



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
03.05.2023 Bulletin 2023/18

(21) Application number: **21206066.9**

(22) Date of filing: **02.11.2021**

(51) International Patent Classification (IPC):
H01Q 1/38 ^(2006.01) **H01Q 1/52** ^(2006.01)
H01Q 13/06 ^(2006.01) **H01Q 21/06** ^(2006.01)
H01Q 21/28 ^(2006.01) **H01Q 3/26** ^(2006.01)
H01Q 1/32 ^(2006.01) **H01Q 5/40** ^(2015.01)

(52) Cooperative Patent Classification (CPC):
H01Q 1/525; H01Q 1/3233; H01Q 1/38;
H01Q 3/267; H01Q 5/40; H01Q 13/06;
H01Q 21/065; H01Q 21/28

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

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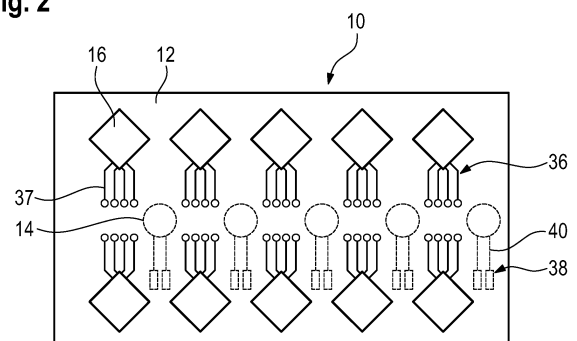
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(54) **ANTENNA ARRAY**

(57) An antenna array (10) is described. The antenna array (10) comprises a printed circuit board (12), at least one reception antenna (14), at least one transmission antenna (16), a reception feeding network (38) associated with the at least one reception antenna (14), and a transmission feeding network (36) associated with the at least one transmission antenna (16). The printed circuit board (12) comprises a first RF layer and a second RF layer, wherein the first RF layer and the second RF layer are arranged on opposite sides of the printed circuit board (12) and/or wherein the first RF layer (18) and the second RF layer (22) form different layers of the printed circuit board (12). The first RF layer comprises the at least one transmission antenna (16) and the transmission feeding network (36). The second RF layer comprises the at least one reception antenna (14) and the reception feeding network (38). At least one waveguide element is provided in the printed circuit board, wherein the at least one waveguide element extends through the printed circuit board. The at least one waveguide element is configured to conduct electromagnetic waves at least between the first RF layer and the second RF layer. The at least one waveguide element is coupled with the at least one transmission antenna (16), such that the at least one transmission antenna (16) can radiate through the at least one waveguide element, and/or the at least one waveguide

element is coupled with the at least one reception antenna (14), such that the at least one reception antenna (14) can be fed through the at least one waveguide element.

Fig. 2



Description

[0001] The invention generally relates to an antenna array.

[0002] Antenna arrays have a large variety of different technical applications in multiple technical fields.

[0003] In general, antenna arrays can be used for testing electronic devices under test over the air in so-called over-the-air (OTA) measurements or rather for security scans, e.g. at airports. Moreover, antenna arrays can also be used for testing radar sensors in advance to employing them in vehicles, e.g. at least partially autonomously driven vehicles. These tests are usually performed in either hardware-in-the-loop (HiL) or vehicle-in-the-loop (ViL) setups. Generally, antenna arrays may be used for RF imaging techniques, particularly for microwave imaging techniques.

[0004] More and more electronic devices to be tested, particularly automotive radar sensors, utilize the multiple-input-multiple-output (MIMO) principle, where virtual arrays are generated in order to increase the system's angular accuracy. However, if the MIMO principle is applied by the respective electronic device, the antennas of the test system need to be monostatic, i.e. the transmission antennas and the reception antennas need to be at the same geometrical position, or need to be at least aligned in a small angular segment.

[0005] Getting the antennas of such systems closely together is a challenging task, as the feeding network of the transmission antennas and the feeding network of the reception antennas require installation space.

[0006] Thus, the object of the present invention is to provide a compact antenna array.

[0007] According to the invention, the problem is solved by an antenna array comprising a printed circuit board, at least one reception antenna, at least one transmission antenna, a reception feeding network associated with the at least one reception antenna, and a transmission feeding network associated with the at least one transmission antenna. The printed circuit board comprises a first RF layer and a second RF layer, wherein the first RF layer and the second RF layer form different layers of the printed circuit board. The first RF layer comprises the at least one transmission antenna and the transmission feeding network. The second RF layer comprises the at least one reception antenna and the reception feeding network. At least one waveguide element is provided in the printed circuit board, wherein the at least one waveguide element extends through the printed circuit board. The at least one waveguide element is configured to conduct electromagnetic waves at least between the first RF layer and the second RF layer. The at least one waveguide element is coupled with the at least one transmission antenna, such that the at least one transmission antenna can radiate through the at least one waveguide element, and/or the at least one waveguide element is coupled with the at least one reception antenna, such that the at least one reception antenna can be fed through the at least one waveguide element.

element.

[0008] The invention is based on the idea to provide the at least one transmission antenna, the at least one reception antenna, and their respectively associated feeding networks in different layers of the printed circuit board. This way, the lateral distance between the at least one transmission antenna and the at least one reception antenna can be reduced significantly since the respective connections of the antennas, namely the feeding networks, can be located in different layers of the printed circuit board.

[0009] In other words, seen from a reference point in front of the antenna array, neighboring transmission antennas and reception antennas are located within a small solid angle.

