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(54) **Title**: GROUND STATION ANTENNA ARRAY FOR AIR TO GROUND COMMUNICATION SYSTEM

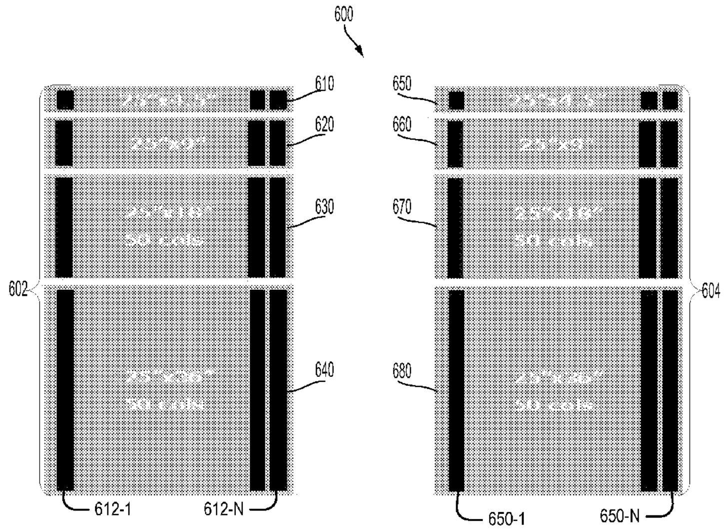

FIG. 6

(57) **Abstract**: A ground station antenna array includes a first array of antenna elements (610). A second array of antenna elements (640) are vertically aligned with the first array of antenna elements. The first array of antenna elements and the second array of antenna elements are coupled to the digital beam forming circuitry and each cover a same sector of azimuth; the first array of antenna elements only covering a first elevation; the second array of antenna elements only covering a second lower elevation. The digital beam forming circuitry directs a radiation pattern of the first array of antenna elements in a first range of elevation angles, and directs a radiation pattern of the second array of antenna elements in a second range of elevation angles. The second array of antenna elements has higher gain than the first array. A respective transceiver is coupled to respective antenna elements of the first and second arrays.

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GROUND STATION ANTENNA ARRAY FOR AIR TO GROUND COMMUNICATION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present Application for Patent claims the benefit of U.S. Provisional Application No. 61/441,231 filed February 9, 2011, in the names of M. Tassoudji et al. and assigned to the assignee hereof and hereby expressly incorporated by reference herein in its entirety.

[0002] This application is related to commonly assigned U.S. patent application entitled "**REAL-TIME CALIBRATION OF AN AIR TO GROUND COMMUNICATION SYSTEM**," in the names of A. JALALI et al. attorney docket 111025U2 and commonly assigned U.S. patent application entitled "**HIGH DATA RATE AIRCRAFT TO GROUND COMMUNICATION ANTENNA SYSTEM**" in the names of A. JALALI et al., attorney docket 111025U1, the disclosures of which are expressly incorporated by reference herein in their entireties.

BACKGROUND

Field

[0003] Aspects of the present disclosure relate generally to wireless communication systems, and more particularly for providing Internet services to aircraft.

Background

[0004] Two main approaches provide Internet access to airplanes. In one approach, an Air to Ground (ATG) system uses terrestrial Ground Base Stations (GBS) using cellular communication techniques to provide Internet access to aircraft flying over land. A currently used ATG system operating over the continental United States uses only 3 MHz of spectrum. Although, this system may become commercially viable, the limited spectrum may be inadequate to accommodate increasing demand for Internet services, such as streaming of Internet content to aircraft. In another approach, satellite links provide Internet service to aircraft. The satellite based systems have more spectrum available but their cost is excessive.

[0005] Because of the excessive cost of satellite links for aircraft Internet communication, it has been preferable to utilize the terrestrial based ATG systems. It would be desirable to increase available spectrum for ATG and provide techniques that would allow such systems to accommodate the increasing demands for aircraft Internet service without substantially increasing cost.

SUMMARY

[0006] According to one aspect of the present disclosure, a high gain multiple beam ground station antenna array is described. The ground station antenna array includes a first array of antenna elements. A second array of antenna elements are vertically aligned with the first array of antenna elements. The first array of antenna elements and the second array of antenna elements are coupled to the digital beam forming circuitry and each cover a same sector of azimuth. The first array of antenna elements only covers a first elevation. The second array of antenna elements only covers a second lower elevation. The digital beam forming circuitry directs a radiation pattern of the first array of antenna elements in a first range of elevation angles, and directs a radiation pattern of the second array of antenna elements in a second range of elevation angles. The second array of antenna elements has higher gain than the first array. A respective transceiver is coupled to respective antenna elements of the first and second arrays.

[0007] In another aspect, a multiple beam aircraft antenna array is described. The aircraft antenna array includes a first array of antenna elements coupled to digital beam forming circuitry. A second array of antenna elements is vertically aligned with the first array of antenna elements and coupled to the digital beam forming circuitry. In one configuration, the first array of antenna elements only covers a first elevation, and the second array of antenna elements only covers a second lower elevation. In one aspect, the digital beam forming circuitry is configured to direct a radiation pattern of the first array of antenna elements in a first range of elevation angles, and configured to direct a radiation pattern of the second array of antenna elements in a second range of elevation angles. In one aspect, the aircraft antenna includes an auxiliary aircraft antenna coupled to a portion of an aircraft distal from the aircraft antenna array.

[0008] This has outlined, rather broadly, the features and technical advantages of the present disclosure in order that the detailed description that follows may be better understood. Additional features and advantages of the disclosure will be described below. It should be appreciated by those skilled in the art that this disclosure may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present disclosure. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the teachings of the disclosure as set forth in the appended claims. The novel features, which are believed to be characteristic of the disclosure, both as to its organization and method of operation, together with further objects and advantages, will be better understood from the following description when considered in connection with the accompanying figures. It is to be expressly understood, however, that each of the figures is provided for the purpose of illustration and description only and is not intended as a definition of the limits of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The features, nature, and advantages of the present disclosure will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout.

[0010] FIGURE 1 is a block diagram conceptually illustrating an example of an air to ground communication system according to an aspect of the present disclosure.

[0011] FIGURE 2 is a diagram conceptually illustrating an example of an aircraft antenna system according to an aspect of the present disclosure.

[0012] FIGURE 3A is a diagram conceptually illustrating an example of a simulated gain pattern vs. an elevation angle of each antenna element of FIGURE 1 over an infinite ground plane according to an aspect of the present disclosure.

[0013] FIGURE 3B is a diagram conceptually illustrating an example of a simulated gain pattern vs. an azimuth angle of adjacent antenna elements of FIGURE 1 and a combined beam according to an aspect of the present disclosure

[0014] FIGURE 4 is a block diagram conceptually illustrating a ground station antenna array system and an aircraft antenna system according to an aspect of the present disclosure.

[0015] FIGURE 5 is a block diagram conceptually illustrating a ground station antenna array system according to one aspect of the present disclosure.

[0016] FIGURE 6 is a block diagram conceptually illustrating a ground station antenna array system according to a further aspect of the present disclosure.

[0017] FIGURE 7 is a flow diagram showing a process for real-time calibration of an air to ground two-way communication system including a ground station antenna array system according to an aspect of the present disclosure.

[0018] FIGURE 8 is a flow diagram showing a process for air to ground communication by an aircraft equipped with a multi-beam switchable array antenna according to an aspect of the present disclosure.

[0019] FIGURE 9 is a flow chart illustrating a process for increasing a transmission power on a forward link from a serving ground base station to mitigate aircraft interference according to one aspect of the present disclosure.

DETAILED DESCRIPTION

[0020] The detailed description set forth below, in connection with the appended drawings, is intended as a description of various configurations and is not intended to represent the only configurations in which the concepts described herein may be practiced. The detailed description includes specific details for the purpose of providing a thorough understanding of the various concepts. However, it will be apparent to those skilled in the art that these concepts may be practiced without these specific details. In some instances, well-known structures and components are shown in block diagram form in order to avoid obscuring such concepts.

[0021] The spectrum available for Internet communication to aircraft by terrestrial Air to Ground (ATG) systems has been limited for practical and economic reasons. Providing seamless communication with aircraft flying at high altitudes over a large area (such as the continental U.S.) involves spectrum that is available over the large area. That is, the spectrum assigned to the ATG system should be available nationwide. It has been problematic, however, to identify a portion of spectrum that is available nationwide, much less arranging to free up such a portion of spectrum that has been allocated for other uses.

[0022] A large amount of spectrum has been assigned to geostationary satellites for use in broadcast TV and two way FSS (Fixed Satellite Service). Aspects of the present disclosure provide a high data rate aircraft to ground communication antenna system for sharing portions of the spectrum between ATG applications and geostationary satellite communication systems. Frequency bands such as C band (4 GHz downlink, 6 GHz uplink), Ku band (12 GHz downlink, 14 GHz uplink) and Ka band (20 GHz downlink, 30 GHz uplink) are currently used by geostationary satellite systems. In one aspect, a high data rate aircraft to ground communications antenna system may share the Ku uplink band to provide an aircraft with Internet service.

[0023] Aspects of the present disclosure provide methods and apparatus for an ATG system in which Ground Base Stations (GBSs) in communication with aircraft transceivers (ATs) in airplanes can use an uplink portion of spectrum assigned for satellite systems without intolerable interference with communications on the satellite systems. The systems and techniques described in the present disclosure may allow coexistence of the incumbent satellite system and the new ATG system on the same spectrum with negligible cross interference between the two systems.

[0024] A system 100 for wireless communication according to an illustrative aspect of the present disclosure is described in FIGURE 1. In one aspect, the system 100 includes a ground base station 102 that transmits and receives signals on a satellite uplink band using a forward link (FL) 108 and a reverse link (RL) 106. An aircraft transceiver (AT) 120 in communication with the ground base station 102 may also transmit and receive signals on the satellite uplink band using the forward link 108 and reverse link 106. In one aspect, the aircraft transceiver 120 may include a multi-beam switchable array antenna. Another ground base station 110 is also shown.

