beamforming. Cellular operators are seeking to support all of these services in base station antennas that are comparable in size to conventional base station antennas that supported far fewer frequency bands.

[00176] The active antenna modules **110** may also be readily replaced in the field. As is well known, base station antennas are typically mounted on towers, often hundreds of feet above the ground. Base station antennas may also be large, heavy and mounted on antenna mounts that extend outwardly from the tower. As such, replacing base station antennas may be difficult and expensive. The active antenna modules **110** with beamforming radios may be field installable and/or replaceable without the need to detach the base station antenna **100** from an antenna mount.

[00177] 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.

[00178] 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.

[00179] 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.)

[00180] 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.

[00181] The term "about" used with respect to a number refers to a variation of +/- 10%.

[00182] 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.

[00183] 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.

[00184] The foregoing is illustrative of the present invention and is not to be construed as limiting thereof. Although a few exemplary embodiments of this invention have been described, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the claims. The invention is defined by the following claims, with equivalents of the claims to be included therein.

That Which is Claimed is:

1. A base station antenna assembly, comprising:
a housing of a base station antenna comprising a passive antenna assembly and a passive reflector in the housing;
a plurality of passive antenna mounting brackets coupled to the housing and configured to attach to a mounting structure; and
an active antenna module comprising at least one active antenna mounting bracket configured to directly attach to the mounting structure, wherein, in an installed position, the active antenna module is behind the housing of the base station antenna.
2. The base station antenna assembly according to Claim 1, wherein the active antenna module is independently attachable to the mounting structure whereby the active antenna module is directly supported by the mounting structure.
3. The base station antenna assembly according to any one of the preceding claims, wherein the at least one active antenna mounting bracket comprises at least one mounting arm that extends rearwardly of a rear of the active antenna module to the mounting structure.
4. The base station antenna assembly according to any one of the preceding claims, wherein the plurality of passive antenna mounting brackets comprise a first passive antenna mounting bracket and a longitudinally spaced apart second passive antenna mounting bracket, wherein the at least one active antenna mounting bracket and the active antenna module resides between the first and second passive antenna mounting brackets.
5. The base station antenna assembly according to any one of the preceding claims, wherein the active antenna module comprises a massive multiple input multiple output (mMIMO) antenna array of radiating elements.
6. The base station antenna assembly according to Claim 5, wherein the mMIMO antenna array is positioned behind a passive reflector in the housing.

7. The base station antenna assembly according to any one of the preceding claims, wherein the plurality of passive antenna mounting brackets are configured to be adjustable to provide an adjustable distance between the active antenna module and a rear of the housing.

8. The base station antenna assembly according to any one of the preceding claims, wherein the plurality of passive antenna mounting brackets are configured to provide an adjustable downtilt of the housing.

9. The base station antenna assembly according to any one of the preceding claims, wherein the at least one active antenna mounting bracket is provided as a plurality of active antenna mounting brackets that are configured to provide an adjustable downtilt of the active antenna module.

10. The base station antenna assembly according to any one of the preceding claims, wherein the plurality of passive antenna mounting brackets are configured to provide an adjustable downtilt of the housing, and wherein the at least one active antenna mounting bracket is a plurality of active antenna mounting brackets that are configured to provide an adjustable downtilt of the active antenna module.

11. The base station antenna assembly according to any one of the preceding claims, wherein the plurality of passive antenna mounting brackets and/or the at least one active antenna mounting bracket are configured to be adjustable to adjust a distance between a front of the active antenna module and a rear of the housing.

12. The base station antenna according to any one of the preceding claims, wherein the plurality of passive antenna mounting brackets comprise mounting arms having a first length in a front to back direction, wherein the at least one active antenna mounting bracket comprises mounting arms having a second length in a front to back direction, wherein the mounting arms of the at least one active antenna mounting bracket extends from a rear of the active antenna module to the mounting structure, and wherein the first length is greater than the second length.

13. The base station antenna assembly according to any one of the preceding claims, wherein the at least one active antenna mounting bracket comprises a pole clamp.

14. A method of installing an active antenna module to a base station antenna comprising a passive antenna housing with a passive antenna, comprising:

attaching a plurality of passive antenna mounting brackets attached to the passive antenna housing to a target mounting structure; and

before or after attaching the plurality of passive antenna brackets to the target mounting structure,

attaching the active antenna module directly to the target mounting structure using at least one active antenna mounting bracket that extends rearwardly outward past a rear of the active antenna module.

15. The method according to Claim 14, further comprising adjusting a distance between the passive antenna housing and the active antenna module after the attaching steps to position the passive antenna housing closer to the active antenna module.

16. The method according to any one of Claims 14 or 15, further comprising moving at least one of the plurality of passive antenna mounting brackets to adjust a downtilt of the passive antenna housing and independently moving at least one of the at least one active antenna mounting bracket to adjust a downtilt of the active antenna module.

17. The method according to any one of Claims 14-16, wherein the passive antenna housing is attached to the target mounting structure before the active antenna module is attached to the target mounting structure.

18. The method according to any one of Claims 14-17, wherein the attaching steps are carried out so that a front of the active antenna module and a rear of the passive antenna housing are separated by a first distance and the active antenna module is supported entirely by the target mounting structure.

19. The method according to Claim 18, the method further comprising moving one or both of the active antenna module and/or the passive antenna housing to be closer together while both remain attached to the target mounting structure.

20. The method according to Claim 24, wherein the active antenna module provides 5G operation and the passive antenna of the base station antenna provides 4G operation.

21. A base station antenna assembly, comprising:
a housing of a base station antenna comprising an antenna assembly; and
a plurality of antenna mounting brackets coupled to the housing and configured to attach to a mounting structure, the plurality of antenna mounting brackets comprise an upper antenna mounting bracket, a middle antenna mounting bracket, and a lower antenna mounting bracket,

wherein the middle antenna mounting bracket comprises a rack and pinion assembly configured to adjust a distance of the housing of the base station antenna from the mounting structure.

22. The base station antenna assembly according to Claim 21, wherein the middle antenna bracket further comprises a main body having two opposing sidewalls, each sidewall comprising an elongated slot, wherein the rack and pinion assembly is coupled to an outer surface of one of the sidewalls.

23. The base station antenna assembly according to Claim 22, wherein the pinion of the rack and pinion assembly is held against an outer surface of one of the sidewalls by a fastener extending through the elongated slot, the fastener configured to allow the pinion to rotate relative to the sidewall such that the pinion can travel back-and-forth along the rack.

24. The base station antenna assembly according to Claim 23, wherein an end of the fastener is configured to engage a wrench used to rotate the pinion.

25. The base station antenna assembly according to any one of Claims 21-24, wherein the middle antenna mounting bracket further comprises a brake slider configured to engage the pinion of the rack and pinion assembly to lock the pinion in a position along the rack.

26. The base station antenna assembly according to Claim 25, wherein the brake slider is secured to the middle antenna mounting bracket via a second fastener extending through the same elongated slot in the sidewall of the bracket as the fastener holding the pinion.

27. The base station antenna assembly according to any one of Claims 25 or 26, wherein at least a portion of the brake slider is configured to be received by and slide within the elongated slot of the bracket.

28. The base station antenna assembly according to any one of Claims 26 or 27, wherein the brake slider comprises an oval-shaped aperture through which the second fastener extends and allows the brake slider to slide back-and-forth relative to the fastener to engage or disengage the pinion.

29. A method of installing an active antenna module to a base station antenna comprising a passive antenna housing with a passive antenna, the method comprising:
providing a mounting system comprising a plurality of antenna mounting brackets coupled to the housing and configured to attach to a mounting structure, the plurality of antenna mounting brackets comprise an upper antenna mounting bracket, a middle antenna mounting bracket, and a lower antenna mounting bracket, the middle antenna mounting bracket comprising a rack and pinion assembly configured to adjust a desired distance of the housing of the base station antenna from the mounting structure and a brake slider configured to engage the pinion of the rack and pinion assembly;

sliding the brake slider to disengage from the pinion of the rack and pinion assembly;
rotating the pinion to travel a desired direction along the rack of the rack and pinion assembly which simultaneously moves the middle antenna mounting bracket, and passive antenna housing coupled thereto, forwardly or rearwardly relative to the mounting structure;
and

sliding the brake slider to engage the pinion, thereby locking the housing at the desired distance from the mounting structure.

30. The method according to Claim 29, further comprising pivoting the housing about the middle antenna mounting bracket to adjust the base station antenna to a desired angle of downtilt or uptilt.

31. The method according to any one of Claims 29 or 30, further comprising:
rotating the pinion in a first direction such that the antenna housing is moved a maximum distance from the mounting structure;
mounting an active antenna module to the mounting structure behind the already mounted passive antenna housing; and
rotating the pinion in a second opposite direction such that the antenna housing is moved to a minimum distance from the mounting structure, proximate to the active antenna module.

32. The method according to Claim 31, further comprising placing a gauge between the active antenna module and the passive antenna housing to prevent the passive antenna housing from contacting the active antenna module.

33. A mounting gauge kit, the kit comprising:
two gauge plates, each gauge plate comprising a rectangular main body having one or more apertures and one or more recesses along a bottom edge;
two fastening mechanisms, each fastening mechanism is configured to be received through the one or more apertures to secure a respective gauge plate to a clamping member of a pipe clamp for an antenna bracket secured to a passive antenna housing,
wherein the gauge plates are configured to define a location along a mounting structure to secure an upper pipe clamp for an active antenna module in relation to the clamping member of the pipe clamp for the antenna bracket.

34. The mounting gauge kit according to Claim 33, wherein the one or more recesses of the gauge plates are configured to engage a fastener of the upper pipe clamp for the active antenna module.

35. The mounting gauge kit according to any one of Claims 33 or 34, wherein the clamping member of the pipe clamp for the antenna bracket comprises a pair of flanges extending downwardly therefrom, each flange comprising an open-ended slot extending into an aperture, the open-ended slot and aperture configured to receive and secure a respective fastening mechanism.

36. The mounting gauge kit according to any one of the Claims 33-35, wherein the one or more apertures include a vertically-extending elongated aperture and a series of spaced-apart horizontally-extending elongated apertures, each horizontally-extending apertures extending outwardly from the vertically-extending elongated aperture such that the horizontally-extending apertures are generally perpendicular to the vertically-extending aperture and generally parallel to each other, wherein each horizontally-extending aperture is in fluid communication with the vertically-extending aperture.

37. The mounting gauge kit according to Claim 36, wherein the horizontally-extending apertures correspond to a defined location for the upper pipe clamp for the active antenna module along the mounting structure in relation to the antenna bracket.

38. The mounting gauge kit according to any one of Claims 33-37, wherein each fastening mechanism has a main body, a transition section extending outwardly from the main body, wherein an end of the transition section is threaded.

39. The mounting gauge kit according to Claim 38, wherein the main body of each fastening mechanism has a cylindrical profile with a locking section extending radially outwardly therefrom, the cylindrical main body being configured to be received through the aperture of a respective flange of the clamping member and the locking section being configured to be received by the corresponding open-ended slot.

40. The mounting gauge kit according to any one of Claims 38 or 39, wherein the main body of each fastening mechanism has a draft or taper of about 1 degree.

41. The mounting gauge kit according to any one of Claims 38-40, wherein the transition section of each fastening mechanism is configured to be received by a horizontally-extending aperture in the gauge plate and configured to traverse and slide therein.

42. The mounting gauge kit according to any one of Claims 38-41, wherein the threaded end is configured to receive a corresponding nut to lock the respective fastening mechanism in place and secure the gauge plate to the clamping member.

43. The mounting gauge kit according to any one of Claims 38-42, wherein the threaded end of the transition section of each fastening mechanism is sized and configured to traverse and slide within the vertically-extending aperture of the gauge plate.

44. The mounting gauge kit according to Claim 33, in combination with a base station assembly, the base station assembly comprising a housing of a base station antenna including an antenna assembly, and a plurality of antenna mounting brackets coupled to the housing and configured to attach to a mounting structure, the plurality of antenna mounting brackets comprising an upper antenna mounting bracket, a middle antenna mounting bracket, and a lower antenna mounting bracket.

