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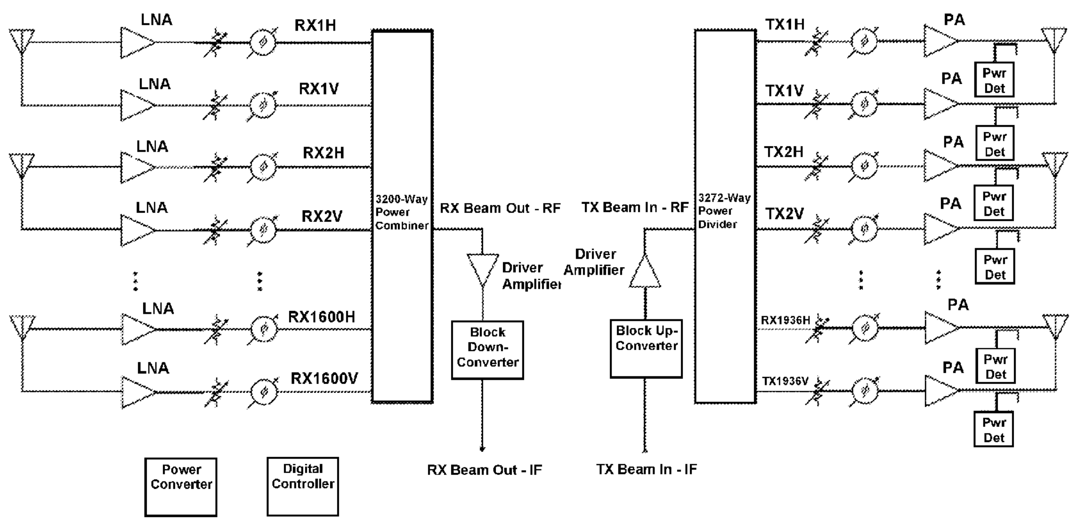


*FIG. 1*

(57) **Abstract:** An exemplary embodiment provides an array antenna, comprising a transmitter aperture and a receiver aperture. The transmitter aperture can comprise a first plurality of printed circuit boards, each comprising first arrays of radiating elements. Each of the radiating elements in the first arrays of radiating elements can comprise first arrays of pixels. Each of the pixels in the first arrays of pixels can be conductive or non-conductive. The receiver aperture can comprise a second plurality of printed circuit boards, each comprising second arrays of radiating elements. Each of the radiating elements in the second arrays of radiating elements can comprise second arrays of pixels. Each of the pixels in the second arrays of pixels can be conductive or non-conductive. The transmitter and receiver apertures can be configured to transmit and receive, respectively, a single beam (such as a wireless communication signal).

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*[Continued on next page]*

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# PHASED ARRAY ANTENNA FOR COMMERCIAL SATCOM

## CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** This application claims the benefit of U.S. Provisional Application Serial No. 63/269,826, filed on 23 March 2022, which is incorporated herein by reference in its entirety as if fully set forth below.

## FIELD OF THE DISCLOSURE

**[0002]** The various embodiments of the present disclosure relate generally to antennas and more particularly for phased array antennas for commercial satellite communications.

## BACKGROUND

**[0003]** As travel becomes more ubiquitous, there is a growing need for satellite communications (SATCOM) from mobile platforms, such as commercial aircrafts and trains. A primary use for SATCOM is internet connectivity for travelers. Traditional SATCOM antennas, however, are mechanically steered. These moving parts tend to break much more easily and frequently than electronic parts, making these conventional antennas unreliable. Active Electronically Scanned Array ("AESA") antennas, on the other hand, are electronically steered and, therefore, have no moving parts. For this reason, AESA-based SATCOM antennas promise improved reliability (e.g., longer operating lifetimes, less frequent replacements, graceful performance degradation, etc.) compared to traditional mechanically-steered SATCOM antennas. Accordingly, there is a need for improved AESA-based SATCOM antennas.

## BRIEF SUMMARY

**[0004]** An exemplary embodiment of the present disclosure provides an array antenna, comprising a transmitter aperture and a receiver aperture. The transmitter aperture can comprise a first plurality of printed circuit boards. Each printed circuit board in the first plurality of printed circuit boards can comprise first arrays of radiating elements. Each of the radiating elements in the first arrays of radiating elements can comprise first arrays of pixels. Each of the pixels in the first arrays of pixels can be conductive or non-conductive. The transmitter aperture can be configured to generate a single beam (such as a wireless communication signal). The receiver aperture can comprise a second plurality of printed circuit boards. Each printed circuit board in the second plurality of printed circuit boards can comprise second arrays of radiating elements. Each of the radiating elements in the second arrays of radiating elements can comprise second arrays of pixels. Each of the pixels in the second arrays of pixels can be conductive or non-conductive. The receiver aperture can be configured to receive a single beam (such as a wireless communication signal).

**[0005]** In any of the embodiments disclosed herein, each radiating element in the first and second arrays of radiating elements can be configured to operate in each of a horizontal and vertical polarization.

**[0006]** In any of the embodiments disclosed herein, the first plurality of printed circuit boards can comprise four printed circuit boards.

**[0007]** In any of the embodiments disclosed herein, each of the first arrays of radiating elements can be arranged in a 22x22 square array of radiating elements.

**[0008]** In any of the embodiments disclosed herein, each radiating element in the first arrays of radiating elements can have a length of 1.07 cm and a width of 1.07 cm.

**[0009]** In any of the embodiments disclosed herein, the radiating elements in the first arrays of radiating elements can have an operating frequency of 13.75-14.5 GHz.

**[00010]** In any of the embodiments disclosed herein, each of the first arrays of pixels can be arranged in a 64 x 64 array of pixels.

**[00011]** In any of the embodiments disclosed herein, each of the conductive pixels in the first arrays of pixels can be metal and each of the non-conductive pixels in the first arrays of pixels can be non-metal.

**[00012]** In any of the embodiments disclosed herein, each of the 64 x 64 first arrays of pixels can be represented by the following hexadecimal sequence:

0x3c33cc0ff033cc3c07e1999e799987e087e1999e799987e183cf0f33ccf0f3c183cf0f3
3ccf0f3c1e187fe1e787fe1877887fe1e787fe1067c0ff0c0030ff0207e0ff0c0030ff07878
01f800001f8018e001f800001f80018000cfc3c3f302071980cfc3c3f306061f8067ffffe6
00609f8067ffffe61861ffe033cff3cc3e61e7f833cff3cc7e7987fe1e1ff8781e7f07e78e1ff
870067e67e1c0f3cf00067efe7860f3cf0006679e1e6181818000071e1fe081811800067
81f840000386600619f9e000061ff80019f980000619f801806180001f99f807e067803c
3fff980e607e003c7fff981e607e00001ffff81fe1ff81801ffe781981ffe1801ffe181981ffe
1801ffe181fe1ff81801ffe781e607e00001ffff81e607e00007fff9817e06780003fff9801
806180811f99f80019f981818619f80619f9e3ffc61ff80781f843ffc3866001e1fe0ffff18

00069e1e61ffff800007fe78633ffcc0066767e1c33ffcc0067e07e7801ff800067e87fe00
1ff8001e7fe7f800ffff007e79ffe000ffff003e619f80819ff98118611f81819ff981806019
83c0fc3f03c6068003c0fc3f03c207e009f9e6679f90017819f9e6679f98187e0000ffff00
00787c0000ffff0000207887f800001fe106e187f800001fe18780c0f000000f030180c0f
000000f030186187e00007e186106187e00007e18603c33cc0ff033cc3c,

wherein a binary 1 can indicate the corresponding pixel is metal and a binary 0 can indicate the corresponding pixel is non-metal.

**[00013]** In any of the embodiments disclosed herein, each of the first plurality of printed circuit boards can further comprise a front-end beam forming integrated circuit.

**[00014]** In any of the embodiments disclosed herein, each of the first plurality of printed circuit boards can further comprise a passive planar beamformer network.

**[00015]** In any of the embodiments disclosed herein, each of the first plurality of printed circuit boards can comprises a substrate having a thickness of 0.060 inches.

**[00016]** In any of the embodiments disclosed herein, each of the first plurality of printed circuit boards can have a dielectric constant of 3.5.

**[00017]** In any of the embodiments disclosed herein, the second plurality of printed circuit boards can comprise four printed circuit boards.

**[00018]** In any of the embodiments disclosed herein, each of the second arrays of radiating elements can be arranged in a 20x20 square array of radiating elements.

**[00019]** In any of the embodiments disclosed herein, each radiating element in the second arrays of radiating elements can have a length of 1.21 cm and a width of 1.21 cm.

**[00020]** In any of the embodiments disclosed herein, the radiating elements in the second arrays of radiating elements can have an operating frequency of 10.7-12.75 GHz.

**[00021]** In any of the embodiments disclosed herein, each of the second arrays of pixels can be arranged in a 64 x 64 array of pixels.

**[00022]** In any of the embodiments disclosed herein, each of the conductive pixels in the second arrays of pixels can be metal and each of the non-conductive pixels in the second arrays of pixels can be non-metal.

**[00023]** In any of the embodiments disclosed herein, each of the 64 x 64 second arrays of pixels can be represented by the following hexadecimal sequence:

0x300cc0cc3303300c0618799ff99e18608618799ff99e186180f0c00ff0030f0300f0c00
ff0030f0660187fe667fe180660187fe667fe18060000f30ff0cf00201800f30ff0cf00601

8067f9ff9fe606618067f9ff9fe61e67e003c33cc3c0380e6003c33cc3c06018061867ffe6
180070060867ffe61180600043c3ffc3c386099863c3ffc3c6079ffe01867e618607967f9
8867e610606067f9c03ffc0200006679e03ffc078000067f807ffe07860007e6007ffe1e0
78067e0000ff0380186e660000ff061980786066600000019e01061ffe0000198600607f9
e00021fe000f9e79f80079e6181ffe7ff80019807877fffff800018079e79ffff80067807f8
79ffff80067807f87fffff800018079effe7ff8001980787f9e79f80079e6181607f9e00021
fe000061ffe0990198600860666199801 9e01e660000c3061980767e0000c3038018607
e60081811e0780067f818181878600 6679e33ffcc7800067f9c33ffcc2000067f98e1818
706060ffe01e18187860799986 0cf00f30607900040cf00f3038600060e018180718068
061e01818078007e60300c00300c6017e0300c00300c38018080667e66011e61818066
7e6601866183003 0ff0c00c600030030ff0c00c2060e1e0018007870661e1e001800787
860000c003c00300068000c003c00300038e6601866180667 11e66018661806678300c
c0cc3303300c,

wherein a binary 1 can indicate the corresponding pixel is metal and a binary 0 can indicate the corresponding pixel is non-metal.

**[00024]** In any of the embodiments disclosed herein, each of the second plurality of printed circuit boards can further comprise a front-end beam forming integrated circuit.

**[00025]** In any of the embodiments disclosed herein, each of the second plurality of printed circuit boards can further comprise a passive planar beamformer network.