[0025] In one aspect, the aircraft transceiver 120 may include an aircraft antenna that is comprised of a multi-beam switchable array that is able to communicate with the ground base station 102 at any azimuth angle. The aircraft antenna may be mounted below the fuselage with a small protrusion and aerodynamic profile to reduce or minimize wind drag. In one aspect, the antenna elevation coverage is from approximately 3° to 10° below horizon. The antenna array may include N elements positioned such that each element directs a separate beam at different azimuth angles, each covering 360/N degrees, for example, as shown in FIGURE 2.

[0026] FIGURE 2 shows one example of an aircraft antenna array system 200 having multiple twelve-beam arrays 202 (202-1,…,202-N) operating at, for example, 14 gigahertz (GHz). Representatively, the aircraft antenna array 202-1 has twelve horn antennas 210 (210-1,…,210-12) each covering 30° sectors in azimuth with an aperture size of approximately 2.0 inches x 0.45 inches, and having a gain of >10dBi (dB isotropic). In one aspect, an overall diameter of the antenna array is roughly 8 inches.

[0027] Although FIGURE 2 illustrates the aircraft antenna arrays 202 in a twelve-beam array configuration, it should be recognized that other configurations are possible while remaining within the scope of the present disclosure and appended claims. In particular, one example configuration includes four-antenna arrays 202 in a four-beam array configuration. In one aspect, the multiple aircraft antenna arrays 202 enable ground base station search at different elevations. In one aspect, the multiple antenna arrays 202 enable sectorization of the ground base station antenna search in elevation. In this aspect, each element is coupled to its own transceiver. As described in further detail below, the ground base station search enables a handoff between the aircraft transceiver 120 and a next ground base station, such as a ground base station 110, as shown in FIGURE 1.

[0028] In one aspect, the aircraft antenna array system 200 is mounted below the fuselage and an auxiliary antenna is mounted onto a separate portion of the aircraft to improve aircraft Internet service. In particular, banking or rolling of the aircraft during flight may interrupt communication between the aircraft antenna array system 200 mounted below the fuselage and the ground base station 102. In one aspect, the auxiliary antenna reduces disruption of the communication between the aircraft transceiver 120 and the ground base station 102 when the aircraft banks or rolls by handling the communications with the ground base station during these times. Characteristics of the aircraft antenna 200 are further illustrated in FIGURES 3A and 3B.

[0029] FIGURE 3A illustrates a diagram 300 of a simulated elevation gain pattern of a single antenna element 210 at azimuth angles of 0, 5, 10, 15 and 20 degrees, according to one aspect of the present disclosure. Representatively, the x-axis in FIGURE 3A represents the theta angle in spherical coordinates where the horizon is at 90°. Because the simulation is performed over an infinite ground plane, the gain pattern above horizon (between -90 and 90) is duplicated due to image theory and should be ignored. FIGURE 3B shows a diagram 350 of the simulated azimuth gain pattern 352 and 354 of two adjacent elements and a digitally combined beam 360 according to one aspect of the present disclosure.

[0030] Operation of the aircraft antenna 200 for providing aircraft Internet service involves detection and aircraft modem handoff between a current ground base station 102 and a next ground base station 110, as shown in FIGURE 1. Various schemes of communication and searching can be employed by the antenna system. In one aspect, a single receive chain is used for communication, with searching being performed in a sequential, time division manner. In another aspect, two receive chains may be used, with one chain for ground station communication and the other chain for ground base station search. In the two receive chain configuration, the searching chain can also be used for diversity combining to increase the gain and throughput while not searching. Ground base station search may be performed as follows.

[0031] In one aspect, ground base station search may include a search of all pilot signals received from ground base stations on a given aircraft antenna element. The received pilot signals are ranked to determine whether or not the aircraft modem should handoff to another ground base station from which it is receiving a stronger pilot signal. Once the search on one antenna element is complete, the search may switch to another element and repeat the pilot search on that element. In one aspect, each of antenna elements 210-2 to 210-12 may continually search for ground stations while data is received by antenna element 210-1, as shown in FIGURE 2.

[0032] In the configurations described above, a switched antenna scheme involves a transceiver that switches between different antenna elements to achieve high gain while maintaining low complexity. Alternatively, the directional beams may be formed by combining multiple antenna elements using phased array techniques. In one aspect, the switched antenna scheme described above may combine two adjacent beams 352 and 354 to form combined beam 360 for further increasing the antenna gain while only slightly increasing the hardware complexity to provide diversity. In one aspect, the switched antenna scheme may use a partial phased array beam combining of adjacent antenna elements. For example, adjacent beams may be combined to improve system performance when a communicating ground base station is at or near a boundary of the adjacent beams.

[0033] FIGURE 4 shows a block diagram of a design of a ground base station 102 and an aircraft transceiver 120. The ground base station 102 may be equipped with antennas 434a through 434t, and the aircraft transceiver 120 may be equipped with antennas 452a through 452r.

[0034] At the ground base station 102, a transmit processor 420 may receive data from a data source 412 and control information from a controller/processor 440. The processor 420 may process (e.g., encode and symbol map) the data and control information to obtain data symbols and control symbols, respectively. The processor 420 may also generate reference symbols. A transmit (TX) multiple-input multiple-output (MIMO) processor 430 may perform spatial processing (e.g., precoding) on the data symbols, the control symbols, and/or the reference symbols, if applicable, and may provide output symbol streams to the modulators (MODs) 432a through 432t. Each modulator 432 may process a respective output symbol stream (e.g., for OFDM, etc.) to obtain an output sample stream. Each modulator 432 may further process (e.g., convert to analog, amplify, filter, and upconvert) the output sample stream to obtain a downlink/forward link signal. Downlink signals from modulators 432a through 432t may be transmitted via the antennas 434a through 434t, respectively.

[0035] At the aircraft transceiver 120, the antennas 452a through 452r may receive the downlink/forward link signals from the ground base station 102 and may provide received signals to the demodulators (DEMODs) 454a through 454r, respectively. Each demodulator 454 may condition (e.g., filter, amplify, downconvert, and digitize) a respective received signal to obtain input samples. Each demodulator 454 may further process the input samples (e.g., for OFDM, etc.) to obtain received symbols. A MIMO detector 456 may obtain received symbols from all the demodulators 454a through 454r, perform MIMO detection on the received symbols if applicable, and provide detected symbols. A receive processor 458 may process (e.g., demodulate, deinterleave, and decode) the detected symbols, provide decoded data for the aircraft transceiver 120 to a data sink 460, and provide decoded control information to a controller/processor 480.

[0036] On the reverse link/uplink, at the aircraft transceiver 120, a transmit processor 464 may receive and process data from a data source 462 and control information from the controller/processor 480. The processor 464 may also generate reference symbols for a reference signal. The symbols from the transmit processor 464 may be precoded by a TX MIMO processor 466 if applicable, further processed by the modulators 454a through 454r, and transmitted to the ground base station 102. At the ground base station 102, the uplink/reverse link signals from the aircraft transceiver 120 may be received by the antennas 434, processed by the demodulators 432, detected by a MIMO detector 436 if applicable, and further processed by a receive processor 438 to obtain decoded data and control information sent by the aircraft transceiver 120. The processor 438 may provide the decoded data to a data sink 439 and the decoded control information to the controller/processor 440.

[0037] The controllers/processors 440 and 480 may direct the operation at the ground base station 102 and the aircraft transceiver 120, respectively. The processor 440 and/or other processors and modules at the ground base station 102 may perform or direct the execution of various processes for the techniques described herein. The processor 480 and/or other processors and modules at the aircraft transceiver 120 may also perform or direct the execution of the functional blocks illustrated in use method flow chart of FIGURE 8, and/or other processes for the techniques described herein. The memories 442 and 482 may store data and program codes for the ground base station 102 and the aircraft transceiver 120, respectively.

[0038] Ground station antenna array systems including antenna arrays for communicating with aircraft antenna 200 are shown in FIGURES 5 and 6 according to aspects of the present disclosure. In one aspect, a ground station antenna array system may include high gain multi-beam antenna arrays capable of communicating with multiple aircrafts simultaneously, for example, as shown in FIGURES 5 and 6. FIGURES 5 and 6 show two examples of the sectorization and antenna array configurations according to aspects of the present disclosure.

[0039] In one aspect, sectorization may include splitting sectors in elevation to increase system throughput, for example, as shown in FIGURES 5 and 6. Representatively, the coverage region in azimuth and elevation may be divided into narrow regions where the antenna array can maintain its gain requirement over all angles in the coverage area. In one configuration, the antennas may be operated in the 14 GHz range with a coverage region of 120° in azimuth and 0.5° to 10° in elevation. The ground base station antenna gain may be 40 dBi at 0.5° elevation and is reduced to 25.5 dBi at 10° elevation due to lower path loss to the aircraft.

[0040] Referring again to FIGURE 5, FIGURE 5 depicts a configuration of a ground base station antenna array system 500 with two antenna panels 510 and 530 each covering 60° in azimuth. In one aspect, each antenna panel 510/530 may consist of an NxM array 520/540 of antenna elements 522 (522-1,…, 522-N), 524 (524-1,…, 524-N), 542 (542-1,…, 542-N), and 544 (544-1,…, 544-N), respectively, which may be referred to herein as ground station antenna arrays. In one aspect, each antenna element includes a transmit/receive (T/R) module. Representatively, ground station antenna arrays 520 and 540 include 50x6 antenna elements; however, other configurations are possible while remaining within the scope of the described aspects and appended claims. In one aspect, digital beam forming may be employed to combine the signal and achieve the overall gain desired. The digital beam forming may be computed over the antenna elements in different columns and rows of each panel.