1/18

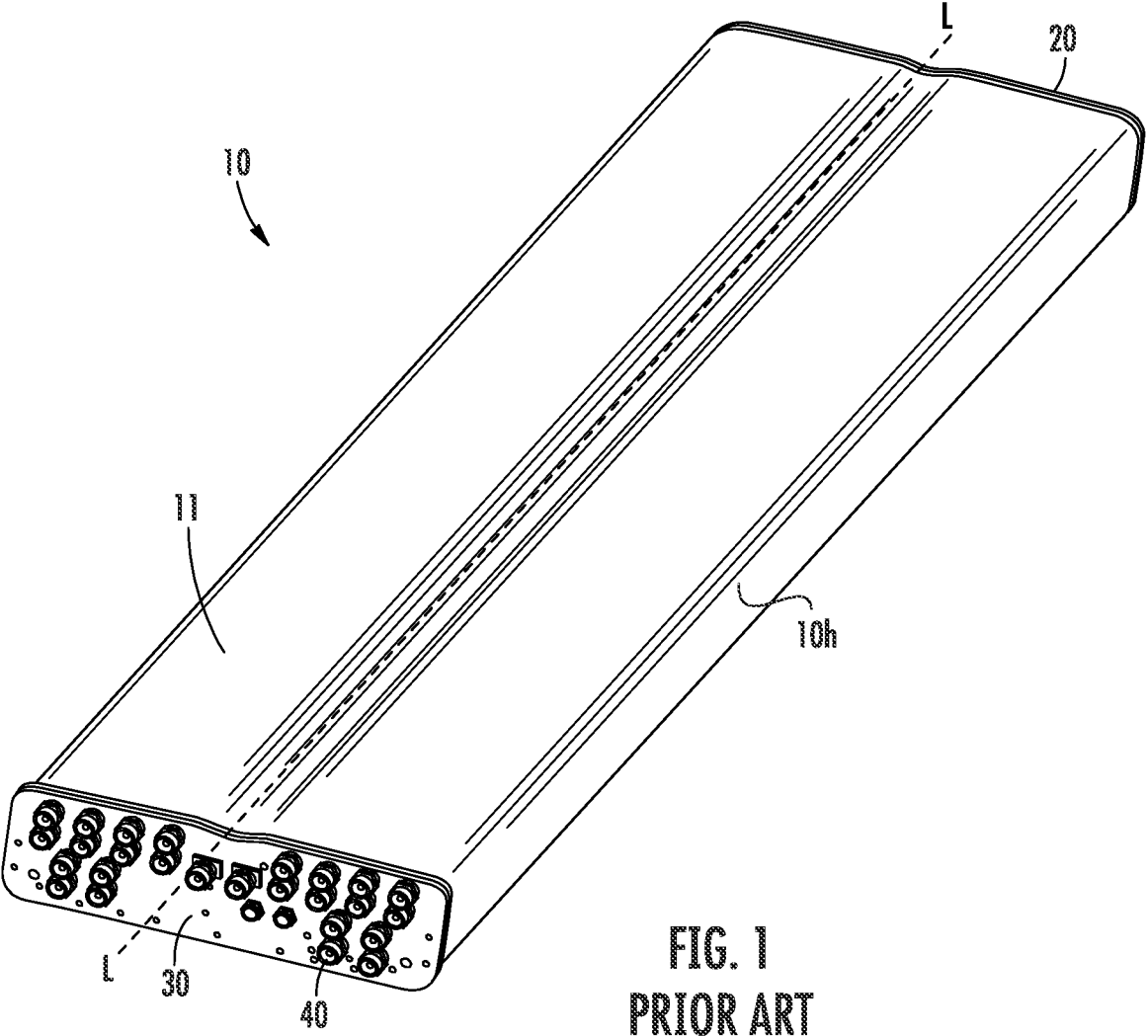
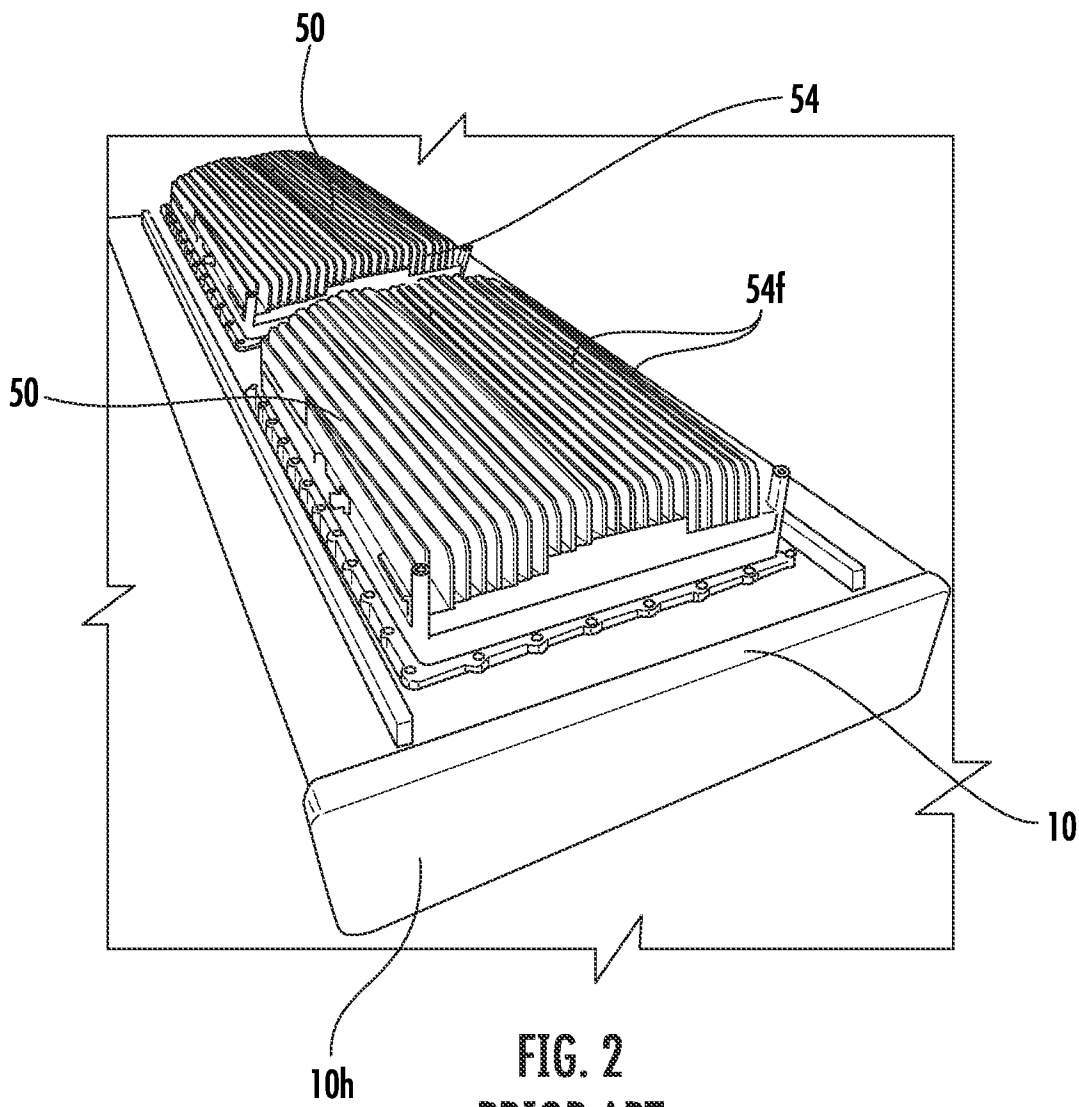


FIG. 1
PRIOR ART

2/18



3/18

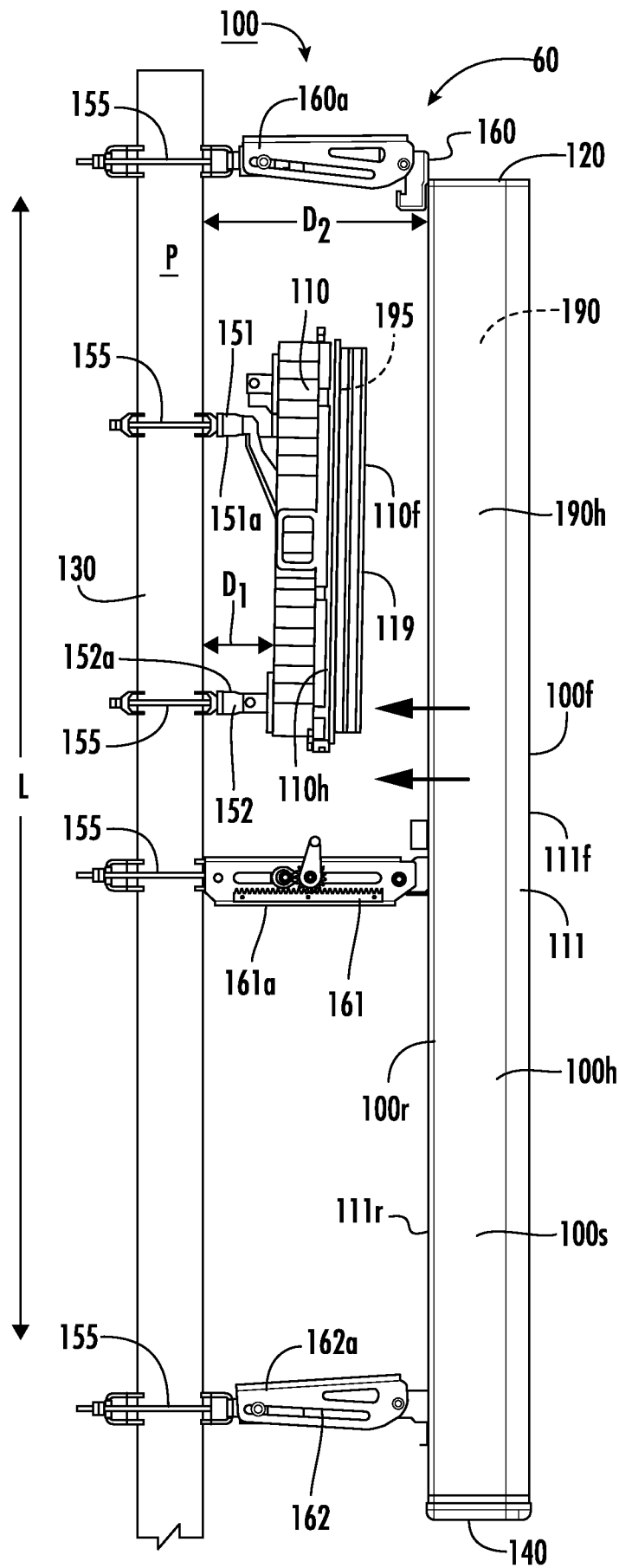
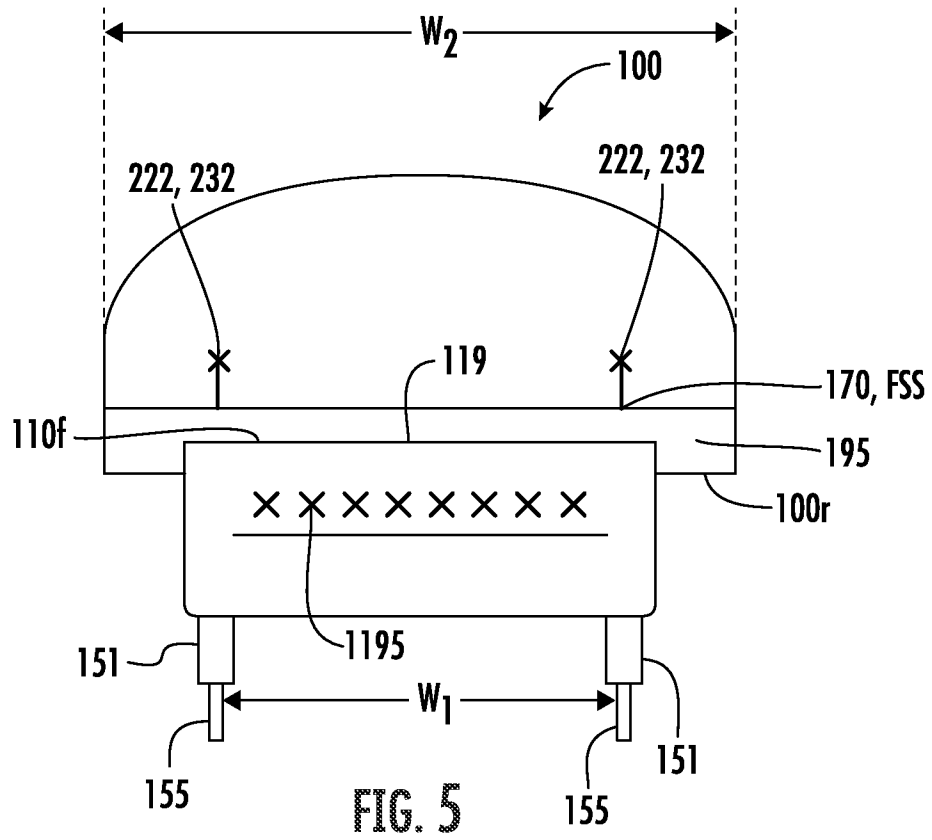
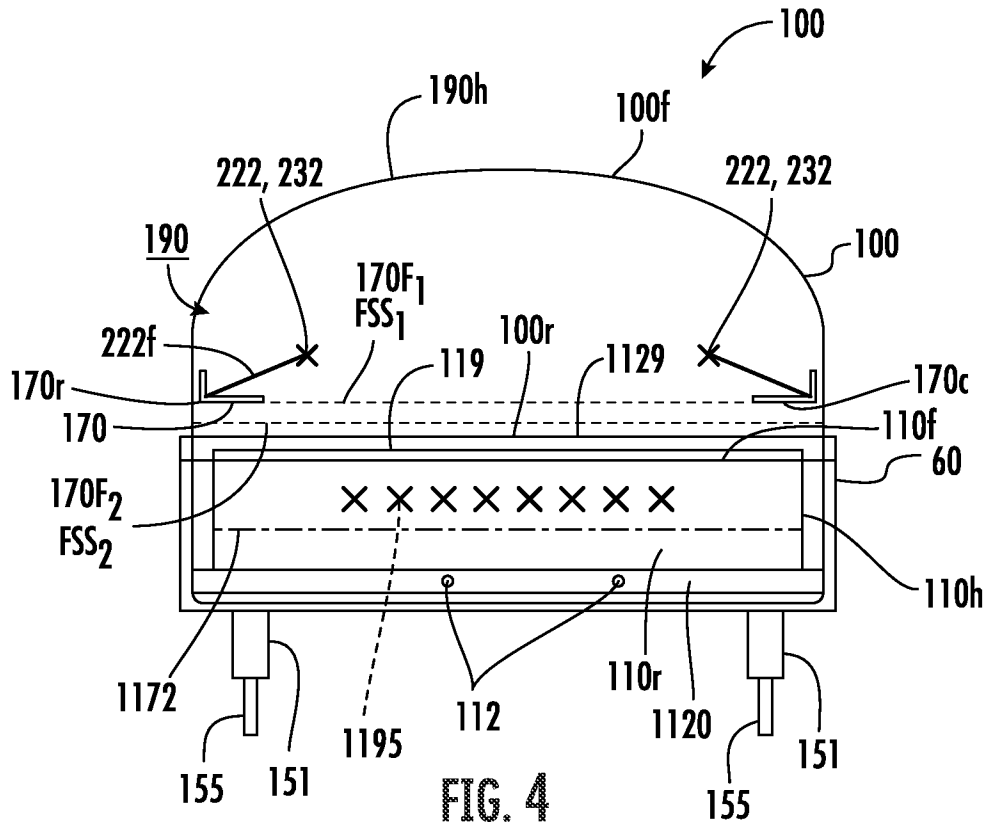


