US012394913B1

(12) **United States Patent**
Strassner

(10) **Patent No.: US 12,394,913 B1**
(45) **Date of Patent: Aug. 19, 2025**

(54) **PLANAR DUAL-POLARIZATION ANTENNA**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 835 days.

(21) Appl. No.: **17/552,707**

(22) Filed: **Dec. 16, 2021**

(51) **Int. Cl.**
H01Q 21/24 (2006.01)
H01Q 1/48 (2006.01)
H01Q 9/04 (2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 21/24*** (2013.01); ***H01Q 1/48*** (2013.01); ***H01Q 9/0457*** (2013.01)

(58) **Field of Classification Search**
CPC H01Q 21/24; H01Q 1/48; H01Q 9/0457
See application file for complete search history.

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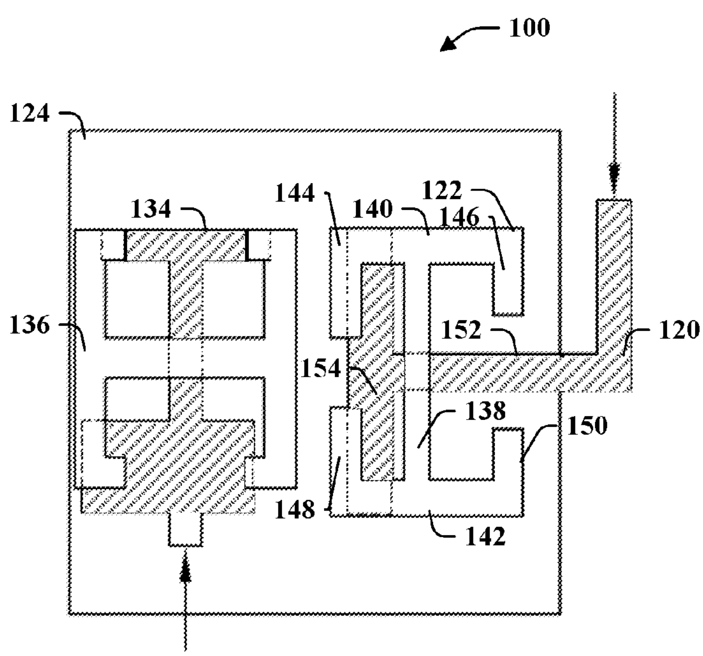
(57) **ABSTRACT**

An antenna includes a first dielectric layer and a second dielectric layer. The first dielectric layer has a first ground plane formed thereon. A stripline conductor is formed on a first side of the second dielectric layer. The second dielectric layer is positioned such that the stripline conductor is positioned between the first dielectric layer and the second dielectric layer. A second ground plane is formed on a second side of the second dielectric layer. The second ground plane has a slot formed therein; the slot aligned with the stripline conductor such that signals propagating along the stripline conductor couple to the slot. The antenna further includes a patch radiating element disposed above the slot such that signals that couple to the slot subsequently couple to the patch radiating element and are radiated outward.

11 Claims, 5 Drawing Sheets



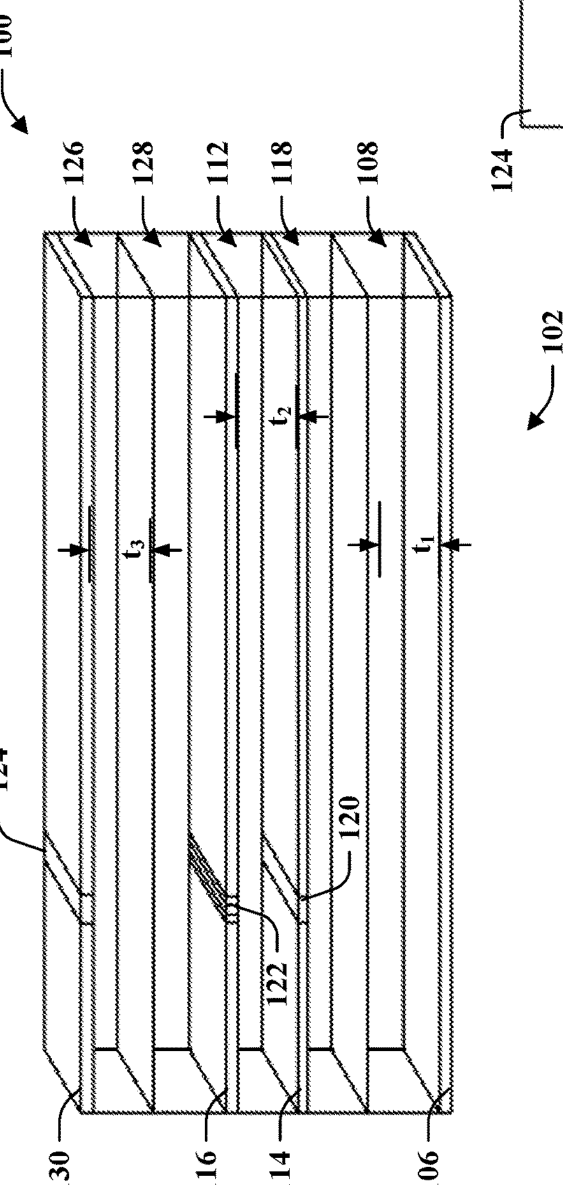
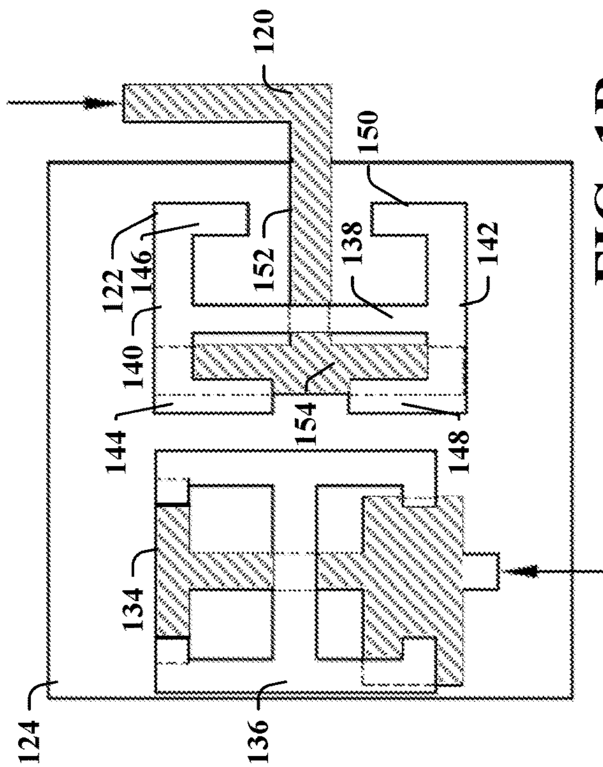