[0041] FIGURE 6 depicts a configuration of a ground station antenna array system 600 in which number of antenna panels 610, 620, 630, and 640/650, 660, 670, and 680 covering the elevation is increased to four and the number of panels 602 and 604 covering the azimuth is maintained at two. In one aspect, the aperture size for the panels (610/650) covering higher elevations is smaller than the aperture size for the panels (640/680) covering low elevations due to lower gain required at higher elevations. Each antenna array 612 (612-1,…, 612-N)/650 (650-1,…, 650-N) may include 50x1 elements where digital beam forming is applied. In one aspect, generation of the digital beam is switched, for example, between adjacent panels 610/650 to next adjacent panels 620/660 depending on an elevation of the aircraft.

[0042] Other configurations that utilize a smaller number of elements for digital beam forming can be achieved by further reducing the coverage region of each panel in azimuth and increasing the antenna aperture of the elements while maintaining the array size. This can lead to a larger overall ground station antenna array size but less complicated digital signal processing. In one aspect, a single element can be used for each sector without any digital beam forming, which corresponds to 100x4 antennas in the above example.

[0043] In one aspect, digital beam forming may be used in each array to provide multiple steerable pencil-beams. The signal for each element of the array may pass through a T/R (transmit/receive) module and is converted into baseband. In one aspect, the phase shifts for a directional beam are calculated by a beam steering computer and applied to each signal. Similar phase factors may be applied to the transmit signal and passed through the transmit/receive module into the antenna element. In one aspect, a calibration procedure equalizes the amplitude and phase of each element and accounts for the time variation of the circuitry.

[0044] As mentioned above, calibration compensates for the different phase/amplitude responses of the antenna and transmit/receive units. One type of calibration may be performed in the factory using built in circuitry. This calibration may use any well known technique. The built in calibration scheme may also be used for periodic calibration in the field to track changes due to temperature and aging. Another approach for calibration may be built into the air interface to provide real-time calibration while performing two-way communication between a ground base station and an aircraft modem. In one aspect, calibration is periodically performed using the communication signaling of an air interface. In particular, an over the air (OTA) real-time calibration may be performed while an air to ground two-way communication system operates.

[0045] In one aspect, the Forward Link (FL) on the Ground Base Station (GBS) unit periodically transmits a pilot signal on a wide beam that covers the whole sector. As described herein, the periodically transmitted pilot signal on the forward link of the ground base station may be referred to as a Sector Wide Pilot (SWP). In one aspect, the sector wide pilot may allow an aircraft to detect new ground base stations, to synchronize to the ground base stations, and to receive system parameters, such as information on a periodic calibration procedure described below. For example, as shown in FIGURE 1, the ground base station 102 may transmit a sector wide pilot over forward link 108.

[0046] In one aspect, the wide beam used to transmit the sector wide pilot may be formed by transmitting on any of the individual ground station antenna array elements (522, 524, 542, 544, 612, or 650), for example, as shown in FIGURES 5 and 6. The aircraft modem may detect this sector wide pilot as part of its search procedure. One possible real time procedure to calibrate the transmit elements of the ground station antenna array elements is performed as follows.

[0047] In one aspect, the ground base station periodically enters a calibration mode. The time of the calibration mode may be sent on the forward link on the same wide beam that carries the sector wide pilot. Calibrating the transmit side of the ground station antenna array may be initially performed. In particular, the ground base station transmitter may sequentially send the sector wide pilot on all ground station antenna array elements during a time period assigned to calibration. Following demodulation, the signal received at the aircraft from the k-th ground station antenna array element is given by:

$$(\alpha_k e^{-j\theta_k})(\beta_k e^{-j\varphi_k})(\delta_k e^{-j\nu_k})(\sigma_k e^{-j\partial_k}) \tag{1}$$

[0048] In equation (1), the first term may correspond to gain (α_k) and delay (θ_k) in the RF chain. The second term may correspond to the amplitude (β_k) and phase (ϕ_k) of coupling between antenna elements. The third term may correspond to the phase (ν_k) from antenna array spacing. The last term may correspond to multipath fading amplitude (σ_k) and phase (∂_k). Also, j in equation (1) represents the imaginary part of a complex number.

[0049] In one aspect, the first three terms are due to the hardware and can be estimated by averaging out the last term by making a number of temporal measurements. For instance, given the high speed at which the aircraft travels, channel changes occur very rapidly (e.g., on the order of milliseconds). In on aspect, a number of measurements of equation (1) may be made over two millisecond intervals. These separate measurements may then be filtered to average out the last term in equation (1), which is due to multi-path. In equation (1), the last term may assume that either the channel is frequency non-selective or that the measurements are made over a narrow bandwidth such as on individual tones of an OFDM (orthogonal frequency division multiplexing) physical layer.

[0050] In one aspect for a wide bandwidth system, the signals may be sent on a sufficient number of tones to ensure calibration of the hardware over all frequencies. The aircraft modem may compute the calibration coefficients as described above and transmits the coefficients to the ground base station so the ground base station may use these coefficients for forward link beam forming toward the aircraft, for example, as shown in FIGURE 1.

[0051] A process for real-time calibration of an air to ground two-way communication system may be performed as follows. FIGURE 7 is a flow chart illustrating a method 700 for real-time calibration of an air to ground two-way communication system including a ground station antenna array system according to one aspect of the present disclosure. At process block 702, the air to ground two-way communication system operates to provide Internet service for an aircraft, for example, as shown in FIGURE 1. At process block 704 it is determined whether a calibration period is detected during operation of the air to ground two-way communication system. Until a calibration period is detected, operation of the air to ground two-way communication system continues. Once a calibration period is detected, calibration of a base station antenna system may be performed as follows.

[0052] At process block 706, a sector wide pilot signal is sequentially transmitted on a wide beam by each antenna element of a base station antenna array. In one aspect, the antenna 500 (FIGURES 5) may transmit a Sector Wide Pilot (SWP) on each element of the ground station antenna arrays 520 and 540. In the configuration illustrated in FIGURE 6, the ground station antenna system 600 may transmit the sector wide pilot on one of the adjacent antenna panels 610 and 650, 620 and 660, 630 and 670, or 640 and 680 depending on an elevation of the aircraft.

[0053] Referring again to FIGURE 7, at process block 708 forward link calibration coefficients of the antenna array may be received from an aircraft in response to the sector wide pilot signals during the calibration periods. In one aspect, the calibration coefficients characterize the sector wide pilot signals received by the aircraft. At process block 710, real-time calibration of an antenna array of the ground station antenna array system is performed according to the received calibration coefficients using, for example, equation (1) in accordance with one aspect of the present disclosure.

[0054] In one aspect, the receive side calibration may be performed in a manner similar to the above scheme but by having the aircraft modem transmit a pilot sequence on the Reverse Link (RL) 106, as shown in FIGURE 1. The pilot signal may be sent with a sufficient amount of energy and with a sufficient amount of time duration to enable detection at each of the antenna elements at the ground base station. Similar to the scheme described above for calibrating the transmit chain, in one aspect the receive chain's phase and amplitude may be estimated by averaging over any variations due to multipath fading.

[0055] Once the ground base station and aircraft antennas are calibrated, beam forming may be performed in any number of ways. In one aspect, the aircraft sends its position to the ground base station based on a current position location, which may be determined with, for example, a position location system such as a global positioning system (GPS). The ground base station may use this information to form a beam in the direction of the aircraft and also on the receive side at the ground base station. In a calibrated antenna system, knowledge of the position of the aircraft and the ground base station can be used to calculate the phased array antenna coefficients to point the bore sight of the beam toward the location of the aircraft. During the flight, the beam may be adjusted using the position of the aircraft that is periodically reported to the ground base station, according to one aspect of the present disclosure.

[0056] In one aspect, the aircraft and the ground base station may adjust their beams to increase or maximize Signal to Noise Plus Interference (SINR) received at the aircraft and at the ground base station. For instance, the ground base station may slightly move its transmit beam. The aircraft will report SINR measurements received at the aircraft to the ground base station. In one aspect, the ground base station may find the improved or optimal transmit beam by adjusting its beam based on the SINR feedback received from the aircraft. In one aspect, the ground base station may send one or more adjacent beams to determine whether one of the adjacent beams provides improved performance based on, for example, measured signal energy. In one aspect, detection of an improved or optimal beam may be used on the reverse link from the aircraft to the ground base station.

[0057] In TDD (Time Division Duplex) channels where the forward link and reverse link are reciprocal, except for the hardware phase and delays which are calibrated, the ground base station may determine the desired or best received beam by comparing SINRs received on adjacent beams. Then, the ground base station may form a beam toward the aircraft based on the desired or optimal beam on its receive side. In one aspect, the ground base station repeatedly determines the desired or optimal receive beam and adjusts the transmit beam accordingly. A process for air to ground communication by an aircraft equipped with a multi-beam switchable array antenna may be performed as follows.

[0058] FIGURE 8 is a flow chart illustrating a method 800 for air to ground communication by an aircraft equipped with multiple antenna arrays of a multi-beam switchable antenna elements according to one aspect of the present disclosure. At process block 802, a first pilot signal is received on a wide beam from a first ground station of a network by a first antenna element of an antenna. In one aspect, the antenna 200 (FIGURE 2) may receive a Sector Wide Pilot (SWP) on a first antenna element 210 (210-1,…, 210-12) covering a first range of azimuth angles from the aircraft. In the configuration illustrated in FIGURE 2, the aircraft antenna 200 has twelve horn antennas 210 (210-1,…,210-12) each covering 30° sectors in azimuth.

[0059] Referring again to FIGURE 8, at process block 804 data is received on a directed beam from the first ground station by the first antenna element (e.g. 210-1). At process block 806, at least one second pilot signal is received on a wide beam from at least one second ground station of the network by a second antenna element of the antenna covering a second range of azimuth angles from the aircraft different than the first range of azimuth angles. For example, a sector wide pilot may be received from the second ground station 110 while data is being received from the first ground base station 102, as shown in FIGURE 1.

[0060] As shown in FIGURE 2, data may be received by the first antenna element 210-1 while a sector wide pilot is received by the second antenna element 210-2. In one configuration, each of the antenna elements 210-2 to 210-12 may continually search for ground stations while data is received by the antenna element 210-1. In an alternative aspect, a time division mode operates by using a single antenna element for receiving data, and when data is not being received, the remaining antenna elements may search for ground stations to determine whether to perform an aircraft modem handoff.

