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(54) **Title:** ANTENNA SYSTEM FOR HIGH-ALTITUDE PLATFORM SYSTEM

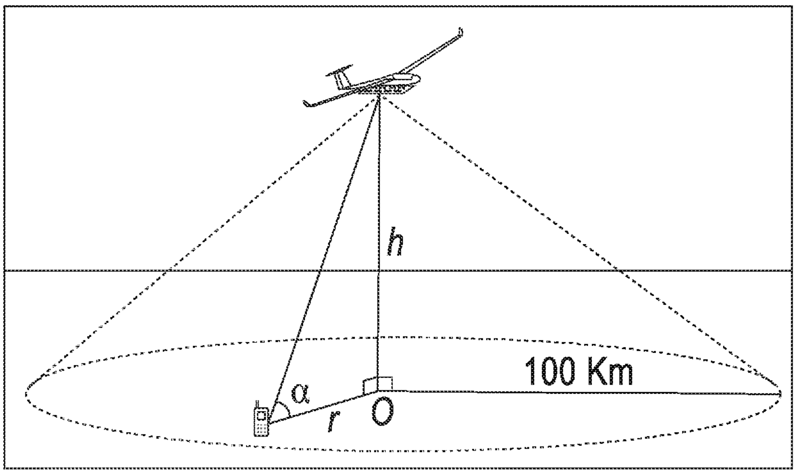

FIG. 1

(57) **Abstract:** Method, apparatuses, and computer program product for enhancing antenna systems for high-altitude platform systems (HAPS) are provided. One method may include selecting a panel from a multi -panel antenna array to serve a coverage sector on a ground. The method may also include forming a sector-specific beam at each panel of the multi-panel antenna array. The method may further include, steering the sector-specific beam to a point in the coverage sector. The method may also include maintaining, with the sector-specific beam, a constant coverage area of the ground corresponding to the coverage sector.

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ANTENNA SYSTEM FOR HIGH-ALTITUDE PLATFORM SYSTEM

FIELD:

[0001] Some example embodiments may generally relate to mobile or wireless telecommunication systems, such as Long Term Evolution (LTE) or fifth generation (5G) radio access technology or new radio (NR) access technology, or other communications systems. For example, certain embodiments may relate to apparatuses, systems, and/or methods for enhancing antenna systems for high-altitude platform systems (HAPS).

BACKGROUND:

[0002] Examples of mobile or wireless telecommunication systems may include the Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (UTRAN), Long Term Evolution (LTE) Evolved UTRAN (E-UTRAN), LTE-Advanced (LTE-A), MulteFire, LTE-A Pro, and/or fifth generation (5G) radio access technology or new radio (NR) access technology. Fifth generation (5G) wireless systems refer to the next generation (NG) of radio systems and network architecture. 5G is mostly built on a new radio (NR), but the 5G (or NG) network can also build on E-UTRA radio. It is estimated that NR will provide maximum bitrates on the order of 10-20 Gbit/s or higher and will support at least enhanced mobile broadband (eMBB) and ultra-reliable low-latency-communication (URLLC) as well as massive machine type communication (mMTC). NR is expected to deliver extreme broadband and ultra-robust, low latency connectivity and massive networking to support the Internet of Things (IoT). With IoT and machine-to-machine (M2M) communication becoming more widespread, there will be a growing need for networks that meet the needs of lower power, low data rate, and long battery life. It is noted that, in 5G, the nodes that can provide radio access functionality to a user equipment (i.e., similar to Node B in UTRAN or eNB in LTE) may be named gNB when built on NR radio and may be named NG-eNB when built on E-UTRA radio.

SUMMARY

[0003] One embodiment may be directed to a method. The method may include selecting a panel from a multi-panel antenna array to serve a coverage sector on a ground. The method may also include forming a sector-specific beam at each panel of the multi-panel antenna array. The method may further include steering the sector-specific beam to a point in the coverage sector. The method may also include maintaining, with the sector-specific beam, a constant coverage area of the ground corresponding to the coverage sector.

[0004] Another example embodiment may be directed to an apparatus. The apparatus may include means for selecting a panel from a multi-panel antenna array to serve a coverage sector on a ground. The apparatus may also include means for forming a sector-specific beam at each panel of the multi-panel antenna array. The apparatus may further include means for steering the sector-specific beam to a point in the coverage sector. The apparatus may also include means for maintaining, with the sector-specific beam, a constant coverage area of the ground corresponding to the coverage sector.

[0005] Another example embodiment may be directed to an apparatus which may include at least one processor and at least one memory including computer program code. The at least one memory and the computer program code may be configured to, with the at least one processor, cause the apparatus at least to select a panel from a multi-panel antenna array to serve a coverage sector on a ground. The at least one memory and the computer program code may also be configured to, with the at least

one processor, cause the apparatus at least to form a sector-specific beam at each panel of the multi-panel antenna array. The at least one memory and the computer program code may further be configured to, with the at least one processor, cause the apparatus at least to steer the sector-specific beam to a point in the coverage sector. The at least one memory and the computer program code may also be configured to, with the at least one processor, cause the apparatus at least to maintain, with the sector-specific beam, a constant coverage area of the ground corresponding to the coverage sector.

[0006] In accordance with some example embodiments, a non-transitory computer readable medium can be encoded with instructions that may, when executed in hardware, perform a method. The method may select a panel from a multi-panel antenna array to serve a coverage sector on a ground. The method may also form a sector-specific beam at each panel of the multi-panel antenna array. The method may further steer the sector-specific beam to a point in the coverage sector. The method may also maintain, with the sector-specific beam, a constant coverage area of the ground corresponding to the coverage sector.

[0007] In accordance with some example embodiments, a computer program product may perform a method. The method may select a panel from a multi-panel antenna array to serve a coverage sector on a ground. The method may also form a sector-specific beam at each panel of the multi-panel antenna array. The method may further steer the sector-specific beam to a point in the coverage sector. The method may also maintain, with the sector-specific beam, a constant coverage area of the ground corresponding to the coverage sector.

[0008] In accordance with some example embodiments, an apparatus may include circuitry configured to select a panel from a multi-panel antenna array to serve a coverage sector on a ground. The apparatus may also include circuitry configured to form a sector-specific beam at each panel of the multi-panel antenna array. The apparatus may further include circuitry configured to steer the sector-specific beam to a point in the coverage sector. The apparatus may also include circuitry configured to maintain, with the sector-specific beam, a constant coverage area of the ground corresponding to the coverage sector.

[0009] In accordance with some example embodiments, antenna system assembly may include a plurality of antenna panels, each disposed around a circumference of the antenna system assembly and facing a different direction. The antenna system assembly may also include a center antenna panel disposed in a center of the plurality of antenna panel. The antenna system assembly may further include a container platform comprising a gimbal assembly, wherein the plurality of antenna panels and the center antenna panel are mounted to the container platform. The antenna system assembly may also include a controller configured to select an antenna panel from the plurality of antenna panels and the center antenna panel to serve a coverage sector on a ground, and to select a beam to use on the selected antenna panel.

BRIEF DESCRIPTION OF THE DRAWINGS:

[00010] For proper understanding of the invention, reference should be made to the accompanying drawings, wherein:

[00011] FIG. 1 illustrates an example high altitude platform system (HAPS) deployment model.

[00012] FIG. 2 illustrates an additional example deployment model for HAPS.

[00013] FIG. 3(a) illustrates an MxNx2 single panel array, according to an example embodiment.

[00014] FIG. 3(b) illustrates a beam design in HAPS covering 7 different sectors covered by 7 parallel beams from the MxNx2 single panel array of FIG. 3(a).

[00015] FIG. 4 illustrates a beam pattern of a beam covering one of the outer

6 cells of a service area on the ground, according to an example embodiment.

[00016] FIG. 5(a) illustrates a signal-to-interference-plus-noise ratio (SINR) on a downlink versus a user equipment (UE) location with respect to a center of the service area on the ground, according to an example embodiment.

[00017] FIG. 5(b) illustrates a downlink throughput SINR versus the UE location with respect to the center of the service area on the ground, according to an example embodiment.

[00018] FIG. 6(a) illustrates an SINR on an uplink versus the UE location with respect to the center of the service area on the ground, according to an example embodiments.

[00019] FIG. 6(b) illustrates an uplink throughput SINR versus the UE location with respect to the center of the service area on the ground, according to an example embodiment.

[00020] FIG. 7(a) illustrates a multi-panel antenna array, according to an example embodiment.

[00021] FIG. 7(b) illustrates 7 sectors on the ground covered by the panels of the multi-panel antenna array of FIG. 7(a), according to an example embodiment.

[00022] FIG. 8 illustrates structural configurations of the multi-panel antenna array of FIG. 7(a), according to an example embodiment.

[00023] FIG. 9 illustrates a beam pattern of the beam covering one of the outer 6 sectors (right) and the beam covering the center sector (left), according to an example embodiment.

[00024] FIG. 10(a) illustrates another SINR on a downlink versus the UE location with respect to the center of the service area on the ground, according to an example embodiment.

[00025] FIG. 10(b) illustrates another downlink throughput SINR versus the UE location with respect to the center of the service area on the ground, according to an example embodiment.

[00026] FIG. 11(a) illustrates another uplink throughput SINR versus the UE location with respect to the center of the service area on the ground, according to an example embodiment.

[00027] FIG. 11(b) illustrates another uplink throughput SINR versus the UE location with respect to the center of the service area on the ground, according to an example embodiment.

[00028] FIG. 12 illustrates an exemplary flow diagram of a method, according to an example embodiment.

[00029] FIG. 13(a) illustrates a block diagram of an apparatus according to an example embodiment

[00030] FIG. 13(b) illustrates a block diagram of another apparatus according to an example embodiment.

DETAILED DESCRIPTION

[0031] It will be readily understood that the components of certain example embodiments, as generally described and illustrated in the figures herein, may be arranged and designed in a wide variety of different configurations. Thus, the following detailed description of some example embodiments of systems, methods, apparatuses, and computer program products for enhancing antenna systems for high-altitude platform systems (HAPS).

[0032] The features, structures, or characteristics of example embodiments described throughout this specification may be combined in any suitable manner in one or more example embodiments. For example, the usage of the phrases “certain embodiments,” “an example embodiment,” “some embodiments,” or other similar language, throughout this specification refers to the fact that a particular feature, structure, or characteristic described in connection with an embodiment may be included in at least one embodiment. Thus, appearances of the phrases "in certain embodiments," "an example embodiment," "in some embodiments," "in other embodiments," or other similar language, throughout this specification do not necessarily all refer to the same group of embodiments, and the described features, structures, or characteristics may be combined in any suitable manner in one or more example embodiments.

[0033] Additionally, if desired, the different functions or steps discussed below may be performed in a different order and/or concurrently with each other. Furthermore, if desired, one or more of the described functions or steps may be optional or may be combined. As such, the following description should be considered as merely illustrative of the principles and teachings of certain example embodiments, and not in limitation thereof.

[0034] HAPS provides a means to extend cellular services to remote regions that lack a communication infrastructure. In one type of HAPS, an aircraft or an airship may operate at altitudes between 20km and 50km and would provide cellular service to a fixed coverage area on the ground. From a telecommunications standpoint, typical design challenges associated with HAPS are the overall antenna system design, including for example, antenna gain, transmit powers at both the user equipment (UE) and the base station, and also the configuration of the cellular system being used (e.g., LTE vs 5G/NR, whether to use MIMO and/or beamforming, etc.). An overall link budget between the base station and the different points within the coverage area may serve as an important indicator of the communications performance of the HAPS design.

[0035] FIG. 1 illustrates an example HAPS deployment model. Here, a base station may be mounted on an aircraft operating at an altitude of h=20km, and must cover a service area having a 100km radius. Additional system requirements are shown in Table 1 below.

Table 1: HAPS Requirements

Parameter	**Requirement**
Service Link	FDD LTE, Band1 (DL:2110 -2170 MHz; UL:1920-1980 MHz); IBW:60MHz/OBW:20 MHz
Deployment	Altitude = 20km, Max Diameter = 200Km
Feeder Link	28/38 GHz, 5G NR, CPE in HAPS, gNB for Ground Gateway, Tx-Rx Separation : 40 Km
Total Payload	75 Kg
Total Power	1500 W
Flight duration	180 days

[0036] A key design problem may exist for the system shown in FIG. 1. For example, the system shown in FIG. 1 may have a design problem associated with the antenna system, which will be used by the aircraft to cover the service area on the ground. One particular challenge concerns the flight path of the aircraft throughout the time period in which the aircraft is providing service. In particular, the aircraft may maneuver through a prescribed flight path over the coverage area, where the flight path could, for example, be a circular flight path or a “figure-8” flight path. As a result, the orientation of the antenna system with respect to the service area of the ground will change significantly over time as the aircraft executes its prescribed flight path.