[0010] Generally, the first RF layer and the second RF layer may be arranged on opposite sides of the printed circuit board, particularly associated with opposite outer sides of the printed circuit board or rather establishing the opposite outer sides of the printed circuit board.

[0011] Hence, the at least one transmission antenna, the at least one reception antenna, and their respectively associated feeding networks may be provided on opposite sides of the printed circuit board. Thus, the lateral distance between the at least one transmission antenna and the at least one reception antenna can be reduced significantly since the respective connections of the antennas, namely the feeding networks, can be located on opposite sides.

[0012] Therein and in the following, the term "in front" is understood to refer to the main transmission direction and/or the main reception direction of the antenna array. Typically, the antenna array has a main side that is associated with the field of view (FOV) of the respective antenna array.

[0013] For instance, the at least one waveguide element provides the possibility to feed the at least one reception antenna through the printed circuit board (i.e. to receive electromagnetic waves via the at least one reception antenna through the printed circuit board) or to radiate electromagnetic waves from the transmission antennas through the printed circuit board towards an area under test, namely an area that is scanned by means of the respective antenna array.

[0014] Thus, it is ensured that the transmission direction of the at least one transmission antenna and the reception direction of the at least one reception antenna are approximately equal to each other even though the at least one transmission antenna and the at least one reception antenna are provided on opposite sides of the printed circuit board and/or in different layers of the printed circuit board.

[0015] The printed circuit board may comprise a plurality of transmission antennas and/or a plurality of reception antennas. Accordingly, a plurality of waveguide elements may be provided that each extend through the printed circuit board. Each transmission antenna and/or

each reception antenna may be coupled with one of the waveguide elements, respectively.

[0016] The antenna array according to the present invention allows for a compact placement of transmission antennas and reception antennas, wherein the transmission directions and the reception directions of the different antennas (substantially) coincide. Accordingly, a good approximation for monostatic antennas is provided by antenna groups comprising at least one transmission antenna and at least one reception antenna each.

[0017] The antenna array may be configured to be operated in a multiple-input-multiple-output (MIMO) operational mode.

[0018] Particularly, each waveguide element is coupled with one of the transmission antennas, respectively, or with one of the reception antennas, respectively. In other words, exactly one waveguide may be provided for each transmission antenna, respectively. Alternatively or additionally, exactly one waveguide may be provided for each reception antenna, respectively.

[0019] Particularly, only reception antennas or only transmission antennas are provided on a common side of the printed circuit board, e.g. on or in the same layer of the printed circuit board.

[0020] In other words, the first RF layer solely comprises the transmission antenna(s) and the transmission feeding network associated with the transmission antenna(s), whereas the second RF layer solely comprises the reception antenna(s) and the reception feeding network associated with the reception antenna(s).

[0021] However, the first RF layer may comprise one or several transmission antennas and one or several reception antennas, as well as a transmission feeding network associated with the one or several transmission antennas and a reception feeding network associated with the one or several reception antennas.

[0022] Likewise, the second RF layer may comprise one or several transmission antennas and one or several reception antennas, as well as a transmission feeding network associated with the one or several transmission antennas and a reception feeding network associated with the one or several reception antennas.

[0023] For instance, the first RF layer may be the one that is closer to the area to be scanned compared with the second RF layer that is further distanced by the thickness of the printed circuit board substantially. However, it is also possible that the second RF layer is the one that is closer to the area to be scanned area compared with the first RF layer that is further distanced by the thickness of the printed circuit board substantially.

[0024] Particularly, the antenna array may be configured to transmit electromagnetic waves to a first area to be scanned and to a second area to be scanned, wherein the first area to be scanned is closer to the first RF layer, and wherein the second area to be scanned is closer to the second RF layer.

[0025] Alternatively or additionally, the antenna array may be configured to receive electromagnetic waves

from a first area to be scanned and from a second area to be scanned, wherein the first area to be scanned is closer to the first RF layer, and wherein the second area to be scanned is closer to the second RF layer.

[0026] In other words, the transmission antenna(s), the reception antenna(s), and the waveguide element(s) may be placed such that the antenna array can scan two different areas to be scanned.

[0027] For example, the first area to be scanned and the second area to be scanned may be located opposite to each other, namely on opposite sides of the printed circuit board. This way, a nearly complete spherical coverage of an area around the antenna array is obtained by means of the antenna array.

[0028] According to an aspect of the present invention, a boresight direction of the at least one transmission antenna and a boresight directions of the at least one reception antenna are parallel to each other. Accordingly, the main transmission directions of the transmission antenna(s) and the main reception directions of the reception antenna(s) are equal to each other, at least within predefined error boundaries. For example, the boresight direction of the at least one transmission antenna and the boresight direction of the at least one reception antennas may differ from each other by 5° or less, particularly by 1° or less.

[0029] Therein and in the following, the boresight direction of a transmission antenna is understood to denote the main transmission direction of the respective transmission antenna, i.e. the direction of highest radiated power.

[0030] Analogously, the boresight direction of a reception antenna is understood to denote the main reception direction of the respective reception antenna, i.e. the direction of highest reception sensitivity.

[0031] According to another aspect of the present invention, a boresight direction of the at least one transmission antenna is perpendicular to the printed circuit board, at least within predefined error boundaries. Alternatively or additionally, a boresight directions of the at least one reception antenna is perpendicular to the printed circuit board, at least within predefined error boundaries. Accordingly, the main transmission direction(s) of the antenna array and/or the main reception direction(s) of the antenna array is (are) perpendicular to the printed circuit board.