**[00026]** In any of the embodiments disclosed herein, each of the second plurality of printed circuit boards can comprise a substrate having a thickness of 0.090 inches.

**[00027]** In any of the embodiments disclosed herein, each of the second plurality of printed circuit boards can have a dielectric constant 3.5.

**[00028]** Another embodiment of the present disclosure provides an array antenna comprising a transmitter aperture and a receiver aperture. The transmitter aperture can comprise four printed circuit boards. Each printed circuit board of the transmitter aperture can comprise a 22x22 array of radiating elements. Each radiating element of the transmitter aperture can comprise a 64x64 array of pixels. The receiver aperture can comprise four printed circuit boards. Each printed circuit board of the receiver aperture can comprise a 20x20 array of radiating elements. Each radiating element of the receiver aperture can comprise a 64x64 array of pixels. Each pixel can be metal or non-metal.

**[00029]** These and other aspects of the present disclosure are described in the Detailed Description below and the accompanying drawings. Other aspects and features of embodiments will become apparent to those of ordinary skill in the art upon reviewing the following description of specific, exemplary embodiments in concert with the drawings. While features of the present disclosure may be discussed relative to certain embodiments and figures, all embodiments of the present disclosure can include one or more of the features discussed herein. Further, while one or more embodiments may be discussed as having certain advantageous features, one or more of such features may also be used with the various embodiments discussed herein. In similar fashion, while exemplary embodiments may be discussed below as device, system, or method embodiments, it is to be understood that such exemplary embodiments can be implemented in various devices, systems, and methods of the present disclosure.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[00030]** The following detailed description of specific embodiments of the disclosure will be better understood when read in conjunction with the appended drawings. For the purpose of illustrating the disclosure, specific embodiments are shown in the drawings. It should be understood, however, that the disclosure is not limited to the precise arrangements and instrumentalities of the embodiments shown in the drawings.

**[00031]** **FIG. 1** provides a block diagram for an antenna array, in accordance with some embodiments of the present disclosure.

**[00032]** **FIG. 2** provides a diagram of subpanel printed circuit boards in transmit and receive apertures, in accordance with some embodiments of the present disclosure.

**[00033]** **FIGS. 3A-B** provide diagrams of radiating element positions (each dot refers to center location of radiating element) for a transmit aperture with a 44x44 array of radiating elements, in accordance with some embodiments of the present disclosure.

**[00034]** **FIG. 4** provides a plot of directivity (elevation cut) of a 44x44 transmit aperture, in accordance with some embodiments of the present disclosure.

**[00035]** **FIG. 5** provides a diagram of radiating element positions (each dot refers to center location of radiating element) for a receive aperture with a 40x40 array of radiating elements, in accordance with some embodiments of the present disclosure.

**[00036]** **FIG. 6** provides a plot of directivity (elevation cut) of a 40x40 receive aperture, in accordance with some embodiments of the present disclosure.

**[00037]** **FIG. 7** provides an illustration of a 64x64 pixel array for a radiating element in a transmit aperture, in accordance with some embodiments of the present disclosure.

**[00038]** **FIGS. 8A-B** provide plots of performance versus frequency of the transmit fragmented aperture radiating elements, in which FIG. 8A provides a plot of realized gain, normalized to 0dB, and FIG. 8B provides a plot of the magnitude of the reflection coefficient (Γ), in accordance with some embodiments of the present disclosure.

**[00039]** **FIG. 9** provides an illustration of a 64x64 pixel array for a radiating element in a receive aperture, in accordance with some embodiments of the present disclosure.

**[00040]** **FIGS. 10A-B** provide plots of performance versus frequency of the receive fragmented aperture radiating elements, in which FIG. 10A provides a plot of realized gain, normalized to 0dB, and FIG. 10B provides a plot of the magnitude of the reflection coefficient (Γ), in accordance with some embodiments of the present disclosure.

**[00041]** **FIG. 11** provides a plot of measured far-field gain of the antenna in transmit mode, steered to boresight, vertical polarization, with a frequency of 14.125 GHz, in accordance with some embodiments of the present disclosure.

**[00042]** **FIG. 12**, provides a plot of measured far-field gain of the antenna in transmit mode, steered to boresight, horizontal polarization, with a frequency of 14.125 GHz, in accordance with some embodiments of the present disclosure.

**[00043]** **FIG. 13** provides a plot of measured far-field gain of the antenna in receive mode, steered to boresight, vertical polarization, with a frequency of 11.725 GHz, in accordance with some embodiments of the present disclosure.

**[00044]** **FIG. 14**, provides a plot of measured far-field gain of the antenna in receive mode, steered to boresight, horizontal polarization, with a frequency of 11.725 GHz, in accordance with some embodiments of the present disclosure.

## DETAILED DESCRIPTION

**[00045]** To facilitate an understanding of the principles and features of the present disclosure, various illustrative embodiments are explained below. The components, steps, and materials described hereinafter as making up various elements of the embodiments disclosed herein are intended to be illustrative and not restrictive. Many suitable components, steps, and materials that would perform the same or similar functions as the components, steps, and materials described herein are intended to be embraced within the scope of the disclosure. Such other components, steps, and materials not described herein can include, but are not limited to, similar components or steps that are developed after development of the embodiments disclosed herein.

**[00046]** Disclosed herein are AESA antenna designs that can be used for Ku-band satellite communications from airborne platforms and/or trains. Embodiments disclosed herein provide a novel application of fragmented aperture antenna technology. FIG. 1 provides a block diagram for an exemplary antenna array of the present disclosure.

**[00047]** Each antenna can comprise two separate apertures—a transmit aperture and a receive aperture. The AESA antennas can support one TX beam and one RX beam. The TX and RX beams can be completely independent and may point in different directions with different polarizations.

**[00048]** As shown in FIG. 2, each of the transmit and receive apertures can comprise one or more printed circuit boards. In an exemplary embodiments of the present disclosure, the transmit and receive apertures each comprise four PCBs. The PCBs can be mounted on a mechanical support structure in a 2x2 array, as shown in FIG. 2. Each of the PCBs can comprise a plurality of integrated circuits to create a beamforming network. For example, each PCB can comprise one or more front-end beam forming integrated circuits and one or more passive planar beamforming networks.

**[00049]** Each of the PCBs can also comprise a substrate including radiating elements (discussed below). The substrate thickness can be different on the transmit and receive PCBs. For example, the substrate can be 0.060 inches on the transmit PCBs and 0.090 inches on the receive PCBs. Both the transmit and receive PCBs can have a dielectric constant of 3.5.

**[00050]** Each PCB can comprise an array of fragmented aperture radiating elements and a beamformer. The transmit and receive PCBs can have different radiating element and beamformer designs. For example, each of the transmit PCBs can comprise a 22x22 square array of radiating elements, which form a 44x44 array when four PCBs are combined, as shown in FIGs. 3A-B. Similarly, each of the receive PCBs can comprise a 20x20 square array of radiating elements, which form a 40x40 array when four PCBs are combined, as shown in FIG. 5. The radiating elements can have different dimensions in the transmit aperture versus the receive aperture. For example, each of the radiating elements in the transmit aperture can have a length and width of 1.07 cm, while each of the radiating elements in the receive aperture can have a length and width of 1.21 cm. The transmit and receive radiating elements can also operate at different frequencies, which can be non-overlapping. For example, the transmit radiating elements can operate within a frequency range of 13.75-14.5 GHz, while the receive radiating elements can operate within a frequency range of 10.7-12.75 GHz.

**[00051]** Each of the radiating elements of the transmit and receive PCBs can comprise an array of pixels, as shown in FIGs. 7 & 9. In some embodiments, each of the transmit and receive radiating elements can comprise a 64x64 array of pixels. Each of the pixels can be conductive (e.g., metal), as shown in the lighter pixels in FIGs. 7 & 9, or non-conductive (e.g., non-metal), as shown in the darker pixels in FIG. 7 & 9 (as also shown in FIGs. 7 & 9 with the lightest squares of 16 pixels, the 64x64 array can also include two polarization inputs). The pixel configurations in the transmit and receive radiating elements, however, can have different pixel arrangements, in which each pixel is either metal (conductive) or non-metal (non-conductive). The arrangement of metal/non-metal pixels in the 64x64 array can be represented by a hexadecimal sequence. When that hexadecimal sequence is converted to a binary sequence, each pixel has a binary value or 1 or 0, in which a binary 1 indicates the corresponding pixel is metal and a binary 0 indicates the corresponding pixel is nonmetal. For example, as shown in FIG. 7, the transmit 64x64 arrays of pixels can be represented with the following hexadecimal sequence:

0x3c33cc0ff033cc3c07e1999e799987e087e1999e799987e183cf0f33ccf0f3c183cf0f3
3ccf0f3c1e187fe1e787fe1877887fe1e787fe1067c0ff0c0030ff0207e0ff0c0030ff07878
01f800001f8018e001f800001f80018000cfc3c3f302071980cfc3c3f306061f8067ffffe6
00609f8067ffffe61861ffe033cff3cc3e61e7f833cff3cc7e7987fe1e1ff8781e7f07e78e1ff
870067e67e1c0f3cf00067efe7860f3cf0006679e1e6181818000071e1fe081811800067
81f84000038660061 9f9e000061ff80019f980000619f801806180001f99f807e067803c
3fff980e607e003c7fff981e607e00001ffff81fe1ff81801ffe781981ffe1801ffe181981ffe
1801ffe181fe1ff81801ffe781e607e00001ffff81e607e00007fff9817e06780003fff9801
806180811f99f80019f981818619f80619f9e3ffc61ff80781f843ffc3866001e1fe0ffff18
00069e1e61ffff800007fe78633ffcc0066767e1c33ffcc0067e07e7801ff800067e87fe00
1ff8001e7fe7f800ffff007e79ffe000ffff003e619f80819ff98118611f81819ff981806019
83c0fc3f03c6068003c0fc3f03c207e009f9e6679f90017819f9e6679f98187e0000ffff00
00787c0000ffff0000207887f800001fe106e187f800001fe18780c0f000000f030180c0f
000000f030186187e00007e186106187e00007e18603c33cc0ff033cc3c.

Similarly, as shown in FIG. 9, the receive 64x64 arrays of pixels can be represented with the following hexadecimal sequence:

0x300cc0cc3303300c0618799ff99e18608618799ff99e186180f0c00ff0030f0300f0c00
ff0030f0660187fe667fe180660187fe667fe18060000f30ff0cf00201800f30ff0cf00601

8067f9ff9fe606618067f9ff9fe61e67e003c33cc3c0380e6003c33cc3c06018061867ffe6
180070060867ffe61180600043c3ffc3c386099863c3ffc3c6079ffe01867e618607967f9
8867e610606067f9c03ffc0200006679e03ffc078000067f807ffe07860007e6007ffe1e0
78067e0000ff0380186e660000ff061980786066600000019e01061ffe0000198600607f9
e00021fe000f9e79f80079e6181ffe7ff80019807877fffff800018079e79ffff80067807f8
79ffff80067807f87fffff800018079effe7ff8001980787f9e79f80079e6181607f9e00021
fe000061ffe09901986008606661998019e01e660000c3061980767e0000c3038018607
e60081811e0780067f8181818786006679e33ffcc7800067f9c33ffcc2000067f98e1818
706060ffe01e181878607999860cf00f30607900040cf00f3038600060e018180718068
061e01818078007e60300c00300c6017e0300c00300c38018080667e66011e61818066
7e66018661830030ff0c00c600030030ff0c00c2060e1e0018007870661e1e001800787
860000c003c00300068000c003c00300038e660186618066711e66018661806678300c
c0cc3303300c.