[0037] In order for the system of FIG. 1 to maintain continuous coverage of the service area on the ground, the antenna system must adapt to the movement and orientation of the aircraft with respect to the service area on the ground. Ideally, the area of coverage provided by the HAPS should not change over time, which means that any antenna pattern formed by the HAPS must adapt to the changing position and orientation of the aircraft to provide sufficient coverage the service areas on the ground.

[0038] FIG. 2 illustrates an additional example deployment model for HAPS. Specifically, another challenge of the system in FIG. 1 is whether to sectorize the coverage area on the ground, as illustrated in FIG. 2, or whether to simply have the HAPS cover the same coverage area with a single cell much like what is illustrated in FIG. 1. In general, a single-cell solution may not have a sufficiently high capacity compared to a sectored solution. The decision to sectorize or not to sectorize may have implications on the antenna system design and overall system capacity and coverage performance.

[0039] With a sectored system, the antenna system must be capable of creating multiple sector-specific beam patterns, where each pattern covers one of the sectors on the ground. As noted above, the overall service area on the ground should not change with the movement and orientation of the aircraft. However, with a sectored system, the coverage area of each sector/cell within the overall service area on the ground should also be unchanged with the movement and orientation of the aircraft. Further, if the coverage area of the sectors within the overall service area changes over time, a stationary UE will experience handoffs at a rate related to the movement of the coverage areas of the beams, which is undesirable. Thus, there is a desire to advantageously minimize the rate at which stationary users must handoff from one cell/sector to another. There is also a desire to design an antenna system that can be used to fulfill the needs described above.

[0040] In addition to the above challenges, there may also be a challenge of providing an antenna system that can cover a rather large service area, such as, for example, a service area having a 100km radius via an aircraft. A further point of difficulty is the fact that the aircraft will have a prescribed flight path that could include circling overhead or performing a figure-8 type of path while servicing the coverage area.

[0041] One approach to address the above challenges may be to use a simple rotatable antenna system or use a single antenna panel. However, such options come with their own drawbacks for covering a large radius on the ground. For instance, a single antenna panel has poor performance. In addition, a rotatable antenna assembly for a mechanically-steered antenna system would need to be able to be oriented over a wide range of motion considering how the aircraft may have to maneuver through the flight path while servicing the coverage area. This type of mechanical solution requires an infinitely rotatable platform on which to mount the antenna(s), which is particularly difficult from an implementation point of view.

[0042] Certain example embodiments described herein may provide antenna system for an aircraft-oriented HAPS operating at a 20km altitude to provide cellular cover to a service area with a 100km radius. Specifically, certain example embodiments may provide antenna system designs. In one example embodiment, a single panel antenna array design may be provided. This type of antenna design may use a single panel array that creates 7 parallel beams, wherein each beam covers a single sector on the ground. For example, FIG. 3(a) illustrates an MxNx2 single panel array, and FIG. 3(b) illustrates a beam design in HAPS covering 7 different sectors covered by 7 parallel beams from the MxNx2 single panel array of FIG. 3(a), according to certain example embodiments. As illustrated in FIG. 3(a), there may be provided a two dimensional array with M rows, N columns, and 2 polarizations (M,N,2). The single panel array, according to certain example embodiments may include various system specifications/configurations as shown in Table 2 below.

Table 2: Single Panel Antenna Array System Specifications/Configurations

HAPS altitude	20 Km
Frequency	DL:2.1 GHz, UL:1.9 GHz
Occupied bandwidth	20 MHz

Pathloss model	Free space path loss
BS Tx power	5W (37 dBm) per cell 5W x 7 = 35 W total
TXRUs per cell	2
BS Antenna array	One 4 (rows) x 4 (columns) x 2 (pol) URA Horizontal spacing = 1/2 λ Vertical spacing = 1/2 λ
BS antenna element gain	5 dBi
BS antenna element half-power beamwidth	Horizontal HPBW = 90° Vertical HPBW = 90°
BS noise figure	5 dB
UE noise figure	7 dB
UE antenna gain	0 dBi, omni gain
UE Tx power	23 dBm

[0043] The single panel antenna array may be designed so that each sector beam is connected to 1 or 2 transceiver units (TXRUs) to create 1 or 2 antenna ports for each cell. To form 2 TXRUs per sector, the array may include cross-polarized elements, and there may also be one beam weight vector per polarization to form 2 ports per sector.

[0044] With the single panel antenna array, the array may form multiple sector-specific beams to cover the one or more sectors of the coverage area. According to an example embodiment, the beams may be electrically steered through the use of beamforming that may adapt in real-time to point each beam to its assigned sector as the aircraft moves throughout its flight path. With the single antenna array, for the geometry of the system illustrated in FIG. 1, the beams that provide coverage to the outer edge of the service area on the ground will need to point at an angle that is relatively far off of the boresight of the antenna array. For example, the 100km radius of the coverage area may be located at an angle of 79 degrees relative to the boresight direction of the antenna array. Pointing a beam this far off the boresight may result in reduced gain due to the rolloff in the antenna patterns of the physical antenna elements that include the array.

[0045] With the single panel antenna array, a 4x4 antenna array with half wavelength spaced physical antenna elements may be provided according to an example embodiment. Here, the physical antenna elements may have a maximum gain of 5dBi and a 90 degree half power beamwidth. The beams may be designed to cover the 7 sectors according to FIG. 2, with one beam covering the center sector and 6 beams covering the 6 outer sectors. Further, Chebyshev tapering may be applied to the beam weights to suppress sidelobes.

[0046] FIG. 4 illustrates a beam pattern of a beam covering one of the outer 6 cells of a service area on the ground (beam direction ($\theta = 20°$, $\phi = 0°$) with respect to array local coordinate system), according to an example embodiment with the single panel antenna array described herein. As illustrated in FIG. 4, large sidelobes pointed at the opposite outer sector can be seen, which would create significant interference. The shape of the pattern is the result of steering the beam to 20 degrees relative to the boresight of the array with realistic antenna element patterns. In addition, the gain in the direction of the beam at 20 degrees is significantly reduced due to the reduced gain of the physical element patterns in that direction.

[0047] FIG 5(a) illustrates a signal-to-interference-plus-noise ratio (SINR) on a downlink versus a UE location with respect to a center of the service area on the ground, according to an example embodiment pertaining to the single panel antenna array described herein. Further, FIG. 5(b) illustrates a downlink throughput SINR versus the UE location with respect to the center of the service area on the ground, according to an example embodiment pertaining to the single panel antenna array described herein. The SINR illustrated in FIGs. 5(a) and 5(b) includes the interference from the other sectors. As illustrated in FIGs. 5(a) and 5(b), the throughput goes to zero, which is due to at least two factors. The first factor includes the loss of gain from needing to cover the outer sectors with a beam that is steered far off the boresight. The second factor is the interference from the back-lobe of the pattern. Both factors are reflected in the SINR plot of FIGS. 5(a) and 5(b).

[0048] FIG. 6(a) illustrates an SINR on an uplink versus the UE location with respect to the center of the service area on the ground, according to an example embodiment pertaining to the single panel antenna array described herein. Further, FIG. 6(b) illustrates an uplink throughout SINR versus the UE location with respect to the center of the service area on the ground, according to an example embodiment pertaining to the single panel antenna array described herein. In particular, FIGs. 6(a) and 6(b) illustrate corresponding results for the uplink in view of the downlink results illustrated in FIGs. 5(a) and 5(b).

[0049] FIG. 7(a) illustrated a multi-panel antenna array, according to an example embodiment. Further, FIG. 7(b) illustrates 7 sectors on the ground covered by the panels of the multi-panel antenna array of FIG. 7(a), according to an example embodiment. In addition, FIG. 8 illustrates structural configurations of the multi-panel antenna array of FIG. 7(a), according to an example embodiment. As illustrated in FIG. 8, the multi-panel antenna array system may have a top circumference of about 50in, a bottom circumference of about 33in, and a height of about 20in. In one example embodiment, the height may be 22in. FIG. 8 also illustrates that the antenna array system may have a side panel tilt angle (η) of 67°, and have a maximum panel size of approximately 21in x 16.5in. The antenna array in FIG. 8 supports a wavelength of 15cm (6”) for 2GHz carrier frequency. Further, the surface of the antenna array may support a 4x4 array with a 1/2 wavelength element spacing, and the downward-facing antenna may fit within a 33in diameter hexagon.

[0050] The multi-panel antenna array, according to certain example embodiments may include various system specifications/configurations as shown in Table 3 below.

Table 3: Multi-Panel Antenna Array System Specifications/Configurations

HAPS altitude	20 Km
Frequency	DL:2.1 GHz, UL:1.9 GHz
Occupied bandwidth	20 MHz
Pathloss model	Free space path loss
BS Tx power	5W (37 dBm) per panel, 5W x 7 = 35 W total
TXRUs per cell	2
BS Antenna array	7 panels of 4 (rows) x 4 (columns) x 2 (pol) URA Horizontal spacing = 1/2 λ Vertical spacing = 1/2 λ
BS antenna element gain	5 dBi
BS antenna element half-power beamwidth	Horizontal HPBW = 90^o Vertical HPBW = 90^o
BS noise figure	5 dB
UE noise figure	7 dB
UE antenna gain	0 dBi, omni gain
UE Tx power	23 dBm

[0051] As illustrated in FIGs. 7(a), 7(b) and 8, the antenna array may include multiple panels, one for each sector of the service area on the ground. In an example embodiment, for a 7 sector implementation, the array structure may include a single panel aimed straight down from the aircraft and 6 additional panels all arranged around the circumference of the structure. The array in each panel may be designed so that the sector beam formed by the panel is connected to 1 or 2 TXRUs to create 1 or 2 antenna ports for each cell. To form 2 TXRUs per sector, the array may include cross-polarized elements, and there may be one beam weight vector per polarization to from 2 ports per sector.

[0052] In certain example embodiments, an aircraft may deploy the multi-panel antenna array system. Specifically, the multi-panel antenna array system may be mounted on a container platform mounted directed under the aircraft. As noted above, the multi-panel antenna array system may include 7 antenna panels, each aimed in different directions, with one panel for each sector on the ground. Further, in an example embodiment, each panel may be capable of creating a beam (where a beam may be either one or two TXRU ports) that can be electrically steered to the point on the ground corresponding to the sector it is assigned to provide coverage for.

[0053] According to certain example embodiments, of the 7 antenna panels, one panel may be oriented facing straight down from the aircraft and covers the center sector on the ground. The other 6 panels may be oriented around the antenna system circumference and oriented to cover the outer 6 sectors on the ground. In an example embodiment, the beams formed by each of the antenna panels may be sector-specific beams. That is, each beam from each panel may specifically be intended to cover a particular sector on the ground. According to an example embodiment, the sector-specific beams may be required to maintain constant coverage of the area of the ground corresponding to the sector being covered. By maintaining constant coverage of the area of the ground, it may be possible to minimize handoffs that a stationary UE would otherwise experience if the coverage area was not constant.

[0054] In certain example embodiments, each antenna panel of the multi-panel antenna array system may maintain a codebook of transmit beamforming weight vectors that are loaded into the panel array to form the beam used to cover its designated sector on the ground. In other example embodiments, the multi-panel antenna array system may include a controller. According to one example embodiment, the controller may be configured to select the best panel to serve each sector on the ground. The controller may also be configured to select the best beam to use on the selected panel. The selection of the antenna panel and the selection of the best beam to be used on the selected panel may be transparent to the UEs being served in the sector. Also, in other embodiments, more sectors (e.g., 19 cells) may be deployed to improve coverage and performance.

[0055] In another example embodiment, the controller may select the best panel and the best beam by leveraging certain information in real-time. In certain example embodiments, the real-time information may include global positioning system (GPS) coordinates, altitude, and velocity (speed and heading) of the aircraft containing the HAPS antenna system. The information may also include for each sector (cell being covered), the GPS coordinates of the location on the ground assumed to be the target point for that sector. In addition, the information may include the aircraft pitch and roll, an orientation of the antenna panels with respect to the aircraft that may be modified.

[0056] For example, the orientation of the antenna panels may be modified with the antenna array being mounted on a container platform. The container platform may include a mechanical gimbal-style assembly that keeps the antenna system assembly oriented such that the bottom of the assembly is always kept parallel to the ground. By keeping the antenna system assembly oriented in such a manner, it may be possible to reduce the steering range needed by the beamforming weights used in the panel to service the sector being covered.

[0057] As noted above, in an example embodiment, the multi-panel antenna array system may support a 4x4 antenna array with half wavelength spaced physical antenna elements for each panel. The physical antenna elements may have a maximum of 5dBi and a 90 degree half power beamwidth. In addition, beams for the downward facing panel may cover the center sector, and beams for the outer panels may cover the corresponding sector in the outer ring of 6 sectors. As with the single panel antenna array previously described, Chebyshev tapering may be applied to the beam weights of the multi-panel antenna array system to suppress sidelobes. FIG. 9 illustrates a beam pattern of the beam covering one of the 6 sectors (right) and the beam covering the center sector (left), according to an example embodiment pertaining to the multi-panel antenna array system.