[0032] For example, the boresight direction of the at least one transmission antenna and the boresight direction of the at least one reception antenna may have an angle with respect to the printed circuit board that differs from 90° by 5° or less, particularly by 1° or less.

[0033] Thus, a measurement region for testing a device under test, such as a radar sensor, may be provided in front of the printed circuit board in a predefined solid angle region around an axis, particularly around a center axis, that is perpendicular to the printed circuit board.

[0034] As already mentioned above, two measurement regions may be provided on opposite sides of the

printed circuit board.

[0035] In an embodiment of the present invention, a distance between neighboring antennas is smaller than an operational wavelength of the antenna array, particularly wherein the distance between neighboring antennas is equal to or smaller than half the operational wavelength. This way, grating lobes in the beam pattern (i.e. in the transmission pattern and/or in the reception pattern) of the antenna array can be avoided for beamforming purposes.

[0036] Therein and in the following, the term "operational wavelength" is understood to denote the wavelength of electromagnetic waves transmitted by the antenna array in the boresight direction of the transmission antennas that have the highest radiated power and/or the wavelength of electromagnetic waves received by the antenna array and the boresight direction of the reception antennas with the highest reception sensitivity. Particularly, these wavelengths are equal to each other.

[0037] If the antenna array is configured to transmit and/or receive different electromagnetic waves with different frequencies, for example in a MIMO operational mode, the term operational wavelength may also refer to a wavelength that is associated with a central frequency of the bandwidth covered by the antenna array.

[0038] Moreover, the term operational wavelength may also refer to the wavelength that is associated with the highest frequency of a certain frequency range used, thereby ensuring that the smallest wavelength associated with the frequency range used is always higher than the distance between the neighboring antennas.

[0039] However, it is to be understood that a distance between at least one pair of neighboring antennas may also be larger than the operational wavelength. Particularly, the distances between several or even all pairs of neighboring antennas may be larger than the operational wavelength.

[0040] In a further embodiment of the present invention, the number of transmission antennas is a multiple of the number of reception antennas, particularly an integer multiple. For example, the number of transmission antennas may be two times, three times, or a higher integer multiple of the number of reception antennas.

[0041] This is particularly useful if the antenna array is used as part of a radar simulator that is configured to simulate radar targets for testing a radar sensor. In that case, two, three or more transmission antennas may be associated with each of the reception antennas, respectively. Accordingly, two, three or more radar targets can be simulated independently by means of the multiple transmission antennas associated with each reception antenna.

[0042] However, it is to be understood that the number of transmission antennas may also be equal to the number of reception antennas or may even be smaller than the number of reception antennas.

[0043] According to a further aspect of the present invention, the at least one waveguide element is at least

partially established as a circular or rectangular aperture extending through the printed circuit board. In other words, the at least one waveguide element is established as a circular or rectangular waveguide extending through the printed circuit board.

[0044] However, it is to be understood that the at least one waveguide element may have any other suitable shape.

[0045] For example, the circular apertures may be established as bores in the printed circuit board.

[0046] A plurality of vias may be provided in the printed circuit board around the at least one waveguide element, particularly around each waveguide element. In general, the vias electrically connect different layers of the printed circuit board, for example the first RF layer and the second RF layer, and optionally any intermediate layer(s). By providing a plurality of these vias around the at least one waveguide element, the reflection properties of a solid metal wall are imitated. In other words, it is not necessary (but possible) that the waveguide elements have an inner metal wall, respectively. Instead, the plurality of vias around the at least one waveguide element are sufficient to ensure these electromagnetically conductive characteristics, namely reflection of electromagnetic waves within the respective waveguide element, and thus the transmission of electromagnetic waves through the respective waveguide element.

[0047] In an embodiment of the present invention, the antenna array further comprises a front side cover located on a transceiver side of the antenna array, wherein the at least one waveguide element extends through the front side cover. The front side cover provides protection for the antenna array, particularly protection from mechanical impacts and from dust or other particles that could impair the functionality of the antenna array.

[0048] Therein and in the following, the term "transceiver side" is understood to denote the side of the antenna array or rather the side of the printed circuit board to which the antenna array transmits electromagnetic waves and/or from which the antenna array receives electromagnetic waves.

[0049] Optionally, the antenna array further comprises a backside cover located on a side of the antenna array that is opposite to the front side cover. The at least one waveguide element may extend through the back side cover, such that the antenna array has two transceiver sides.

[0050] The explanations given in the following with respect to the front side cover likewise apply for the back side cover.

[0051] The front side cover may at least partially consist of metal. For example, the front side cover may consist of a resin body that is coated with a metal. Alternatively, the front side cover may completely consist of metal. The metal may for example be copper.

[0052] In any way, at least inner walls of the portions of the at least one waveguide element extending through the front side cover may be covered with or consist of a

metal, particularly copper, such that the inner walls reflect electromagnetic waves.

[0053] According to an aspect of the present invention, the at least one waveguide element comprises a radome, particularly wherein the radome fills the at least one waveguide element at least partially. The radome may fill the at least one waveguide element completely. In general, the radome provides mechanical protection for the at least one transmission antenna or for the at least one reception antenna. For example, the radome prevents direct contact of the antennas with an object touching or hitting the antenna array. Moreover, the radome prevents dust or other particles from soiling the at least one waveguide element.