[0061] Referring again to FIGURE 8, at process block 808 a signal strength of the second pilot signal(s) is compared with a signal strength of the first pilot signal. At process block 810, reception of the data may be switched from the first antenna element to the second antenna element in response to determining that the second pilot signal strength received by the second antenna is greater than the first pilot signal strength received on the first antenna element. In one aspect, the method 800, as shown in FIGURE 8, is repeated for each aircraft antenna array 202 (FIGURE 2) for configurations having multiple aircraft antenna arrays. In an alternative aspect, the method 800 is performed for a selected aircraft antenna array (e.g. 202-1).

[0062] Transmissions from non-geostationary satellite terminals may interfere with communications from a ground base station to an aircraft transceiver on a served aircraft. Also, other aircraft may interfere with communications from a ground base station to an aircraft transceiver on the served aircraft. In addition, signal degradation may be caused by rain when either the Ka band or the Ku band is used by an air to ground communication system. Aspects of the present disclosure may mitigate this type of interference and signal degradation to the aircraft terminal.

[0063] As shown in FIGURE 1, the transmission power on the forward link 108 of ground base station 102 may be increased to overcome interference, with an equal decrease in the forward link transmission power of the ground base station 110. In one aspect, a ground base station controller/processor 440 (FIGURE 4) is responsible for adjusting the transmission power among the various base stations so that the sum of the overall transmission power over the various ground base stations remains constant.

[0064] In particular, the aircraft receiver may measure the Signal to Interference plus Noise Ratio (SINR) and send an index of the measured SINR to the ground base station. In one aspect, the ground base station adjusts the transmit power on the forward link beam to maintain the SINR received at the aircraft above a target value. In case of rain, the signal becomes attenuated, resulting in a reduction in the received SINR at the aircraft. Each beam may be allowed a maximum transmit power. The base station controller will impose a limit on the overall transmit power from all ground base stations. In case of interference from other systems into the aircraft receiver, the interference term of SINR will increase, reducing the SINR received by the aircraft. In one aspect, the ground base station controller may increase the forward link power in response to the SINR feedback from the aircraft modem.

[0065] FIGURE 9 is a flow chart illustrating a method 900 for increasing a transmission power on the forward link from a serving ground base station to mitigate aircraft interference according to one aspect of the present disclosure. At process block 902, interference is detected during transmission of data on a forward link of a ground base station antenna array from the serving ground base station to the aircraft. At process block 904, the serving ground base station may increase a transmission power on the forward link to mitigate aircraft interference. In one aspect, increasing the transmission power for the serving ground base station involves an equal decrease in transmission power of one or more other ground base stations. Accordingly, at process block 906, a decrease in transmission power of one or more other ground base stations is performed. In one aspect, the decrease in transmission power is performed so that the sum of the overall transmission power over the various ground base stations remains constant.

[0066] In one configuration, an aircraft is configured for wireless communication including a first array of antenna element means coupled to digital beam forming means. In one aspect, the digital beam forming means may be the modulators 454a-r, transmit processor 464, antenna 452a-r, controller/processor 480, and/or memory 482 of FIGURE 4. In a further aspect, the first array of antenna element means may be the aircraft antenna array 202-1, as shown FIGURE 2 and/or the antenna 452a-r, demodulator 454a-r, receive processor 458, controller/processor 480, and/or memory 482 of FIGURE 4. The aircraft is also configured to include a second array of antenna element means vertically aligned with the first array of antenna element means and coupled to the digital beam forming means. In one configuration the first array of antenna element means only covering a first elevation, and the second array of antenna element means only cover a second lower elevation. In one aspect, the second array of antenna element means may be the aircraft antenna array 202-N, as shown FIGURE 2 and/or the antenna 452a-r, demodulator 454a-r, receive processor 458, controller/processor 480, and/or memory 482 of FIGURE 4.

[0067] In one configuration, a ground base station 102 is configured for wireless communication including a first array of antenna element means coupled to digital beam forming means. In one aspect, the digital beam forming means may be the modulators 432a-t, transmit processor 420, antenna 434a-t, controller/processor 440, and/or memory 442 of FIGURE 4. In a further aspect, the first array of antenna element means may be antenna elements 520/540 of ground station antenna array 500 of FIGURE 5. The ground base station 102 is also configured to include a second array of antenna element means vertically aligned with the first array of antenna element means and coupled to the digital beam forming means. In one configuration, the first array of antenna element means and the second array of antenna element means each cover a same sector of azimuth. In another configuration, the first array of antenna element means only covers a first elevation, and the second array of antenna element means only covers a second lower elevation. In one aspect, the second array of antenna element means may antenna elements 520/540 of ground station antenna array 500 of FIGURE 5. In another aspect, the aforementioned means may be a module or any apparatus configured to perform the functions recited by the aforementioned means.

[0068] Those of skill would further appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the disclosure herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present disclosure.

[0069] The various illustrative logical blocks, modules, and circuits described in connection with the disclosure herein may be implemented or performed with a general-purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

[0070] The steps of a method or algorithm described in connection with the disclosure herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal. In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.

[0071] In one or more exemplary designs, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media may be any available media that can be accessed by a general purpose or special purpose computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code means in the form of instructions or data structures and that can be accessed by a general-purpose or special-purpose computer, or a general-purpose or special-purpose processor. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

[0072] The previous description of the disclosure is provided to enable any person skilled in the art to make or use the disclosure. Various modifications to the disclosure will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other variations without departing from the spirit or scope of the disclosure. Thus, the disclosure is not intended to be limited to the examples and designs described herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

CLAIMS

What is claimed is:

1. A high gain multiple beam ground station antenna array, comprising:

a first array of antenna elements coupled to digital beam forming circuitry;

a second array of antenna elements vertically aligned with the first array of antenna elements and coupled to the digital beam forming circuitry, the first array of antenna elements and the second array of antenna elements each covering a same sector of azimuth, the first array of antenna elements only covering a first elevation, and the second array of antenna elements only covering a second lower elevation; and

the digital beam forming circuitry configured to direct a radiation pattern of the first array of antenna elements in a first range of elevation angles, and configured to direct a radiation pattern of the second array of antenna elements in a second range of elevation angles.

2. The ground station antenna array of claim 1, in which the first array of antenna elements comprises smaller elements than the second array of antenna elements.

3. The ground station antenna array of claim 1, in which the second array of antenna elements comprise a larger number of elements than the first array of antenna elements.

4. The ground station antenna array of claim 1, in which the second array of antenna elements is configured with higher gain than the first array of antenna elements.

5. The ground station antenna array of claim 1, further comprising a plurality of transceiver modules, each coupled to a respective antenna element of one of the first array of antenna elements and the second array of antenna elements.

6. A high gain multiple beam ground station antenna array, comprising:

a first array of antenna elements coupled to digital beam forming circuitry;

a second array of antenna elements vertically aligned with the first array of antenna elements and coupled to the digital beam forming circuitry, the first array of antenna elements and the second array of antenna elements each covering a same sector of azimuth, the first array of antenna elements configured with higher gain than the second array of antenna elements; and

the digital beam forming circuitry configured to direct a radiation pattern of the first array of antenna elements in a first range of elevation angles, and configured to direct a radiation pattern of the second array of antenna elements in a second range of elevation angles.

7. The ground station antenna array of claim 6, in which the first array of antenna elements comprises smaller elements than the second array of antenna elements.

8. The ground station antenna array of claim 6, in which the second array of antenna elements comprises a larger number of elements than the first array of antenna elements.

9. The ground station antenna array of claim 6, in which the first array of antenna elements covers higher elevations than the second array of antenna elements.

10. The ground station antenna array of claim 6, further comprising a plurality of transceiver modules, each coupled to a respective antenna element of one of the first array of antenna elements and the second array of antenna elements.

11. A multiple beam aircraft antenna array, comprising:

a first array of antenna elements coupled to digital beam forming circuitry;

a second array of antenna elements vertically aligned with the first array of antenna elements and coupled to the digital beam forming circuitry, the first array of antenna elements only covering a first elevation, and the second array of antenna elements only covering a second lower elevation; and

the digital beam forming circuitry configured to direct a radiation pattern of the first array of antenna elements in a first range of elevation angles, and configured to direct a radiation pattern of the second array of antenna elements in a second range of elevation angles.

12. The aircraft antenna array of claim 11, further comprising a plurality of transceiver modules, each coupled to a respective antenna element of one of the first array of antenna elements and the second array of antenna elements.

13. The aircraft antenna array of claim 11, further comprising:

an auxiliary aircraft antenna coupled to a portion of an aircraft distal from the aircraft antenna array.

14. A high gain multiple beam ground station antenna array, comprising:

a first array of antenna element means coupled to digital beam forming means;

a second array of antenna element means vertically aligned with the first array of antenna element means and coupled to the digital beam forming means, the first array of antenna element means and the second array of antenna element means each covering a same sector of azimuth, the first array of antenna element means only covering a first elevation, and the second array of antenna element means only covering a second lower elevation; and

the digital beam forming means for directing a radiation pattern of the first array of antenna element means in a first range of elevation angles, and for directing a radiation pattern of the second array of antenna element means in a second range of elevation angles.

15. The ground station antenna array of claim 14, in which the second array of antenna element means is configured with higher gain than the first array of antenna element means.

16. The ground station antenna array of claim 14, further comprising a plurality of transceiver means, each coupled to a respective antenna element means of one of the first array of antenna element means and the second array of antenna element of antenna element means.

17. A high gain multiple beam ground station antenna array, comprising:

a first array of antenna element means coupled to digital beam forming means;

a second array of antenna element means vertically aligned with the first array of antenna element means and coupled to the digital beam forming means, the first array of antenna element means and the second array of antenna element means each covering a same sector of azimuth, the first array of antenna element means configured with higher gain than the second array of antenna element means; and

the digital beam forming means for directing a radiation pattern of the first array of antenna element means in a first range of elevation angles, and for directing a radiation pattern of the second array of antenna element means in a second range of elevation angles.