[0058] FIG. 10(a) illustrates another SINR on a downlink versus the UE location with respect to the center of the service area on the round, according to an example embodiment pertaining to the multi-panel antenna array system. Further FIG. 10(b) illustrates another downlink throughput SINR versus the UE location with respect to the center of the service area on the ground, according to an example embodiment pertaining to the multi-panel antenna array system. As illustrated in FIGs. 10(a) and 10(b), the SINR takes into account the interference from the other sectors. Further, FIGs. 11(a) and 11(b) illustrate corresponding results for the uplink with regard to the downlink illustrated in FIGs. 10(a) and 10(b).

[0059] As illustrated in FIGs. 10(b) and 11(b), a reasonable throughput may be obtained in a large portion of the 100km radius coverage area (37% of the coverage area has a throughput greater than 20Mbps). In addition, according to an example embodiment, coverage of the full 100km radius may be achieved, and the UEs at the far edge of the coverage area may achieve a downlink throughput of 10Mbps in a 20MHz bandwidth.

[0060] According to certain example embodiments, the beams in the HAPS system for each sector may be sector-specific, not UE specific. In other words, the beam for a sector may create sector-specific antenna ports (using the 3GPP definition) that the system operates with. That is, for a cross-polarized array that creates 2 antenna beam ports per sector, the LTE/NR system covering that sector may become a 2-antenna port system. Further, for LTE rel-8, the cell-specific reference signals (CRS) for the physical downlink shared channel (PDSCH) may be 2 ports. For LTE rel-10 and NR, the channel state information reference signals (CSI-RS) may be a 2-port CSI-RS. Then, with transmission mode 4 / 10 (TM4 / TM10) with LTE rel8/10 or with NR, the precoder matrix indicator (PMI) feedback from the UE may be a 2-port PMI.

[0061] As noted above, certain example embodiments may provide a mechanism to determine where the beams covering the sectors are pointed in real-time as the aircraft moves in its flight path around the coverage area. For example, the beam for each sector may need to be pointed at the center spot on the ground for that sector (or some other designated spot within that sector). Further, the pointing direction of the beam may be calculated based on various real-time inputs including those previously mentioned such as, for example GPS coordinates of the aircraft plus the height velocity, orientation (pitch, roll, yaw) of the aircraft, and the GPS coordinates of the spot on the ground corresponding to the center of the sector being covered by the beam. In one example embodiment, a pre-determined codebook in each panel may be used. The pre-determined codebook may be of beam weight vectors, which may contain one beam weight vector for each anticipated pointing angle. A best beam weight in the codebook is selected based on the aircraft’s position and orientation so as to maximize the beamforming gain to the center of the sector. The velocity of the aircraft and the change of orientation (pitch, roll, yaw) are used as input to determine the period for beam selection. In addition, a controller of the antenna array may compute the necessary pointing angle for the beam for the panel, and the corresponding beam weight vector in the codebook may be used to form the beam with the array. In another embodiment, instead of leveraging a codebook of pre-determined beam weight vectors, the beam weights for the anticipated pointing angle may be calculated directly in real time and updated as needed to provide the constant coverage of the assigned sector. The rate of update may be based on the aircraft velocity, heading, orientation (pitch, roll, yaw) and GPS location of the aircraft relative to the GPS location of the designated location in sector being covered.

[0062] According to certain example embodiments, the multi-panel antenna array system or other antenna systems with multiple differently-oriented panels may be configured to select which panel will cover each of the sectors on the ground. In an example embodiment, a one-to-one mapping between the antenna panel and each ground sector must be determined. As previously noted, this type of panel selection determination may be performed based on a variety of real-time parameters, such as the aircraft GPS coordinates, height, velocity, and orientation. The panel with its boresight best matched to the direction pointed to the center of a sector is selected to serve that sector. The velocity of the aircraft is used as input to determine the period for panel selection. Once the panels are assigned to their respective sectors, the beam direction for that panel may be determined to point at the designated spot for the assigned sector, and the corresponding beam weights may be used in the array to form the beam. In addition, according to an example embodiment, the panel selection and beam direction determination may be controlled independently of the operation of the cellular air interface.

[0063] As previously described the multi-panel antenna array system may be mounted on a container platform, which is mounted under an aircraft, and the container platform may include a mechanical gimbal-style assembly. According to an example embodiment, the gimbal-type assembly may help keep the antenna system assembly oriented such that the bottom of the assembly is parallel with the ground. This type of mechanism may need to account for the pitch and roll of the aircraft's orientation. In particular, the aircraft's angular orientation with respect to the coverage area on the ground may then be handled by the electronic beam steering that creates the sector-specific beams that cover the sectors on the ground. In certain example embodiments, the additional mechanical orientation mechanism may reduce the steering range needed by the beam weights used to form the beams within each panel. In addition, according to a further example embodiment, the controller that determines which panel and which beam within the panel is to be used for a specific sector may be designed to account for the use of this type of additional orientation mechanism.

[0064] FIG. 12 illustrates an example flow diagram of a method according to an example embodiment. In certain example embodiments, the flow diagram of FIG. 12 may be performed by a controller of an antenna array system. The antenna array system may include, for example, a multi-panel antenna array system. According to one example embodiment, the method of FIG. 12 may initially include, at 100, selecting a panel from a multi-panel antenna array to serve a coverage sector on a ground. The method may also include at 105, forming a sector-specific beam at each panel of the multi-panel antenna array. In addition, the method may include, at 110, steering the sector-specific beam to a point in the coverage sector. The method may also include at 115, maintaining, with the sector-specific beam, a constant coverage area of the ground corresponding to the coverage sector.

[0065] As further illustrated in FIG. 12, the method may include, at 120, selecting a best sector-specific beam to use on the panel. According to an example embodiment, the selection of the panel and the best sector-specific beam may be determined based on real-time parameters, which may include at least one of GPS coordinates of an aircraft, an altitude of the aircraft, a velocity of the aircraft, a height of the aircraft relative to the ground, and an orientation of the aircraft. The method may also include, at 125, determining a pointing angle for the sector-specific beam and corresponding beam weight vector in the codebook. The method may further include, at 130, orienting the multi-panel antenna array so that a bottom face of the multi-panel antenna array is always kept parallel to the ground. According to an example embodiment, each panel of the multi-panel antenna array may maintain a codebook of transmit beamforming weight vectors that are loaded into the multi-panel antenna array to from the sector-specific beam. In another example embodiment, the multi-panel antenna array may be mounted onto a container platform directly under an aircraft. According to an example embodiment, the transmit beamforming weights are directly calculated based on the desired pointing direction instead of being selected from a codebook.

[0066] FIG. 13(a) illustrates an example of an apparatus 10 according to another embodiment. In an embodiment, apparatus 10 may be a node or element in a communications network or associated with such a network, such as a UE, mobile equipment (ME), mobile station, mobile device, stationary device, IoT device, or other device. As described herein, UE may alternatively be referred to as, for example, a mobile station, mobile equipment, mobile unit, mobile device, user device, subscriber station, wireless terminal, tablet, smart phone, IoT device, sensor or NB-IoT device, or the like.

[0067] In some example embodiments, apparatus 10 may include one or more processors, one or more computer-readable storage medium (for example, memory, storage, or the like), one or more radio access components (for example, a modem, a transceiver, or the like), and/or a user interface. In some embodiments, apparatus 10 may be configured to operate using one or more radio access technologies, such as GSM, LTE, LTE-A, NR, 5G, WLAN, WiFi, NB-IoT, Bluetooth, NFC, MulteFire, and/or any other radio access technologies. It should be noted that one of ordinary skill in the art would understand that apparatus 10 may include components or features not shown in FIG. 13(a).

[0068] As illustrated in the example of FIG. 13(a), apparatus 10 may include or be coupled to a processor 12 for processing information and executing instructions or operations. Processor 12 may be any type of general or specific purpose processor. In fact, processor 12 may include one or more of general-purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs), field-programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), and processors based on a multi-core processor architecture, as examples. While a single processor 12 is shown in FIG. 13(a), multiple processors may be utilized according to other embodiments. For example, it should be understood that, in certain example embodiments, apparatus 10 may include two or more processors that may form a multiprocessor system (e.g., in this case processor 12 may represent a multiprocessor) that may support multiprocessing. According to certain example embodiments, the multiprocessor system may be tightly coupled or loosely coupled (e.g., to form a computer cluster).

[0069] Processor 12 may perform functions associated with the operation of apparatus 10 including, as some examples, precoding of antenna gain/phase parameters, encoding and decoding of individual bits forming a communication message, formatting of information, and overall control of the apparatus 10.

[0070] Apparatus 10 may further include or be coupled to a memory 14 (internal or external), which may be coupled to processor 12, for storing information and instructions that may be executed by processor 12. Memory 14 may be one or more memories and of any type suitable to the local application environment, and may be implemented using any suitable volatile or nonvolatile data storage technology such as a semiconductor-based memory device, a magnetic memory device and system, an optical memory device and system, fixed memory, and/or removable memory. For example, memory 14 can be comprised of any combination of random access memory (RAM), read only memory (ROM), static storage such as a magnetic or optical disk, hard disk drive (HDD), or any other type of non-transitory machine or computer readable media. The instructions stored in memory 14 may include program instructions or computer program code that, when executed by processor 12, enable the apparatus 10 to perform tasks as described herein.

[0071] In an embodiment, apparatus 10 may further include or be coupled to (internal or external) a drive or port that is configured to accept and read an external computer readable storage medium, such as an optical disc, USB drive, flash drive, or any other storage medium. For example, the external computer readable storage medium may store a computer program or software for execution by processor 12 and/or apparatus 10 to perform any of the methods illustrated in FIGs. 1-4.

[0072] In some embodiments, apparatus 10 may also include or be coupled to one or more antennas 18 for receiving a downlink signal and for transmitting via an uplink from apparatus 10. Apparatus 10 may further include a transceiver 18 configured to transmit and receive information. The transceiver 28 may also include a radio interface (e.g., a modem) coupled to the antenna 15. The radio interface may correspond to a plurality of radio access technologies including one or more of GSM, LTE, LTE-A, 5G, NR, WLAN, NB-IoT, Bluetooth, BT-LE, NFC, RFID, UWB, and the like. The radio interface may include other components, such as filters, converters (for example, digital-to-analog converters and the like), symbol demappers, signal shaping components, an Inverse Fast Fourier Transform (IFFT) module, and the like, to process symbols, such as OFDMA symbols, carried by a downlink or an uplink.

[0073] For instance, transceiver 18 may be configured to modulate information on to a carrier waveform for transmission by the antenna(s) 15 and demodulate information received via the antenna(s) 15 for further processing by other elements of apparatus 10. In other embodiments, transceiver 18 may be capable of transmitting and receiving signals or data directly. Additionally or alternatively, in some embodiments, apparatus 10 may include an input and/or output device (I/O device). In certain embodiments, apparatus 10 may further include a user interface, such as a graphical user interface or touchscreen.

[0074] In an embodiment, memory 14 stores software modules that provide functionality when executed by processor 12. The modules may include, for example, an operating system that provides operating system functionality for apparatus 10. The memory may also store one or more functional modules, such as an application or program, to provide additional functionality for apparatus 10. The components of apparatus 10 may be implemented in hardware, or as any suitable combination of hardware and software. According to an example embodiment, apparatus 10 may optionally be configured to communicate with apparatus 10 via a wireless or wired communications link 70 according to any radio access technology, such as NR.

[0075] According to certain example embodiments, processor 12 and memory 14 may be included in or may form a part of processing circuitry or control circuitry. In addition, in some embodiments, transceiver 28 may be included in or may form a part of transceiving circuitry.

[0076] As discussed above, according to certain example embodiments, apparatus 10 may be a UE, mobile device, mobile station, ME, IoT device and/or NB-IoT device, for example. According to certain embodiments, apparatus 10 may be controlled by memory 14 and processor 12 to perform the functions associated with example embodiments described herein.

[0077] FIG. 13(b) illustrates an example of an apparatus 20 according to an example embodiment. In an example embodiment, apparatus 20 may be an antenna, such as an antenna array. In certain example embodiments, the antenna array may be a single panel antenna array or a multi-panel antenna array. According to other example embodiments, the antenna array may serve as an access point associated with a radio access network (RAN), such as an LTE network, 5G or NR. The antenna array may extend cellular services to remote regions that lack a communication infrastructure.