100
104
102
126
128
112
118
108
t_3
t_2
t_1
124
120
122
130
116
114
106

FIG. 1A


100
120
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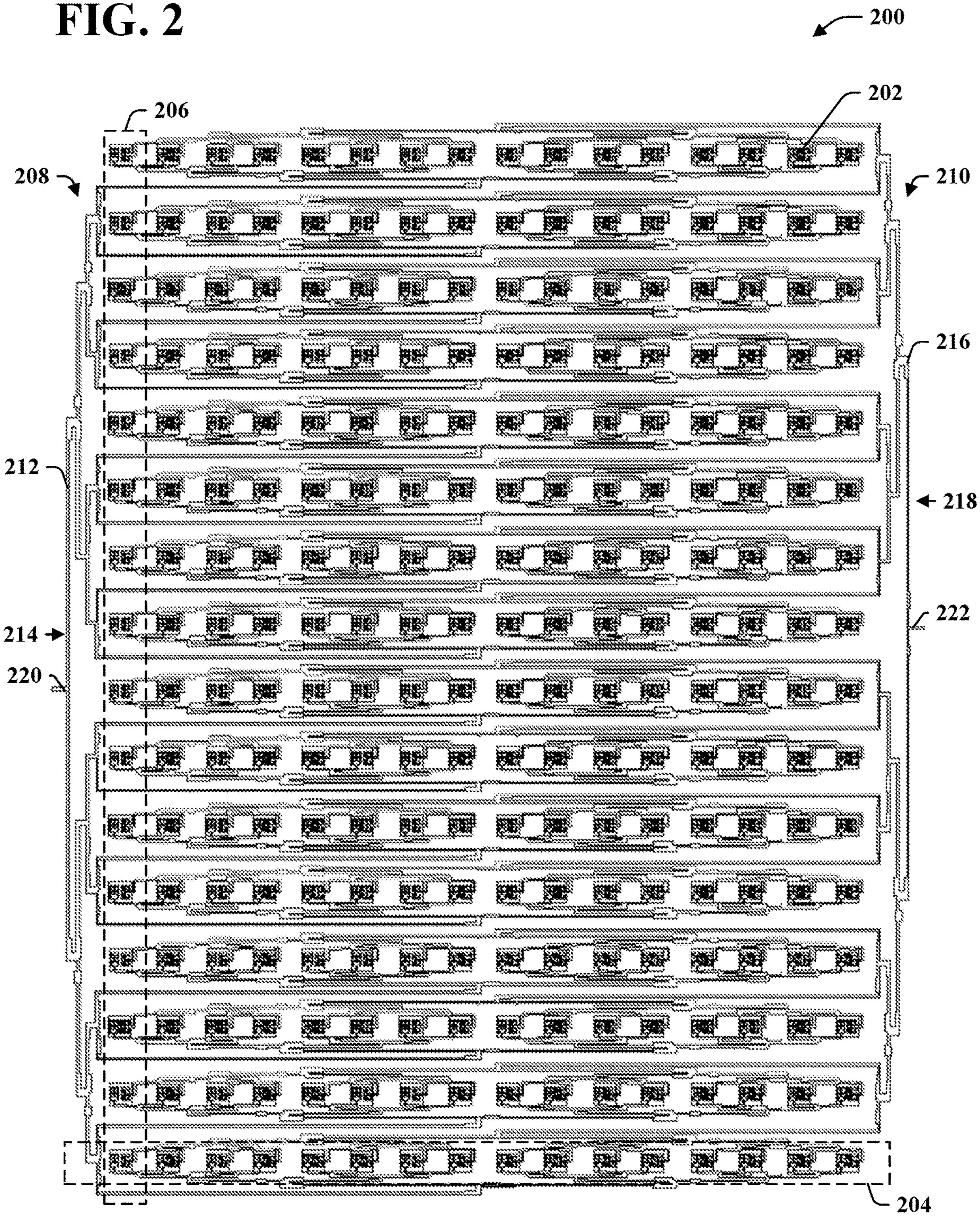
122
146
152
138
142
140
154
144
148
134
124
136