When each of these hexadecimal sequences are converted to a binary sequency, the first 64 bits correspond to the first row of 64 pixels, the next 64 bits correspond to the second row of 64 pixels (above the first row), and so on.

**[00052]** Each radiating element in the transmit and receive PCBs can have dual polarization capability, e.g., they can operate in each of a horizontal and vertical polarization, so any desired polarization can be achieved by adjusting the relative phase and amplitude of each element's two terminals.

## EXAMPLE

**[00053]** Below, an exemplary phased array antenna is described along with its performance. This example is disclosed for illustration purposes only, however, and should not be construed as limiting the scope of the present disclosure.

**[00054]** A block diagram of the designed active electronically scanned array (AESA) is shown in Figure 1. It consists of two separate apertures, one for transmit (TX) and one for receive (RX). The RX antenna has a total of 1600 radiating elements and the TX antenna has 1936.

**[00055]** Each AESA design consists of four printed circuit boards (PCBs) in a 2 × 2 arrangement, with an overall physical aperture area of 50 cm × 50 cm. Each TX PCB contains a 22 × 22 subarray (element spacing of 1.07 cm), and each RX PCB contains a 20 x 20 subarray (element spacing of 1.21 cm). Each PCB contains the subarray radiating elements, TX/RX front-end beamforming integrated circuits, a passive planar beamformer network, and supporting electronics. The subpanel PCBs are identical for each type of AESA (TX and RX) and are intended to be mounted in a windmill-like arrangement as shown in Figure 2.

**[00056]** FIGS. 3A-B provide a diagram of radiating element positions in the exemplary antenna for the 44 x 44 element transmit aperture. The circular dots indicate the center of each radiating element. The array was designed in the square arrangement shown in FIG. 3B; however, the aperture can operate only a circular subset of the radiating elements in the full square array (FIG. 3A) in order to reduce the sidelobes. Similarly, FIG. 5 provides a diagram of radiating element positions in the exemplary antenna for the 40 x 40 element receive aperture.

**[00057]** FIG. 7 provides an illustration of the dual-polarized (vertical and horizontal) fragmented aperture radiating element for the transmit array antenna. The size of the element is a 1.21 cm square. Each dark square indicates where metal is not present, and each light square indicates where metal is present. The very light squares represent the feed locations for the two polarization inputs. The element was designed with a 60 mil substrate thickness with a dielectric constant of 3.5.

**[00058]** FIG. 9 provides an illustration of the dual-polarized (vertical and horizontal) fragmented aperture radiating element for the transmit array antenna. The size of the element is a 1.07 cm square. Each dark square indicates where metal is not present, and each light square indicates where metal is present. The very light squares represent the feed locations for the two polarization inputs. The element was designed with a 90 mil substrate thickness with a dielectric constant of 3.5.

**[00059] Performance of Full Array**

**[00060]** **Table 1** shows the expected directivity and beamwidth for a full 44 × 44 element TX aperture, and **Table 2** shows the expected directivity and beamwidth for a full 40 × 40 element RX aperture.

**Table 1. Performance of the TX antenna**

| Frequency (GHz) | Wavelength (cm) | Directivity (dB) | Half Power Beamwidth (°) |
|---|---|---|---|
| 13.75 | 2.18 | 36.1 | 3.25 |
| 13.9375 | 2.15 | 36.3 | 3.21 |

| | | | |
|---|---|---|---|
| 14.125 | 2.12 | 36.4 | 3.16 |
| 14.3125 | 2.09 | 36.5 | 3.12 |
| 14.5 | 2.07 | 36.6 | 3.08 |

**Table 2. Performance of the RX antenna**

| **Frequency (GHz)** | **Wavelength (cm)** | **Directivity (dB)** | **Half Power Beamwidth (°)** |
|---|---|---|---|
| 10.7 | 2.80 | 35.3 | 2.93 |
| 11.2125 | 2.67 | 35.7 | 2.80 |
| 11.725 | 2.56 | 36.1 | 2.68 |
| 12.375 | 2.42 | 36.6 | 2.54 |
| 12.75 | 2.35 | 36.8 | 2.46 |

**[00061]** FIG. 4 shows the directivity (elevation cut) of the 44x44 element transmit aperture at 12.75 GHz, in which all elements are active and steered to boresight, assuming 90% uniform illumination. Similarly, FIG. 6 shows the directivity (elevation cut) of the 40x40 element receive aperture at 12.75 GHz, in which all elements are active and steered to boresight, assuming 90% uniform illumination.

**[00062]** FIGS. 8A-B provide plots of performance versus frequency of the transmit fragmented aperture radiating elements. FIG. 8A provides a plot of realized gain, normalized to 0dB, and FIG. 8B provides a plot of the magnitude of the reflection coefficient (Γ).

**[00063]** FIGS. 10A-B provide plots of performance versus frequency of the receive fragmented aperture radiating elements. FIG. 10A provides a plot of realized gain, normalized to 0dB, and FIG. 10B provides a plot of the magnitude of the reflection coefficient (Γ).

**[00064]** FIG. 11 provides a plot of measured far-field gain of the antenna in transmit mode, steered to boresight, vertical polarization, with a frequency of 14.125 GHz. FIG. 12, provides a plot of measured far-field gain of the antenna in transmit mode, steered to boresight, horizontal polarization, with a frequency of 14.125 GHz.

**[00065]** FIG. 13 provides a plot of measured far-field gain of the antenna in receive mode, steered to boresight, vertical polarization, with a frequency of 11.725 GHz. FIG. 14, provides a plot of measured far-field gain of the antenna in receive mode, steered to boresight, horizontal polarization, with a frequency of 11.725 GHz.

**[00066]** It is to be understood that the embodiments and claims disclosed herein are not limited in their application to the details of construction and arrangement of the components set forth in the description and illustrated in the drawings. Rather, the description and the drawings provide examples of the embodiments envisioned. The embodiments and claims disclosed herein are further capable of other embodiments and of being practiced and carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein are for the purposes of description and should not be regarded as limiting the claims.

**[00067]** Accordingly, those skilled in the art will appreciate that the conception upon which the application and claims are based may be readily utilized as a basis for the design of other structures, methods, and systems for carrying out the several purposes of the embodiments and claims presented in this application. It is important, therefore, that the claims be regarded as including such equivalent constructions.

**[00068]** Furthermore, the purpose of the foregoing Abstract is to enable the United States Patent and Trademark Office and the public generally, and especially including the practitioners in the art who are not familiar with patent and legal terms or phraseology, to determine quickly from a cursory inspection the nature and essence of the technical disclosure of the application. The Abstract is neither intended to define the claims of the application, nor is it intended to be limiting to the scope of the claims in any way.

What is claimed is:

1. An array antenna, comprising:

a transmitter aperture comprising a first plurality of printed circuit boards, each printed circuit board in the first plurality of printed circuit boards comprising first arrays of radiating elements, each of the radiating elements in the first arrays of radiating elements comprising first arrays of pixels, each of the pixels in the first arrays of pixels being conductive or non-conductive, wherein the transmitter aperture is configured to generate a single beam; and

a receiver aperture comprising a second plurality of printed circuit boards, each printed circuit board in the second plurality of printed circuit boards comprising second arrays of radiating elements, each of the radiating elements in the second arrays of radiating elements comprising second arrays of pixels, each of the pixels in the second arrays of pixels being conductive or non-conductive, wherein the receiver aperture is configured to receive a single beam.

2. The array antenna of claim 1, wherein each radiating element in the first and second arrays of radiating elements is configured to operate in each of a horizontal and vertical polarization.

3. The array antenna of claim 1, wherein the first plurality of printed circuit boards comprises four printed circuit boards.

4. The array antenna of claim 3, wherein each of the first arrays of radiating elements are arranged in a 22x22 square array of radiating elements.

5. The array antenna of claim 4, wherein each radiating element in the first arrays of radiating elements has a length of 1.07 cm and a width of 1.07 cm.

6. The array antenna of claim 4, wherein the radiating elements in the first arrays of radiating elements have an operating frequency of 13.75-14.5 GHz.

7. The array antenna of claim 4, wherein each of the first arrays of pixels is arranged in a 64 x 64 array of pixels.

8. The array antenna of claim 7, wherein each of the conductive pixels in the first arrays of pixels is metal and each of the non-conductive pixels in the first arrays of pixels is non-metal.

9. The array antenna of claim 8, wherein each of the 64 x 64 first arrays of pixels can be represented by the following hexadecimal sequence:

0x3c33cc0ff033cc3c07e1999e799987e087e1999e799987e183cf0f33ccf0f3c183cf0f3
3ccf0f3c1e187fe1e787fe1877887fe1e787fe1067c0ff0c0030ff0207e0ff0c0030ff07878

01f800001f8018e001f800001f80018000cfc3c3f302071980cfc3c3f306061f8067ffffe6
00609f8067ffffe61861ffe033cff3cc3e61e7f833cff3cc7e7987fe1e1ff8781e7f07e78e1ff
870067e67e1c0f3cf00067efe7860f3cf0006679e1e6181818000071e1fe081811800067
81f84000038660061 9f9e000061ff80019f980000619f801806180001f99f807e067803c
3fff980e607e003c7fff981e607e00001ffff81fe1ff81801ffe781981ffe1801ffe181981ffe
1801ffe181fe1ff81801ffe781e607e00001ffff81e607e00007fff9817e06780003fff9801
806180811f99f80019f981818619f80619f9e3ffc61ff80781f843ffc3866001e1fe0ffff18
00069e1e61ffff800007fe78633ffcc0066767e1c33ffcc0067e07e7801ff800067e87fe00
1ff8001e7fe7f800ffff007e79ffe000ffff003e619f80819ff98118611f81819ff981806019
83c0fc3f03c6068003c0fc3f03c207e009f9e6679f90017819f9e6679f98187e0000ffff00
00787c0000ffff0000207887f800001fe106e187f800001fe18780c0f000000f030180c0f
000000f030186187e00007e186106187e00007e18603c33cc0ff033cc3c,

wherein a binary 1 indicates the corresponding pixel is metal and a binary 0 indicates the corresponding pixel is non-metal.

10. The array antenna of claim 3, wherein the first printed circuit board further comprises a front-end beam forming integrated circuit.