FIG. 3

4/18



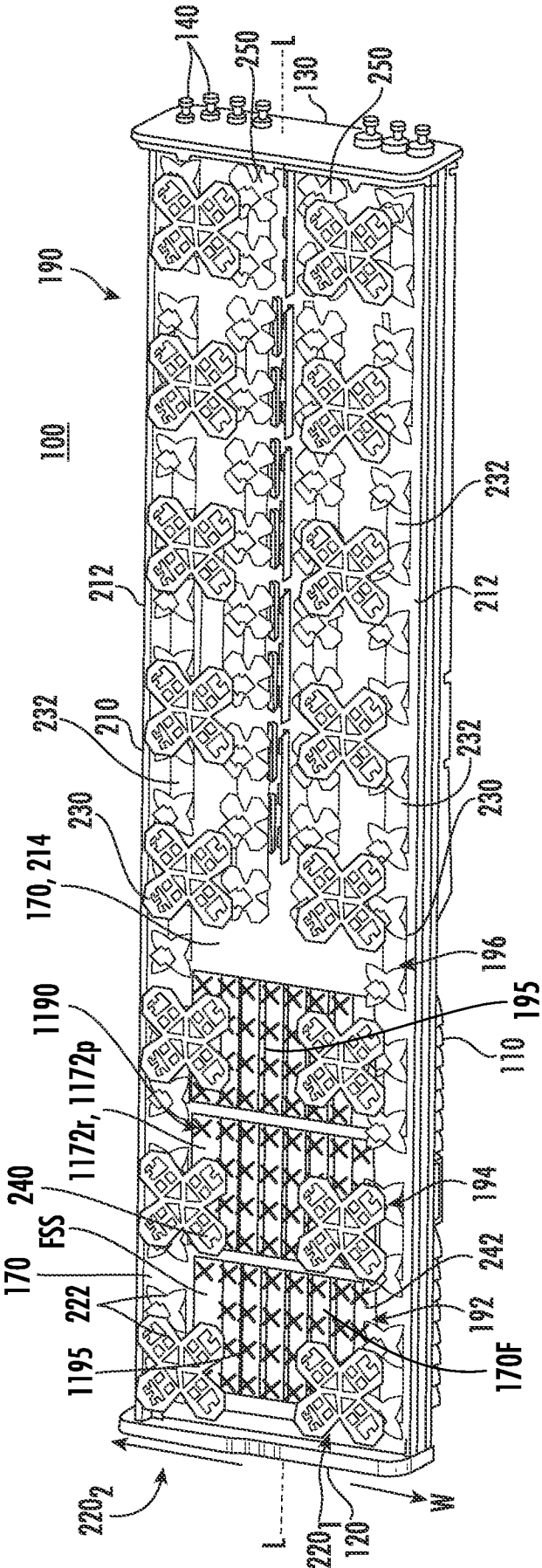


FIG. 6

6/18

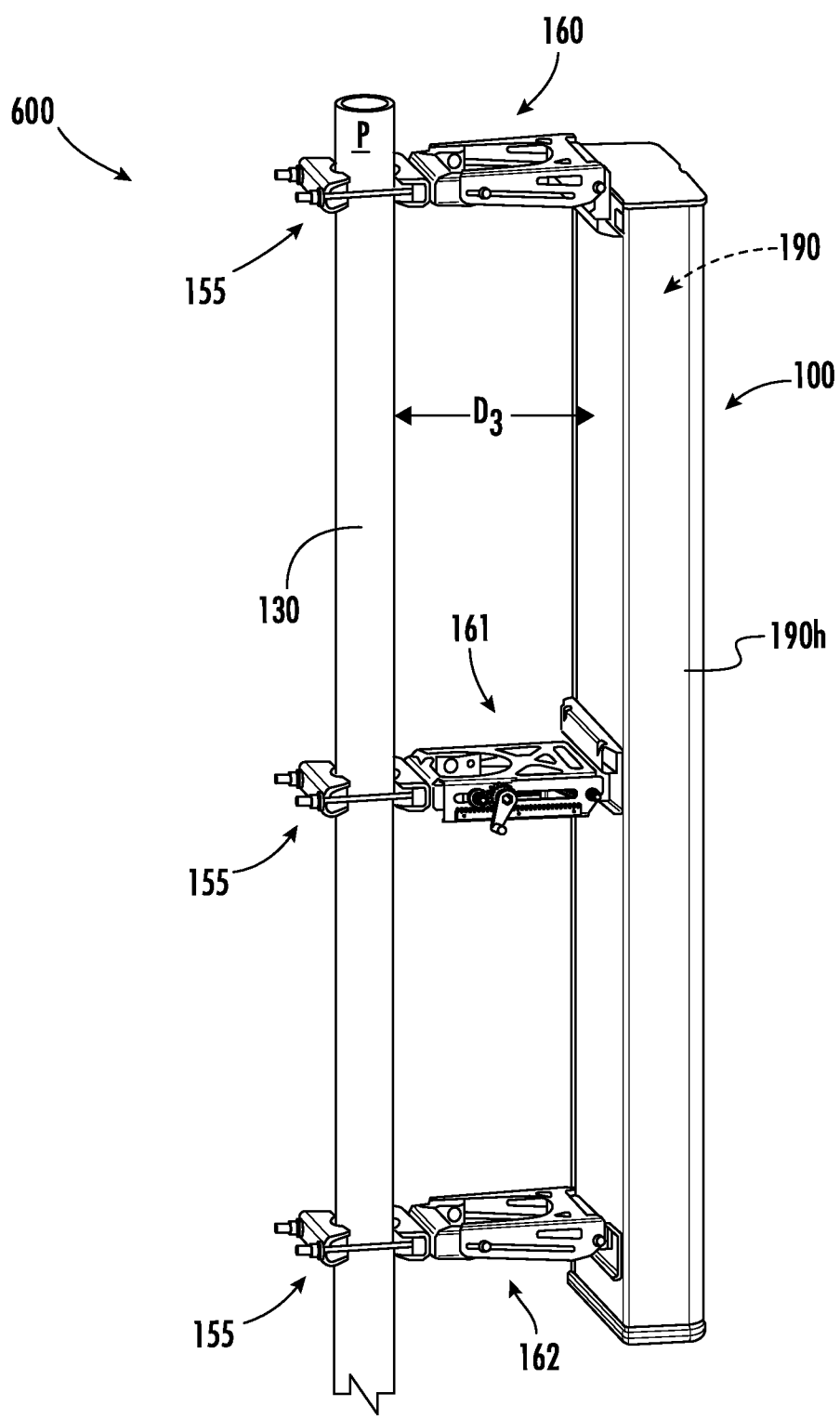


FIG. 7

7/18

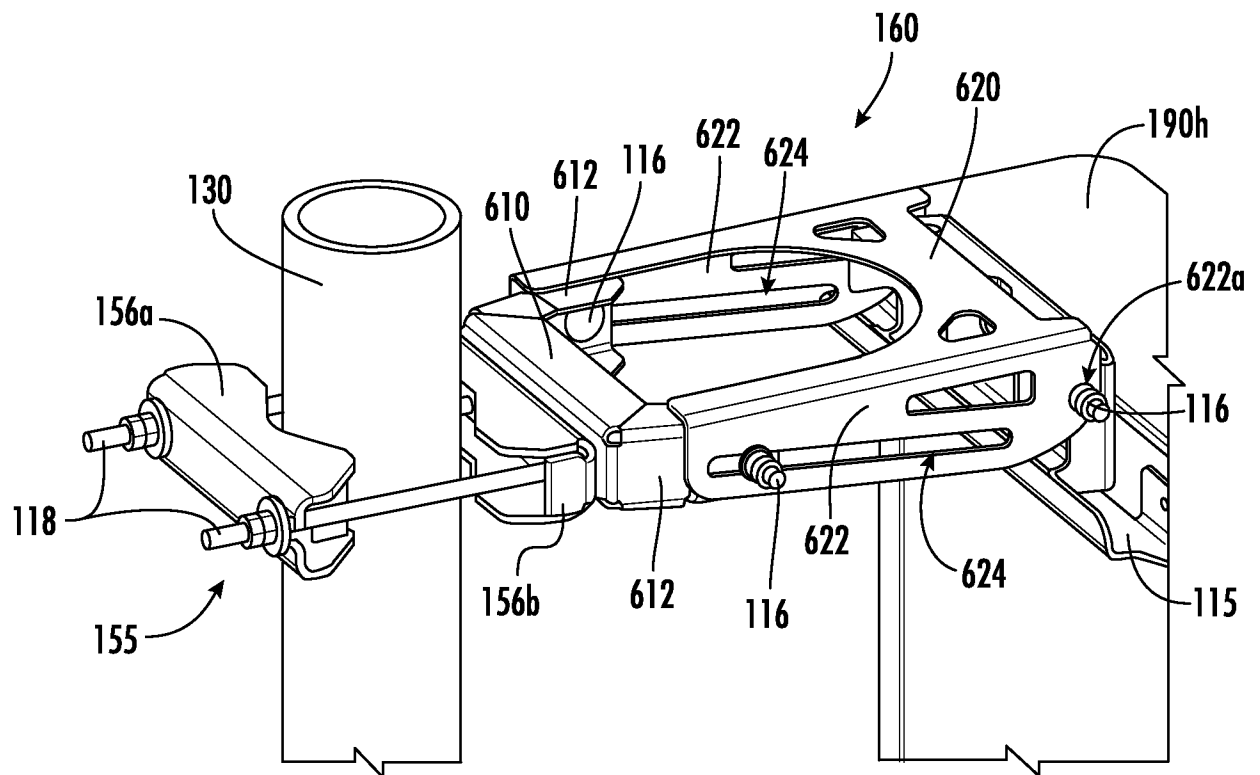


FIG. 8A

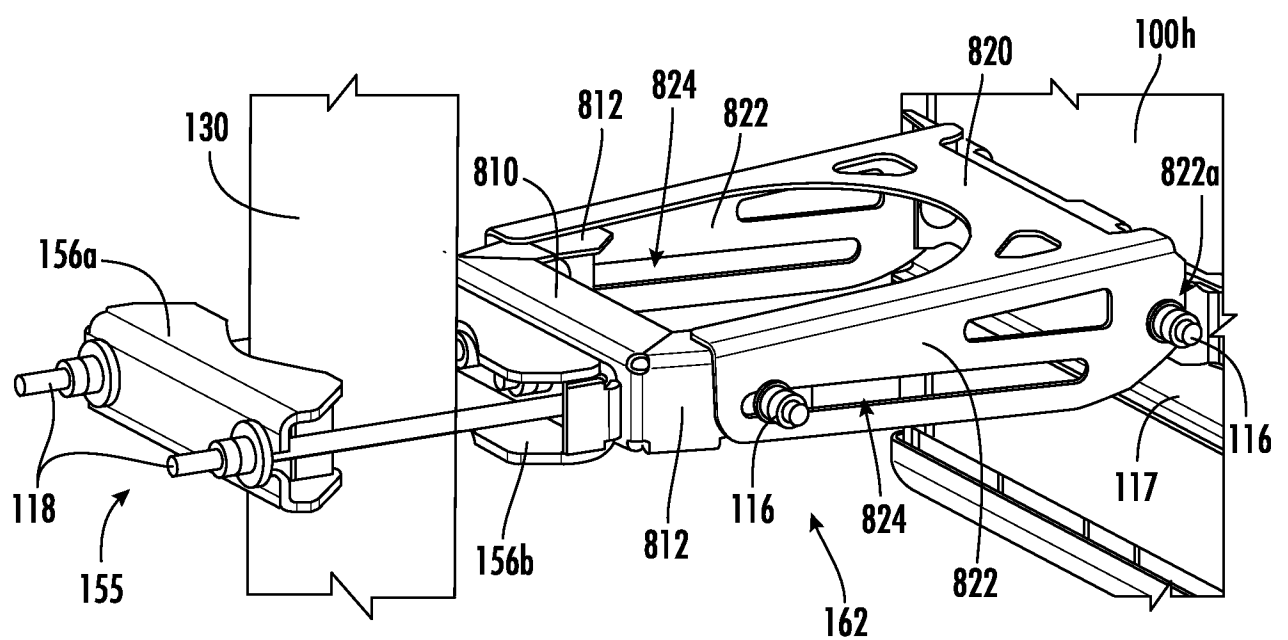


FIG. 8B