FIG. 1B

FIG. 2



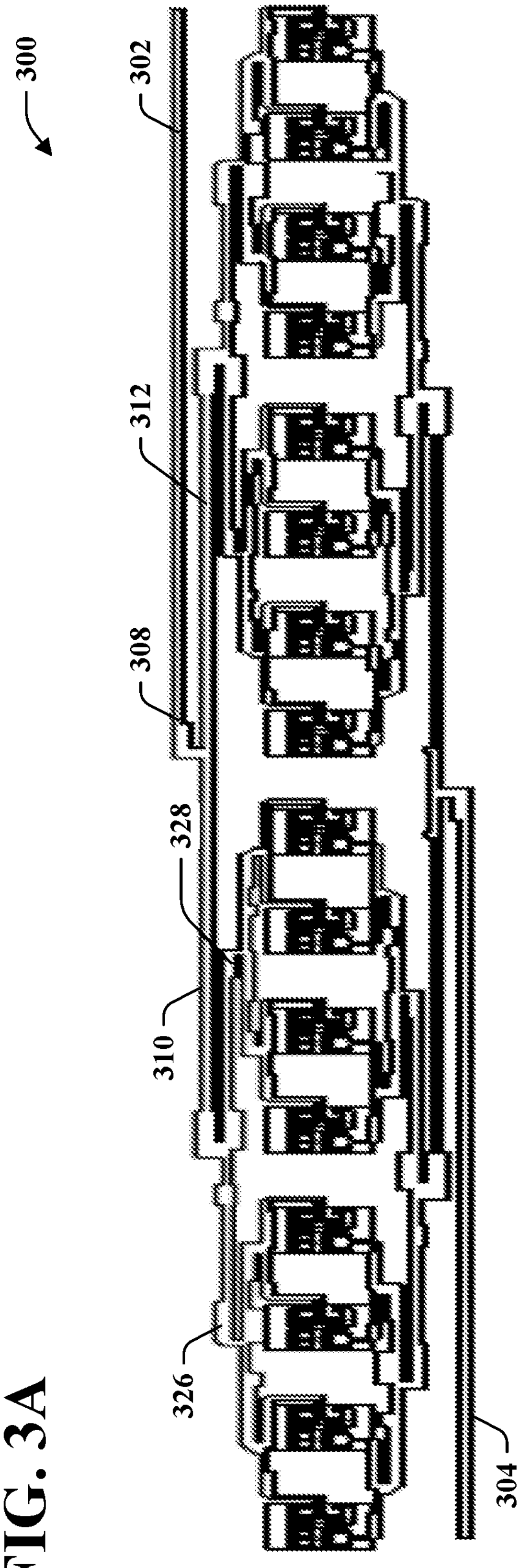


FIG. 3A

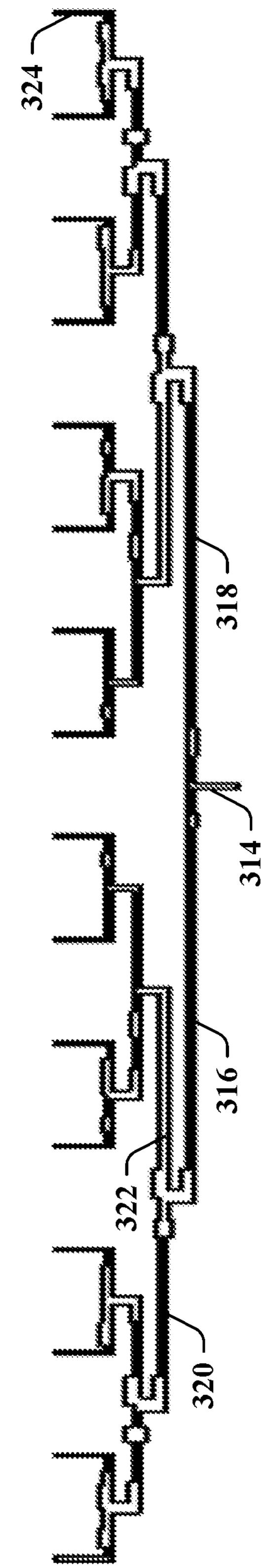


FIG. 3B

FIG. 4A

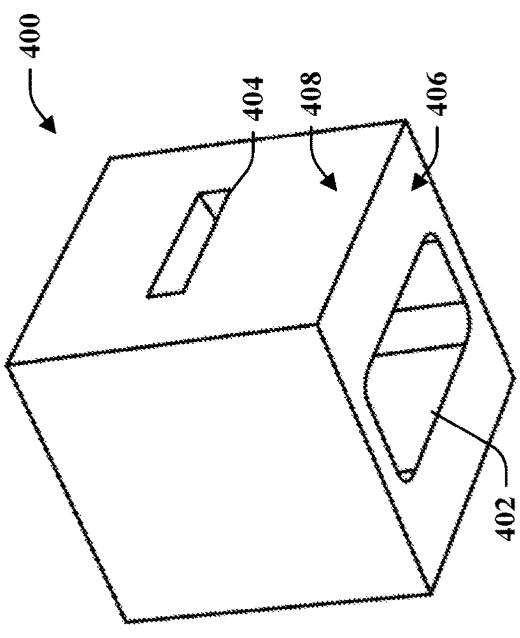


FIG. 4B

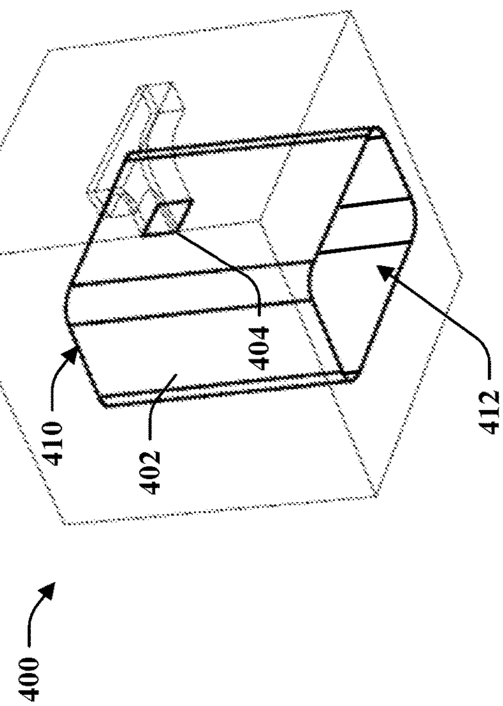


FIG. 4C

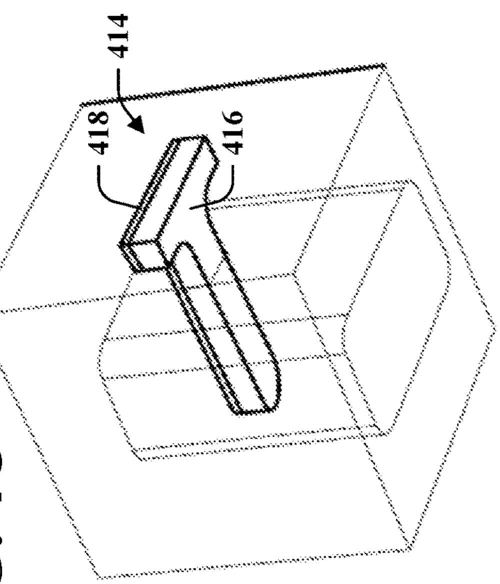


FIG. 4D

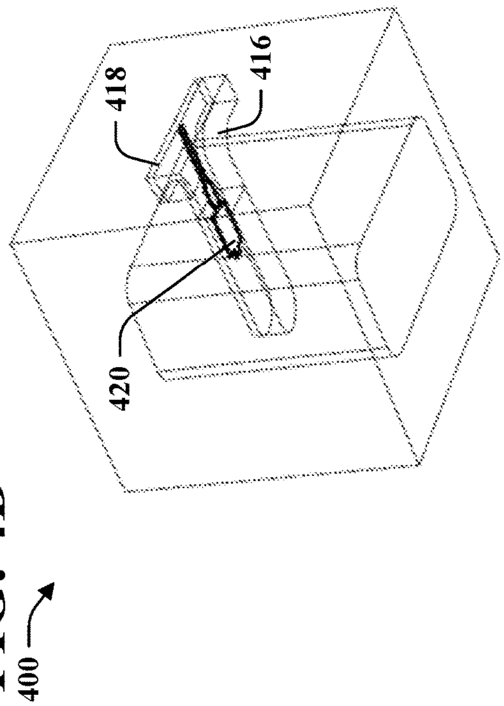
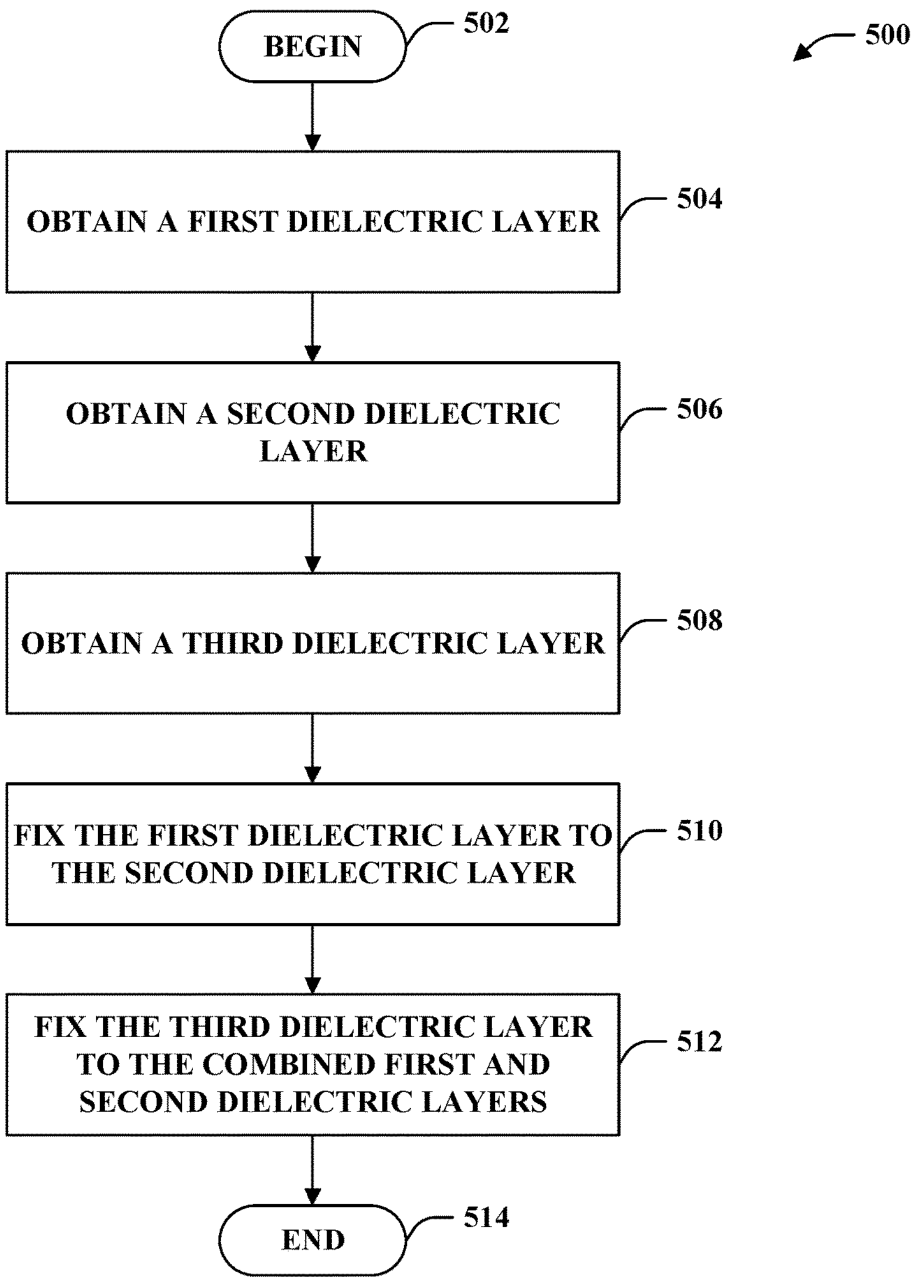


FIG. 5


500
BEGIN
502
OBTAIN A FIRST DIELECTRIC LAYER
504
OBTAIN A SECOND DIELECTRIC LAYER
506
OBTAIN A THIRD DIELECTRIC LAYER
508
FIX THE FIRST DIELECTRIC LAYER TO THE SECOND DIELECTRIC LAYER
510
FIX THE THIRD DIELECTRIC LAYER TO THE COMBINED FIRST AND SECOND DIELECTRIC LAYERS
512
END
514

PLANAR DUAL-POLARIZATION ANTENNA

STATEMENT OF GOVERNMENTAL INTEREST

This invention was made with Government support under Contract No. DE-NA0003525 awarded by the United States Department of Energy/National Nuclear Security Administration. The U.S. Government has certain rights in the invention.