[0054] If the antenna array comprises several waveguide elements, several or all of the waveguide elements may comprise a radome, respectively.

[0055] The radome may consist of a non-conductive material, particularly wherein the radome consists of polystyrene. By this choice of material, the radome does not significantly dampen electromagnetic waves traveling through the at least one waveguide element. Moreover, the radome lowers the (lower) cutoff frequency of the at least one waveguide element, which is desirable for certain applications.

[0056] In a further embodiment of the present invention, the at least one antenna connected to the at least one waveguide element is provided with a back cap, particularly wherein the back cap consists of metal at least partially. The back cap prevents electromagnetic waves from exiting the respective waveguide element to the back side of the antenna array. In the case of reception antennas, this improves the reception efficiency of the reception antennas. In the case of transmission antennas, this improves the total radiated power transmitted to the front side.

[0057] According to another aspect of the present invention, at least the at least one antenna connected to the at least one waveguide element is established as patch antenna elements, particularly wherein a shape of the patch antenna element matches a shape of the at least one waveguide element. For example, circular patch antenna elements are particularly advantageous in combination with circular waveguide elements. Likewise, rectangular patch antenna elements are particularly advantageous in combination with rectangular waveguide elements. The geometry, particularly the size and/or radius, of the patch antenna elements may match the geometry the waveguide elements, such that both an optimal transmission and an optimal reception of electromagnetic waves are guaranteed.

[0058] The printed circuit board may comprise a plurality of transmission antennas and a plurality of reception antennas, wherein the transmission antennas and the reception antennas may be arranged in, particularly parallel, rows or columns. For example, two rows or columns of transmission antennas may be provided, wherein one row or column of reception antennas is provided between

the two rows or columns of transmission antennas. Particularly, rows or columns of transmission antennas may alternate with rows or columns of reception antennas.

[0059] According to an aspect of the present invention, the printed circuit board is established as a multi-layer circuit board. Accordingly, besides the two RF layers, the printed circuit board may comprise at least one FR-4 layer and/or at least one additional metal layer. In general, the at least one FR-4 layer is an insulating, i.e. non-conductive layer that is flame retardant. The at least one additional metal layer may serve for conducting low-frequency signals, such as control signals for controlling the transmission antennas and/or the reception antennas.

[0060] The first RF layer and/or the second RF layer may form the outermost layer(s) of the printed circuit board. However, it is to be understood that the first RF layer and/or the second RF layer may be an inner layer of the printed circuit board, respectively.

[0061] In an embodiment of the present disclosure, the transmission feeding network comprises microstrip lines and/or a coplanar feeding. Alternatively or additionally, the reception feeding network comprises microstrip lines and/or a coplanar feeding. Accordingly, the transmission antennas may be established as microstrip patch antennas with coplanar feed lines. Alternatively or additionally, the reception antennas may be established as microstrip patch antennas with coplanar feed lines.

[0062] However, the transmission feeding network and/or the reception feeding network may comprise at least one strip line, particularly several strip lines.

[0063] The foregoing aspects and many of the attendant advantages of the claimed subject matter will become more readily appreciated as the same become better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

- Figure 1 schematically shows a cross section of an antenna array according to the present invention;
- Figure 2 schematically shows a top view of the antenna array of Figure 1; and
- Figures 3 to 5 show different perspective views of a portion of the antenna array of Figure 1.

[0064] The detailed description set forth below in connection with the appended drawings, where like numerals reference like elements, is intended as a description of various embodiments of the disclosed subject matter and is not intended to represent the only embodiments. Each embodiment described in this disclosure is provided merely as an example or illustration and should not be construed as preferred or advantageous over other embodiments. The illustrative examples provided herein are not intended to be exhaustive or to limit the claimed subject matter to the precise forms disclosed.

[0065] For the purposes of the present disclosure, the

phrase "at least one of A, B, and C", for example, means (A), (B), (C), (A and B), (A and C), (B and C), or (A, B, and C), including all further possible permutations when more than three elements are listed. In other words, the term "at least one of A and B" generally means "A and/or B", namely "A" alone, "B" alone or "A and B".

[0066] Figure 1 shows a cross section of an antenna array 10. The antenna array 10 comprises a printed circuit board 12, a plurality of reception antennas 14, and a plurality of transmission antennas 16.

[0067] In general, the antenna array 10 may be used for various applications. The antenna array 10 may be used for testing an electronic device over the air. Alternatively or additionally, the antenna array 10 may be used in RF imaging applications, particularly in microwave imaging applications.

[0068] For example, the antenna array 10 may be utilized in a radar target simulator for testing radar sensors in hardware-in-the-loop (HiL) or vehicle-in-the-loop (ViL) setups.

[0069] The printed circuit board 12 comprises a first RF layer 18 on a front side 20 of the antenna array 10, wherein the first RF layer 18 comprises the plurality of transmission antennas 16.

[0070] The printed circuit board 12 further comprises a second RF layer 22 on a back side 24 of the antenna array 10, wherein the second RF layer 22 comprises the plurality of reception antennas 14.

[0071] It is noted that the printed circuit board 12 may comprise only a single transmission antenna 16 and/or only a single reception antenna 14.

[0072] Without restriction of generality, an embodiment of the antenna array 10 comprising a plurality of transmission antennas and a plurality of reception antennas 14 is described in the following.

[0073] Both RF layers 18, 22 are substantially distanced from each other by the thickness of the printed circuit board 12.

[0074] In other words, the first RF layer 18 and the second RF layer 22 are provided on opposite sides of the printed circuit board 12.