8/18

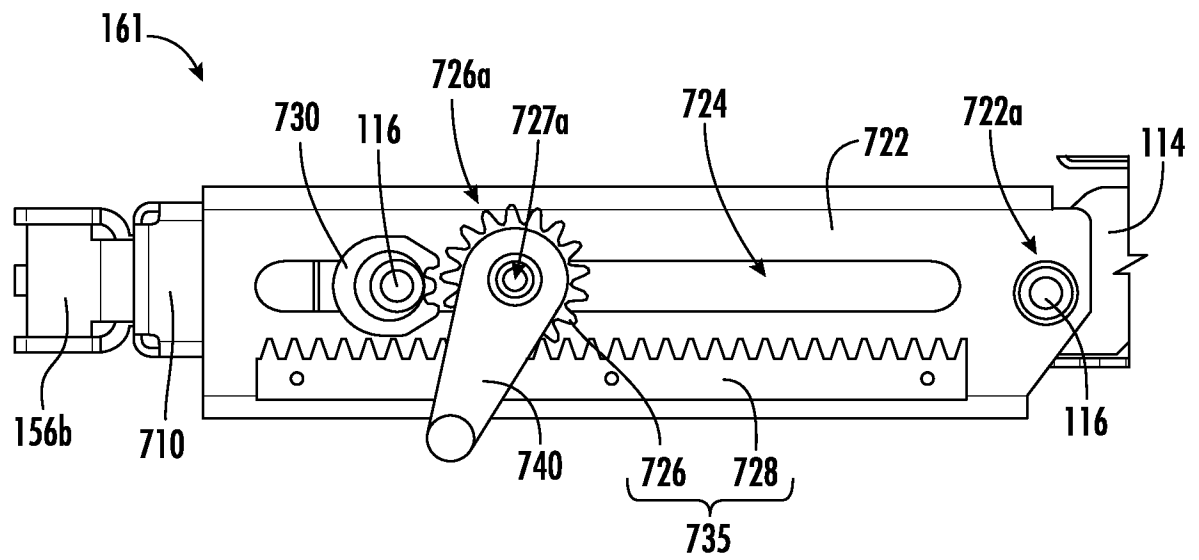


FIG. 9A

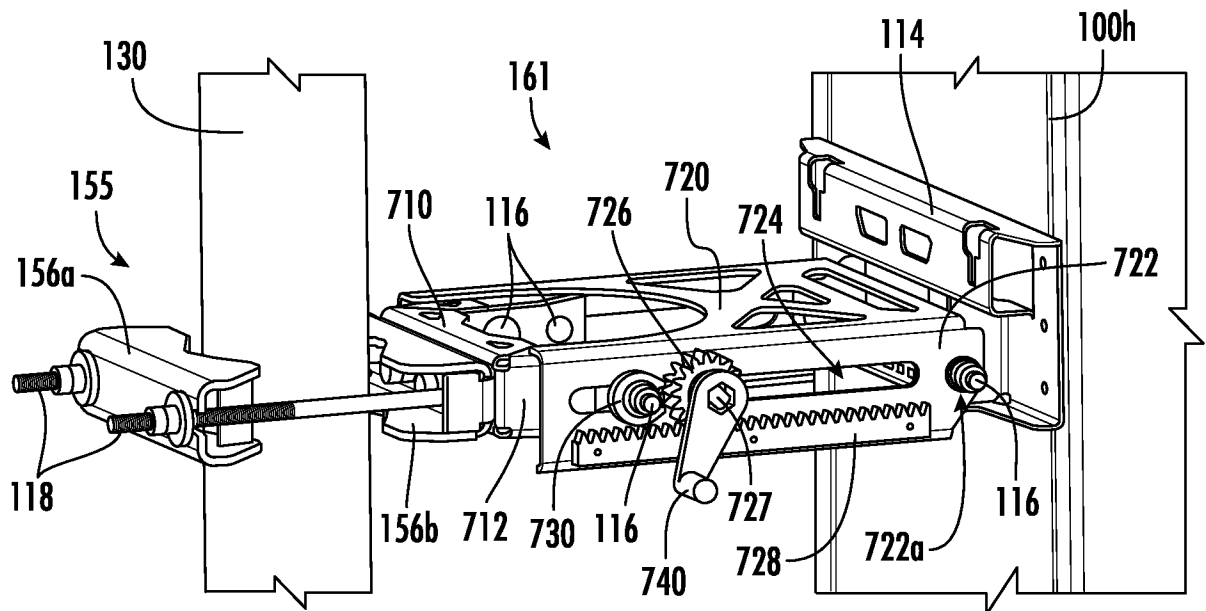


FIG. 9B

9/18

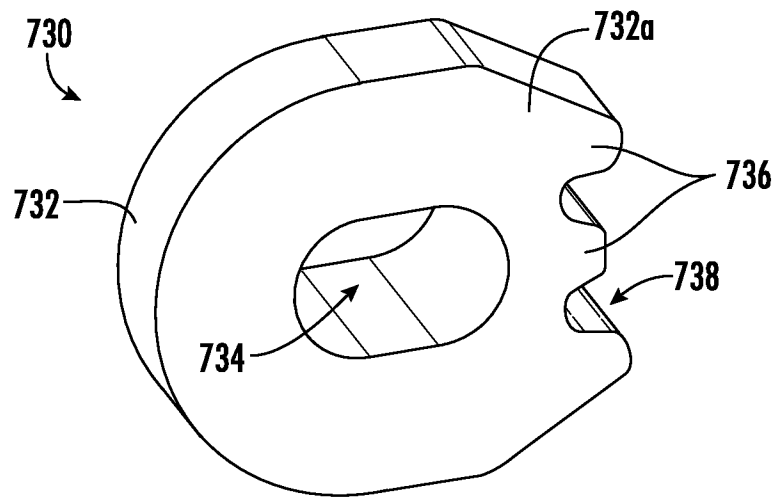


FIG. 10A

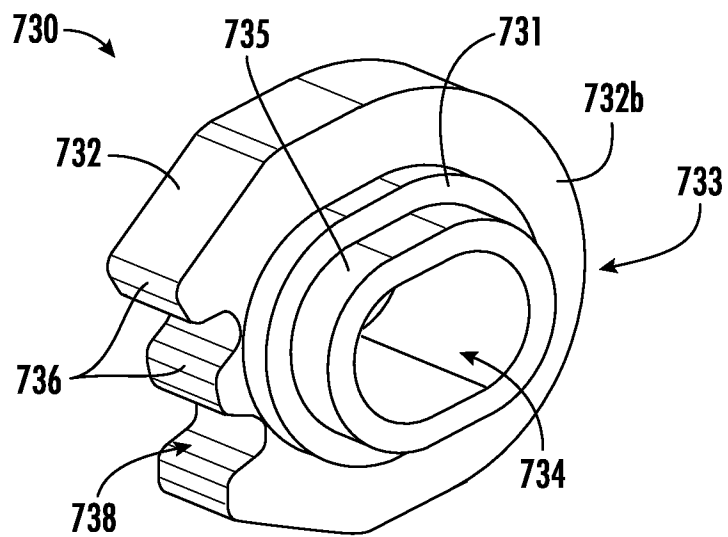