BACKGROUND

Planar antenna arrays are useful for various applications in which a compact form factor is desirable, particularly when employed on airborne or seaborne platforms. Furthermore, antennas and antenna arrays capable of transmitting dual-polarized signals can provide improved performance in determining the size and shapes of targets when incorporated in a radar system as compared to single-polarized radar systems.

Various dual-polarized radiating elements exhibiting wideband performance have been proposed. Some of these elements are unsuitable for use in a planar antenna array that can be mounted on a flat surface because they rely on microstrip transmission lines that would be shorted or made lossy when mounted on a surface. Other dual-polarized radiating elements incorporate air gaps to accomplish wideband performance, using either standoffs or foam-based layers. These radiating elements are difficult to reliably incorporate in an array of antennas due to variations in thickness of radiating elements across the array. Other radiating elements use multiple radiating patches to establish resonances that yield wideband performance. However, these elements require additional substrate layers to separate the patches from one another, creating difficulties in registration among multiple layers as the scale of an array formed from such elements increases.

SUMMARY

The following is a brief summary of subject matter that is described in greater detail herein. This summary is not intended to be limiting as to the scope of the claims.

Various technologies pertaining to a dual-polarization planar antenna array are described herein. With more particularity, technologies for a dual-polarization antenna element that does not incorporate an air gap layer are described herein. In an exemplary embodiment, an antenna includes a first ground plane, a first solid dielectric layer, a stripline conductor, a second solid dielectric layer, a second ground plane, a third solid dielectric layer, and a radiating patch element. The first ground plane can be a substantially solid layer that isolates the antenna from electromagnetic interference originating from the direction of a surface on which the antenna is mounted. The first dielectric layer is positioned above the first ground plane. In some embodiments, the first ground plane is deposited as a metallization layer on a bottom side of the first dielectric layer. The stripline conductor is positioned above the first dielectric layer. The second dielectric layer is positioned above the stripline conductor such that the stripline conductor is sandwiched between the first dielectric layer and the second dielectric layer. The second ground plane is positioned above the second dielectric layer (e.g., as a metallization layer on the second dielectric layer). The second ground plane has a slot formed therein; the slot positioned above the stripline conductor such that energy couples from the stripline conductor to the slot. The third dielectric layer is positioned above the second ground plane. A radiating patch element is positioned above the third dielectric layer such that the third dielectric layer separates the radiating patch element from the second ground plane. The radiating patch element is aligned with the slot in the second ground plane, such that energy couples from the slot to the radiating patch element.

Unlike conventional stripline conductors, which are generally surrounded by dielectric layers of equal thickness, the first dielectric layer has a first thickness that is greater than a second thickness of the second dielectric layer. The second dielectric layer can be configured to have a thickness that facilitates coupling between the stripline conductor and the slot in the second ground plane. The first dielectric layer is configured to have a thickness that is sufficiently great that the first ground plane does not inhibit coupling of energy between the stripline conductor and the slot in the second ground plane. Thus, the first ground plane can provide electromagnetic isolation between the stripline conductor and a surface that the antenna element is mounted on without inhibiting coupling of energy from the stripline conductor to the slot in the second ground plane and on to the radiating patch element.

The antenna can further be configured to include a second stripline conductor formed on a same layer as the first stripline conductor, and a second slot in the same second ground plane in which the first slot is formed. The second stripline and the second slot are aligned such that energy couples from the second stripline into the second slot. The second slot is further positioned such that energy couples from the second slot to the same patch radiating element that receives energy from the first slot. The antenna can be configured to receive input signals with a linear horizontal polarization by way of the first stripline and to receive input signals with a linear vertical polarization by way of the second stripline. The antenna radiates both the horizontal polarization signals and the vertical polarization signals. Hence, the antenna can be configured as a dual-polarization antenna.

The dual-polarization antenna described above can be included in an array of similarly configured antennas that are constructed on common substrates. For example, the stripline conductors of the antennas can be sandwiched between same first and second dielectric layers, slots of the antennas can be formed in a common ground plane, patch radiating elements of the antennas can be formed in a common plane, etc. In various embodiments, the stripline conductors of the antennas can be fed by common feed networks that are configured to deliver different amounts of power to different antennas depending upon their position in the array. The feed networks can be staged branching feed networks, wherein each subsequent stage of the feed network has twice as many traces as a preceding stage of the feed network.

The feed networks can each be configured to deliver input signals to the antennas of the array for each of two orthogonal polarizations. For example, the antenna array can include a first feed network that is configured to provide linear horizontal polarized input signals to first stripline conductors of the antennas. Continuing the example, the antenna array can include a second feed network that is configured to provide linear vertical polarized input signals to second stripline conductors of the antennas.

The above summary presents a simplified summary in order to provide a basic understanding of some aspects of the systems and/or methods discussed herein. This summary is not an extensive overview of the systems and/or methods discussed herein. It is not intended to identify key/critical elements or to delineate the scope of such systems and/or methods. Its sole purpose is to present some concepts in a simplified form as a prelude to the more detailed description that is presented later.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a perspective cross-sectional view of an exemplary antenna.

FIG. **1**B is a top-down view of the exemplary antenna depicted in FIG. **1**A.

FIG. **2** is a top-down view of an exemplary antenna array.

FIG. **3**A is a view of an exemplary row feed network.

FIG. **3**B is a view of an exemplary row-combining feed network.

FIGS. **4**A-**4**D are partial-transparency perspective views of an exemplary stripline-to-waveguide coupler.

FIG. **5** is a flow diagram that illustrates an exemplary methodology for making an antenna.

DETAILED DESCRIPTION

Various technologies pertaining to a dual-polarization antenna are now described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. With more specificity, a dual-polarization antenna is described herein that is suitable for use in a planar, dual-polarization antenna array. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of one or more aspects. It may be evident, however, that such aspect(s) may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form in order to facilitate describing one or more aspects. Further, it is to be understood that functionality that is described as being carried out by certain system components may be performed by multiple components. Similarly, for instance, a component may be configured to perform functionality that is described as being carried out by multiple components.

Moreover, the term "or" is intended to mean an inclusive "or" rather than an exclusive "or." That is, unless specified otherwise, or clear from the context, the phrase "X employs A or B" is intended to mean any of the natural inclusive permutations. That is, the phrase "X employs A or B" is satisfied by any of the following instances: X employs A; X employs B; or X employs both A and B. In addition, the articles "a" and "an" as used in this application and the appended claims should generally be construed to mean "one or more" unless specified otherwise or clear from the context to be directed to a singular form. Additionally, as used herein, the term "exemplary" is intended to mean serving as an illustration or example of something, and is not intended to indicate a preference.