18. The ground station antenna array of claim 17, in which the first array of antenna element means covers higher elevations than the second array of antenna element means.

19. The ground station antenna array of claim 17, further comprising a plurality of transceiver means, each coupled to a respective antenna element means of one of the first array of antenna element means and the second array of antenna element means.

20. A multiple beam aircraft antenna array, comprising:

a first array of antenna element means coupled to digital beam forming means;

a second array of antenna element means vertically aligned with the first array of antenna element means and coupled to the digital beam forming means, the first array of antenna element means only covering a first elevation, and the second array of antenna element means only covering a second lower elevation; and

the digital beam forming means for directing a radiation pattern of the first array of antenna element means in a first range of elevation angles, and for directing a radiation pattern of the second array of antenna element means in a second range of elevation angles.

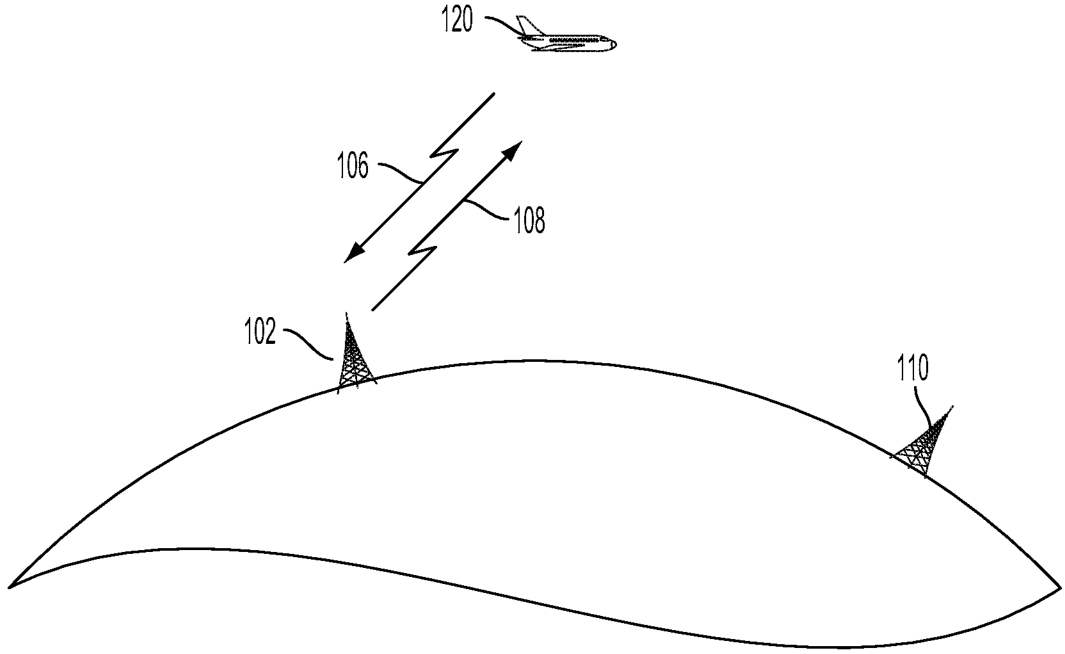
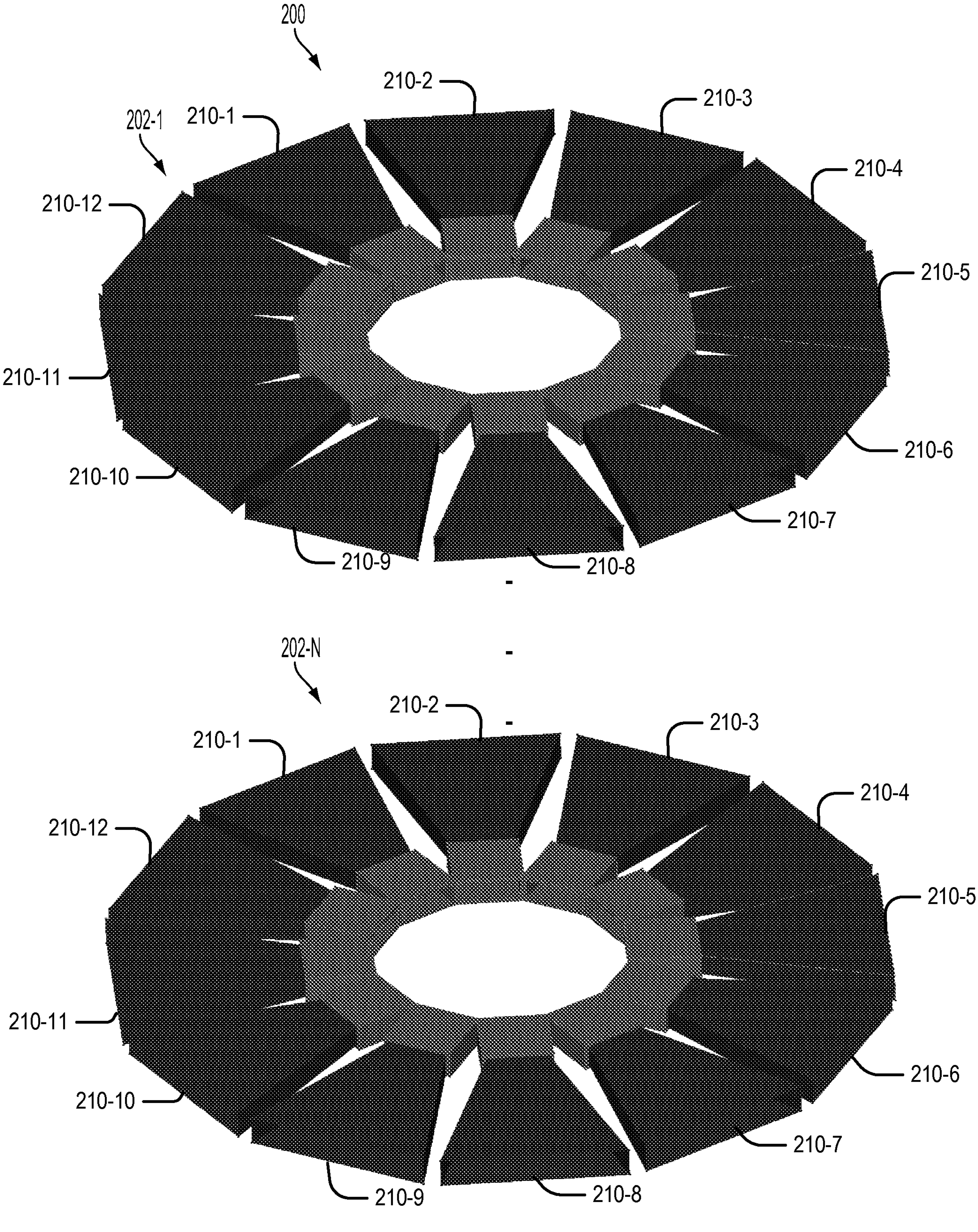


FIG. 1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202-1
210-1
210-2
210-3
210-4
210-5
210-6
210-7
210-8
210-9
210-10
210-11
210-12
202-N
210-1
210-2
210-3
210-4
210-5
210-6
210-7
210-8
210-9
210-10
210-11
210-12