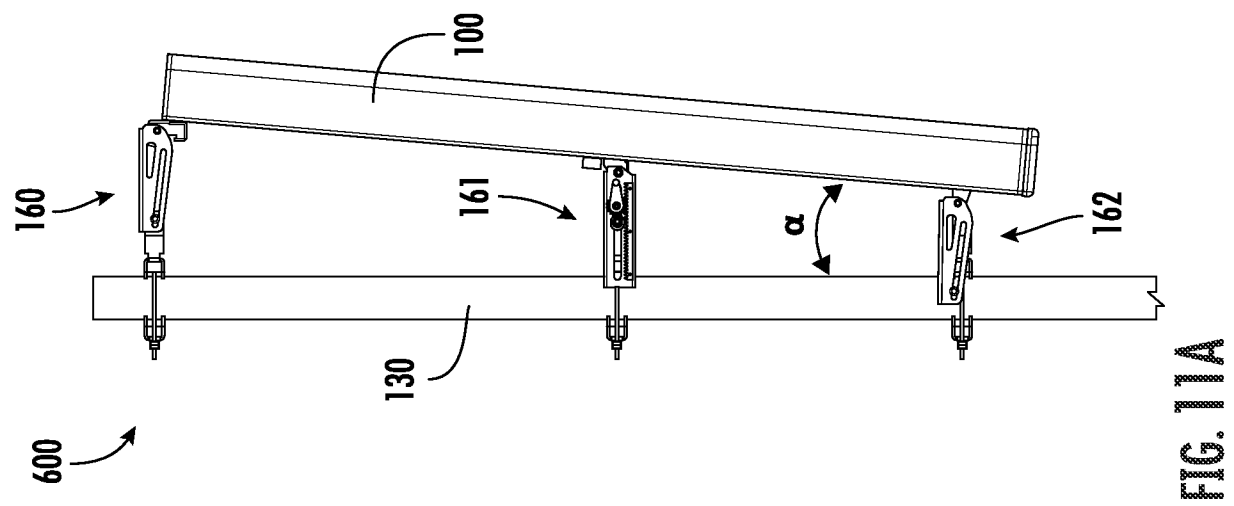
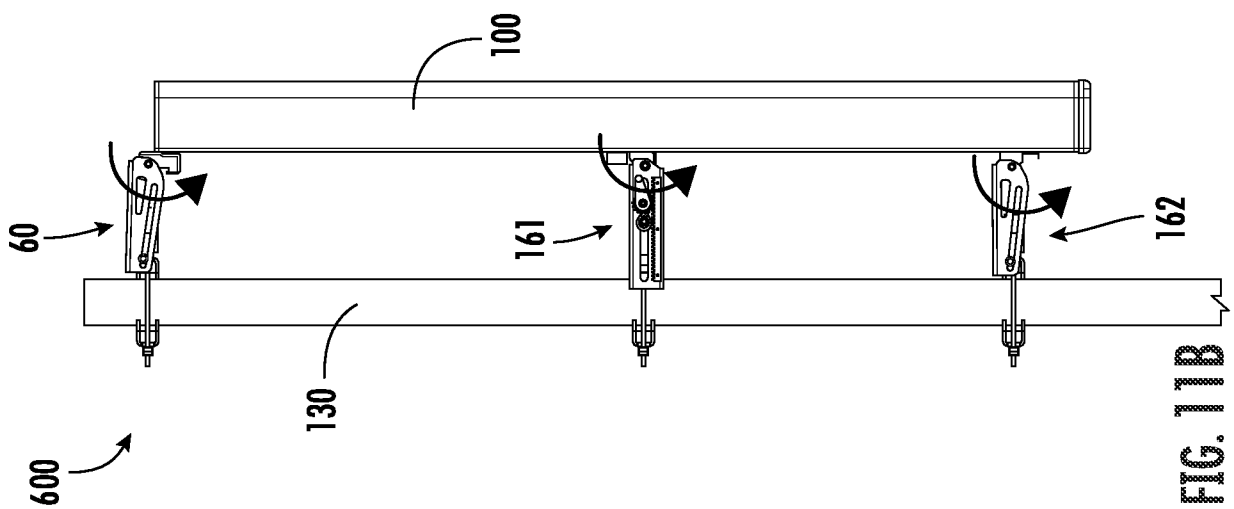
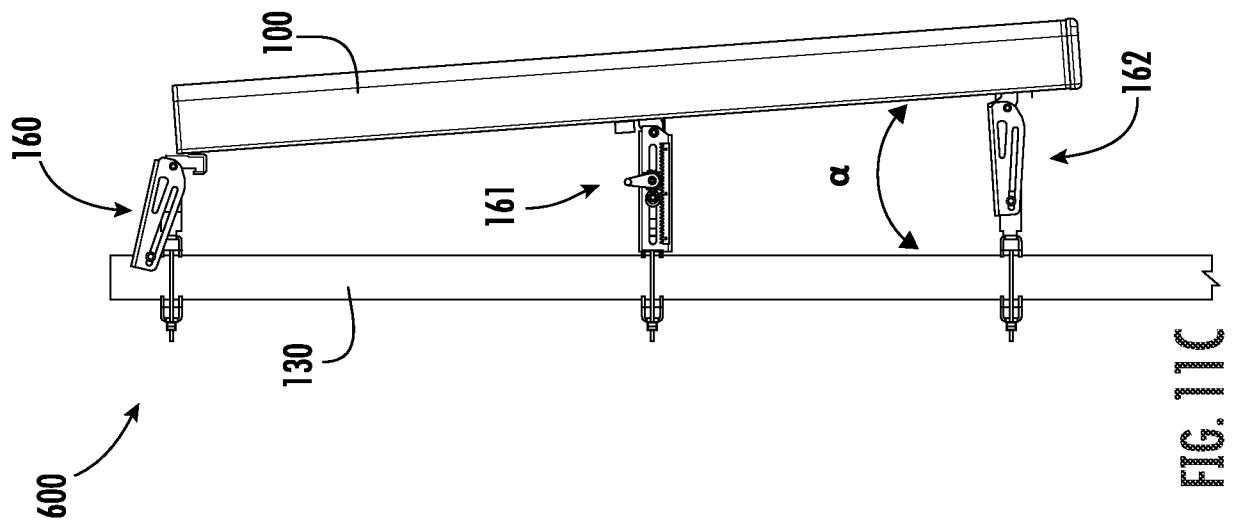
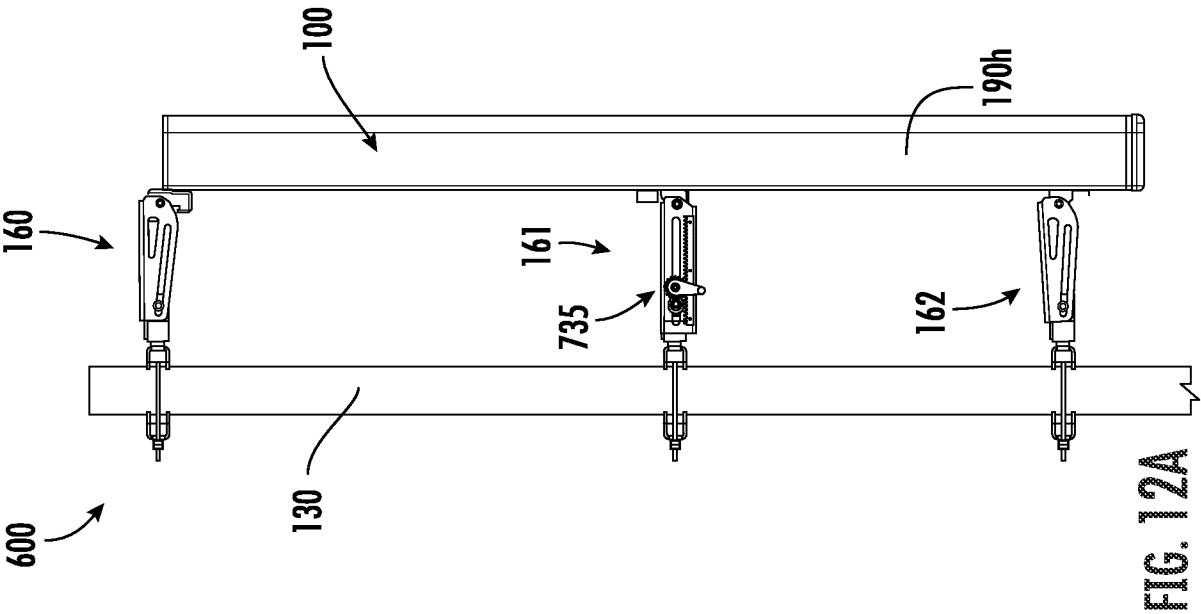
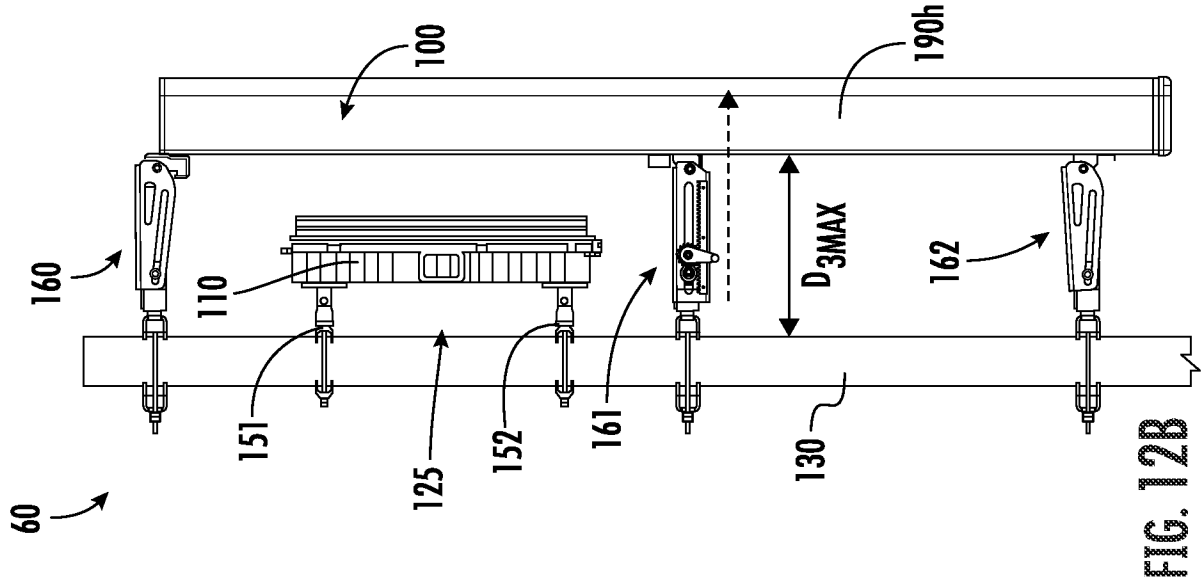
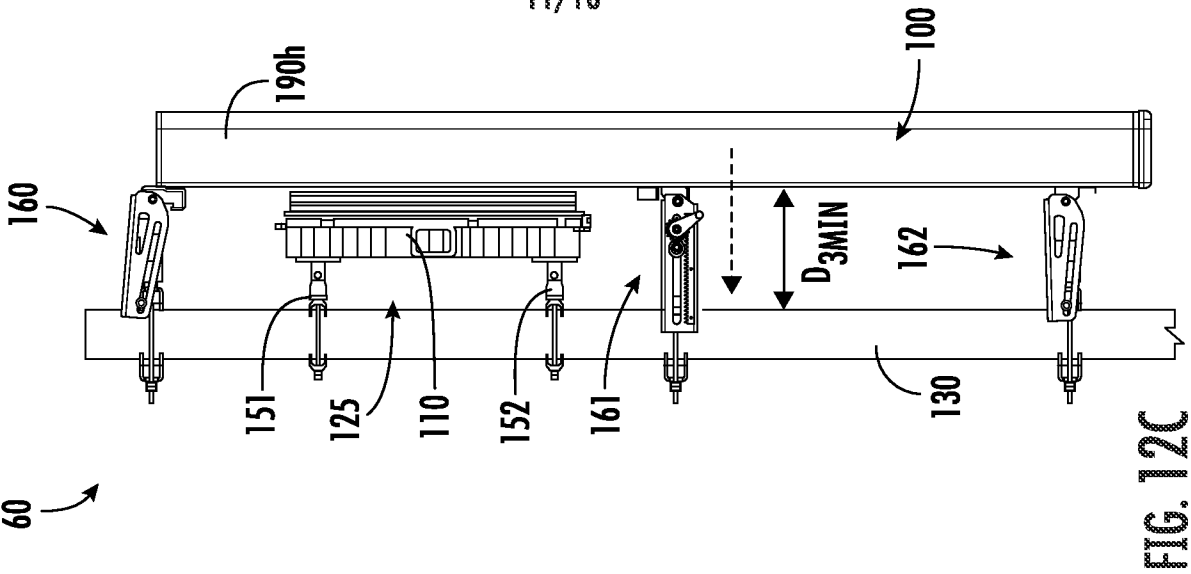