With reference to FIGS. **1**A and **1**B, an exemplary dual-polarization antenna **100** suitable for wideband operation is illustrated. FIG. **1**A depicts a cross-sectional perspective view of the antenna **100**. FIG. **1**B is a top-down partial-transparency view of the antenna **100**. Referring now solely to FIG. **1**A, a plurality of layers of the antenna **100** are shown. The antenna **100** has a bottom side **102** and a top side **104**, wherein the antenna **100** is configured such that signals input to the antenna **100** are radiated outward from the top side **104** of the antenna **100**. For the sake of clarity, as used herein in reference to FIGS. **1**A and **1**B, relative terms such as "above" and "below" consider the top side **104** of the antenna **100** as being above the bottom side **102** of the antenna **100**. However, it is to be understood that in practical application, the top side **104** of the antenna **100** could be positioned below the bottom side **102** of the antenna **100**. For instance, if the antenna **100** is employed in a ground-pointed radar mounted on an aircraft, the top side **104** of the antenna **100** may be positioned closer to the ground than the bottom side **102** of the antenna.

The antenna **100** includes a first ground plane **106** that forms the bottom side **102** of the antenna **100**. The antenna **100** further includes a solid first dielectric layer **108** positioned above the ground plane **106**. The first dielectric layer **108** can be a substrate material on which various additional materials, such as metallization layers, can be printed or otherwise deposited. By way of example, and not limitation, the first dielectric layer **108** comprises a laminate material such as a PTFE composite reinforced by glass microfibers. The first ground plane **106** can be deposited on the first dielectric layer **108** as a metallization layer. The first ground plane **106** can be a layer of copper or other conductive material formed on a bottom side of the first dielectric layer **108**.

The antenna **100** further includes a solid second dielectric layer **112** that is positioned above the first dielectric layer **108**. Like the first dielectric layer **108**, the second dielectric layer **112** can be formed from a substrate material on which various additional materials can be printed or deposited. The second dielectric layer **112** has a bottom-side metallization layer **114** and a top-side metallization layer **116**. An adhesive layer **118** can be positioned between the first dielectric layer **108** and the second dielectric layer **112** (e.g., between and in contact with the metallization layers **114**). The adhesive layer **118** holds the dielectric layers **108**, **112** and their associated metallization layers **106**, **114**, **116** in a fixed relative position.

The bottom-side metallization layer **114** includes a stripline conductor **120**. The stripline conductor **120** is a strip of metal that can conduct signals that are input to the antenna **100** (e.g., by way of a feed network, as will be described in greater detail below). The stripline conductor **120** is sandwiched between the first dielectric layer **108** and the second dielectric layer **112**. The top-side metallization layer **116** is a substantially continuous, solid conductive layer such that the top-side metallization layer **116** forms a second ground plane. Thus, the stripline conductor **120** is surrounded by the dielectric materials of the dielectric layers **108**, **112** and positioned between a first ground plane **106** and a second ground plane **116**. The stripline conductor **120** is therefore configured to function as a planar transmission line.

The first ground plane **106** functions to isolate the stripline conductor **120** from electrical interference originating from an interference source located on the opposite side of the ground plane **106** from the stripline conductor **120** (i.e., the bottom side **102** of the antenna **100**). If the stripline conductor **120** is positioned too close to the first ground plane **106**, the first ground plane **106** can adversely affect propagation of an input signal along the stripline conductor **120**. The first dielectric layer **108** has a thickness that is sufficiently large to prevent the first ground plane **106** from interfering with propagation of signals along the stripline conductor **120**. In exemplary embodiments, the first dielectric layer **108** has a thickness, t_1 defined by the following inequality:

$$t_1 \geq (0.13\lambda \div \sqrt{\varepsilon_{r1}}), \tag{Eq. 1}$$

where λ is the free-space wavelength of the center frequency of a signal desirably transmitted by the antenna **100** and ε_{r1} is the relative permittivity, or dielectric constant, of the first dielectric layer **108**. In a specific example, the first dielectric layer **108** can have a thickness t_1 of 59-65 mil, inclusive, (e.g., 62 mil) in embodiments wherein the antenna **100** is configured to transmit a signal having a center frequency of 16.7 GHz, within the Ku-band. In various embodiments, the first dielectric layer **108** has a dielectric constant ε_{r1} of approximately 2.2. It is to be understood that the antenna **100** can be configured to transmit signals within other bands (e.g., the K band, the Ka band, or the X band) at different center frequencies in part by appropriate selection of the thickness t_1 of the first dielectric layer **108** (e.g., according to Eq. 1).

The top-side metallization layer **116**, positioned on the second dielectric layer **112**, has a slot **122** formed therein. The slot **122** is positioned above and aligned with the stripline conductor **120** such that energy transmitted along the stripline conductor **120** couples to the slot **122**. As will be described in greater detail below, signals that are coupled into the slot **122** by transmission through the stripline conductor **120** are ultimately coupled to a patch radiating element for radiation by the antenna **100**.

The second dielectric layer **112** is configured to be sufficiently thin so that energy transmitted along the stripline conductor **120** efficiently couples to the slot **122**. The second dielectric layer **112** has a second thickness, t_2, that is less than the thickness t_1 of the first dielectric layer **108**. In exemplary embodiments, the thickness t_2 of the second dielectric layer **112** can be defined by:

$$t_2=(0.042\lambda\div\sqrt{\varepsilon_{r,2}})\pm5\%, \tag{Eq. 2}$$

where ε_{r2} is the relative permittivity of the second dielectric layer **112**. In a specific example, the second dielectric layer **112** can have a thickness t_2 of 19-21 mil, inclusive, (e.g., 20 mil) in embodiments wherein the antenna **100** is configured to transmit a signal having a center frequency of 16.7 GHz. In such embodiments, the dielectric constant ε_{r2} of the second dielectric layer **112** can be about 2.2. It is again to be understood that the antenna **100** can be configured to transmit signals within other bands at different center frequencies in part by appropriate selection of the thickness t_2 of the second dielectric layer **112** (e.g., according to Eq. 2).

As noted above, the antenna **100** further includes a patch radiating element **124** that is aligned with the slot **122**. The patch radiating element **124** is configured such that signals coupled into the slot **122** by way of the stripline conductor **120** are in turn coupled to the patch radiating element **124** from the slot **122**. Thus, signals transmitted along the stripline conductor **120** are radiated by way of the patch radiating element **124**. In exemplary embodiments, the patch radiating element **124** is a rectangular patch radiator. However, it is to be understood that the patch radiating element **124** can have any of various other geometries.

The antenna **100** is constructed such that the antenna **100** can emit wideband signals. In non-limiting exemplary embodiments, a signal emitted by the patch radiating element **124** can have a fractional bandwidth of greater than or equal to 10%, greater than or equal to 15%, or greater than or equal to 20%.

To support the patch radiating element **124**, the antenna **100** includes a third dielectric layer **126**. The third dielectric layer **126** can be adhered to the second dielectric layer **112** by way of a second adhesive layer **128** that is disposed between the second dielectric layer **112** and the third dielectric layer **126**. The third dielectric layer **126** can include a top-side metallization layer **130**. The patch radiating element **124** can be formed on the top-side metallization layer **130**. A thickness, t_3, of the third dielectric layer **126** can be selected to facilitate efficient coupling between the slot **122** and the patch radiating element **124**. In an exemplary embodiment, the thickness t_3 of the third dielectric layer **126** is selected to be a same thickness as the first dielectric layer **108**. In other embodiments, the thickness t_3 of the third dielectric layer **126** can be selected according to the following equation:

$$t_3=(0.13\lambda\div\sqrt{\varepsilon_{r,3}})\pm5\%, \tag{Eq. 3}$$

where ε_{r3} is the relative permittivity of the third dielectric layer **126**.