[0078] As illustrated in the example of FIG. 13(b), apparatus 20 may include a processor 22 for processing information and executing instructions or operations. Processor 22 may be any type of general or specific purpose processor. For example, processor 22 may include one or more of general-purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs), field-programmable gate arrays (FPGAs), application-specific integrated circuits (ASICs), and processors based on a multi-core processor architecture, as examples. While a single processor 22 is shown in FIG. 13(b), multiple processors may be utilized according to other embodiments. For example, it should be understood that, in certain embodiments, apparatus 20 may include two or more processors that may form a multiprocessor system (e.g., in this case processor 22 may represent a multiprocessor) that may support multiprocessing. In certain embodiments, the multiprocessor system may be tightly coupled or loosely coupled (e.g., to form a computer cluster).

[0079] According to certain example embodiments, processor 22 may perform functions associated with the operation of apparatus 20, which may include, for example, precoding of antenna gain/phase parameters, encoding and decoding of individual bits forming a communication message, formatting of information, and overall control of the apparatus 20, including processes illustrated in FIGs. 1-3, 5-7, 10, 11, and 12.

[0080] Apparatus 20 may further include or be coupled to a memory 24 (internal or external), which may be coupled to processor 22, for storing information and instructions that may be executed by processor 22. Memory 24 may be one or more memories and of any type suitable to the local application environment, and may be implemented using any suitable volatile or nonvolatile data storage technology such as a semiconductor-based memory device, a magnetic memory device and system, an optical memory device and system, fixed memory, and/or removable memory. For example, memory 24 can be comprised of any combination of random access memory (RAM), read only memory (ROM), static storage such as a magnetic or optical disk, hard disk drive (HDD), or any other type of non-transitory machine or computer readable media. The instructions stored in memory 24 may include program instructions or computer program code that, when executed by processor 22, enable the apparatus 20 to perform tasks as described herein.

[0081] In an embodiment, apparatus 20 may further include or be coupled to (internal or external) a drive or port that is configured to accept and read an external computer readable storage medium, such as an optical disc, USB drive, flash drive, or any other storage medium. For example, the external computer readable storage medium may store a computer program or software for execution by processor 22 and/or apparatus 20 to perform the methods illustrated in FIGs. 1-3, 5-7, 10, 11, and 12.

[0082] In certain example embodiments, apparatus 20 may also include or be coupled to one or more antennas 25 for transmitting and receiving signals and/or data to and from apparatus 20. Apparatus 20 may further include or be coupled to a transceiver 28 configured to transmit and receive information. The transceiver 28 may include, for example, a plurality of radio interfaces that may be coupled to the antenna(s) 25. The radio interfaces may correspond to a plurality of radio access technologies including one or more of GSM, NB-IoT, LTE, 5G, WLAN, Bluetooth, BT-LE, NFC, radio frequency identifier (RFID), ultrawideband (UWB), MulteFire, and the like. The radio interface may include components, such as filters, converters (for example, digital-to-analog converters and the like), mappers, a Fast Fourier Transform (FFT) module, and the like, to generate symbols for a transmission via one or more downlinks and to receive symbols (for example, via an uplink).

[0083] As such, transceiver 28 may be configured to modulate information on to a carrier waveform for transmission by the antenna(s) 25 and demodulate information received via the antenna(s) 25 for further processing by other elements of apparatus 20. In other embodiments, transceiver 18 may be capable of transmitting and receiving signals or data directly. Additionally or alternatively, in some embodiments, apparatus 20 may include an input and/or output device (I/O device).

[0084] In an embodiment, memory 24 may store software modules that provide functionality when executed by processor 22. The modules may include, for example, an operating system that provides operating system functionality for apparatus 20. The memory may also store one or more functional modules, such as an application or program, to provide additional functionality for apparatus 20. The components of apparatus 20 may be implemented in hardware, or as any suitable combination of hardware and software.

[0085] According to some embodiments, processor 22 and memory 24 may be included in or may form a part of processing circuitry or control circuitry. In addition, in some embodiments, transceiver 28 may be included in or may form a part of transceiving circuitry.

[0086] As used herein, the term "circuitry" may refer to hardware-only circuitry implementations (e.g., analog and/or digital circuitry), combinations of hardware circuits and software, combinations of analog and/or digital hardware circuits with software/firmware, any portions of hardware processor(s) with software (including digital signal processors) that work together to case an apparatus (e.g., apparatus 20) to perform various functions, and/or hardware circuit(s) and/or processor(s), or portions thereof, that use software for operation but where the software may not be present when it is not needed for operation. As a further example, as used herein, the term “circuitry” may also cover an implementation of merely a hardware circuit or processor (or multiple processors), or portion of a hardware circuit or processor, and its accompanying software and/or firmware. The term circuitry may also cover, for example, a baseband integrated circuit in a server, cellular network node or device, or other computing or network device.

[0087] As introduced above, in certain embodiments, apparatus 20 may be a network node or RAN node, such as a base station, access point, Node B, eNB, gNB, WLAN access point, or the like. According to certain embodiments, apparatus 10 may be controlled by memory 24 and processor 22 to perform the functions associated with any of the embodiments described herein, such as the flow or signaling diagrams illustrated in FIGs. 1-3, 5-7, 10, 11, and 12.

[0088] For instance, in one embodiment, apparatus 20 may be controlled by memory 24 and processor 22 to select a panel from a multi-panel antenna array to serve a coverage sector on a ground. The apparatus 20 may further be controlled by memory 24 and processor 22 to form a sector-specific beat at each panel of the multi-panel antenna array. In addition, the apparatus 20 may be controlled by memory 24 and processor 22 to steer the sector-specific beam to a point in the coverage sector. The apparatus 20 may further be controlled by memory 24 and processor 22 to maintain, with the sector-specific beam, a constant coverage area of the ground corresponding to the coverage sector.

[0089] In an example embodiment, the apparatus 20 may be controlled by memory 24 and processor 22 to select a best sector-specific beam to use on the panel. The selection of the panel and the selection of the best sector-specific beam may be based on real-time parameters. The real-time parameters may include at least one of GPS coordinates of an aircraft, an altitude of the aircraft, a velocity of the aircraft, a height of the aircraft relative to the ground, and an orientation of the aircraft. In an example embodiment, each panel of the multi-panel antenna array may maintain a codebook of transmit beamforming weight vectors that are loaded into the multi-panel antenna array to form the sector-specific beam. Further, apparatus 20 may be controlled by memory 24 and processor 22 to orient the multi-panel antenna array so that a bottom face of the multi-panel antenna array is always kept parallel to the ground. In other example embodiments, the multi-panel antenna array may be mounted onto a container platform directly under an aircraft. Further, the apparatus 20 may be controlled by memory 24 and processor 22 to determine a pointing angle for the sector-specific beam and a corresponding beam weight vector in the codebook. Further, the apparatus 20 may directly compute the beam weight vector based on the pointing angle of the sector-specific beam.

[0090] Certain example embodiments described herein provide several technical improvements, enhancements, and/or advantages. In some example embodiments, it may be possible to provide an antenna system design for an aircraft-oriented HAPS operating at 20km altitude to provide cellular coverage to a service area with a 100km radius. According to other example embodiments, the multi-panel arrangement makes the boresight directions of each panel much closer to the direction of the point on the ground corresponding to the centers of the corresponding sectors being covered. As a result, there is no severe loss in gain from pointing off significantly from the boresight.

[0091] A computer program product may comprise one or more computer-executable components which, when the program is run, are configured to carry out some example embodiments. The one or more computer-executable components may be at least one software code or portions of it. Modifications and configurations required for implementing functionality of an example embodiment may be performed as routine(s), which may be implemented as added or updated software routine(s). Software routine(s) may be downloaded into the apparatus.

[0092] As an example, software or a computer program code or portions of it may be in a source code form, object code form, or in some intermediate form, and it may be stored in some sort of carrier, distribution medium, or computer readable medium, which may be any entity or device capable of carrying the program. Such carriers may include a record medium, computer memory, read-only memory, photoelectrical and/or electrical carrier signal, telecommunications signal, and software distribution package, for example. Depending on the processing power needed, the computer program may be executed in a single electronic digital computer or it may be distributed amongst a number of computers. The computer readable medium or computer readable storage medium may be a non-transitory medium.

[0093] In other example embodiments, the functionality may be performed by hardware or circuitry included in an apparatus (e.g., apparatus 10 or apparatus 20), for example through the use of an application specific integrated circuit (ASIC), a programmable gate array (PGA), a field programmable gate array (FPGA), or any other combination of hardware and software. In yet another example embodiment, the functionality may be implemented as a signal, a non-tangible means that can be carried by an electromagnetic signal downloaded from the Internet or other network.

[0094] According to an example embodiment, an apparatus, such as a node, device, or a corresponding component, may be configured as circuitry, a computer or a microprocessor, such as single-chip computer element, or as a chipset, including at least a memory for providing storage capacity used for arithmetic operation and an operation processor for executing the arithmetic operation.

[0095] One having ordinary skill in the art will readily understand that the invention as discussed above may be practiced with steps in a different order, and/or with hardware elements in configurations which are different than those which are disclosed. Therefore, although the invention has been described based upon these preferred embodiments, it would be apparent to those of skill in the art that certain modifications, variations, and alternative constructions would be apparent, while remaining within the spirit and scope of the invention. Although the above embodiments refer to 5G NR and LTE technology, the above embodiments may also apply to any other present or future 3GPP technology, such as LTE-advanced, and/or fourth generation (4G) technology.

[0096] Partial Glossary

[0097] CSI-RS Channel State Information Reference Signals

[0098] eNB Enhanced Node B (LTE base station)

[0099] gNB 5G or NR Base Station

[00100] GPS Global Positioning System

[00101] HAPS High Altitude Platform System

[00102] LTE Long Term Evolution

[00103] NR New Radio

[00104] PDSCH Physical Downlink Shared Channel

[00105] PMI Precoder Matrix Indicator

[00106] TM4 / TM10 Transmission Mode 4 / 10

[00107] TXRU Transceiver Unit

[00108] UE User Equipment

WE CLAIM:

1. A method, comprising:

selecting a panel from a multi-panel antenna array to serve a coverage sector on a ground;

forming a sector-specific beam at each panel of the multi-panel antenna array;

steering the sector-specific beam to a point in the coverage sector; and

maintaining, with the sector-specific beam, a constant coverage area of the ground corresponding to the coverage sector.

2. The method according to claim 1, further comprising selecting a best sector-specific beam to use on the panel.

3. The method according to claims 1 or 2, wherein the selection of the panel and the selection of the best sector-specific beam is determined based on real-time parameters comprising at least one of:

global positioning system coordinates of an aircraft;

an altitude of the aircraft;

a velocity of the aircraft;

a height of the aircraft relative to the ground; and

an orientation of the aircraft.

4. The method according to any of claims 1-3, wherein each panel of the multi-panel antenna array maintains a codebook of transmit beamforming weight vectors that are loaded into the multi-panel antenna array to form the sector-specific beam.

5. The method according to claim 1, further comprising orienting the multi-

panel antenna array so that a bottom face of the multi-panel antenna array is always kept parallel to the ground.

6. The method according to claim 1, wherein the multi-panel antenna array is mounted onto a container platform directly under an aircraft.

7. The method according to any of claims 1-4, further comprising determining a pointing angle for the sector-specific beam and a corresponding beam weight vector in the codebook.

8. An apparatus, comprising:

at least one processor; and

at least one memory comprising computer program code,

the at least one memory and the computer program code are configured, with the at least one processor to cause the apparatus at least to

select a panel from a multi-panel antenna array to serve a coverage sector on a ground;

form a sector-specific beam at each panel of the multi-panel antenna array;

steer the sector-specific beam to a point in the coverage sector; and

maintain, with the sector-specific beam, a constant coverage area of the ground corresponding to the coverage sector.

9. The apparatus according to claim 8, wherein the at least one memory and the computer program code are further configured, with the at least one processor to cause the apparatus at least to select a best sector-specific beam to use on the panel.

10. The apparatus according to claims 8 or 9, wherein the selection of the panel

and the selection of the best sector-specific beam is determined based on real-time parameters comprising at least one of:

global positioning system coordinates of an aircraft;

an altitude of the aircraft;

a velocity of the aircraft;

a height of the aircraft relative to the ground; and

an orientation of the aircraft.

11. The apparatus according to any of claims 8-10, wherein each panel of the multi-panel antenna array maintains a codebook of transmit beamforming weight vectors that are loaded into the multi-panel antenna array to form the sector-specific beam.

12. The apparatus according to claim 8, wherein the at least one memory and the computer program code are further configured, with the at least one processor to cause the apparatus at least to orient the multi-panel antenna array so that a bottom face of the multi-panel antenna array is always kept parallel to the ground.

13. The apparatus according to claim 8, wherein the multi-panel antenna array is mounted onto a container platform directly under an aircraft.

14. The apparatus according to any of claims 8-11, wherein the at least one memory and the computer program code are further configured, with the at least one processor to cause the apparatus at least to determine a pointing angle for the sector-specific beam and a corresponding beam weight vector in the codebook.