FIG. 10B

10/18





12/18

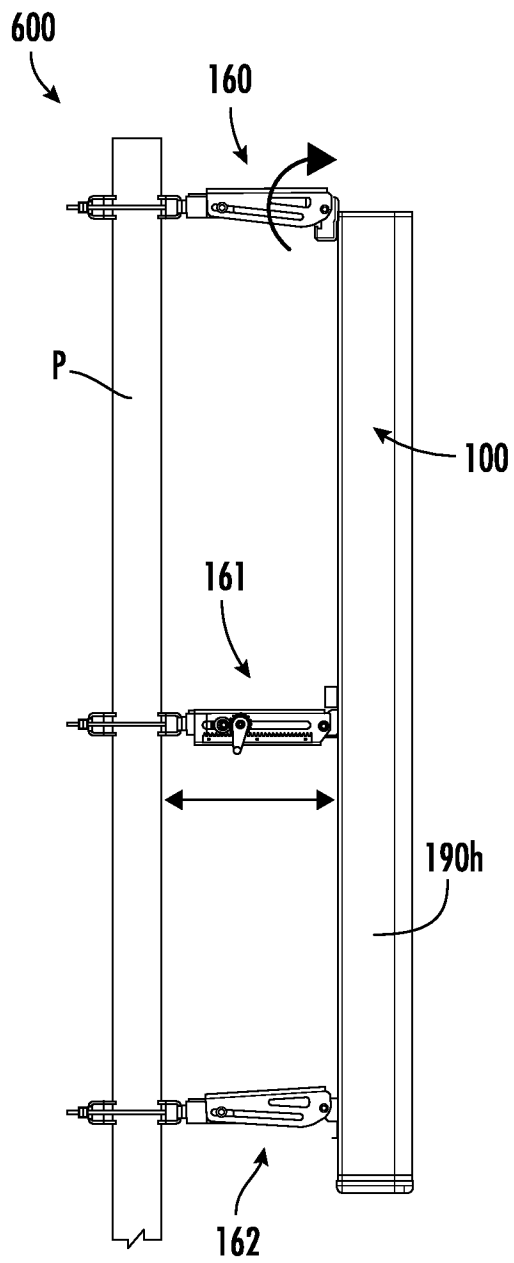


FIG. 13A

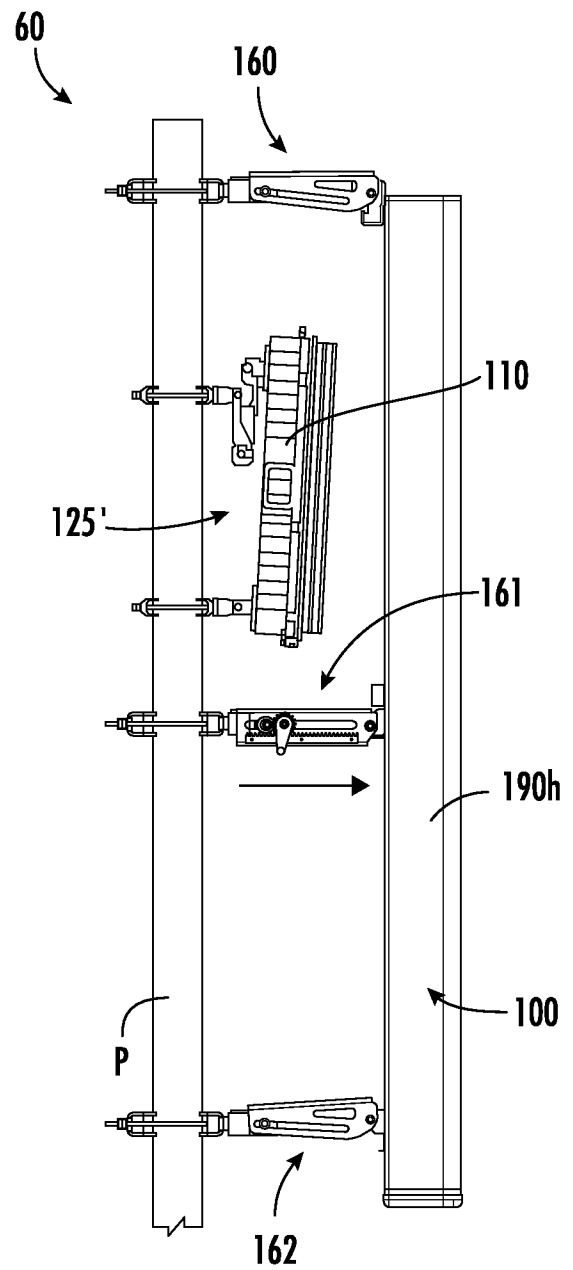


FIG. 13B

13/18

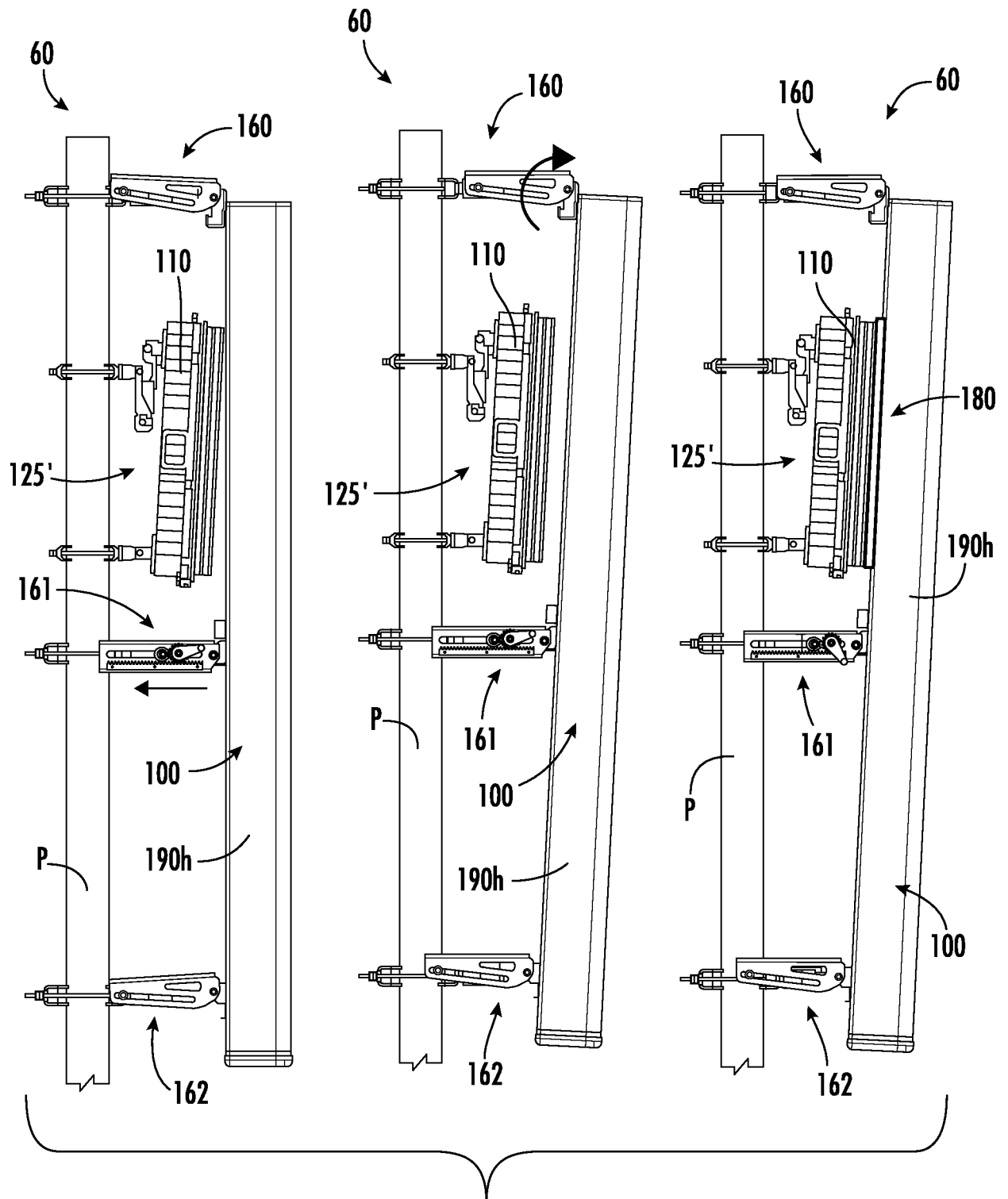
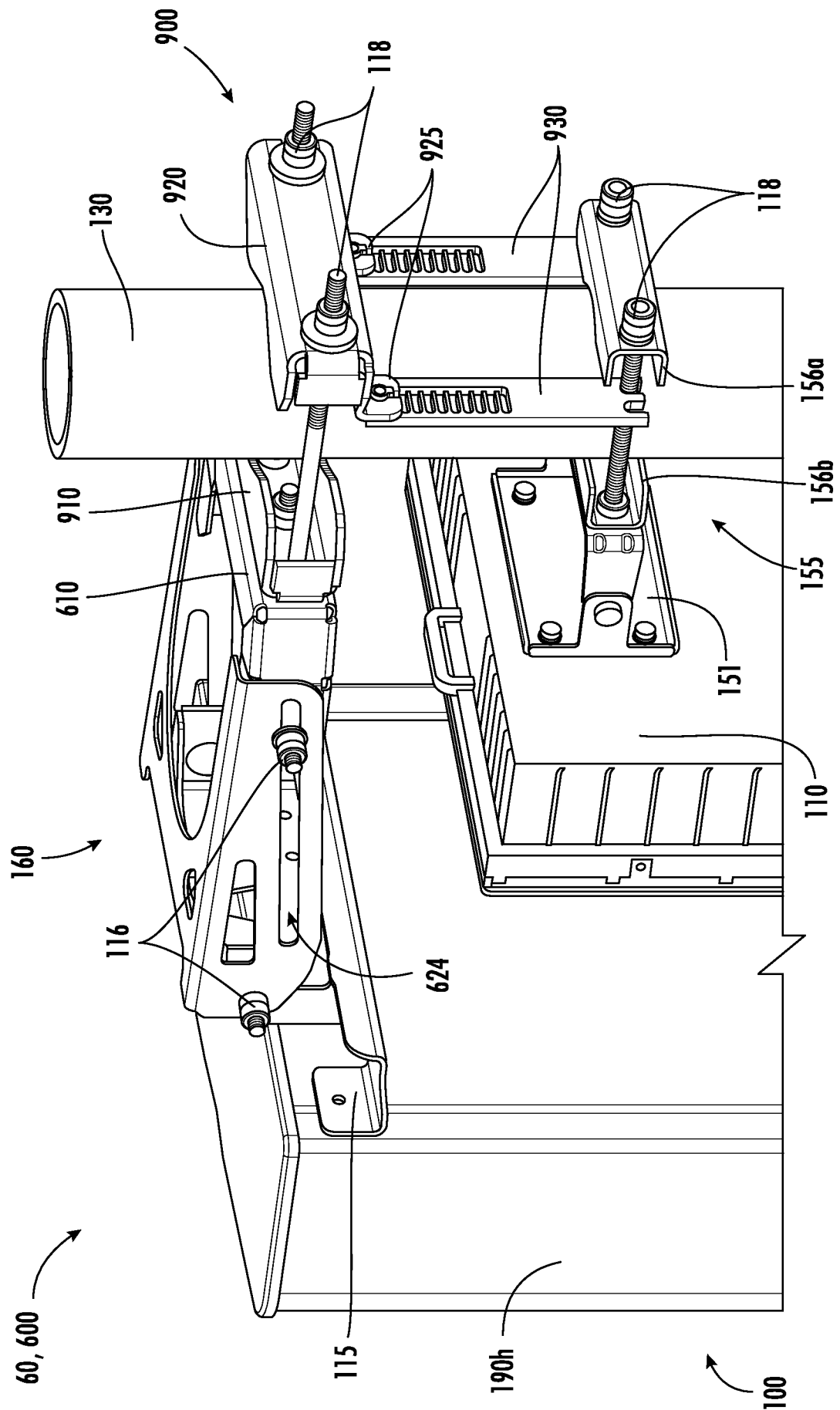
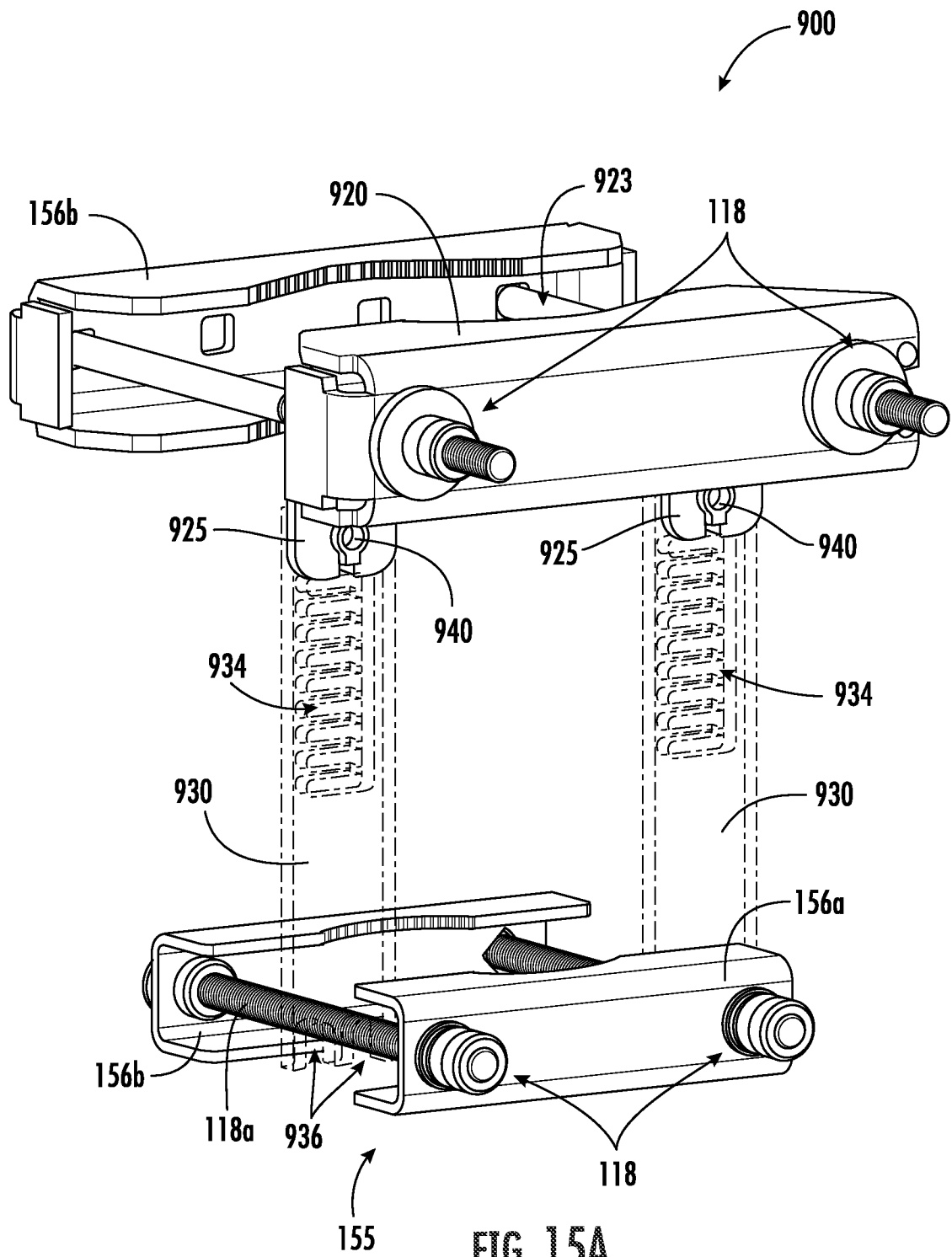