[0075] Accordingly, the plurality of reception antennas 14 and the plurality of transmission antenna 16 are provided on opposite sides of the printed circuit board 12.

[0076] It is noted that the first RF layer 18 and/or the second RF layer 22 may be established as an inner layer of the printed circuit board 12.

[0077] Without restriction of generality, an embodiment of the antenna array 10 with the RF layers 18, 22 forming the outermost layers of the printed circuit board 12 is described in the following.

[0078] Moreover, the first RF layer 18 and/or the second RF layer 22 may comprise a mixture of transmission antennas 16 and reception antennas 14, respectively, and the corresponding feeding networks.

[0079] Without restriction of generality, an embodiment of the antenna array 10 with the first RF layer 18 comprising only transmission antennas 16 and the sec-

ond RF layer 22 comprising only reception antennas 14 is described in the following.

[0080] Between the first RF player 18 and the second RF player 22, several insulating layers 26 and metal layers 28 are provided, wherein the insulating layers 26 and the metal layers 28 alternate.

[0081] The insulating layers 26 may be established as FR-4 layers. The metal layers 28 may be used for transmitting low-frequency signals within the printed circuit board 12, for example control signals for controlling the transmission antennas 16 and the reception antennas 14.

[0082] The antenna array 10 further comprises a front side cover 30 that is attached to the printed circuit board 12 on the transceiver side of the antenna array 10, i.e. on the front side 20.

[0083] The front side cover 30 may at least partially consist of a metal. For example, the front side cover 30 may consist of a resin body that is coated with a metal. Alternatively, the front side cover 30 may completely consist of a metal. The metal may for example be copper.

[0084] Optionally, the antenna array 10 may comprise a back side cover that is attached to the printed circuit board 12 on a side of the antenna array 10 that is opposite to the front side cover 30.

[0085] The antenna array 10 further comprises a plurality of waveguide elements 32.

[0086] In general, the waveguide elements 32 each extend through the printed circuit board 12 from the first RF layer 18 to the second RF layer 22. Moreover, the waveguide elements 32 also extend through the front side cover 30.

[0087] Preferably, the waveguide elements 32 have cylindrical shape, particularly circular-cylindrical shape. For example, the waveguide elements 32 may be established as cylindrical bores, particularly as circular-cylindrical bores through the front side cover 30 and through the printed circuit board 12.

[0088] However, the waveguide elements 32 may have any other suitable cross section. For example, the waveguide elements 32 may have a rectangular cross-section. Thus, the waveguide-elements 32 may have a rectangular-cylindrical shape.

[0089] In the exemplary embodiment shown in Figure 1, the waveguide elements 32 are each coupled with one of the reception antennas 14.

[0090] In other words, the waveguide elements 32 allow the reception antennas 14 to receive electromagnetic waves from the front side 20 of the antenna array 10 through the waveguide elements 32.

[0091] However, it is to be understood that alternatively to the waveguide elements 32 being coupled to the reception antennas 14, the waveguide elements 32 may also be coupled to the transmission antennas 16. In that case, the transmission antennas 16 may be provided in or on the second RF layer 22, while the reception antennas 14 are provided in or on the first RF layer 18.

[0092] The front side cover 30 comprises openings 34

that are associated with the transmission antennas 16 and that allow the transmission antennas 16 to emit electromagnetic waves through the openings 34 to the front side 20 of the antenna array 10.

[0093] Boresight directions B_T of the transmission antennas 16 and the boresight directions B_R of the reception antennas 14 are (essentially) parallel to each other, such that the main transmission direction of the transmission antennas 16 matches the main reception direction of the reception antennas 14.

[0094] For example, the boresight directions B_T of the transmission antennas 16 and the boresight directions B_R of the reception antennas 14 may differ from each other by 5° or less, particularly by 1° or less.

[0095] Particularly, the boresight directions B_T of the transmission antennas 16 and the boresight directions B_R of the reception antennas 14 are (essentially) perpendicular to the printed circuit board 12.

[0096] For example, the boresight directions B_T of the transmission antennas 16 and the boresight directions B_R of the reception antennas 14 may have an angle with respect to the printed circuit board 12 that differs from 90° by 5° or less, particularly by 1° or less.

[0097] In a possible embodiment, the antenna array 10 may be configured to transmit electromagnetic waves to a first area to be scanned and to a second area to be scanned, wherein the first area to be scanned is closer to the first RF layer 18, and wherein the second area to be scanned is closer to the second RF layer 22.

[0098] Alternatively or additionally, the antenna array 10 may be configured to receive electromagnetic waves from a first area to be scanned and from a second area to be scanned, wherein the first area to be scanned is closer to the first RF layer 18, and wherein the second area to be scanned is closer to the second RF layer 22.

[0099] In other words, the transmission antennas 16, the reception antennas 14, and the waveguide elements 32 may be placed and configured such that the antenna array 10 can scan two different areas to be scanned, particularly on opposite sides of the antenna array 10.

[0100] Without restriction of generality, the embodiment depicted in Figure 1 will be explained in more detail in the following. However, it is to be understood that the explanations given below likewise apply to the other possible embodiments described above, possibly with suitable adaptations.

[0101] Figure 2 shows a front side view of a portion of the antenna array 10 described above.

[0102] As is illustrated in Figure 2, the antenna array 10 further comprises a transmission feeding network 36 that is provided in and/or on the first RF layer 18, and that is connected to the plurality of transmission antennas 16.