15. A computer program embodied on a non-transitory computer readable

medium, the computer program, when executed by a processor, causes the processor to:

select a panel from a multi-panel antenna array to serve a coverage sector on a ground;

form a sector-specific beam at each panel of the multi-panel antenna array;

steer the sector-specific beam to a point in the coverage sector; and

maintain, with the sector-specific beam, a constant coverage area of the ground corresponding to the coverage sector.

16. The computer program according to claim 15, wherein the processor is further caused to select a best sector-specific beam to use on the panel.

17. The computer program according to claims 15 or 16, wherein the selection of the panel and the selection of the best sector-specific beam is determined based on real-time parameters comprising at least one of:

global positioning system coordinates of an aircraft;

an altitude of the aircraft;

a velocity of the aircraft;

a height of the aircraft relative to the ground; and

an orientation of the aircraft.

18. The computer program according to any of claims 15-17, wherein each panel of the multi-panel antenna array maintains a codebook of transmit beamforming weight vectors that are loaded into the multi-panel antenna array to form the sector-specific beam.

19. The computer program according to claim 15, wherein the processor is

further caused to orient the multi-panel antenna array so that a bottom face of the multi-panel antenna array is always kept parallel to the ground.

20. The computer program according to claim 15, wherein the multi-panel antenna array is mounted onto a container platform directly under an aircraft.

21. The computer program according to any one of claims 15-18, wherein the processor is further caused to determine a pointing angle for the sector-specific beam and a corresponding beam weight vector in the codebook.

22. An antenna system assembly, comprising:

a plurality of antenna panels, each disposed around a circumference of the antenna system assembly and facing a different direction;

a center antenna panel disposed in a center of the plurality of antenna panel;

a container platform comprising a gimbal assembly, wherein the plurality of antenna panels and the center antenna panel are mounted to the container platform; and

a controller configured to select an antenna panel from the plurality of antenna panels and the center antenna panel to serve a coverage sector on a ground, and to select a beam to use on the selected antenna panel.

23. The antenna system assembly according to claim 22, wherein the center antenna panel is positioned so that a face of the center antenna panel is parallel to the ground.

24. The antenna system assembly according to claims 22 or 23, wherein the plurality of antenna panels and the center antenna panel each comprise a codebook

of transmit beamforming weight vectors that are loaded into the plurality of antenna panels and the center antenna panel.

25. The antenna system assembly according to any of claims 22-24,

wherein each of the plurality of antenna panels and the center antenna panel forms a sector beam to serve a different coverage sector on the ground, and

wherein each sector comprises one or two transceiver units.

26. The antenna system assembly according to claim 22, wherein the selection of the antenna panel is determined based on one or a combination of real-time parameters comprising at least one of:

global positioning system coordinates of an aircraft;

an altitude of the aircraft;

a velocity of the aircraft;

a height of the aircraft relative to the ground; and

an orientation of the aircraft.

27. The antenna system assembly according to claim 22, wherein the antenna system assembly is mounted onto a container platform directly under an aircraft.

28. An apparatus comprising means for performing a process according to any of claims 1-7.

29. An apparatus comprising circuitry configured to cause the apparatus to perform a process according to any of claims 1-7.