11. The array antenna of claim 3, wherein the first printed circuit board further comprises a passive planar beamformer network.

12. The array antenna of claim 3, wherein the first printed circuit board comprises a substrate having a thickness of 0.060 inches.

13. The array antenna of claim 3, wherein each printed circuit board in the first plurality of printed circuit boards has a dielectric constant of 3.5.

14. The array antenna of claim 1, wherein the second plurality of printed circuit boards comprises four printed circuit boards.

15. The array antenna of claim 14, wherein each of the second arrays of radiating elements are arranged in a 20x20 square array of radiating elements.

16. The array antenna of claim 15, wherein each radiating element in the second arrays of radiating elements has a length of 1.21 cm and a width of 1.21 cm.

17. The array antenna of claim 15, wherein the radiating elements in the second arrays of radiating elements have an operating frequency of 10.7-12.75 GHz.

18. The array antenna of claim 15, wherein each of the second arrays of pixels is arranged in a 64 x 64 array of pixels.

19. The array antenna of claim 18, wherein each of the conductive pixels in the second arrays of pixels is metal and each of the non-conductive pixels in the second arrays of pixels is non-metal.

20. The array antenna of claim 19, wherein each of the 64 x 64 second arrays of pixels can be represented by the following hexadecimal sequence:

0x300cc0cc3303300c0618799ff99e18608618799ff99e186180f0c00ff0030f0300f0c00
ff0030f0660187fe667fe180660187fe667fe18060000f30ff0cf00201800f30ff0cf00601
8067f9ff9fe606618067f9ff9fe61e67e003c33cc3c0380e6003c33cc3c06018061867ffe6
180070060867ffe61180600043c3ffc3c386099863c3ffc3c6079ffe01867e618607967f9
8867e610606067f9c03ffc0200006679e03ffc078000067f807ffe07860007e6007ffe1e0
78067e0000ff0380186e660000ff06198078606660000019e01061ffe0000198600607f9
e00021fe000f9e79f80079e6181ffe7ff80019807877fffff800018079e79ffff80067807f8
79ffff80067807f87fffff800018079effe7ff8001980787f9e79f80079e6181607f9e00021
fe000061ffe0990198600860666199801 9e01e660000c3061980767e0000c3038018607
e60081811e0780067f8181818786006679e33ffcc7800067f9c33ffcc2000067f98e1818
706060ffe01e18187860799986 0cf00f30607900040cf00f3038600060e018180718068
061e01818078007e60300c00300c6017e0300c00300c38018080667e66011e61818066
7e66018661830030ff0c00c600030030ff0c00c2060e1e0018007870661e1e001800787
860000c003c00300068000c003c00300038e66018661806671 1e66018661806678300c
c0cc3303300c,

wherein a binary 1 indicates the corresponding pixel is metal and a binary 0 indicates the corresponding pixel is non-metal.

21. The array antenna of claim 12, wherein the second printed circuit board further comprises a front-end beam forming integrated circuit.

22. The array antenna of claim 12, wherein the second printed circuit board further comprises a passive planar beamformer network.

23. The array antenna of claim 12, wherein the second printed circuit board comprises a substrate having a thickness of 0.090 inches.

24. The array antenna of claim 12, wherein each printed circuit board in the second plurality of printed circuit boards has a dielectric constant 3.5.

25. An array antenna, comprising:

a transmitter aperture comprising four printed circuit boards, each printed circuit board comprising a 22x22 array of radiating elements, each of the radiating elements comprising a 64x64 array of pixels, each of the pixels being metal or non-metal; and

a receiver aperture comprising four printed circuit boards, each printed circuit board comprising a 20x20 array of radiating elements, each of the radiating elements comprising a 64x64 array of pixels, each of the pixels being metal or non-metal.

26. The array antenna of claim 25, wherein each radiating element in the transmitter and receiver apertures is configured to operate in each of a horizontal and vertical polarization.

27. The array antenna of claim 25, wherein each radiating element in the transmitter aperture has a length of 1.07cm and a width of 1.07cm.

28. The array antenna of claim 25, wherein each radiating element in the transmitter aperture has an operating frequency of 13.75-14.5 GHz

29. The array antenna of claim 25, wherein the 64 x 64 array of pixels of each radiating element of the transmitter aperture can be represented by the following hexadecimal sequence:

0x3c33cc0ff033cc3c07e1999e799987e087e1999e799987e183cf0f33ccf0f3c183cf0f3
3ccf0f3c1e187fe1e787fe1877887fe1e787fe1067c0ff0c0030ff0207e0ff0c0030ff07878
01f800001f8018e001f800001f80018000cfc3c3f302071980cfc3c3f306061f8067ffffe6
00609f8067ffffe61861ffe033cff3cc3e61e7f833cff3cc7e7987fe1e1ff8781e7f07e78e1ff
870067e67e1c0f3cf00067efe7860f3cf0006679e1e6181818000071e1fe081811800067
81f84000038660061 9f9e000061ff80019f980000619f801806180001f99f807e067803c
3fff980e607e003c7fff981e607e00001ffff81fe1ff81801ffe781981ffe1801ffe181981ffe
1801ffe181fe1ff81801ffe781e607e00001ffff81e607e00007fff9817e06780003fff9801
806180811f99f80019f981818619f80619f9e3ffc61ff80781f843ffc3866001e1fe0ffff18
00069e1e61ffff800007fe78633ffcc0066767e1c33ffcc0067e07e7801ff800067e87fe00
1ff8001e7fe7f800ffff007e79ffe000ffff003e619f80819ff98118611f81819ff981806019
83c0fc3f03c6068003c0fc3f03c207e009f9e6679f90017819f9e6679f98187e0000ffff00
00787c0000ffff0000207887f800001fe106e187f800001fe18780c0f000000f030180c0f
000000f030186187e00007e186106187e00007e18603c33cc0ff033cc3c,

wherein a binary 1 indicates the corresponding pixel is metal and a binary 0 indicates the corresponding pixel is non-metal.

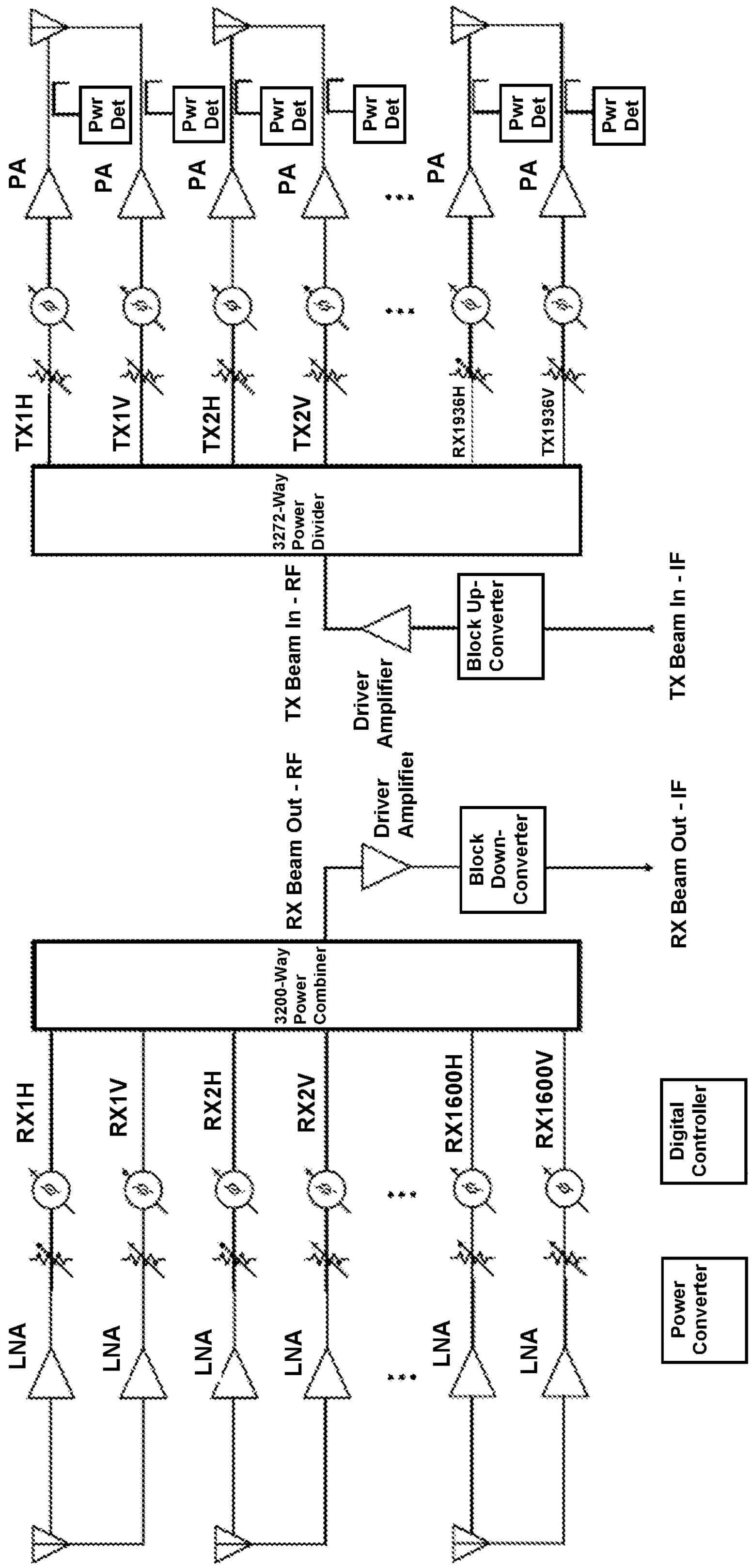
30. The array antenna of claim 25, wherein each radiating element in the receiver aperture has a length of 1.21 cm and a width of 1.21cm.

31. The array antenna of claim 25, wherein each radiating element in the transmitter aperture has an operating frequency of 10.7-12.75 GHz

32. The array antenna of claim 25, wherein the 64 x 64 array of pixels of each radiating element of the receiver aperture can be represented by the following hexadecimal sequence:

0x300cc0cc3303300c0618799ff99e18608618799ff99e186180f0c00ff0030f0300f0c00
ff0030f0660187fe667fe180660187fe667fe18060000f30ff0cf00201800f30ff0cf00601
8067f9ff9fe606618067f9ff9fe61e67e003c33cc3c0380e6003c33cc3c06018061867ffe6
180070060867ffe61180600043c3ffc3c386099863c3ffc3c6079ffe01867e618607967f9
8867e610606067f9c03ffc0200006679e03ffc078000067f807ffe07860007e6007ffe1e0
78067e0000ff0380186e660000ff06198078606660000019e01061ffe0000198600607f9
e00021fe000f9e79f80079e6181ffe7ff80019807877fffff800018079e79ffff80067807f8
79ffff80067807f87fffff800018079effe7ff8001980787f9e79f80079e6181607f9e00021
fe000061ffe0990198600860666199801 9e01e660000c3061980767e0000c3038018607
e60081811e0780067f8181818786006679e33ffcc7800067f9c33ffcc2000067f98e1818
706060ffe01e181878607999860cf00f30607900040cf00f3038600060e018180718068
061e01818078007e60300c00300c6017e0300c00300c38018080667e66011e61818066
7e66018661830030ff0c00c600030030ff0c00c2060e1e0018007870661e1e001800787
860000c003c00300068000c003c00300038e66018661806671 1e66018661806678300c
c0cc3303300c,

wherein a binary 1 indicates the corresponding pixel is metal and a binary 0 indicates the corresponding pixel is non-metal.