The stripline conductor **120** and the slot **122** are formed on opposite sides of a same substrate, the second dielectric layer **112**. The stripline conductor **120** and the slot **122** can be accurately registered to one another by way of registration techniques that have been developed for alignment of features on printed circuit boards (PCBs). These techniques can provide greater alignment accuracy than techniques that require physically separate layers to be aligned and then bonded to one another. As shown in FIG. **1**A, in various embodiments the exemplary antenna **100** can formed from only three laminate layers **108**, **112**, **126** joined by adhesives **118**, **128**. The first dielectric layer **108** can be configured to support only the first ground plane **106** so that close alignment between the first dielectric layer **108** and the other layers **112**, **126** may be unnecessary. The antenna **100** can therefore be constructed by comparatively simple alignment between the second dielectric layer **112** that supports the stripline conductor **120** and the slot **122** and the third dielectric layer **126** that supports the patch radiating element **124**. Such two-layer alignment can be accomplished more simply than alignment of a greater number of layers.

The antenna **100** can be configured for dual-polarization operation by inclusion of an additional stripline conductor in the bottom-side metallization layer **114** and a corresponding additional slot in the top-side metallization layer **116**. Referring now to FIG. **1**B, a top-down view of the antenna **100** is shown. FIG. **1**B illustrates aligned placement of the stripline conductor **120** and the slot **122**. FIG. **1**B further illustrates a second stripline conductor **134** and a second slot **136** that is aligned with the second stripline conductor **134**. The antenna **100** can be configured such that the first stripline conductor **120** receives a first input signal having a linear horizontal polarization and the second stripline conductor **134** receives a second input signal having a linear vertical polarization. The second stripline conductor **134** can be included in the same metallization layer **114** as the first stripline conductor **120**. Similarly, the second slot **136** can be included in the same metallization layer **116** as the first slot **122**.

As shown in FIG. **1**B, the slots **122**, **136** can be configured as H-shaped slots. For example, the slot **122** has a first straight portion **138**, a second straight portion **140** positioned at a first end of the first straight portion **138**, and a third straight portion **142** positioned at a second end of the first straight portion **138** opposite the first end. The second straight portion **140** and the third straight portion **142** are perpendicular to the first straight portion **138** and parallel with one another. The slots **122**, **136** can further include tuning features that are configured to increase the fractional bandwidth of signals radiated by the antenna **100**. For example, the slot **122** can include additional straight portions **144-150** that each extend from one of the second straight portion **140** or the third straight portion **142** inward toward the other of the second straight portion **140** or the third straight portion **142**. These straight portions **144-150** serve as tuning features, the lengths and widths of which can be selected to increase the fractional bandwidth of signals radiated by the antenna **100** (e.g., as compared with a similarly configured antenna that does not include these portions **144-150**).

The geometry and alignment of the slots **122**, **136** are configured to facilitate coupling of signals propagating along the stripline conductors **120**, **134** into the slots **122**, **136**. For example, the stripline conductors **120**, **134** can be configured to cross under the slots **122**, **136**, respectively, such that signals propagating along the stripline conductors **120**, **134** couple into the slots **122**, **136**. In exemplary embodiments, the stripline conductors **120**, **134** are configured to cross under the slots **122**, **136** such that a linear portion of each of the conductors **120**, **134** crosses under a perpendicular linear portion of its corresponding slot **122**, **136**. For example, the stripline conductor **120** can include a first linear portion **152**. The first linear portion **152** of the stripline conductor **120** extends under the first straight portion **138** of the slot **122** such that, if the stripline conductor **120** were coplanar with the slot **122**, the stripline conductor **120** and the slot **122** would be perpendicular with one another.

The stripline conductors **120**, **134** can also include tuning features designed to increase the fractional bandwidth of signals radiated by the antenna **100**. For instance, the stripline conductor **120** can further include a second linear portion **154** that is perpendicular with the first linear portion **152** of the stripline conductor **120**. The second linear portion **154** extends below each of the second straight portion **140** and the third straight portion **142** of the slot **122**. The second linear portion **154** can further extend at least partially below the additional straight portions **144**, **148** of the slot **122**, thereby further facilitating coupling between the stripline conductor **120** and the slot **122**.

While the slots **122**, **136** have been described herein as having an H-shaped configuration and various tuning features, it is to be understood that the slots **122**, **136** can instead be configured as linear slots each consisting of a single straight portion. For example, in some embodiments the slot **122** can consist of the first straight portion **138**. Similarly, the stripline conductors **120**, **134** can be configured as substantially linear elements. For instance, in some embodiments the stripline conductor **120** can consist of the first linear portion **152**. In various embodiments, the patch radiating element **124** can be configured to cover the entirety of the slots **122**, **136**.

The antenna **100** can be employed in an array of similarly configured antennas that can all be formed on a common set of layers. By way of example, a plurality of antennas configured in accordance with the antenna **100** can have stripline conductors formed on the same metallization layer **114** as the stripline conductor **120**, slots formed on the same metallization layer **116** as the slot **122**, and patch radiating elements formed on the same metallization layer **130**.

Referring now to FIG. **2**, an exemplary antenna array **200** is shown, wherein the array comprises a plurality of antennas (e.g., an antenna **202**) that are configured for wideband dual-polarization operation in a manner similar to the antenna **100** as shown in FIG. **1**B. The antennas of the array **200** are arranged in a rectangular configuration of rows (e.g., row **204**) and columns (e.g., column **206**). The exemplary array **200** includes 256 antennas arranged in 16 columns and 16 rows. However, it is to be understood that an array of antennas configured in accordance with embodiments of a dual-polarization antenna described herein can have substantially any number of elements.

Each of the antennas of the array **200** includes a first input port and a second input port. In dual-polarization operation of the array **200**, first signals having a first polarization are input to the antennas by way of the first input ports of the antennas. Second signals having a second polarization are input to the antennas of the array **200** by way of the second input ports. The array **200** comprises a first feed network **208** that is configured to provide the first signals to the first input ports and a second feed network **210** that is configured to provide the second signals to the second input ports. In other words, each of the antennas of the array **200** receives separate input from each of the feed networks **208**, **210**, with the first feed network **208** providing signals having a first polarization, and the second feed network **210** providing signals having a second polarization. The antennas of the array **200** are configured to radiate both the signals having the first polarization and the signals having the second polarization. The first feed network **208** and the second feed network **210** can be disposed in a same metallization layer as the stripline conductors of the antennas of the array **200** (e.g., the metallization layer **114** of the antenna **100**).

Each of the feed networks **208**, **210** comprises a plurality of m row feed networks, where m is a positive integer, and a row-combining feed network. Stated differently, each of the feed networks **208**, **210** includes a sub-feed network that is configured to receive an array input signal and to distribute row input signals to each of the rows of the array **200**, and a plurality of additional sub-feed networks that are each configured to receive a respective row input signal and distribute that row input signal across the antennas of its corresponding row.

Referring now to FIG. **3**A, a row **300** of the antenna array **200** is shown, wherein the row **300** is fed by a first row feed network **302** (e.g., part of the first feed network **208**) configured to carry input signals having a first polarization, and further fed by a second row feed network **304** (e.g., part of the second feed network **210**) that is configured to carry input signals having a second polarization. Referring now to FIG. **3**B, a row-combining feed network **306** that is configured to distribute an array input signal to the rows of the array **200** is shown. Collectively, the first row feed network **302** and the row-combining feed network **306** form part of a same feed network (e.g., one of the feed networks **208**, **210**) that is configured to provide signals having a first polarization to the antennas of the array **200**.