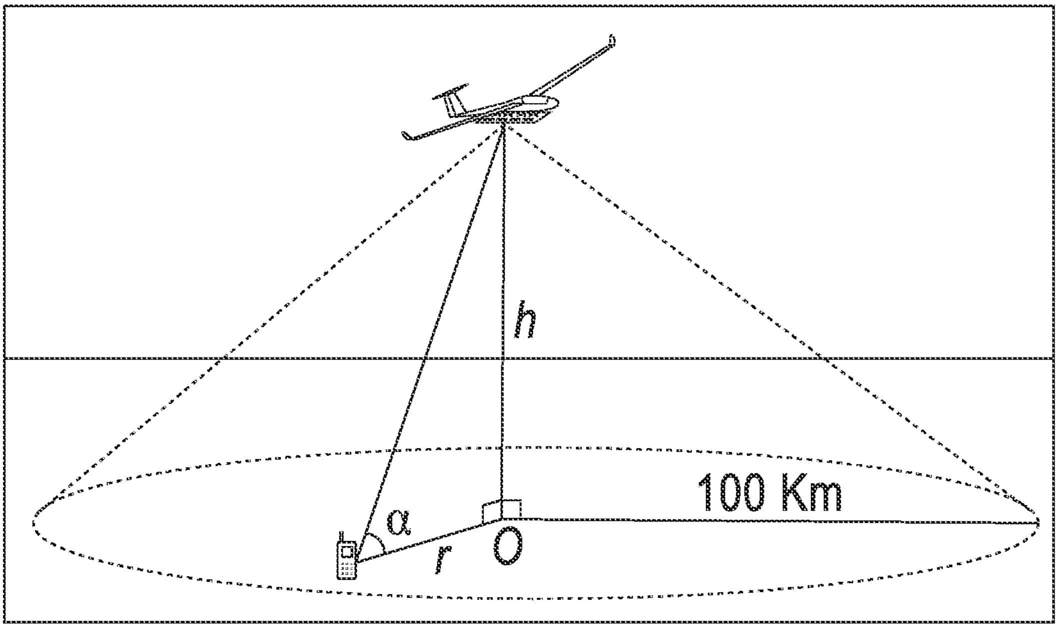


FIG. 1

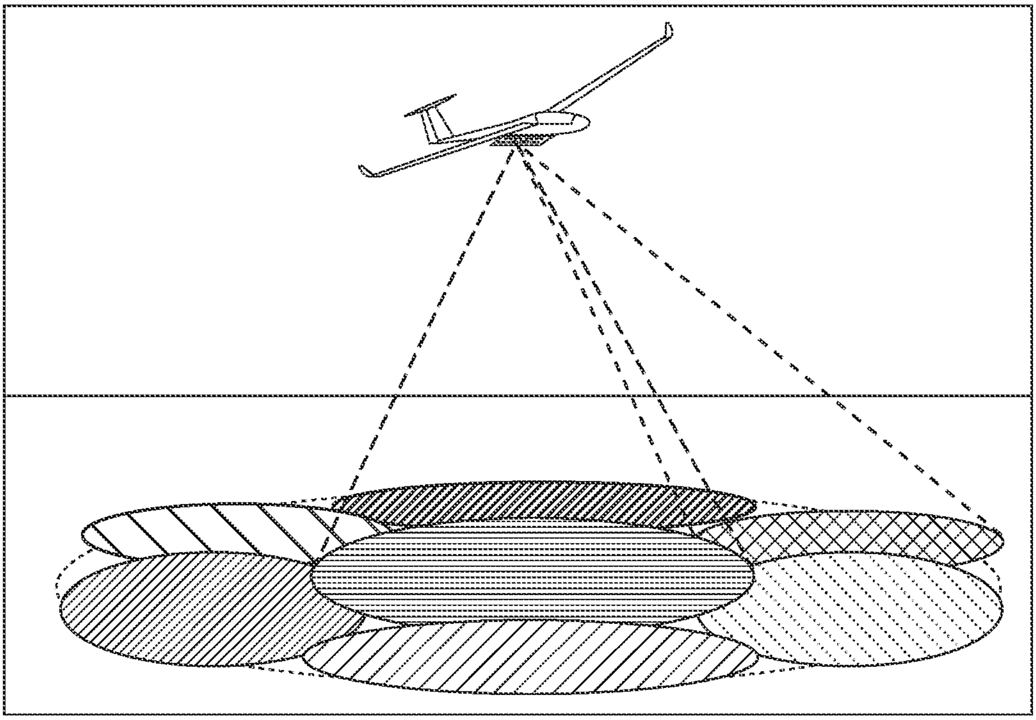


FIG. 2

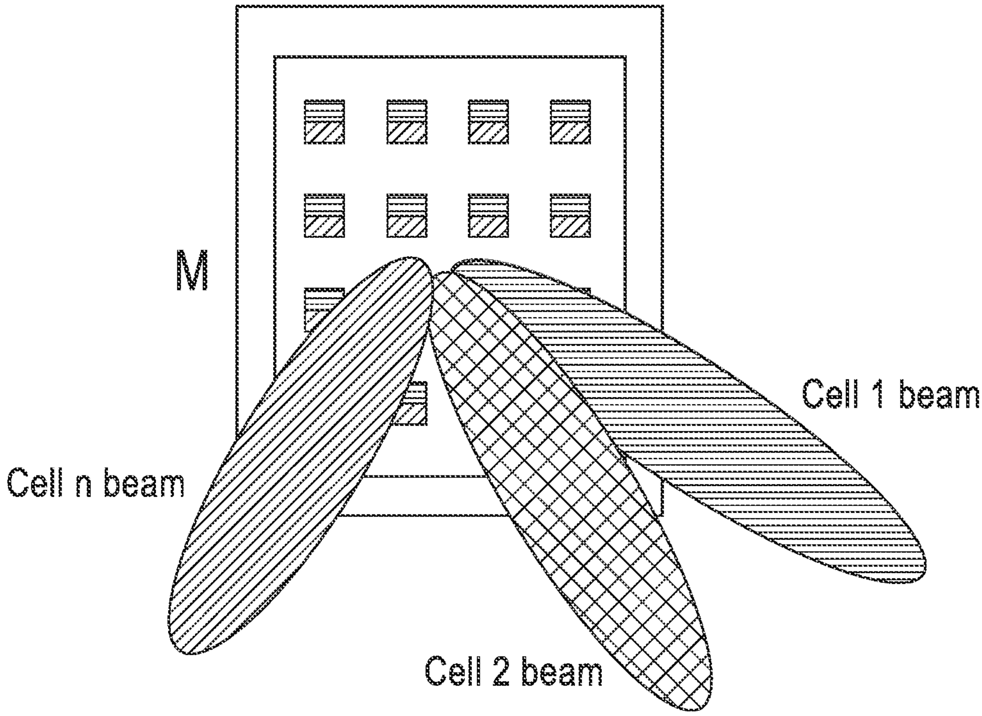


FIG. 3A

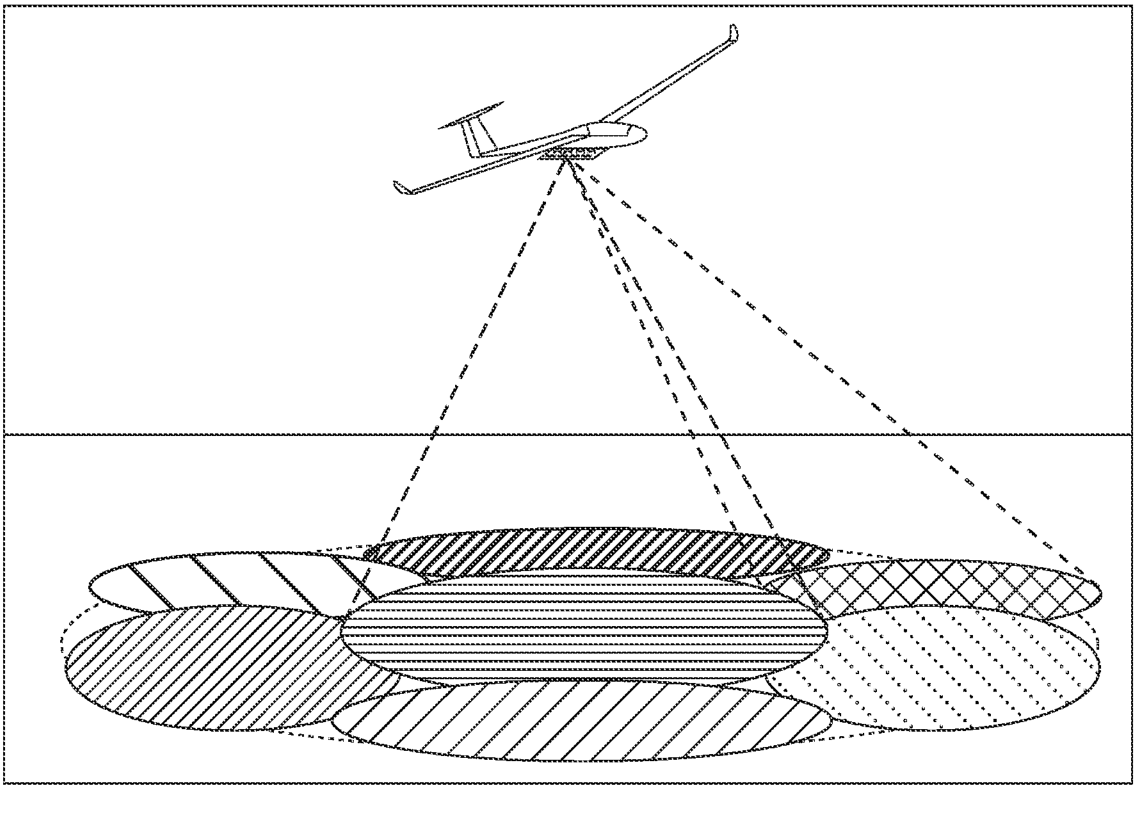


FIG. 3B

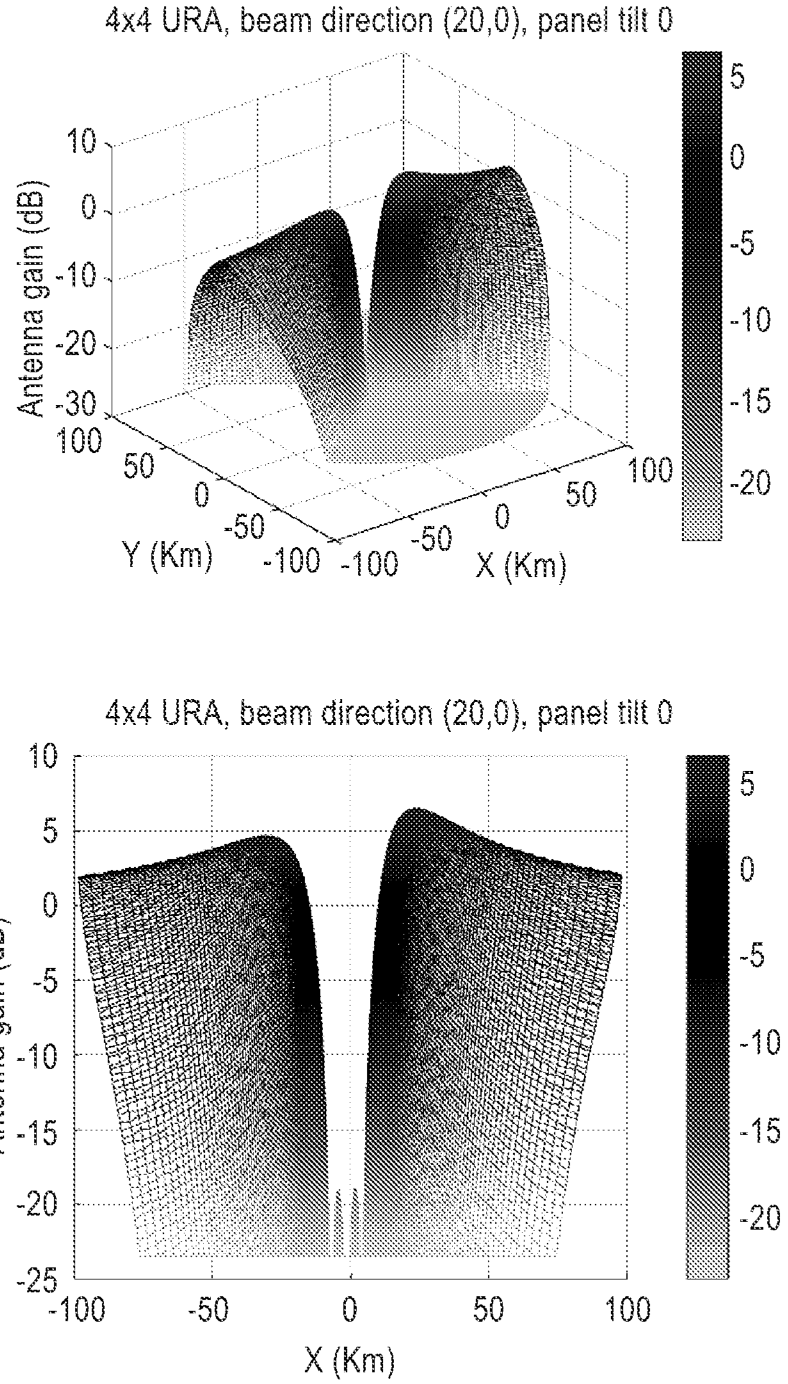

4x4 URA, beam direction (20,0), panel tilt 0
Antenna gain (dB)
10
0
-10
-20
-30
100
50
0
-50
-100
Y (Km)
-100
-50
0
50
100
X (Km)
5
0
-5
-10
-15
-20
4x4 URA, beam direction (20,0), panel tilt 0
Antenna gain (dB)
10
5
0
-5
-10
-15
-20
-25
-100
-50
0
50
100
X (Km)
5
0
-5
-10
-15
-20

FIG. 4

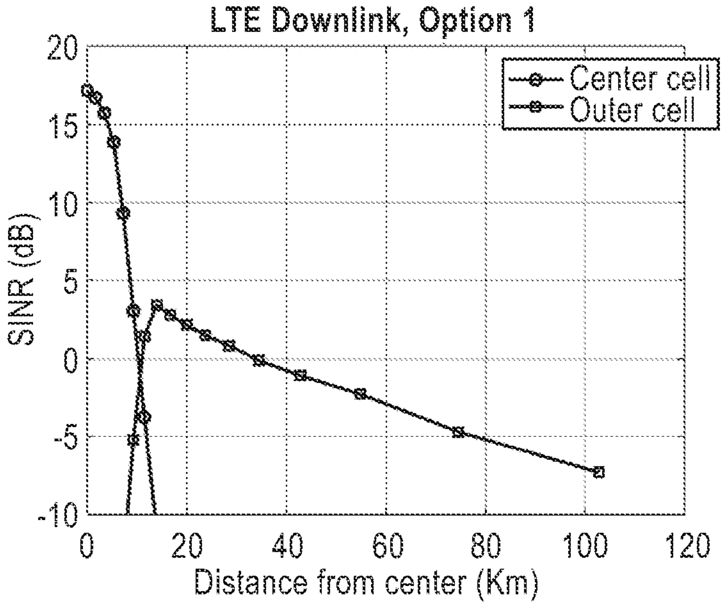

LTE Downlink, Option 1
Center cell
Outer cell
SINR (dB)
20
15
10
5
0
-5
-10
0
20
40
60
80
100
120
Distance from center (Km)

FIG. 5A

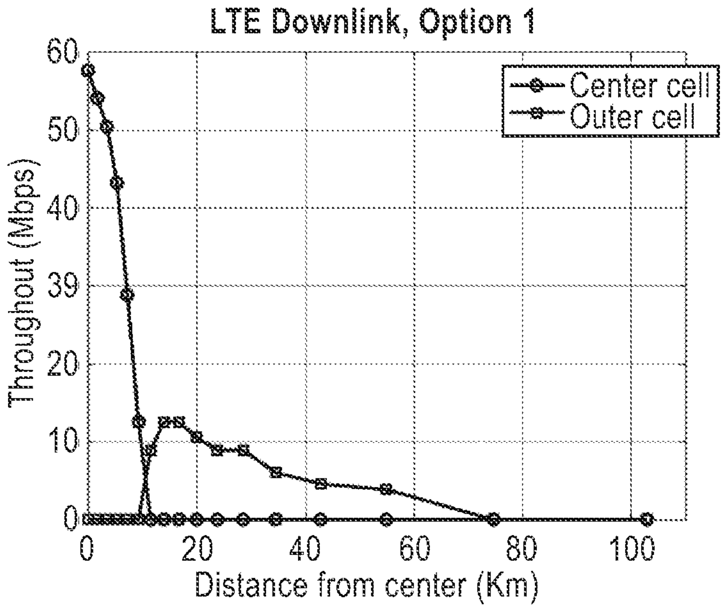

LTE Downlink, Option 1
Center cell
Outer cell
Throughout (Mbps)
60
50
40
39
20
10
0
0
20
40
60
80
100
Distance from center (Km)

FIG. 5B

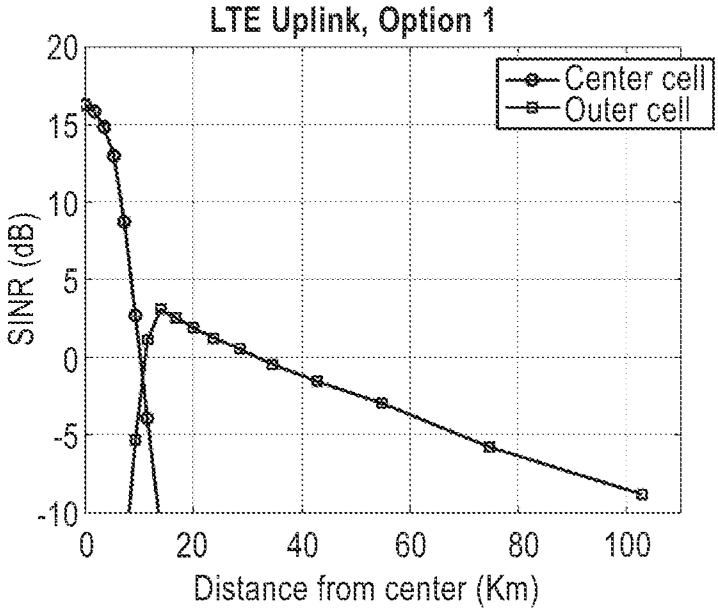

LTE Uplink, Option 1
20
15
10
5
0
-5
-10
SINR (dB)
0
20
40
60
80
100
Distance from center (Km)
Center cell
Outer cell

FIG. 6A

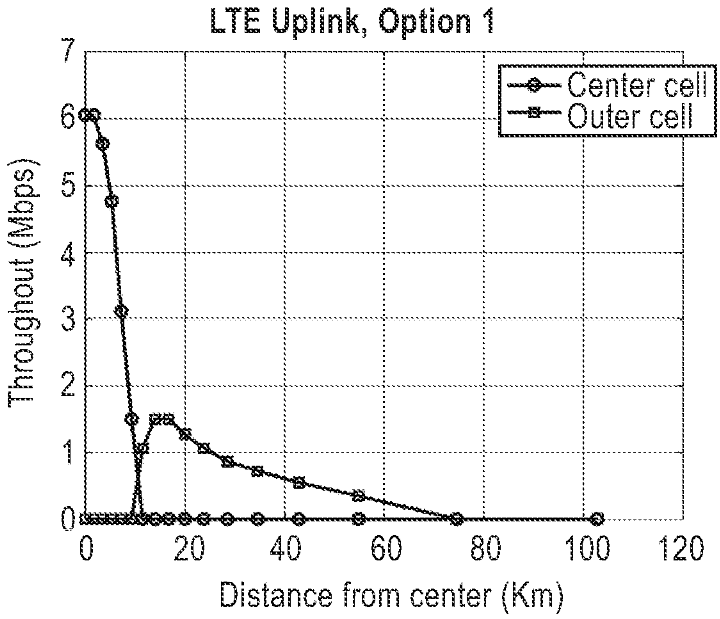

LTE Uplink, Option 1
7
6
5
4
3
2
1
0
Throughout (Mbps)
0
20
40
60
80
100
120
Distance from center (Km)
Center cell
Outer cell