[0103] The transmission feeding network 36 may comprise microstrip lines 37, which may also be called microstrip feed lines.

[0104] The microstrip lines 37 may be arranged in the same plane as the transmission antennas 16, i.e. in or

on the first RF layer 18, such that a coplanar feeding of the transmission antennas 16 is provided.

[0105] In general, the transmission feeding network 36 is configured to provide signals to be transmitted to the transmission antennas 16.

[0106] Moreover, the transmission antennas 16 may be controlled via the transmission feeding network 36, for example with respect to phase and/or amplitude.

[0107] As is indicated by the dashed lines in Figure 2, the antenna array 10 further comprises a reception feeding network 38 that is provided in and/or on the second RF layer 22, and that is connected to the plurality of reception antennas 14.

[0108] The reception feeding network 38 may comprise microstrip lines 40, which may also be called microstrip feed lines.

[0109] The microstrip lines 40 may be arranged in the same plane as the reception antennas 14, i.e. in or on the second RF layer 22, such that a coplanar feeding of the reception antennas 14 is provided.

[0110] In general, the reception feeding network 38 is configured to forward signals received by means of the reception antennas 14 to other electronic components, for example to a measurement instrument, to an analysis module of a radar target simulator, etc.

[0111] Moreover, the reception antennas 14 may be controlled via the reception feeding network 36, for example with respect to phase and/or amplitude.

[0112] In the exemplary embodiment shown in Figure 2, the transmission antennas 16 and the reception antennas 14 are arranged in rows, particularly wherein the rows are parallel to each other.

[0113] More precisely, two rows of transmission antennas 16 and one row of reception antennas 14 are provided, wherein the single row of reception antennas 14 is provided between the two rows of transmission antennas 16.

[0114] However, it is to be understood that any other arrangement of the reception antennas 14 and the transmission antennas 16 may also be possible, depending on the application of the antenna array 10.

[0115] For example, the reception antennas 14 and the transmission antennas 16 may be arranged in columns or in any other suitable geometrical shape.

[0116] In the exemplary embodiment shown in Figure 2, the number of transmission antenna 16 is twice the number of reception antennas 14.

[0117] If the antenna array 10 is used in a radar target simulator, this implies that at least two radar targets may be simulated independently of each other.

[0118] However, it is to be understood that the number of transmission antennas 16 may be any other multiple, particularly integer multiple, of the number of reception antennas 14. Accordingly, three, four, or even more radar targets may be simulated independently of each other.

[0119] Alternatively, the number of transmission antennas 16 and the number of reception antennas 14 may be equal or the number of transmission antennas 16 may

be smaller than the number of reception antennas 14.

[0120] Figure 3 shows a perspective view of a portion of the antenna array 10 comprising a single reception antenna 14 and a single waveguide element 32.

[0121] As is indicated in Figure 3, each waveguide element 32 may be provided with a radome 42 that fills the respective waveguide element 32 at least partially, particularly completely. Furthermore, the respective radome 42 may be even longer than an opening of the waveguide element 32 as shown in Figure 3.

[0122] Analogously, radomes 42 may be provided in the openings 34 in the front side cover 30.

[0123] In general, the radomes 42 in the waveguide elements 32 provide mechanical protection for the reception antennas 14, while the radomes in the openings 34 provide mechanical protection for the transmission antennas 16.

[0124] For example, the radomes 42 prevents direct contact of the reception antennas 14 with an object touching or hitting the antenna array 10. Moreover, the radomes 42 prevent dust or other particles from soiling the waveguide elements 32.

[0125] The radomes 42 may consist of a non-conductive material, for example polystyrene. By this choice of material, the radomes 42 do not significantly dampen electromagnetic waves traveling through the waveguide elements 32.

[0126] Moreover, the radomes 42 lower the (lower) cut-off frequency of the waveguide elements 32, which is desirable for certain applications.

[0127] As is further illustrated in Figure 3, the reception antennas 14 may be provided with a back cap 44, respectively.

[0128] In general, the back caps 44 prevent electromagnetic waves from exiting the waveguide elements 32 to the back side 24 of the antenna array 10.

[0129] In the case of reception antennas 14, this improves the reception efficiency of the reception antennas 14. In the case of transmission antennas 16, this improves the total radiated power transmitted to the front side 20.

[0130] Figure 4 shows a further perspective view of a portion of the antenna array 10 comprising a single reception antenna 14 and a single waveguide element 32.

[0131] As is illustrated in Figure 4, the reception antennas 14 may be established as a circular patch antenna element 44, respectively.

[0132] This geometry of the reception antennas 14 is particularly advantageous in combination with the circular waveguide elements 32. The size or rather the radius of the circular patch antenna elements 44 may match the size or rather the radius of the waveguide elements 32, such that an optimal reception (or in the case of transmission antennas an optimal transmission) of electromagnetic waves through the waveguide elements 32 is guaranteed.

[0133] If the waveguide elements 32 have another shape, for example a rectangular-cylindrical shape, the

reception antennas 14 may have a shape that matches the shape of the waveguide elements 32. For example, the reception antennas 14 may be established as rectangular patch antenna elements.

[0134] As is further illustrated in Figure 4, a plurality of vias 46 is provided in the printed circuit board 12 around the waveguide elements 32, particularly around each of the waveguide elements 32. As shown in Figure 4, the vias 46 are located on a common portion of a circle around the respective reception antenna 14, particularly in an equally distanced manner.