FIG. 2

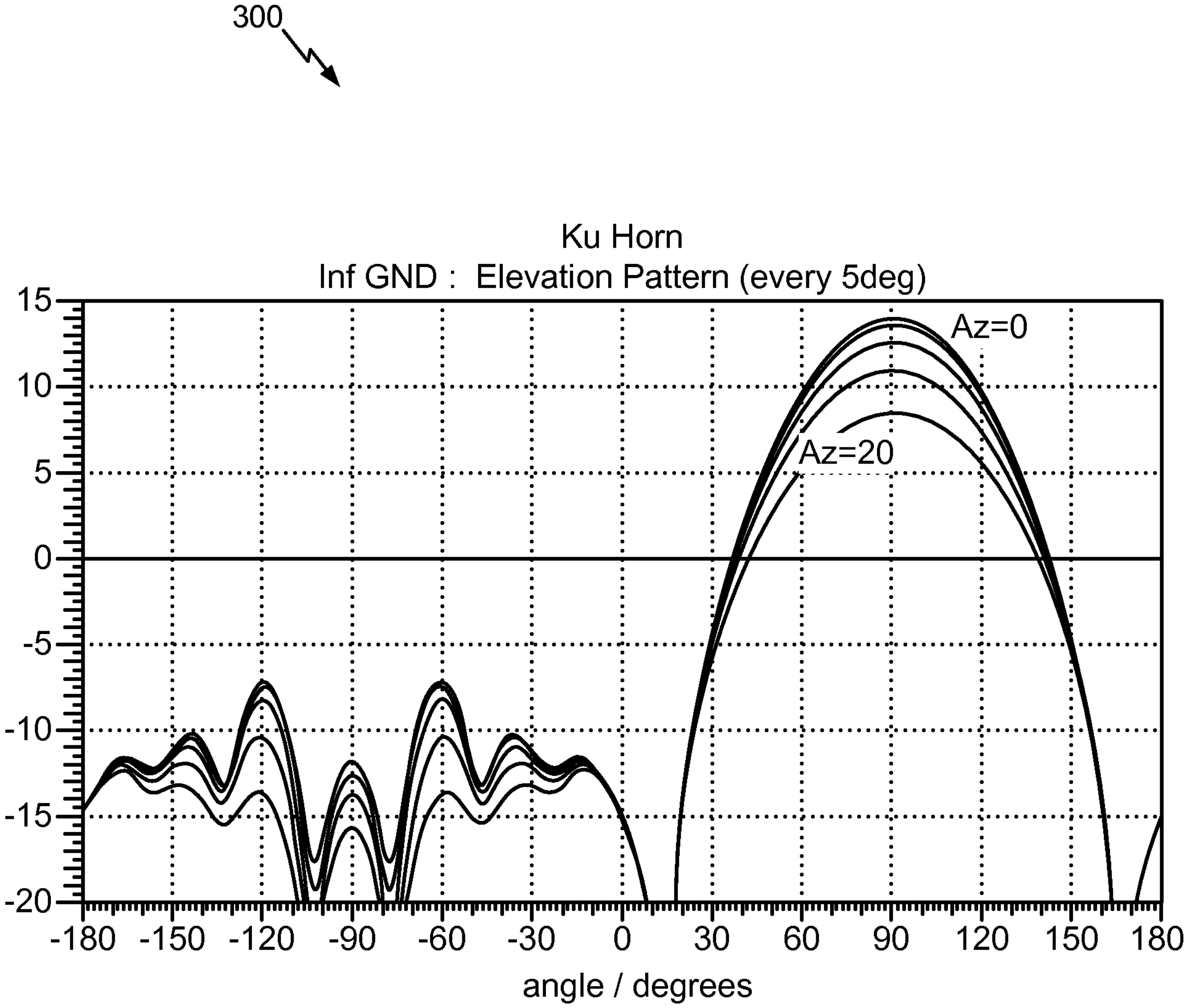
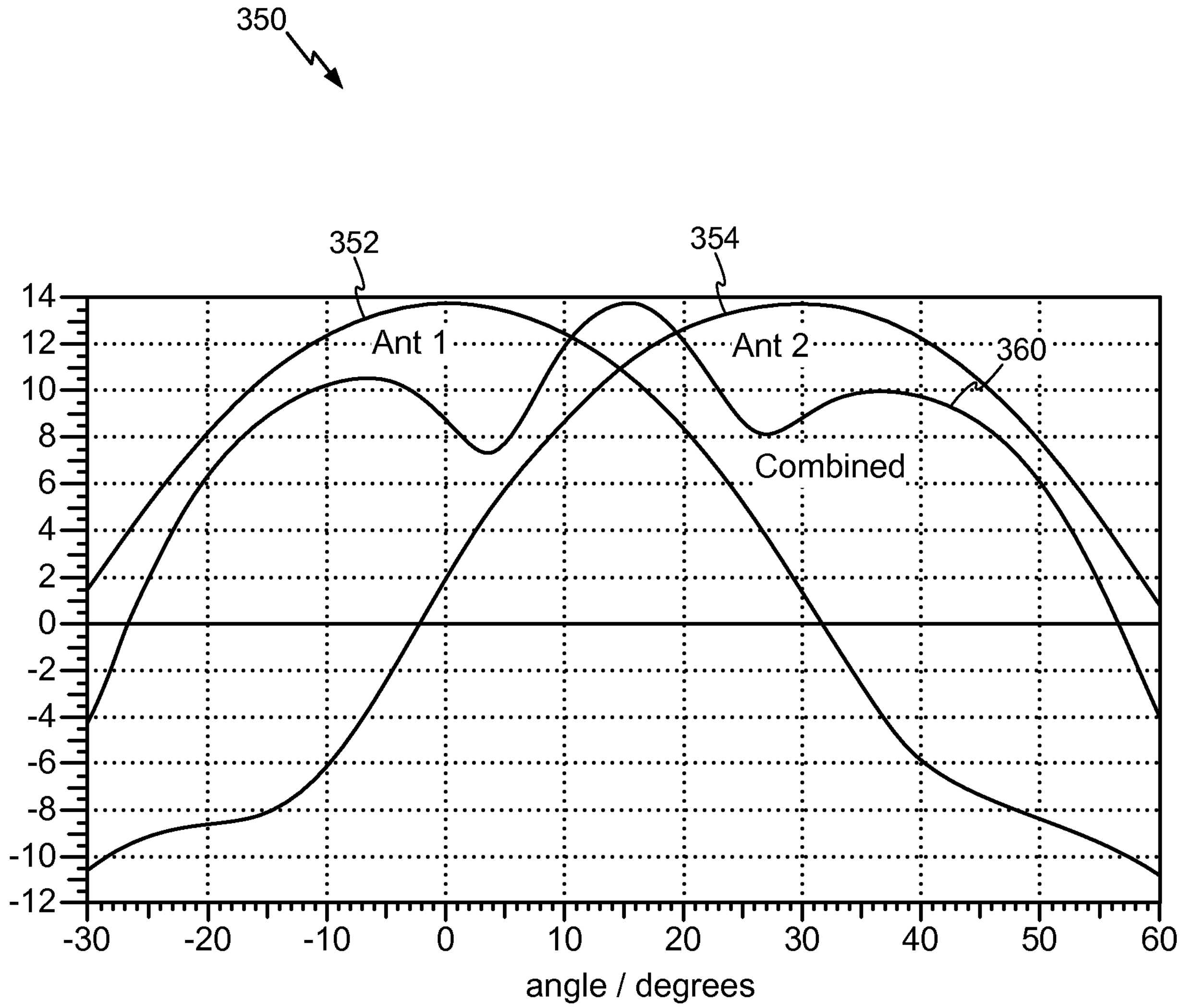

300
Ku Horn
Inf GND : Elevation Pattern (every 5deg)
Az=0
Az=20
15
10
5
0
-5
-10
-15
-20
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
180
angle / degrees

FIG. 3A



350
352
354
360
Ant 1
Ant 2
Combined
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-30
-20
-10
0
10
20
30
40
50
60
angle / degrees

FIG. 3B

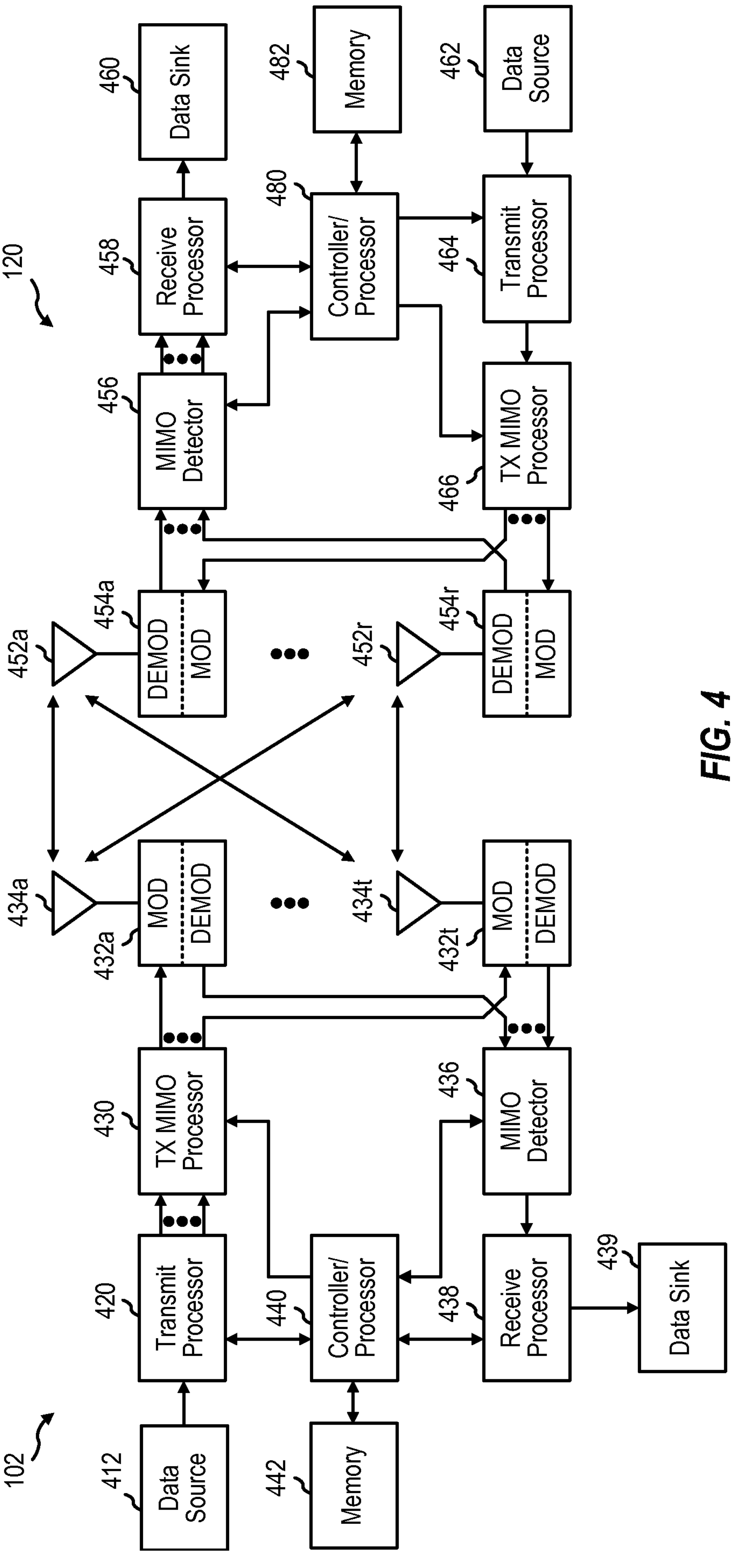

120
460
Data Sink
482
Memory
462
Data Source
458
Receive Processor
480
Controller/ Processor
464
Transmit Processor
456
MIMO Detector
466
TX MIMO Processor
452a
454a
DEMOD
MOD
452r
454r
DEMOD
MOD
434a
MOD
DEMOD
432a
434t
MOD
DEMOD
432t
430
TX MIMO Processor
436
MIMO Detector
420
Transmit Processor
440
Controller/ Processor
438
Receive Processor
439
Data Sink
102
412
Data Source
442
Memory