TX1H
TX1V
TX2H
TX2V
RX1936H
TX1936V
PA
Pwr Det
3272-Way Power Divider
TX Beam In - RF
Driver Amplifier
Block Up-Converter
TX Beam In - IF
RX Beam Out - RF
Block Down-Converter
RX Beam Out - IF
3200-Way Power Combiner
RX1H
RX1V
RX2H
RX2V
RX1600H
RX1600V
LNA
Digital Controller
Power Converter


*FIG. 1*

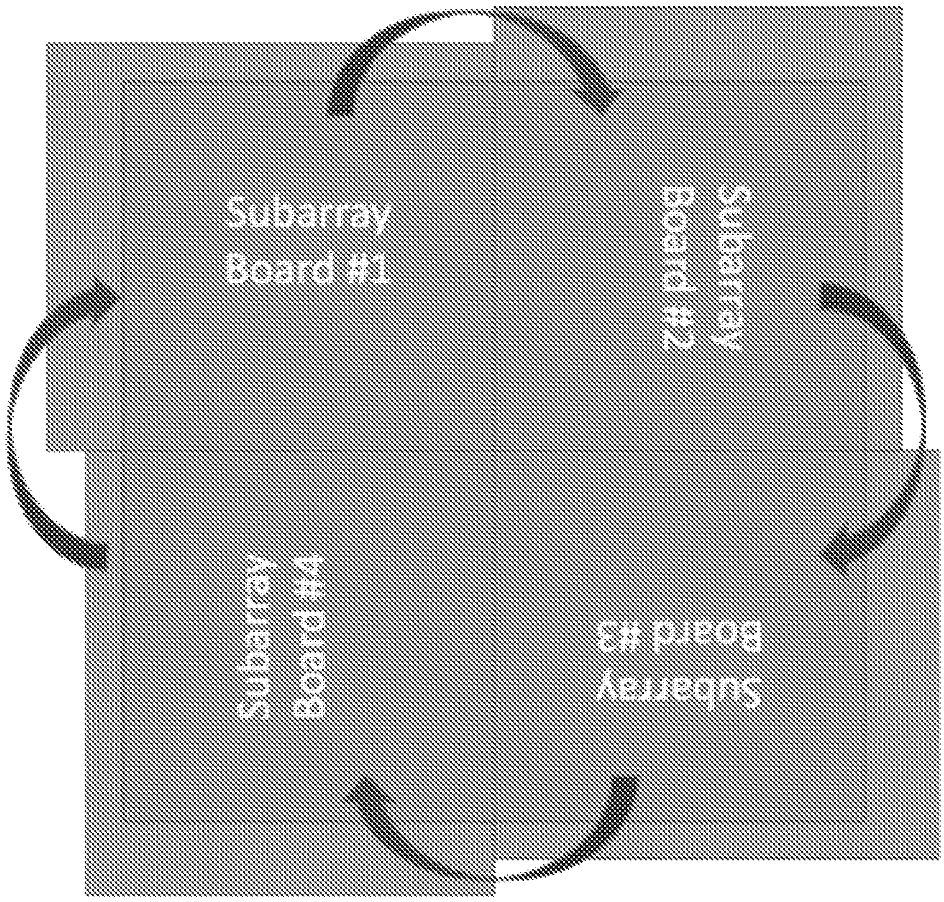

Subarray
Board #1
Subarray
Board #2
Subarray
Board #3
Subarray
Board #4

*FIG. 2*

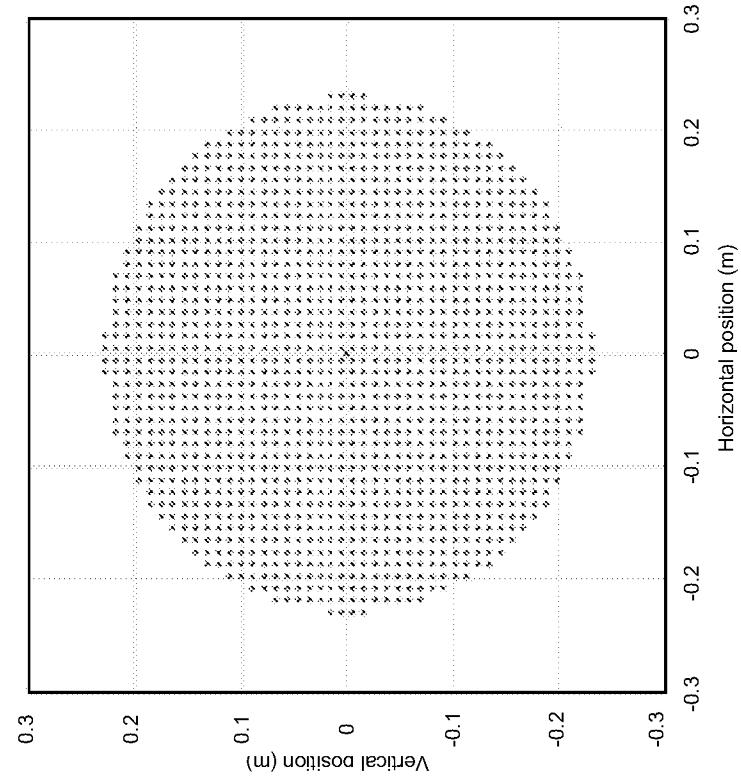

Vertical position (m)
Horizontal position (m)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3

FIG. 3A

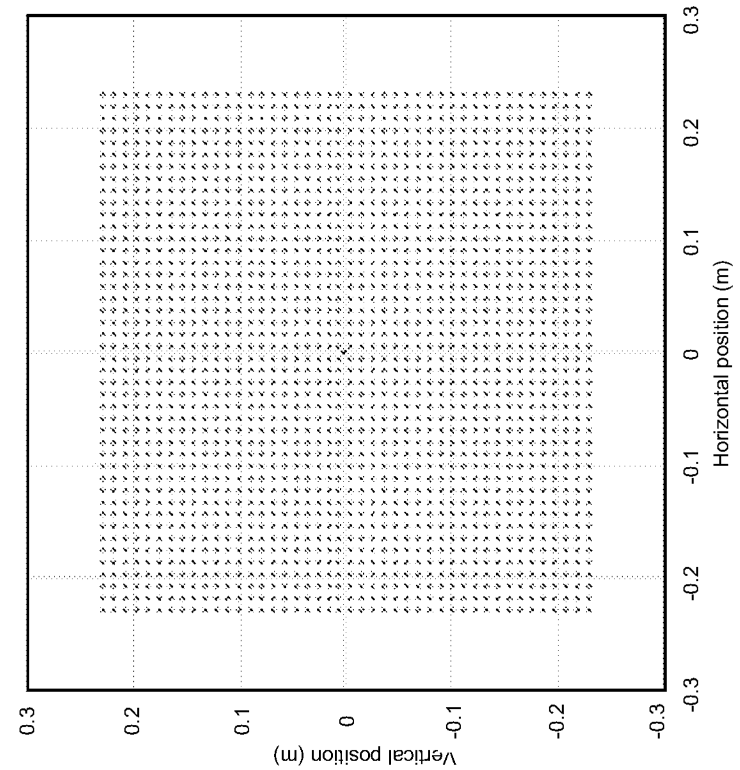

Vertical position (m)
Horizontal position (m)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3

FIG. 3B

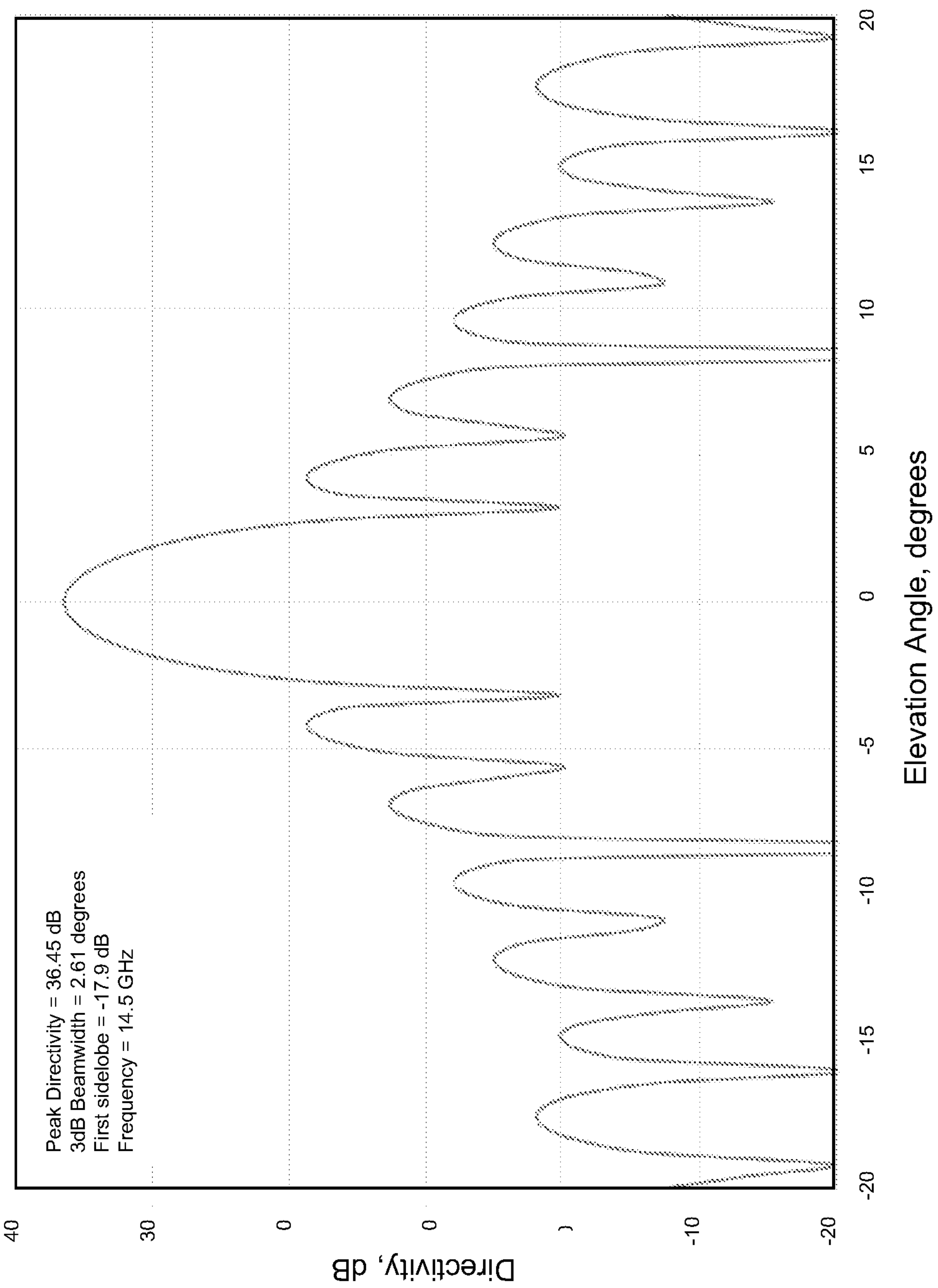
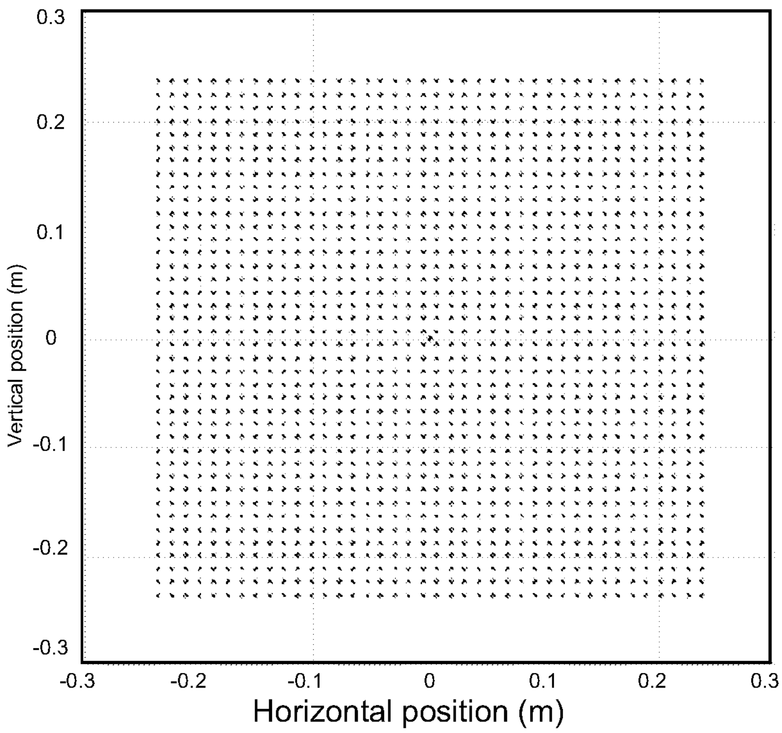