[0135] As is shown in Figure 5, the vias 46 may extend through all layers of the printed circuit board 12, i.e. from the first RF layer 18 to the second RF layer 22. However, the vias 46 may also extend only through all layers of the printed circuit board 12 despite the first RF layer 18 and the second RF layer 22.

[0136] By providing a plurality of these vias 46 around the waveguide elements 32, the reflection properties of a solid metal wall are imitated. In other words, it is not necessary that the waveguide elements 32 have an inner metal wall.

[0137] However, it is also conceivable that the waveguide elements 32 are provided with a solid inner metal wall.

[0138] However, the plurality of vias 46 around the waveguide elements 32 are sufficient to ensure reflection of electromagnetic waves within the waveguide elements 32 and thus the transmission of electromagnetic waves through the waveguide elements 32.

[0139] Summarizing, the antenna array 10 described above comprises transmission antennas 16 and reception antennas 14 in different layers, particularly on opposite sides, of the printed circuit board 12.

[0140] Due to this arrangement, a compact placement of the transmission antennas 16 and of the reception antennas 14 is possible. Accordingly, a good approximation for monostatic antennas may be provided by antenna groups comprising at least one transmission antenna 16 and at least one reception antenna 14 each.

[0141] Particularly, a distance between neighboring antennas may be smaller than an operational wavelength of the antenna array 10, particularly wherein the distance between neighboring antennas is equal to or smaller than half the operational wavelength.

[0142] In other words, distances between the transmission antennas 16 and the neighboring reception antennas 14 may be smaller than the so-called "lambda-packing-rate", which corresponds to the distances being equal to the operational wavelength of the antenna array 10.

Claims

1. An antenna array, the antenna array (10) comprising a printed circuit board (12), at least one reception antenna (14), at least one transmission antenna (16),

a reception feeding network (38) associated with the at least one reception antenna (14), and a transmission feeding network (36) associated with the at least one transmission antenna (16),

wherein the printed circuit board (12) comprises a first RF layer (18) and a second RF layer (22), wherein the first RF layer (18) and the second RF layer (22) form different layers of the printed circuit board (12), wherein the first RF layer (18) comprises the at least one transmission antenna (16) and the transmission feeding network (36), wherein the second RF layer (22) comprises the at least one reception antenna (14) and the reception feeding network (38), wherein at least one waveguide element (32) is provided in the printed circuit board (12), wherein the at least one waveguide element (32) extends through the printed circuit board (12), wherein the at least one waveguide element (32) is configured to conduct electromagnetic waves at least between the first RF layer (18) and the second RF layer (22), and wherein the at least one waveguide element (32) is coupled with the at least one transmission antenna (16), such that the at least one transmission antenna (16) can radiate through the at least one waveguide element (32), and/or the at least one waveguide element (32) is coupled with the at least one reception antenna (14), such that the at least one reception antenna (14) can be fed through the at least one waveguide element (32).

2. The antenna array of claim 1, wherein a boresight direction of the at least one transmission antenna (16) and a boresight direction of the at least one reception antenna (14) are parallel to each other.
3. The antenna array according to any one of the preceding claims, wherein a boresight direction of the at least one transmission antenna (16) is perpendicular to the printed circuit board (12), and/or wherein a boresight direction of the at least one reception antenna (14) is perpendicular to the printed circuit board (12).
4. The antenna array according to any one of the preceding claims, wherein a distance between neighboring antennas is smaller than an operational wavelength of the antenna array (10), particularly wherein the distance between neighboring antennas is equal to or smaller than half the operational wavelength.
5. The antenna array according to any one of the preceding claims, wherein the number of transmission antennas (16) is a multiple of the number of reception

antennas (14), particularly an integer multiple.

6. The antenna array according to any one of the preceding claims, wherein the at least one waveguide element (32) is at least partially established as a circular or rectangular aperture extending through the printed circuit board (12).
7. The antenna array according to any one of the preceding claims, wherein a plurality of vias (46) is provided in the printed circuit board (12) around the at least one waveguide element (32), particularly around each waveguide element (32).
8. The antenna array according to any one of the preceding claims, further comprising a front side cover (30) located on a transceiver side of the antenna array (10), wherein the at least one waveguide element (32) extends through the front side cover (30), particularly wherein the front side cover (30) consists of metal at least partially.
9. The antenna array according to any one of the preceding claims, wherein the at least one waveguide element (32) comprises a radome (42), particularly wherein the radome (42) fills the at least one waveguide element (32) at least partially.
10. The antenna array according to claim 9, wherein the radome (42) consists of a non-conductive material, particularly wherein the radome (42) consists of polystyrene.
11. The antenna array according to any one of the preceding claims, wherein the at least one antenna connected to the at least one waveguide element (32) is provided with a back cap (44), particularly wherein the back cap (44) consists of metal at least partially.
12. The antenna array according to any one of the preceding claims, wherein at least the at least one antenna connected to the at least one waveguide element (32) is established as a patch antenna element, particularly wherein a shape of the patch antenna element matches a shape of the at least one waveguide element (32).
13. The antenna array according to any one of the preceding claims, wherein the printed circuit board (12) comprises a plurality of transmission antennas (16) and a plurality of reception antennas (14), and wherein the transmission antennas (16) and the reception antennas (14) are arranged in, particularly parallel, rows or columns.
14. The antenna array according to any one of the preceding claims, wherein the printed circuit board (12) is established as a multi-layer circuit board.