Referring now solely to FIG. **3**A, the row feed network **302** is a staged feed network. The row feed network **302** includes a plurality of x stages, where x is a positive integer, and wherein further a number of the x stages is related to the number of antennas in a row, n, by

$$n=2^x. \quad \text{(Eq. 4)}$$

In each subsequent stage of the row feed network **302**, the traces of a preceding stage are split into two traces, such that at each subsequent stage a number of the traces doubles. By way of example, the row feed network **302** includes a primary row input trace **308**. In a first stage of the row feed network **302**, the primary row input trace **308** splits into a first trace **310** and a second trace **312**. Similarly, in a second stage of the row feed network **302**, each of the first trace **310** and the second trace **312** splits into a respective pair of traces, and so on until the number of traces is equal to the number of antennas in the row **300**. Hence, each of the antennas of the row **300** can be provided an input signal having a first polarization by way of a common primary row input trace **308**.

Referring again to FIG. **3**B, the row-combining feed network **306** is similarly configured to provide an input signal having a first polarization to each of the rows of the array **200**. The row-combining feed network **306** includes a primary array input trace **314**. The primary array input trace **314** serves as a common input to the array for signals having a first polarization. Thus, a signal that is input to the primary array input trace **314** can drive a radiating output of each of the antennas of the array **200**. Like the row feed network **302**, the row-combining feed network **306** is a staged feed network. A number of stages, y, of the row-combining feed network **306** can be related to the number of rows m of the array **200** by:

$$m=2^y. \quad \text{(Eq. 5)}$$

A first stage of the row-combining feed network **306** subsequent to the primary array input trace **314** includes a first trace **316** and a second trace **318**. The first trace **316** delivers input signals to a first half of the rows of the array **200**, and the second trace **318** delivers input signals to a second half of the rows of the array **200**. A second stage of the row-combining feed network **306** can include a pair of additional traces corresponding to each of the traces **316**, **318** of the first stage of the row-combining feed network **306**. For example, the second stage can include a third trace **320** and a fourth trace **322** that each branch from the first trace **316**. The third trace **320** delivers input signals to a first quarter of the rows of the array **200** (i.e., a first half of the first half of the rows driven by the first trace **316**). The fourth trace **322** delivers input signals to a second quarter of the rows of the array **200** (i.e., a second half of the first half of the rows driven by the first trace **316**). The row-combining feed network **306** includes a plurality of m output traces (e.g., output trace **324**) that each deliver input signals to a respective row of the array **200**. For example, the output trace **324** can be coupled to the primary row input trace **308** of the row feed network **302** such that the output trace **324** delivers input signals to the row feed network **302**.

Referring once again to FIG. **2**, the feed networks **208**, **210** can be configured to facilitate compact arrangement of the array **200**. In an exemplary embodiment, the feed network **208** has a vertically-arranged row-combining feed network **212** aligned along a left side **214** of the array **200**. The row-combining feed network **212** of the feed network **208** is arranged such that the row feed networks of the feed network **208** (i.e., that are connected to the row-combining feed network **212**) are each aligned along a bottom side of a respective row of antennas. The feed network **210** has a vertically-arranged row-combining feed network **216** aligned along a right side **218** of the array **200**. The row-combining feed network **216** is arranged such that the row feed networks of the feed network **210** that are connected to the row-combining feed network **216** are each arranged along a top side of a respective row of antennas in the array **200**. The arrangement of the feed networks **208**, **210** can facilitate spacing of antennas of the array **200** to avoid grating lobes. For example, in an embodiment wherein the array **200** is configured to transmit signals having a center frequency of 16.7 GHz, a spacing between antennas within each row can be about 10 mm and a spacing between antennas in adjacent rows can be about 13.8 mm. It is to be understood that a spacing of antennas within rows and between rows of the array **200** that inhibits grating lobes can be a function of a free space wavelength of a signal desirably transmitted or received by way of the array **200**.

The feed networks **208**, **210** can be configured to apply a non-uniform weighting to input signals provided to the antennas of the array **200**. For example, to limit undesirable sidelobes, a Taylor weighting can be applied to the power delivered to the antennas of the array **200**, such that a greatest power is emitted from antennas toward a center of the array **200** and a least power is emitted from antennas at corners of the array **200**. The feed networks **208**, **210** are configured to apply the non-uniform weighting to the input signals provided to the antennas of the array **200** by way of variations in the geometry of the traces of the feed networks **208**, **210**.

Referring once again to FIGS. **3**A and **3**B, the traces of the row feed network **302** and the row-combining feed network **306** can be configured to have different dimensions according to which antennas the traces deliver signals to. By way of example, and referring now to FIG. **3**A, the first and second traces **310**, **312** of the row feed network **302** can be configured to have substantially similar geometry so that each half of the row **300** supplied by the first and second traces **310**, **312** receives a same input power. A third trace **326** and a fourth trace **328** that branch from the first trace **310** of the row feed network **302** can have different geometries in order to deliver different amounts of power to the groups of antennas served by the third trace **326** and the fourth trace **328**. For example, the third trace **326** can be configured such that the third trace **326** receives less input power than the fourth trace **328**, since the third trace **326** feeds antennas that are further from the center of the row **300** than antennas fed by the fourth trace **328**. The differences in input power received by the third trace **326** and the fourth trace **328** can be realized by selectively configuring the geometries of the traces **326**, **328** such that the impedance looking into the fourth trace **328** is better matched to the impedance looking into the first trace **310** than is the impedance looking into the third trace **326**. In general, geometries of traces of the feed networks **208**, **210** can be configured to deliver different amounts of input power to different antennas of the array **200** by way of differential impedance matching.

While certain exemplary feed networks **208**, **210** that are configured to provide input signals to multiple antennas in the array **200** have been described herein, it is to be understood that in other embodiments, the array **200** can be configured such that each of its antennas has its own distinct input lines that are not used to feed any of the other antennas. In an exemplary embodiment, each antenna of the array **200** can be fed by a first input line connected solely to a first stripline conductor of the antenna, and by a second input line connected solely to a second stripline conductor of the antenna. In such embodiments, the first input line can provide input signals that have a linear horizontal polarization, and the second input line can provide input signals that have a linear vertical polarization. Embodiments in which each of the antennas of the array **200** have their own input lines can facilitate operation of the array **200** as a phased array.

The array **200** can be coupled to one or more waveguides to facilitate efficient coupling between the array **200** and a driver of the array, such as a signal generator. Referring now to FIGS. **4**A-**4**D, a plurality of partial-transparency perspective views of a stripline-to-waveguide coupler **400** are illustrated. The coupler **400** is configured to allow signals propagating in a waveguide to be coupled to the feed networks **208**, **210** of the array **200** by way of primary array input ports **220**, **222**. However, it is to be understood that the coupler **400** is suitable for use in any of various applications wherein signals are desirably coupled from a waveguide to a stripline.

Referring now specifically to FIG. **4**A, a perspective view of an exterior of the coupler **400** is shown. The coupler **400** includes a waveguide **402** and a coupling slot **404**. The waveguide **402** extends from a first face **406** of the coupler **400** and into an interior of the coupler **400**. The waveguide **402** is configured to propagate signals (e.g., TE10 signals) that are desirably transmitted by way of a stripline. The coupling slot **404** extends from a second face **408** of the coupler **400** and into the interior of the coupler **400**. The coupling slot **404** is configured to accommodate a stripline assembly.