FIG. 4

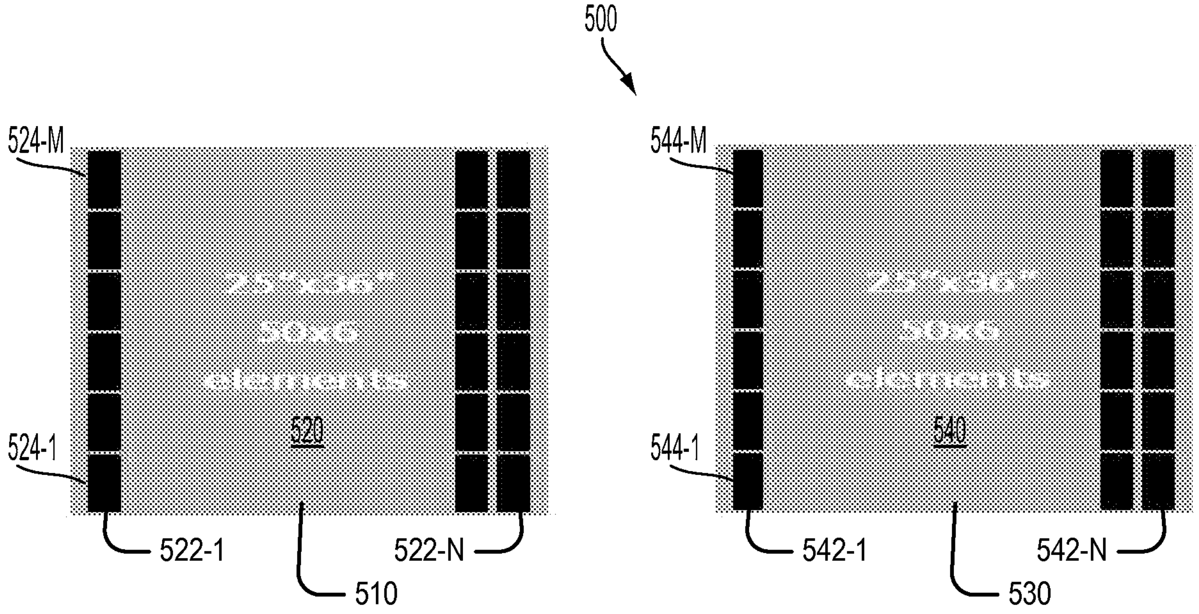
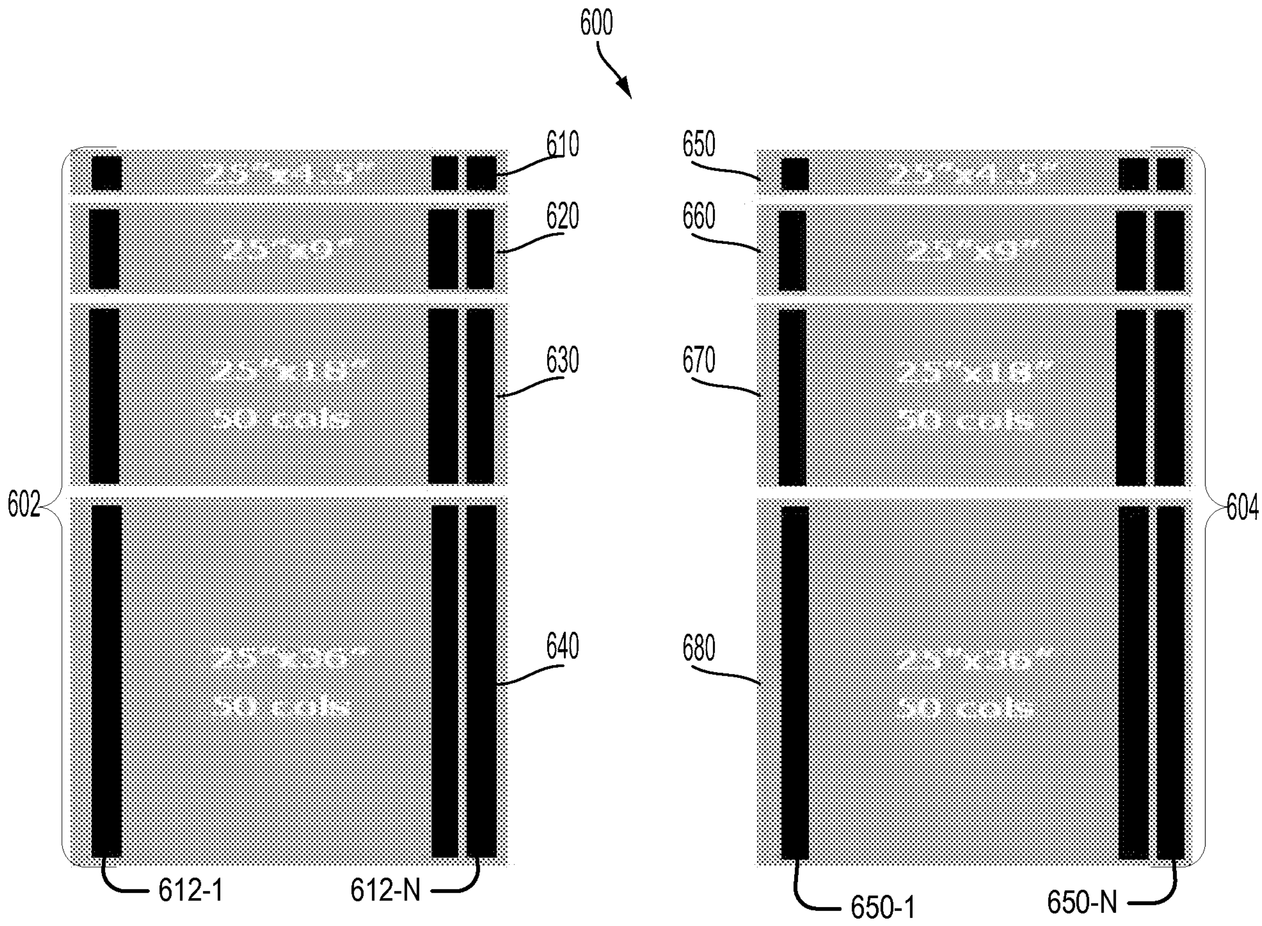

500
524-M
524-1
25"x36"
50x6
elements
520
522-1
510
522-N
544-M
544-1
25"x36"
50x6
elements
540
542-1
530
542-N

FIG. 5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610
25"x4.5"
620
25"x9"
630
25"x18"
50 cols
640
25"x36"
50 cols
602
612-1
612-N
650
660
670
680
604
650-1
650-N

FIG. 6

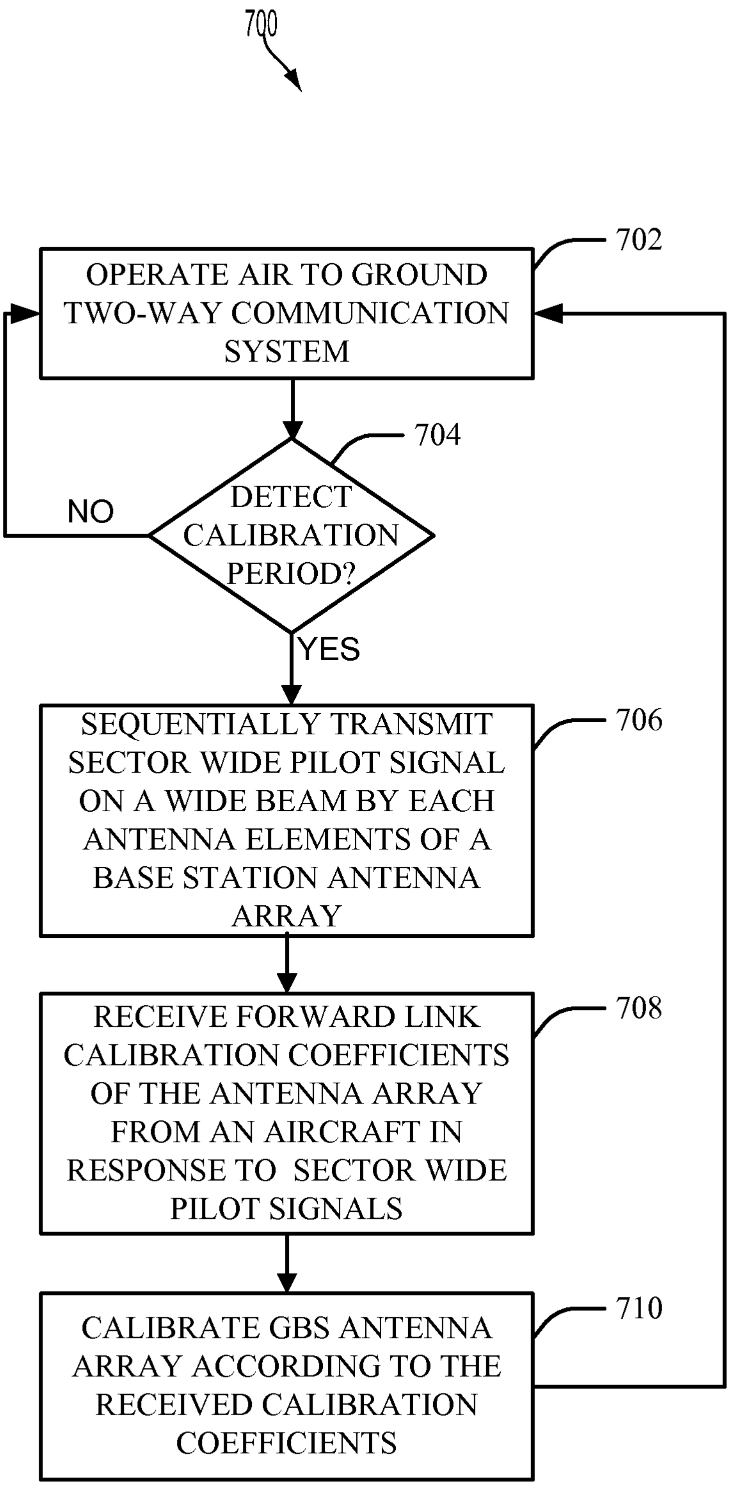
700
OPERATE AIR TO GROUND TWO-WAY COMMUNICATION SYSTEM
702
DETECT CALIBRATION PERIOD?
704
NO
YES
SEQUENTIALLY TRANSMIT SECTOR WIDE PILOT SIGNAL ON A WIDE BEAM BY EACH ANTENNA ELEMENTS OF A BASE STATION ANTENNA ARRAY
706
RECEIVE FORWARD LINK CALIBRATION COEFFICIENTS OF THE ANTENNA ARRAY FROM AN AIRCRAFT IN RESPONSE TO SECTOR WIDE PILOT SIGNALS
708
CALIBRATE GBS ANTENNA ARRAY ACCORDING TO THE RECEIVED CALIBRATION COEFFICIENTS
710