FIG. 6B

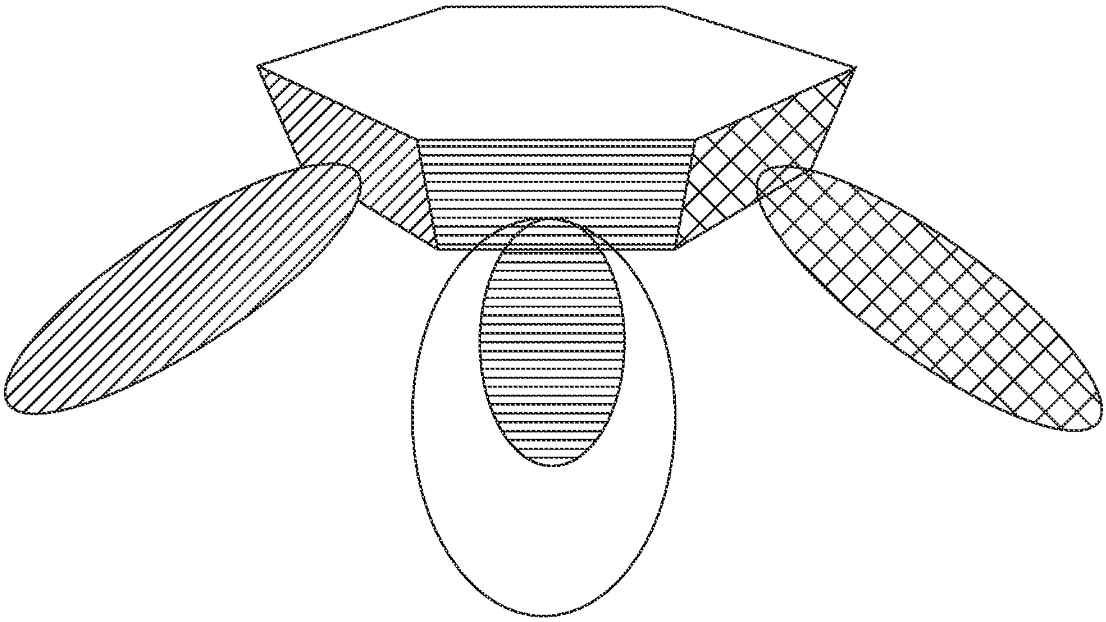


FIG. 7A

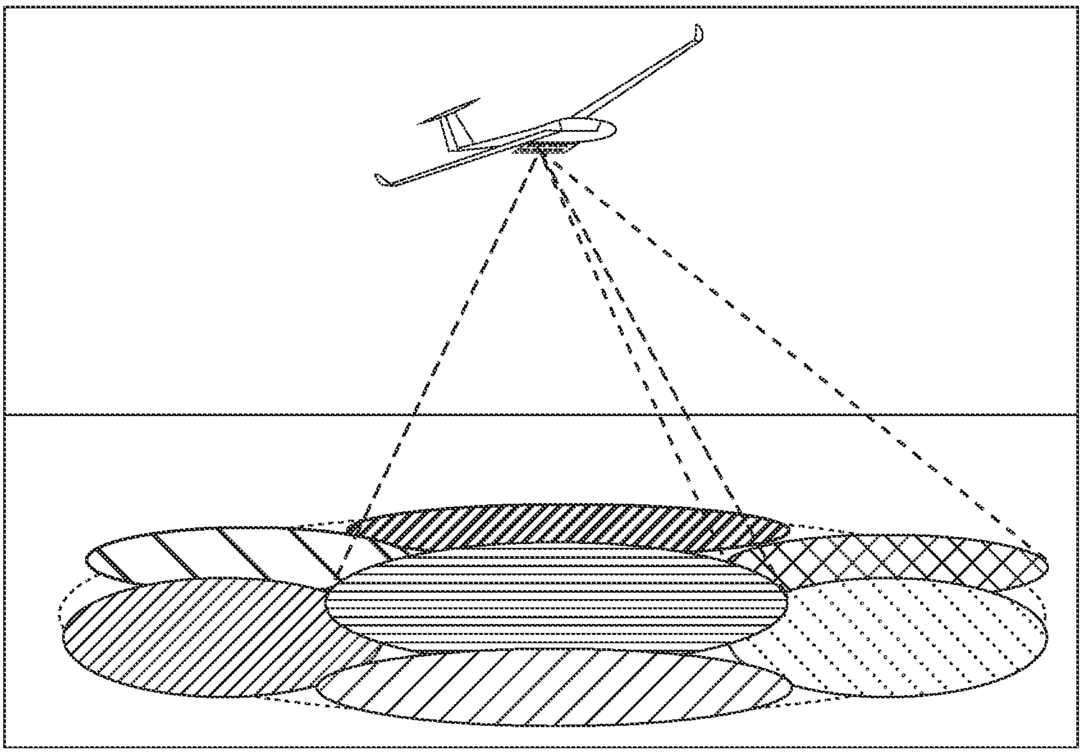
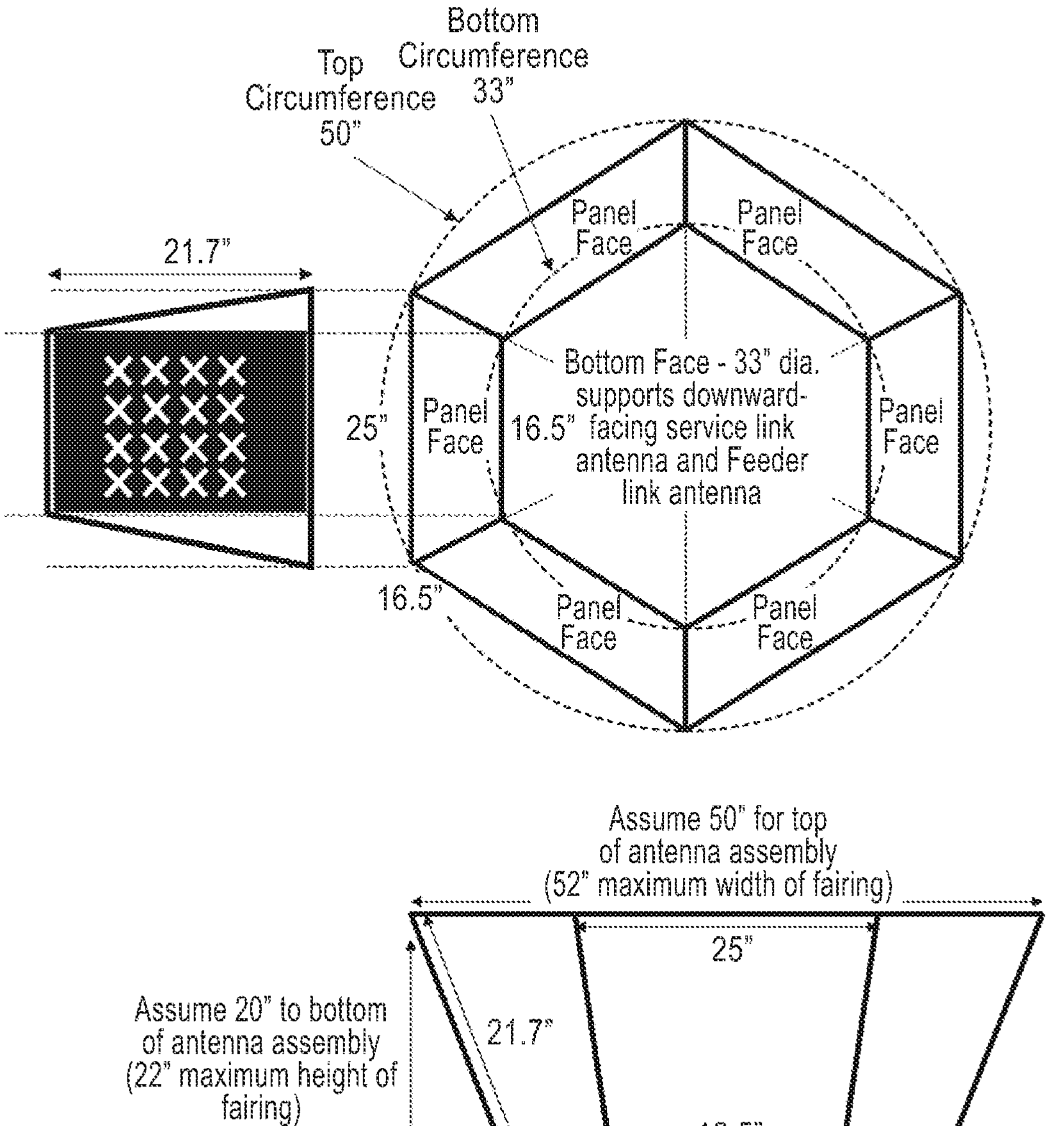


FIG. 7B



Bottom Circumference 33"
Top Circumference 50"
21.7"
Panel Face
Panel Face
Panel Face
Panel Face
Panel Face
Panel Face
25"
16.5"
16.5"
Bottom Face - 33" dia. supports downward-facing service link antenna and Feeder link antenna
Assume 50" for top of antenna assembly (52" maximum width of fairing)
25"
21.7"
Assume 20" to bottom of antenna assembly (22" maximum height of fairing)
67°
16.5"
8.5"
33"

FIG. 8

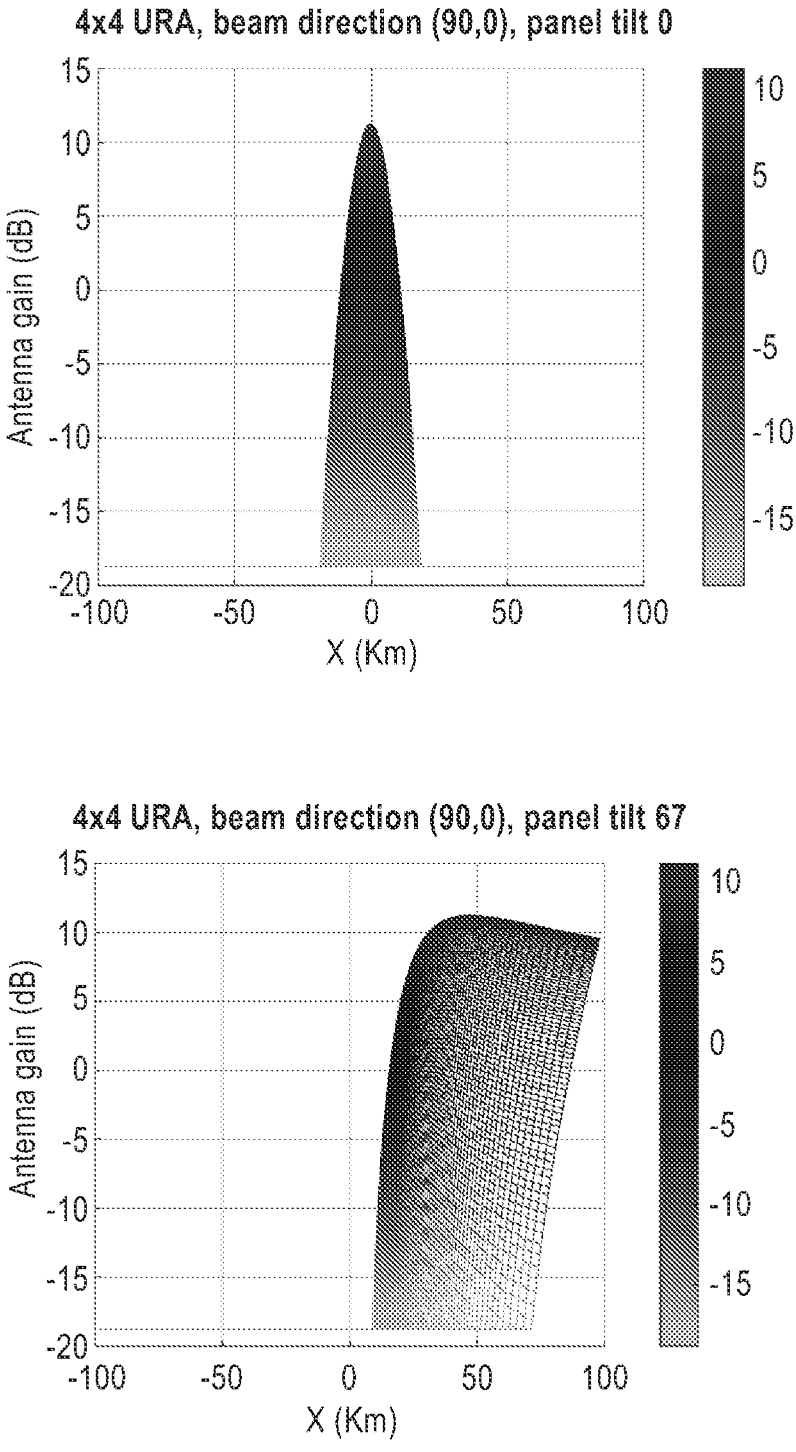

4x4 URA, beam direction (90,0), panel tilt 0
Antenna gain (dB)
15
10
5
0
-5
-10
-15
-20
-100
-50
0
50
100
X (Km)
10
5
0
-5
-10
-15
4x4 URA, beam direction (90,0), panel tilt 67
Antenna gain (dB)
X (Km)