Referring now specifically to FIG. **4**B, a perspective view of the coupler **400** is shown wherein an exterior of the coupler **400** is partially transparent. The perspective view of FIG. **4**B illustrates certain features of the waveguide **402** and the coupling slot **404**. The waveguide **402** extends into, but not through, the coupler **400**. In other words, the waveguide **402** has a solid top **410**. The coupling slot **404** extends through the coupler **400** and into the waveguide **402** such that a stripline assembly inserted into the coupling slot **404** can extend into the waveguide **402**. An interior **412** of the waveguide **402** can be an air-filled cavity. A distance between the slot **404** and the top **410** of the waveguide can be approximately equal to $\lambda/4$ where λ is the free-space wavelength of a signal desirably coupled between the waveguide **402** and a stripline positioned in the slot **404**.

Referring now to FIG. **4**C, a perspective view of the coupler **400** is illustrated, wherein the exterior of the coupler **400** and the waveguide **402** are partially transparent such that a stripline assembly **414** positioned in the coupling slot **404** is visible. The stripline assembly **414** includes a first dielectric layer **416** and a second dielectric layer **418**. Referring now to FIG. **4**D, a perspective view of the coupler **400** is illustrated, wherein the exterior of the coupler **400**, the waveguide **402**, and the dielectric layers **416**, **418** of the stripline assembly **414** are partially transparent. As shown in FIG. **4**D, the stripline assembly **414** further includes a stripline conductor **420** that is sandwiched between the first dielectric layer **416** and the second dielectric layer **418**. Signals propagating in the waveguide **402** couple to the stripline conductor **420** and vice versa. In exemplary embodiments, the stripline conductor **420** can be connected to one of the primary array inputs **220**, **222** of the feed networks **208**, **210**, thereby facilitating input of signals to the array **200** by way of the waveguide **402**. In such embodiments, the dielectric layers **416**, **418** can be the same dielectric layers used to form antennas of the array **200** (e.g., the dielectric layers **108** and **112** of the antenna **100**).

FIG. **5** illustrates an exemplary methodology relating to making an antenna suitable for inclusion in a planar array. While the methodology is shown and described as being a series of acts that are performed in a sequence, it is to be understood and appreciated that the methodology is not limited by the order of the sequence. For example, some acts can occur in a different order than what is described herein. In addition, an act can occur concurrently with another act. Further, in some instances, not all acts may be required to implement a methodology described herein.

Referring now to FIG. **5**, a methodology **500** for making an antenna is illustrated. The methodology **500** begins at **502**, and at **504**, a first dielectric layer is obtained. The first dielectric layer has a first thickness and can have a first ground plane formed thereon. At **506**, a second dielectric layer is obtained. The second dielectric layer can have a first side and a second side opposite the first side. The first side can have a stripline conductor formed thereon. The second side can have a second ground plane formed thereon. The second ground plane can include a slot (e.g., an H-slot or a linear slot) that is aligned with the stripline conductor formed on the first side of the second dielectric layer. The slot is configured such that signals propagating along the stripline conductor couple into the slot.

At **508**, a third dielectric layer is obtained, wherein the third dielectric layer has a patch radiating element formed thereon. For example, the patch radiating element can be formed as part of a metallization layer applied to the third dielectric layer. At **510**, the first dielectric layer is fixed to the second dielectric layer such that the first dielectric layer is positioned between the first ground plane and the stripline conductor formed on the first side of the second dielectric layer. In exemplary embodiments, the first dielectric layer can be fixed to the second dielectric layer by way of an adhesive applied between the first dielectric layer and the second dielectric layer. In various other embodiments, the first dielectric layer and the second dielectric layer can be fixed together by way of clamps, fasteners, or the like. The second dielectric layer has a second thickness that is less than the first thickness of the first dielectric layer. For example, the first thickness can be sufficiently great that propagation of signals in the stripline conductor is not adversely affected by the presence of the first ground plane, whereas the second thickness can be sufficiently small that signals propagating in the stripline conductor readily couple into the slot. At **512**, the third dielectric layer is fixed to the combined first and second dielectric layers such that the third dielectric layer is positioned between the patch radiating element and the slot. The second dielectric layer is further fixed to the third dielectric layer such that the patch radiating element is aligned with the slot, so that signals coupled into the slot from the stripline conductor are subsequently coupled to the patch radiating element and radiated outward from the patch radiating element. The methodology **500** ends at **514**.

What has been described above includes examples of one or more embodiments. It is, of course, not possible to describe every conceivable modification and alteration of the above devices or methodologies for purposes of describing the aforementioned aspects, but one of ordinary skill in the art can recognize that many further modifications and permutations of various aspects are possible. Accordingly, the described aspects are intended to embrace all such alterations, modifications, and variations that fall within the spirit and scope of the appended claims. Furthermore, to the extent that the term "includes" is used in either the detailed description or the claims, such term is intended to be inclusive in a manner similar to the term "comprising" as "comprising" is interpreted when employed as a transitional word in a claim.

The invention claimed is:

1. An antenna system, comprising:

a first ground plane;

a first dielectric layer, the first dielectric layer being a solid positioned over the first ground plane, the first dielectric layer having a first thickness;

a stripline conductor positioned over the first dielectric layer;

a second dielectric layer, the second dielectric layer being a solid positioned such that the stripline conductor is disposed between the first dielectric layer and the second dielectric layer, the second dielectric layer having a second thickness that is less than the first thickness;

a second stripline conductor;

a second ground plane positioned over the second dielectric layer, the second ground plane having a slot and a second slot formed therein, wherein the slot is adapted to couple energy from the stripline conductor to the slot and the second slot is adapted to couple energy from the second stripline conductor to the second slot; and

a patch radiating element positioned over the slot, wherein the patch radiating element is adapted to couple energy from the slot to the patch radiating element, whereupon the patch radiating element radiates at least a portion of the energy coupled from the slot and radiates at least a portion of the energy coupled from the second slot.

2. The antenna system of claim **1**, wherein the second slot is positioned such that energy couples from the second slot to the patch radiating element, whereupon the patch radiating element radiates at least a portion of the energy coupled from the second slot.

3. The antenna system of claim **1**, wherein the second slot is aligned in an orthogonal direction to the first slot.

4. The antenna system of claim **1**, wherein the antenna system is adapted to radiate in the Ku-band, wherein the first thickness is between 59 and 65 mil, inclusive, and the second thickness is between 19 and 21 mil, inclusive.

5. The antenna system of claim **1**, wherein a signal radiated by the patch radiating element has a fractional bandwidth of at least 10%.

6. The antenna system of claim **1**, wherein the first ground plane is formed as a metallization layer on the first dielectric layer.

7. The antenna system of claim **1**, wherein the stripline conductor is formed as a metallization layer on a first side of the second dielectric layer, the second ground plane formed as a metallization layer on a second side of the second dielectric layer.

8. The antenna system of claim **1**, further comprising a plurality of antennas, wherein the plurality of antennas includes a first antenna, the first antenna comprising the first dielectric layer, the stripline conductor, the second dielectric layer, the second ground plane, and the patch radiating element.

9. The antenna system of claim **8**, wherein the plurality of antennas further includes a second antenna, the antenna system further comprising a feed network, the feed network configured such that responsive to the feed network receiving an input signal, the feed network delivers a first signal having a first power to the first antenna and delivers a second signal having a second power to the second antenna, wherein the first power is different from the second power.

10. The antenna system of claim **1**, further comprising a third solid dielectric layer positioned between the second ground plane and the patch radiating element.

11. The antenna system of claim **1**, wherein the slot is an H-slot that includes at least one tuning feature, a first tuning feature extending from a first straight portion of the slot toward a second straight portion of the slot that is parallel to the first straight portion.

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