FIG. 7

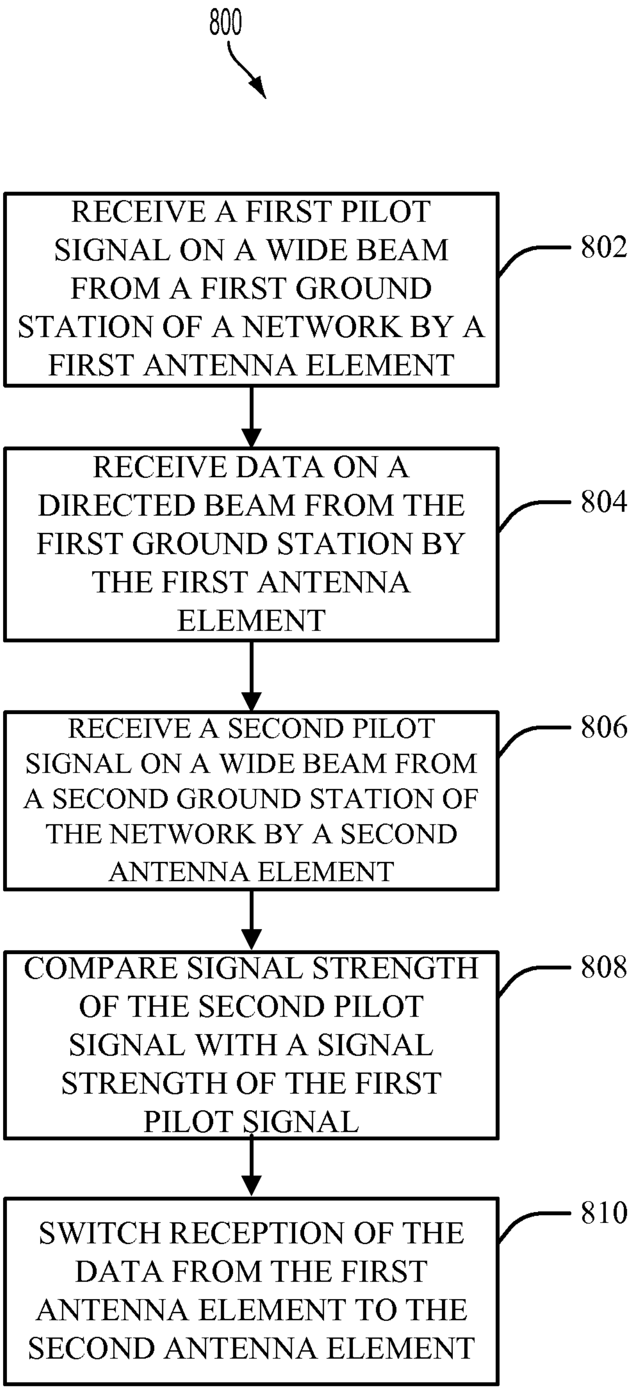
800
RECEIVE A FIRST PILOT SIGNAL ON A WIDE BEAM FROM A FIRST GROUND STATION OF A NETWORK BY A FIRST ANTENNA ELEMENT
802
RECEIVE DATA ON A DIRECTED BEAM FROM THE FIRST GROUND STATION BY THE FIRST ANTENNA ELEMENT
804
RECEIVE A SECOND PILOT SIGNAL ON A WIDE BEAM FROM A SECOND GROUND STATION OF THE NETWORK BY A SECOND ANTENNA ELEMENT
806
COMPARE SIGNAL STRENGTH OF THE SECOND PILOT SIGNAL WITH A SIGNAL STRENGTH OF THE FIRST PILOT SIGNAL
808
SWITCH RECEPTION OF THE DATA FROM THE FIRST ANTENNA ELEMENT TO THE SECOND ANTENNA ELEMENT
810

FIG. 8

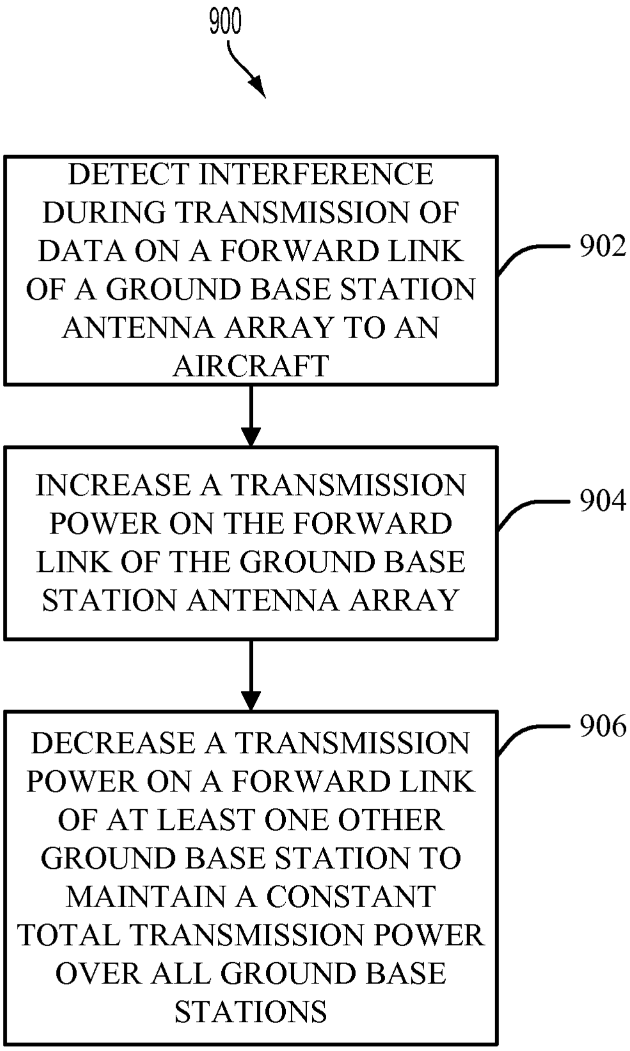
900
DETECT INTERFERENCE DURING TRANSMISSION OF DATA ON A FORWARD LINK OF A GROUND BASE STATION ANTENNA ARRAY TO AN AIRCRAFT
902
INCREASE A TRANSMISSION POWER ON THE FORWARD LINK OF THE GROUND BASE STATION ANTENNA ARRAY
904
DECREASE A TRANSMISSION POWER ON A FORWARD LINK OF AT LEAST ONE OTHER GROUND BASE STATION TO MAINTAIN A CONSTANT TOTAL TRANSMISSION POWER OVER ALL GROUND BASE STATIONS
906

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/024546

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01Q1/24 H01Q1/28 H01Q3/24 H01Q13/02 H01Q21/06
H01Q21/20 H01Q25/00 H01Q3/26 H04B7/185 H01Q1/22
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)
H01Q H04B

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, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/186611 A1 (STILES W HERSCHEL [US] ET AL) 23 July 2009 (2009-07-23) paragraph [0066] - paragraph [0069]; figure 6	1,3-7, 10, 14-17,19
A	WO 2006/123227 A2 (ERICSSON TELEFON AB L M [SE]; DENT PAUL WILKINSON [US]) 23 November 2006 (2006-11-23) page 9 - page 11; figures 6,7	1-10, 14-19
A	EP 2 161 855 A1 (ALCATEL LUCENT [FR]) 10 March 2010 (2010-03-10) column 7 - column 8; figures 1,2	1-10, 14-19

-/--

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

[X] 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

"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	Date of mailing of the international search report
24 July 2012	30/07/2012

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	Kaleve, Abraham

INTERNATIONAL SEARCH REPORT

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.:
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:

see additional sheet

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 an 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.:

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.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-10, 14-19

   A high gain multiple beam ground station antenna array, comprising: a first array of antenna elements coupled to digital beam forming circuitry; a second array of antenna elements vertically aligned with the first array of antenna elements and coupled to the digital beam forming circuitry, the first array of antenna elements and the second array of antenna elements each covering a same sector of azimuth, the first array of antenna elements only covering a first elevation, and the second array of antenna elements only covering a second lower elevation; and the digital beam forming circuitry configured to direct a radiation pattern of the first array of antenna elements in a first range of elevation angles, and configured to direct a radiation pattern of the second array of antenna elements in a second range of elevation angles, wherein the first array of antenna elements comprises smaller elements than the second array of antenna elements.

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2. claims: 11-13, 20

   A multiple beam aircraft antenna array, comprising: a first array of antenna elements coupled to digital beam forming circuitry; a second array of antenna elements vertically aligned with the first array of antenna elements and coupled to the digital beam forming circuitry, the first array of antenna elements only covering a first elevation, and the second array of antenna elements only covering a second lower elevation; and the digital beam forming circuitry configured to direct a radiation pattern of the first array of antenna elements in a first range of elevation angles, and configured to direct a radiation pattern of the second array of antenna elements in a second range of elevation angles.

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	EP 1 271 694 A2 (ROKE MANOR RESEARCH [GB]) 2 January 2003 (2003-01-02) paragraph [0032] - paragraph [0045]; figures 7,8A,9A,10A,11A,12A	11-13,20
A	WO 99/43048 A1 (MARCONI AEROSPACE SYSTEMS INC [US]) 26 August 1999 (1999-08-26) page 7 - page 11	11-13,20

INTERNATIONAL SEARCH REPORT

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PCT/US2012/024546

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