Peak Directivity = 36.45 dB
3dB Beamwidth = 2.61 degrees
First sidelobe = -17.9 dB
Frequency = 14.5 GHz
Elevation Angle, degrees
Directivity, dB
-20
-15
-10
-5
0
5
10
15
20
40
30
0
0
-10
-20

*FIG. 4*

FIG. 5


0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Vertical position (m)
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
Horizontal position (m)

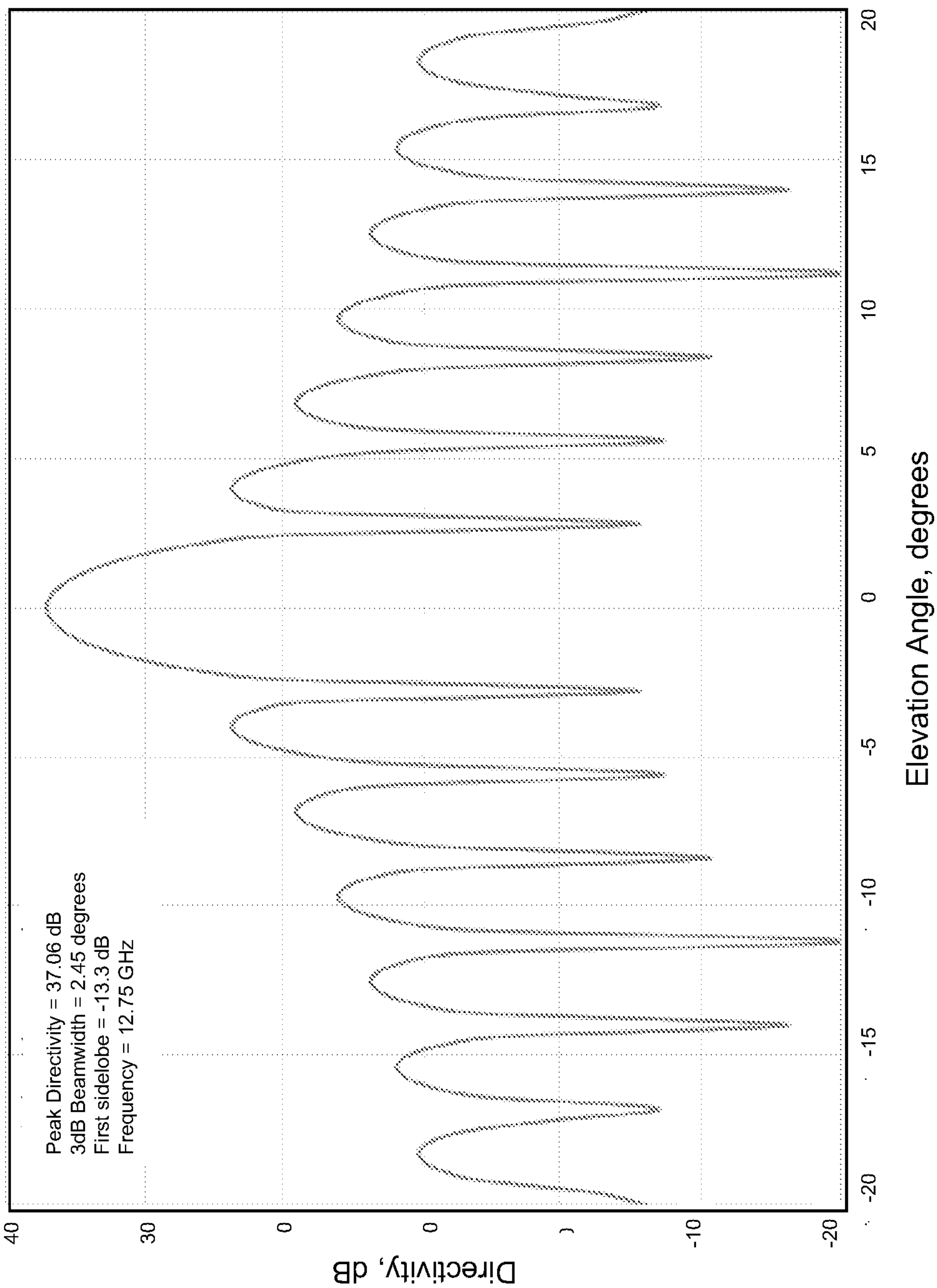

Peak Directivity = 37.06 dB
3dB Beamwidth = 2.45 degrees
First sidelobe = -13.3 dB
Frequency = 12.75 GHz
Directivity, dB
Elevation Angle, degrees
40
30
-10
-20
-20
-15
-10
-5
0
5
10
15
20