FIG. 13C



15/18



16/18

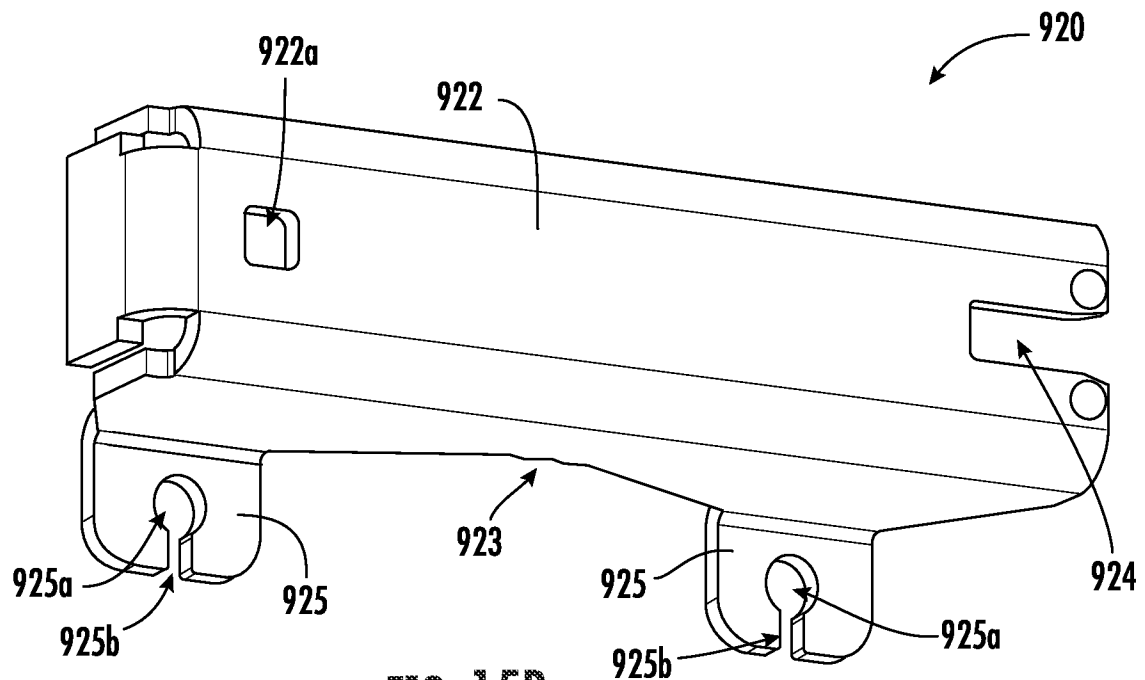


FIG. 15B

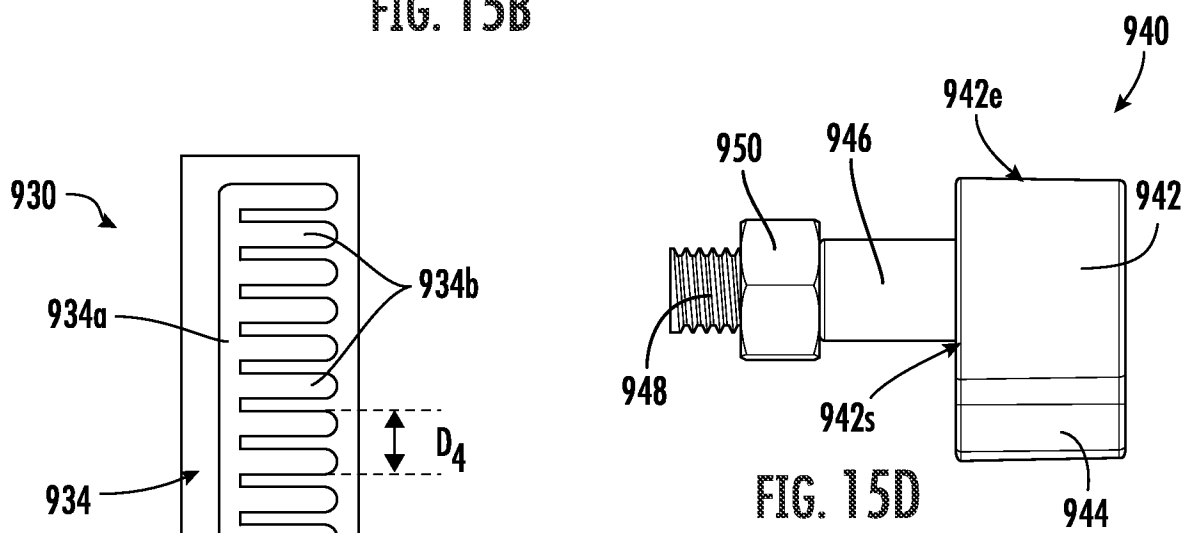


FIG. 15D

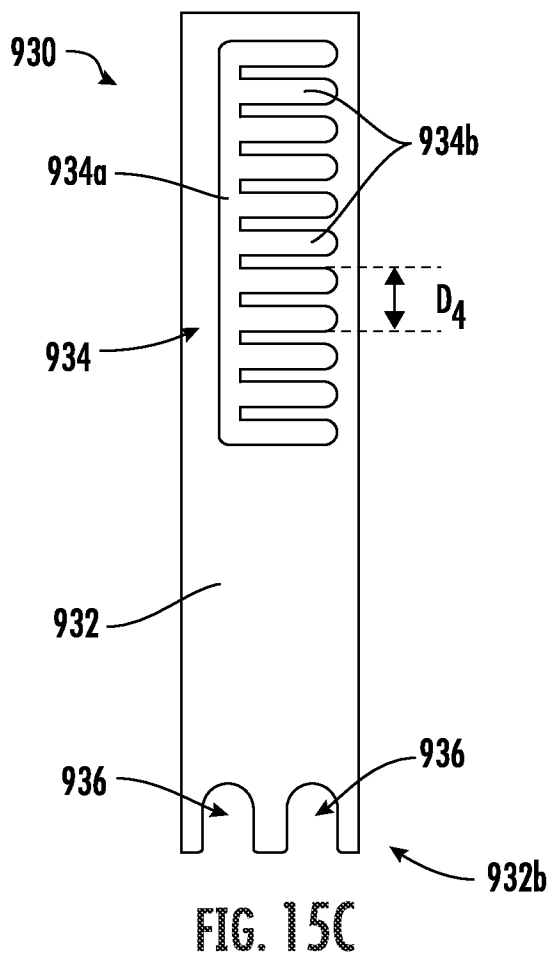


FIG. 15C

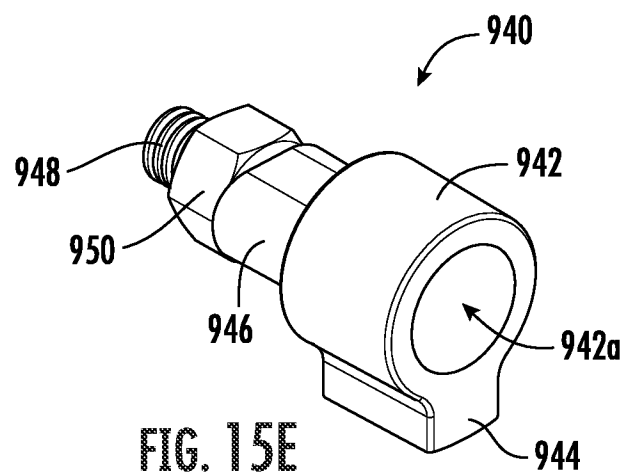
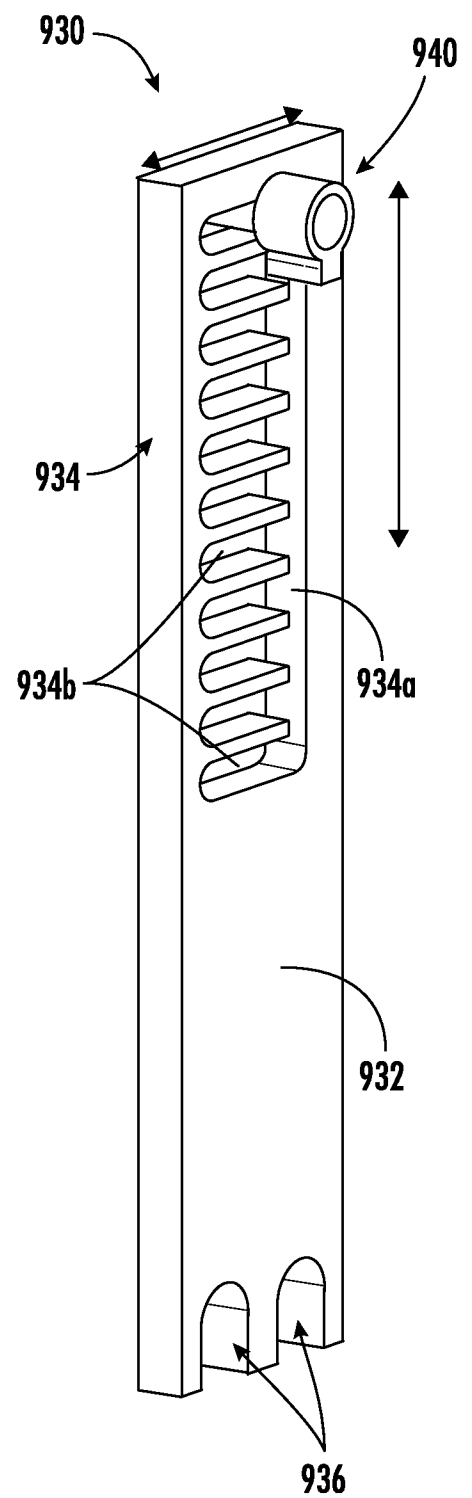
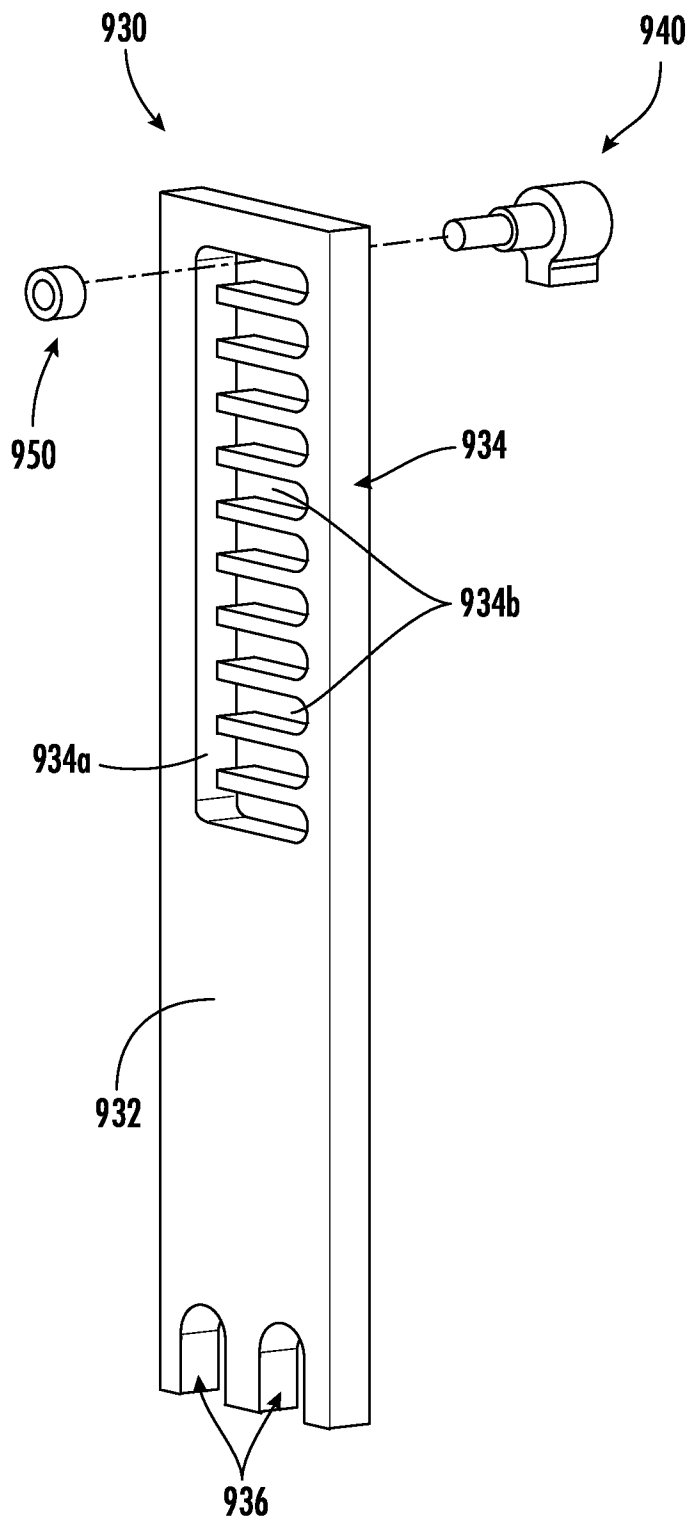


FIG. 15E

17/18



18/18

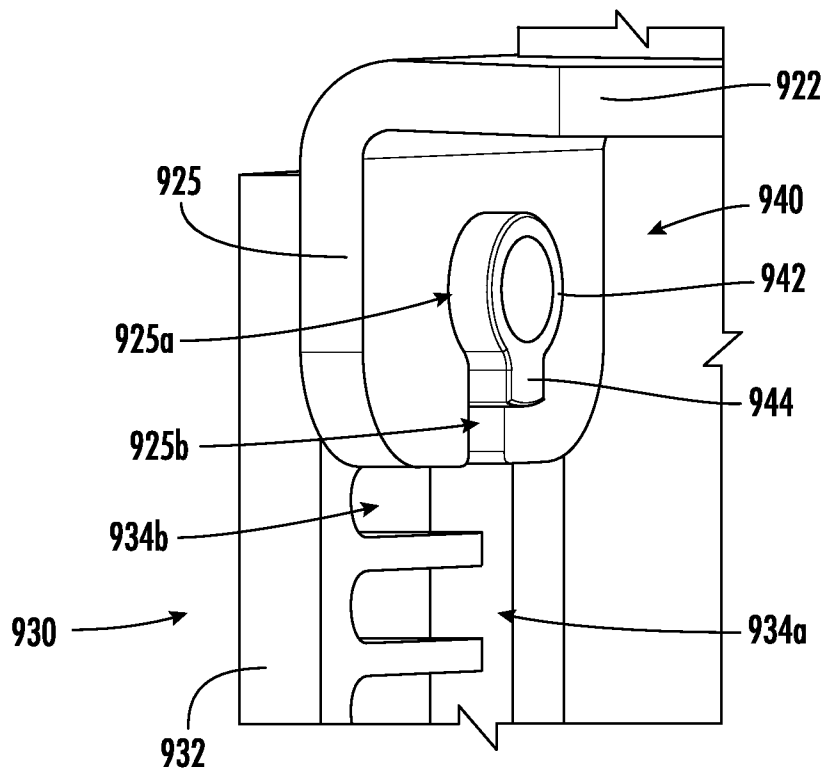


FIG. 17A

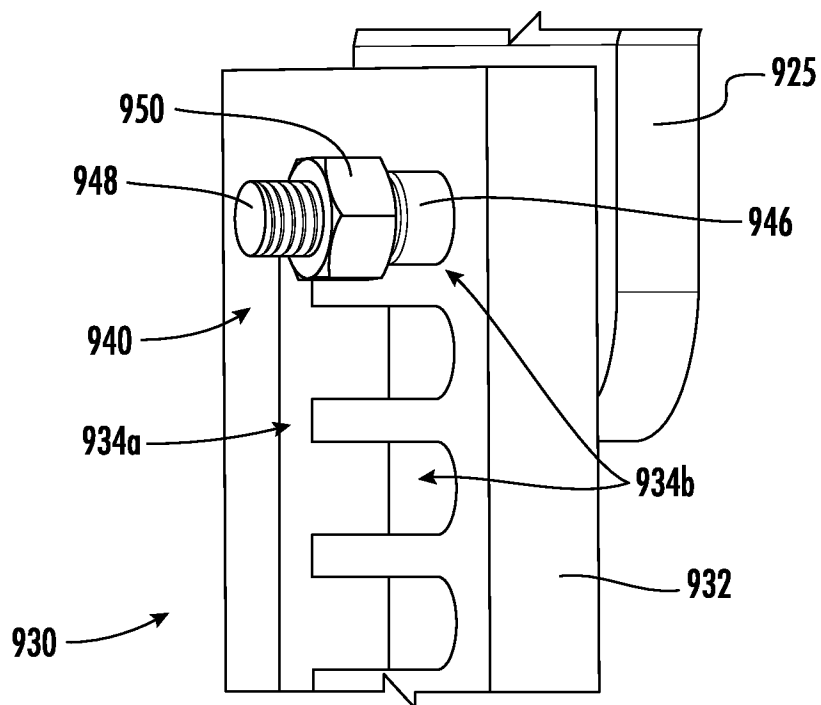


FIG. 17B

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 23/25740

A. CLASSIFICATION OF SUBJECT MATTER

IPC - INV. H01Q 1/12, H01Q 21/00 (2023.01)

ADD. H01Q 5/00, H01Q 1/52 (2023.01)

CPC - INV. H01Q 1/1207, H01Q 1/1242, H01Q 1/20, H01Q 21/00

ADD. H01Q 5/00, H01Q 1/52

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.
Y	— CN 216362158 U (Convert Tech Limited Responsibility Company) 22 April 2022 (22.04.2022); entire document, especially, abstract, FIG. 2, Page 9, para 1-3, Page 10, para 2	1-3, 14-16, 20
Y	US 2021/0336331 A1 (Commscope Design & Integration UK Limited) 28 October 2021 (28.10.2021); entire document, especially, FIG.2-3, para [0064]-[0066]	1-3, 14-16, 20
Y	US 2015/0091777 A1 (Rucki et al.) 02 April 2015 (02.04.2015); entire document, especially, abstract, FIG. 1,2, para [0021]-[0024], [0032]	3, 14-16, 20
Y	→ WO 2022/111408 A1 (Huawei Technologies Co., Ltd.) 02 June 2022 (02.06.2022); entire document, especially, abstract, Page 31, para 1-2, Page 33, para 2-3, Page 34, para 4-5	16

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"D" document cited by the applicant in the international application
"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

02 October 2023

Date of mailing of the international search report

OCT 30 2023

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents

P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-8300

Authorized officer

Kari Rodriguez

Telephone No. PCT Helpdesk: 571-272-4300

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 23/25740

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 4-13, 17-19, 27, 28 and 36-43
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I: Claims 1-3, 14-16 and 20 drawn to a base station assembly with an active and passive antenna assemblies.

Group II: Claims 21-26 and 29-32 drawn to a base station assembly with a rack and pinion assembly.

Group III: Claims 33-35 and 44 drawn to a mounting gauge kit.

---See Continuation on Supplemental Page---

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
Claims 1-3, 14-16 and 20

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 23/25740

Continuation of Box No. III - Lack of Unity of Invention -

Shared Technical Features:

The only technical features shared by Groups I-III that would otherwise unify the groups are: an antenna bracket secured to a passive antenna housing, and an active antenna module.