FIG. 9

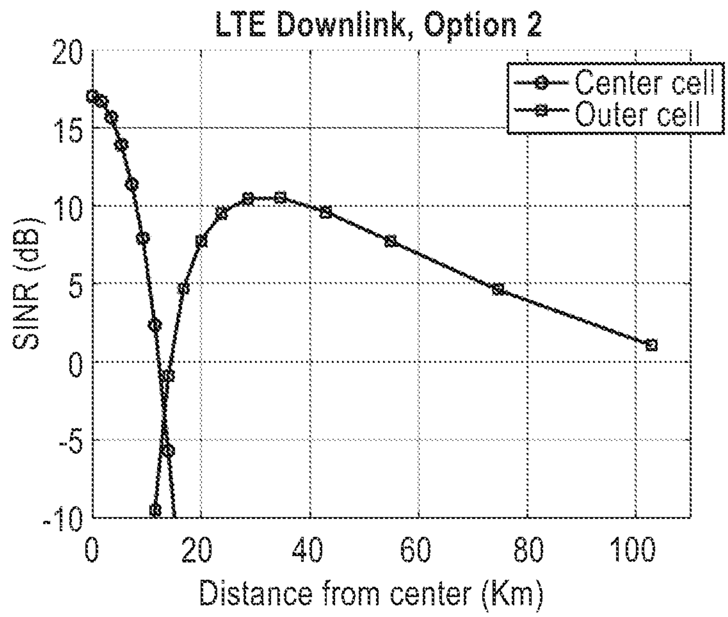


FIG. 10A

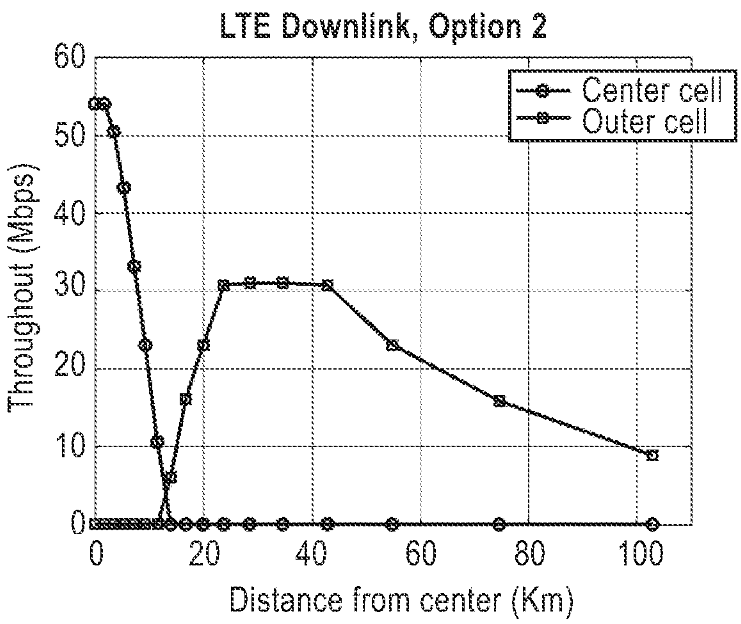


FIG. 10B

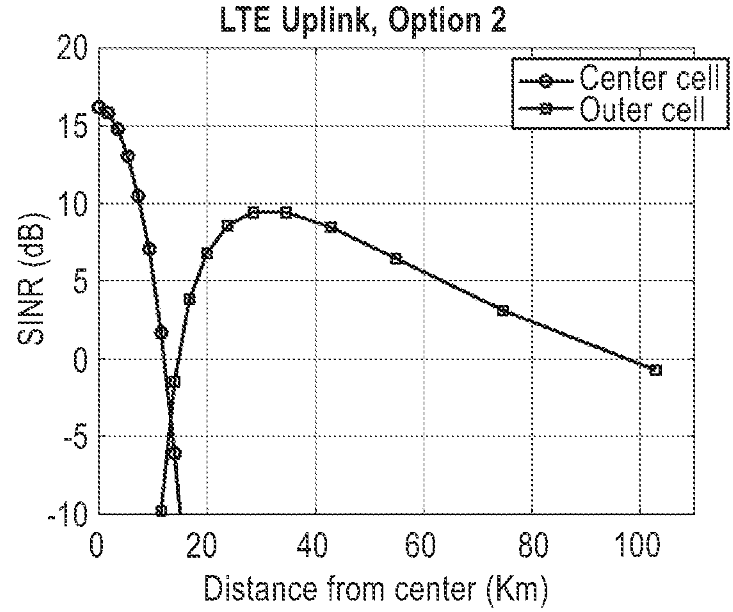


FIG. 11A

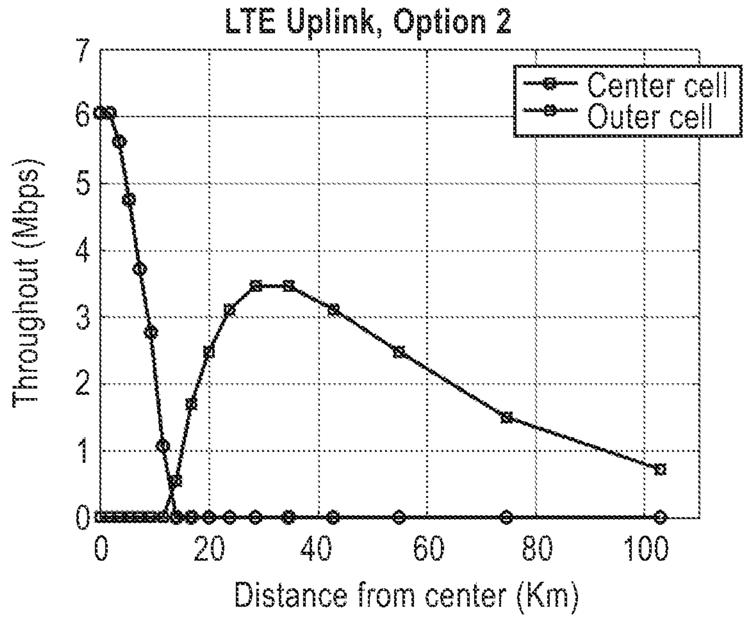


FIG. 11B

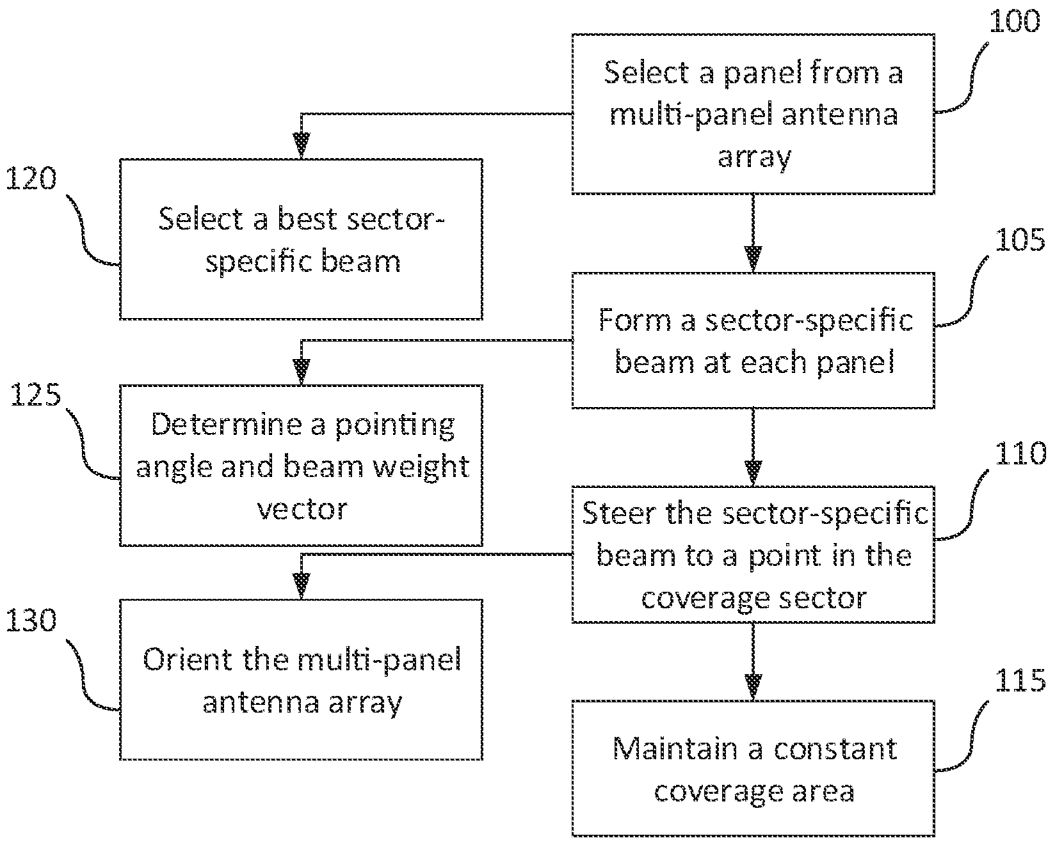

100
Select a panel from a multi-panel antenna array
120
Select a best sector-specific beam
105
Form a sector-specific beam at each panel
125
Determine a pointing angle and beam weight vector
110
Steer the sector-specific beam to a point in the coverage sector
130
Orient the multi-panel antenna array
115
Maintain a constant coverage area

FIG. 12

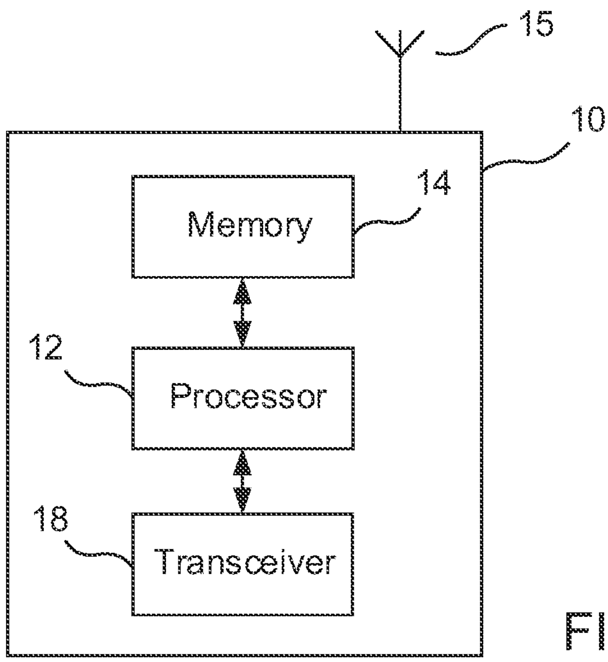


FIG. 13A

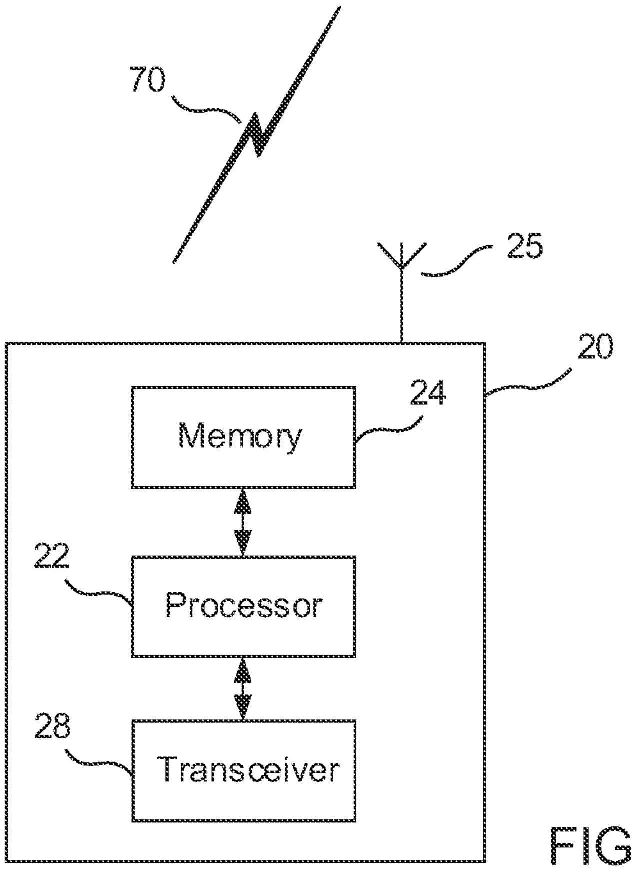


FIG. 13B

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2019/019840

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/185 H01Q3/00 H01Q21/00
ADD.

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)
H04B H01Q

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 99/23769 A1 (RAYTHEON CO [US]) 14 May 1999 (1999-05-14) figures 1, 4A, 4B, 5 page 8, line 1 - line 7 page 10, line 3 - line 14 page 14, line 29 - line 31 page 15, line 3 - line 12 page 16, line 7 - line 15 page 16, line 28 - line 31 page 17, line 1 - line 4 page 17, line 10 - line 23 page 17, line 26 - line 30 page 18, line 15 - line 22 -----	1-29

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"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	Date of mailing of the international search report
12 November 2019	19/11/2019

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Akhertouz Moreno, Y

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International application No
PCT/US2019/019840

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 3 333 974 A1 (BOEING CO [US]) 13 June 2018 (2018-06-13)	1-3,6, 8-10,13, 15-17, 20,28,29
A	figure 2 column 16, line 31 - line 36 column 19, line 14 - line 22 column 20, line 17 - line 20 paragraph [0027] -----	4,5,7, 11,12, 18,19, 21-27

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2019/019840

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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			DE	69838225	T2	08-05-2008
			EP	1027775	A1	16-08-2000
			EP	1826920	A1	29-08-2007
			IL	135826	A	28-03-2004
			JP	4582908	B2	17-11-2010
			JP	2001522191	A	13-11-2001
			KR	20010031643	A	16-04-2001
			US	6061562	A	09-05-2000
			WO	9923769	A1	14-05-1999
EP 3333974	A1	13-06-2018	CA	2981889	A1	09-06-2018
			CN	108232469	A	29-06-2018
			EP	3333974	A1	13-06-2018
			JP	2018127201	A	16-08-2018
			KR	20180066826	A	19-06-2018
			RU	2017135841	A	09-04-2019
			US	2018166779	A1	14-06-2018