*FIG. 6*

FIG. 7

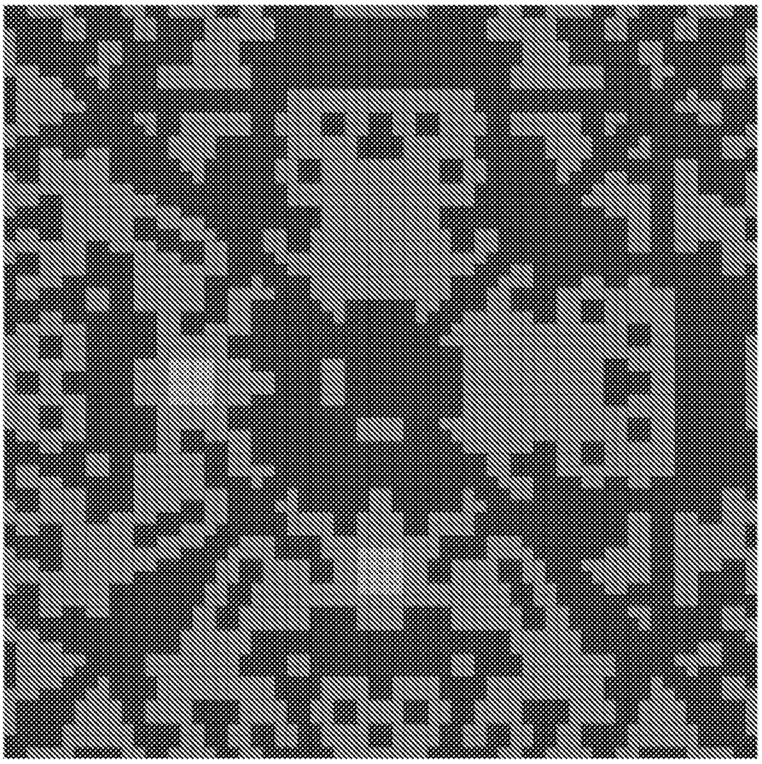


FIG. 9

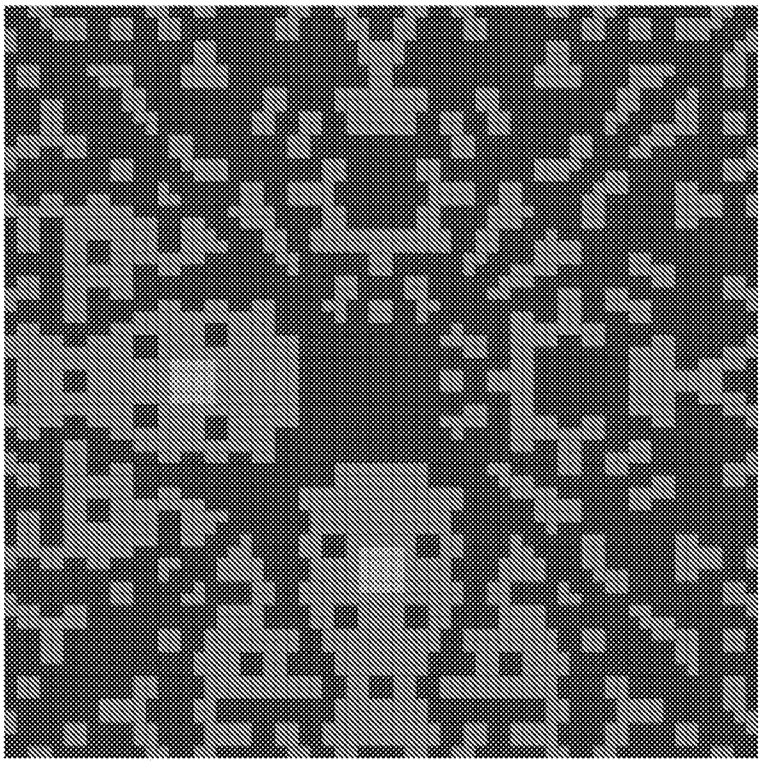


FIG. 8A

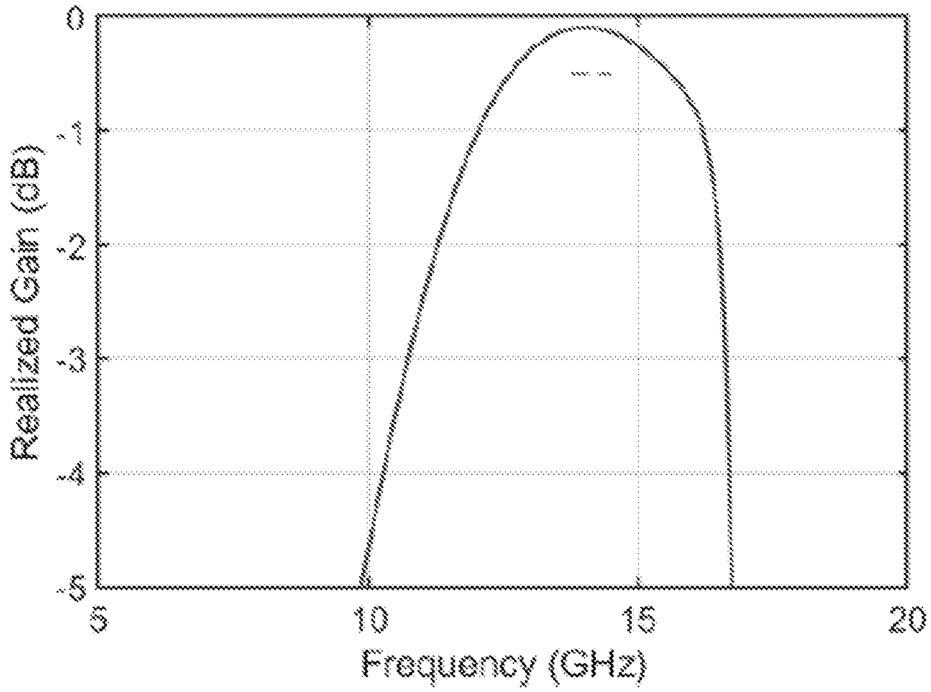

0
-1
-2
-3
-4
-5
Realized Gain (dB)
5
10
15
20
Frequency (GHz)

FIG. 8B

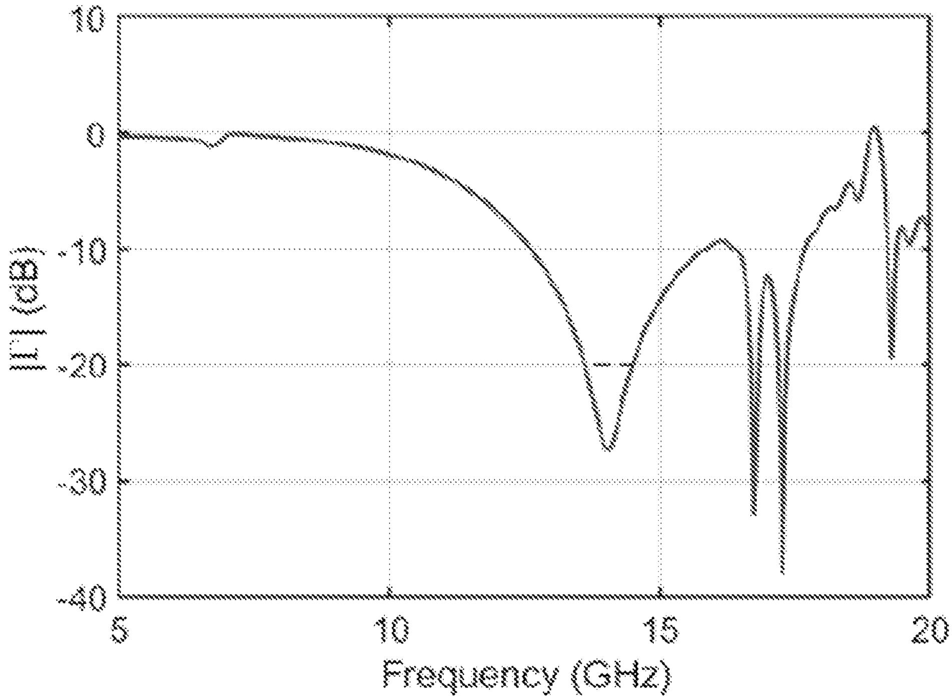

10
0
-10
-20
-30
-40
|Γ| (dB)
5
10
15
20
Frequency (GHz)

FIG. 10A

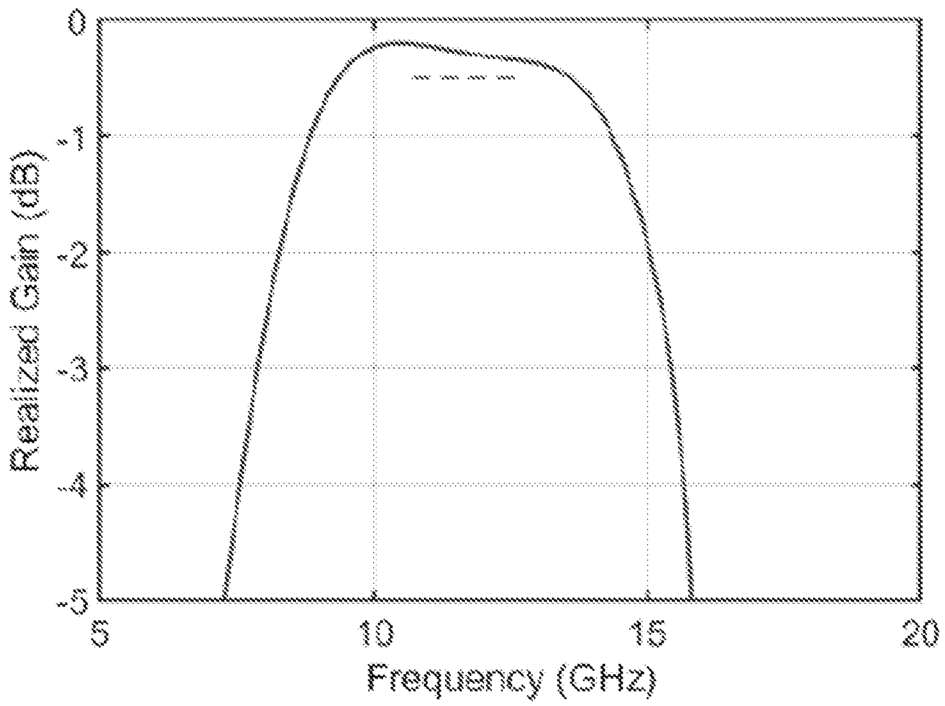



FIG. 10B

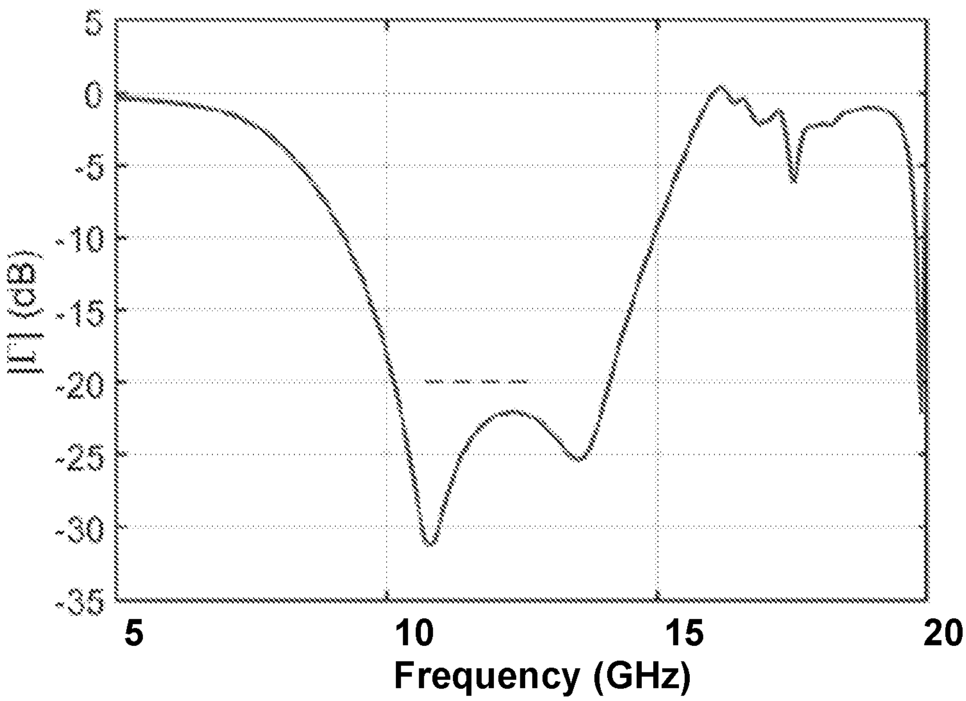


FIG. 11

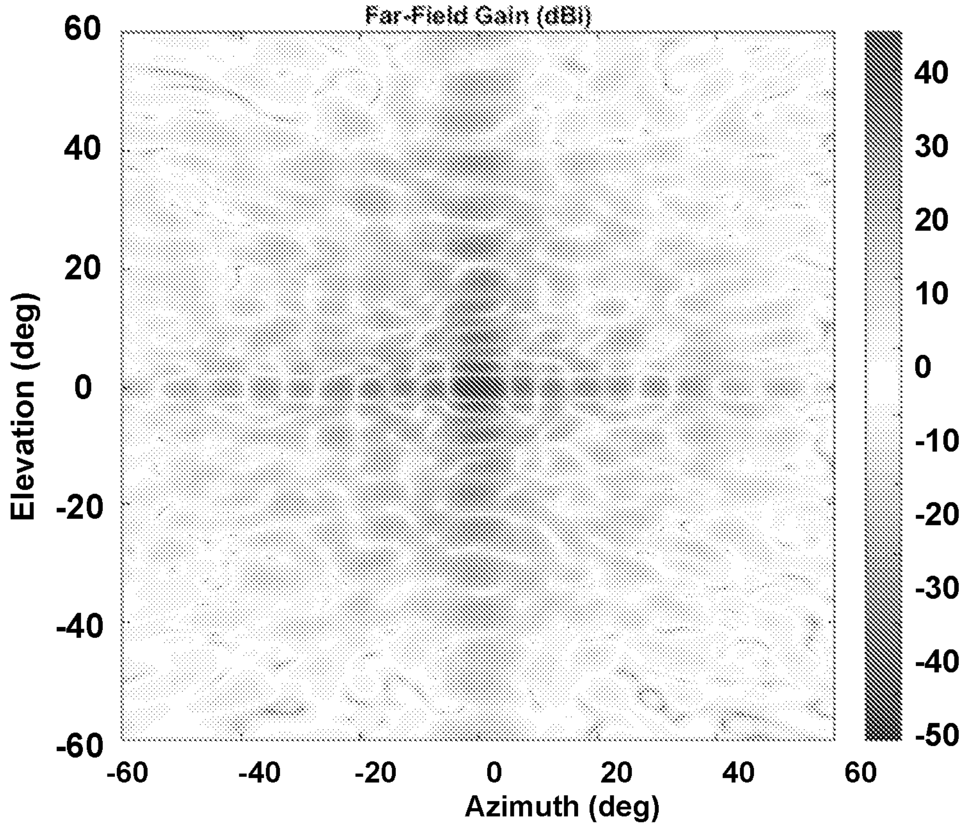

Far-Field Gain (dBi)
Elevation (deg)
Azimuth (deg)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60
40
30
20
10
0
-10
-20
-30
-40
-50