The only technical features shared by Groups I and II that would otherwise unify the groups are: a base station antenna assembly, and a plurality of antenna mounting brackets coupled to the housing and configured to attach to a mounting structure.

However, these shared technical features do not represent a contribution over prior art, because the shared technical features are disclosed by US 2015/0091777 A1 to Rucki et al. (hereinafter 'Rucki') published on 02 April 2015 (02.04.2015).

Rucki discloses an antenna bracket (106(1) or 106 (2), fig 1) secured to a passive antenna housing (radome 102, fig 1.4, para [0024] "Note that first and second antenna arrays 132 and 134 are merely passive devices that radiate and receive signals, without actively modifying the signals."),

an active antenna module (active electronics module 110, fig 1, fig 4, para [0021] "FIG. 1 shows a side view of a cellular antenna assembly 100 according to one embodiment of the disclosure, and FIG. 2 shows a top view of cellular antenna assembly 100. Antenna assembly 100 comprises a radome 102, an active electronics module 110..."),

a base station antenna assembly (para [0029] "Second antenna array 134 is served by a second electronics module (not shown) that is installed on the ground at the base station."; para [0020] "To accommodate the preferences of cellular phone carriers that favor the base-station electronics in close proximity to antenna assemblies and those that do not, there is a need for a reconfigurable antenna assembly that permits the electronics serving the antenna array or arrays in the antenna assembly to be selectively located (i) at the base of cell the tower or (ii) in close proximity to the antenna arrays. "),

a plurality of antenna mounting brackets coupled to the housing and configured to attach to a mounting structure (para [0021]-[0022] "In FIG. 2, bracket 106(1) is shown as a two-part clamp, having first part 130(1) and second part 130(2), which together clamp around pipe 104; however, numerous other types of brackets may be employed. Typically, antenna assembly 100 is installed by sliding pipe 104 over a mating pole or pipe (not shown) on a cell tower, such that the mating pole or pipe (not shown) rests inside pipe 104. Note that, as used herein, the term "cell tower" is used to refer to an elevated structure on which a cellular antenna is mounted, including, but not limited to, actual towers, tops of buildings, water towers, and high-tension towers.").

As the shared technical features were known in the art at the time of the invention, they cannot be considered special technical features that would otherwise unify the groups.

Note: Claim 20 is written as depending upon claim 24. Based on the preamble, specification, and other similar claims, Claim 20 has been interpreted to be dependent upon claim 14.

Item 4 continued: Claims 4-13, 17-19, 27, 28 and 36-43 are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).