FIG. 12

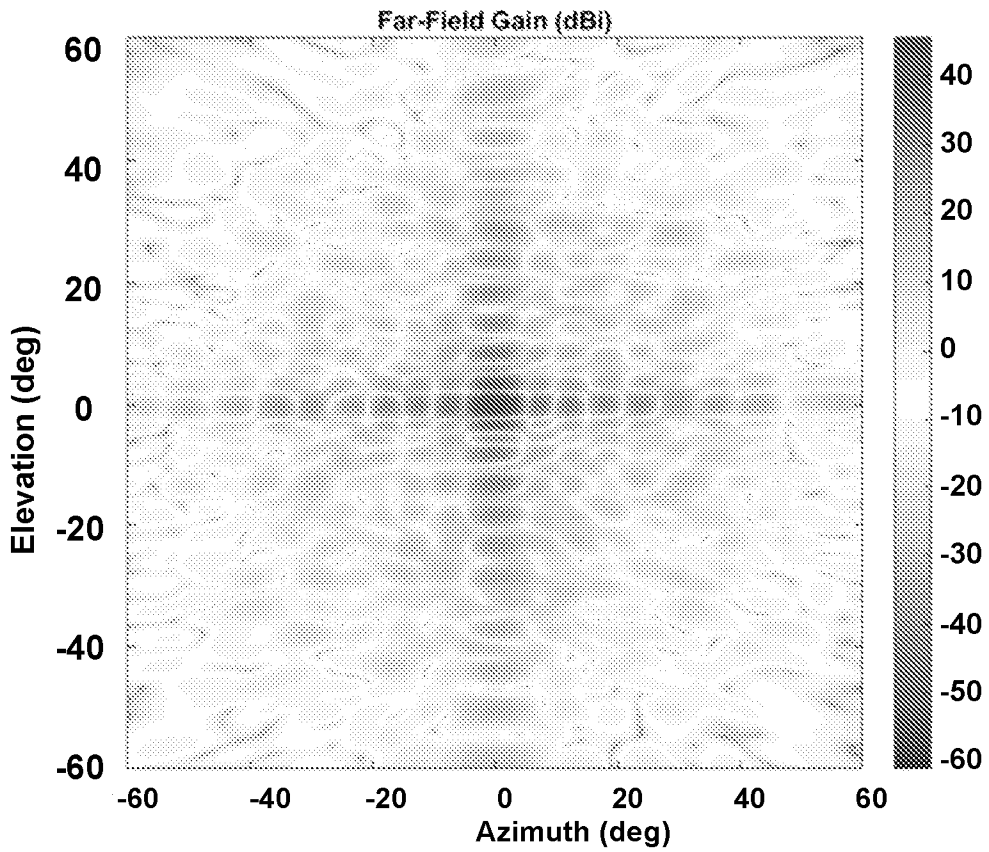

Far-Field Gain (dBi)
Elevation (deg)
Azimuth (deg)
60
40
20
0
-20
-40
-60
-60
-40
-20
0
20
40
60
40
30
20
10
0
-10
-20
-30
-40
-50
-60

FIG. 13

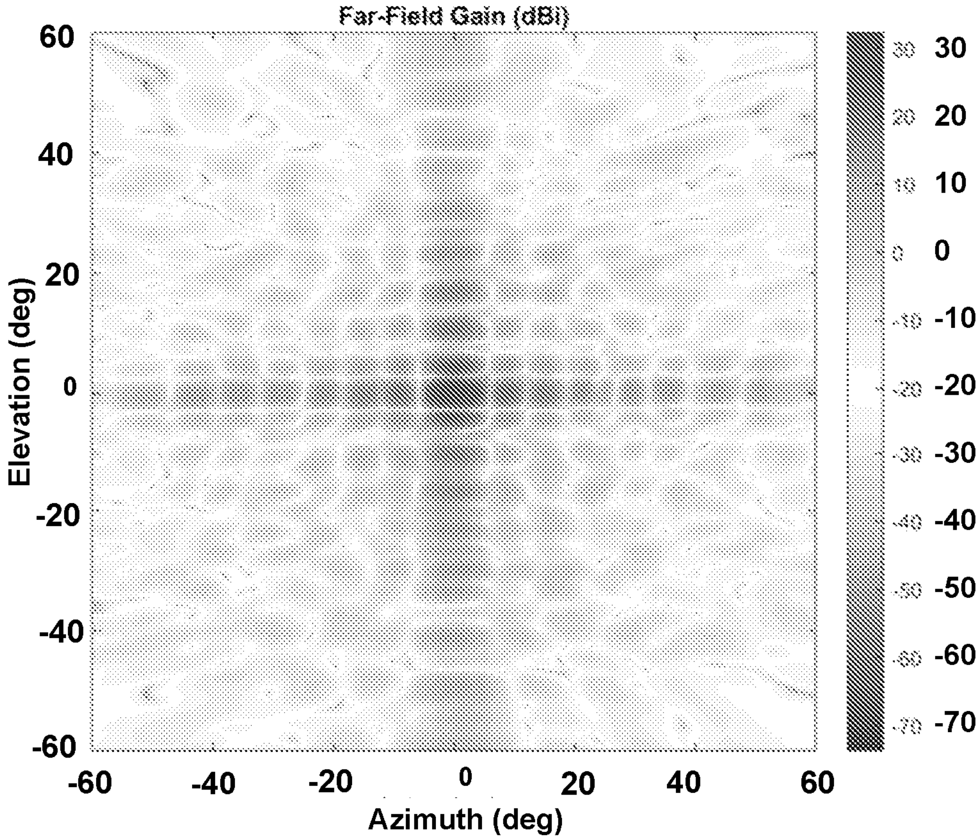
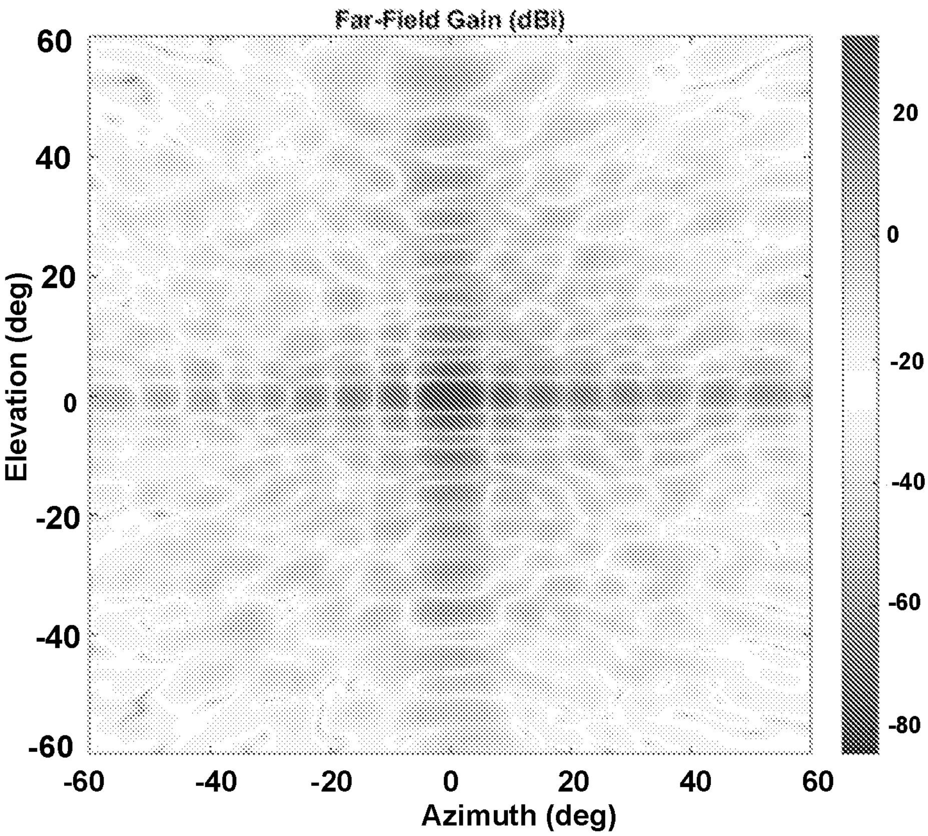

Far-Field Gain (dBi)
Elevation (deg)
60
40
20
0
-20
-40
-60
Azimuth (deg)
-60
-40
-20
0
20
40
60
30
20
10
0
-10
-20
-30
-40
-50
-60
-70

FIG. 14


Far-Field Gain (dBi)
Elevation (deg)
60
40
20
0
-20
-40
-60
Azimuth (deg)
-60
-40
-20
0
20
40
60
20
0
-20
-40
-60
-80

## INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 23/64842

A. CLASSIFICATION OF SUBJECT MATTER

IPC - INV. H01Q 1/28, H01Q 3/24, H01Q 3/26, H01Q 23/00 (2023.01)

ADD. H01Q 21/00 (2023.01)

CPC - INV. H01Q 1/288, H01Q 3/24, H01Q 3/26, H01Q 23/00

ADD. H01Q 21/00

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | US 2009/0278762 A1 (Lopez et al.) 12 November 2009 (12.11.2009); entire document, especially, abstract, FIG. 10, 13, 16, para [0038], [0051], [0054], [0055] [0061] | 1-32 |
| A | US 10,224,979 B1 (Georgia Tech Research Corporation) 05 March 2019 (05.03.2019); entire document, especially, abstract, FIG. 1,2,10, col.4, ln 35-39, col. 5, ln 2-5, col. 6, ln 30-36, col.6, ln 54-61 | 1-32 |
| A | US 2015/0200453 A1 (Government of the United States as represented by the Secretary of the Air Force) 16 July 2015 (16.07.2015); entire document, especially, abstract, FIG. 1-3, para [0028], [0039] | 1-32 |
| A | US 2020/0020276 A1 (a.u. Vista, Inc.) 16 January 2020 (16.01.2020); entire document | 1-32 |
| A | US 2017/0229775 A1 (The Boeing Company) 10 August 2017 (10.08.2017); entire document | 1-32 |

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

* Special categories of cited documents:

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

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