15. The antenna array according to any one of the preceding claims, wherein the transmission feeding network (36) comprises microstrip lines (37) and/or a coplanar feeding and/or wherein the reception feeding network (38) comprises microstrip lines (40) and/or a coplanar feeding.

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Fig. 1

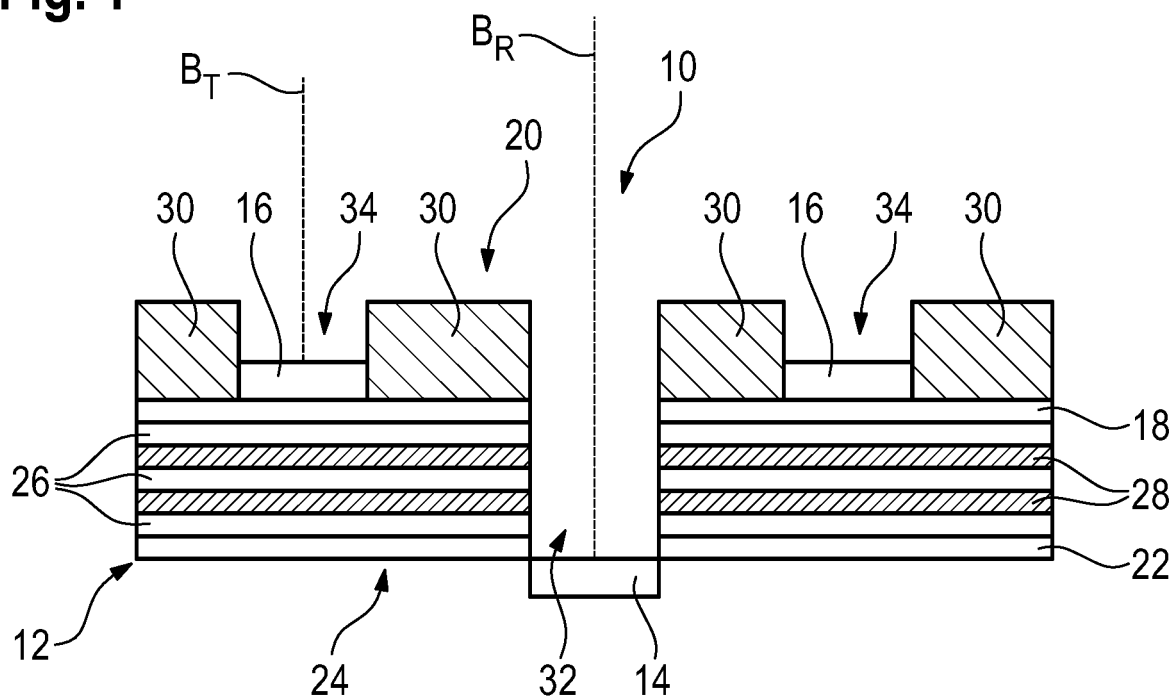


Fig. 2

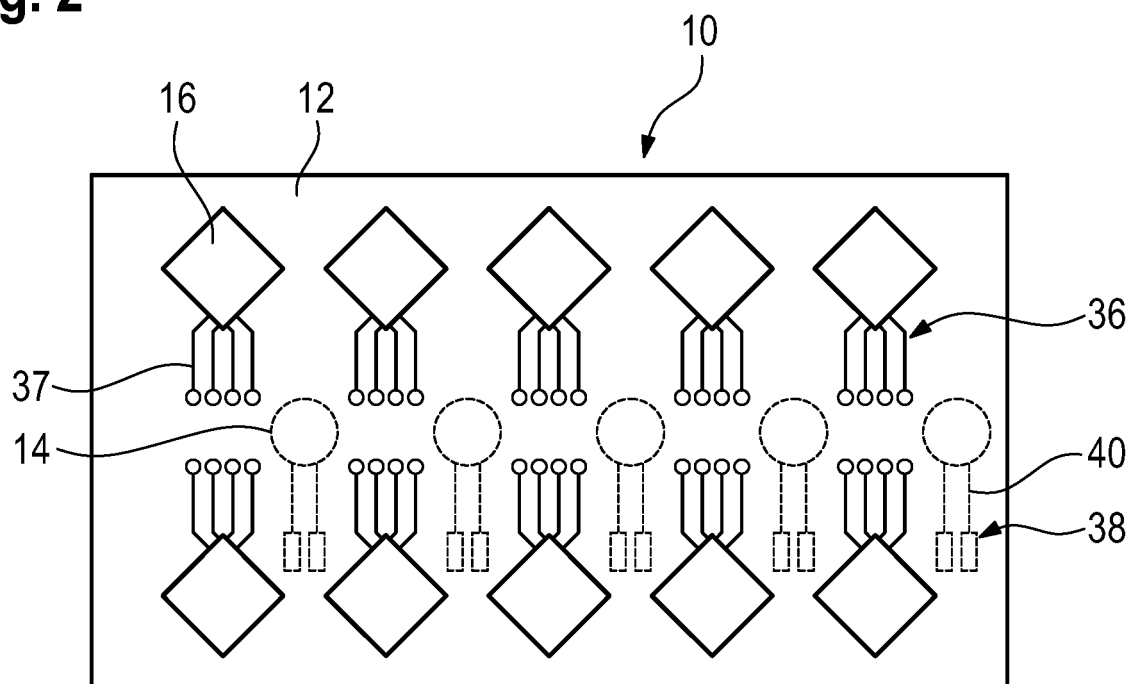


Fig. 3

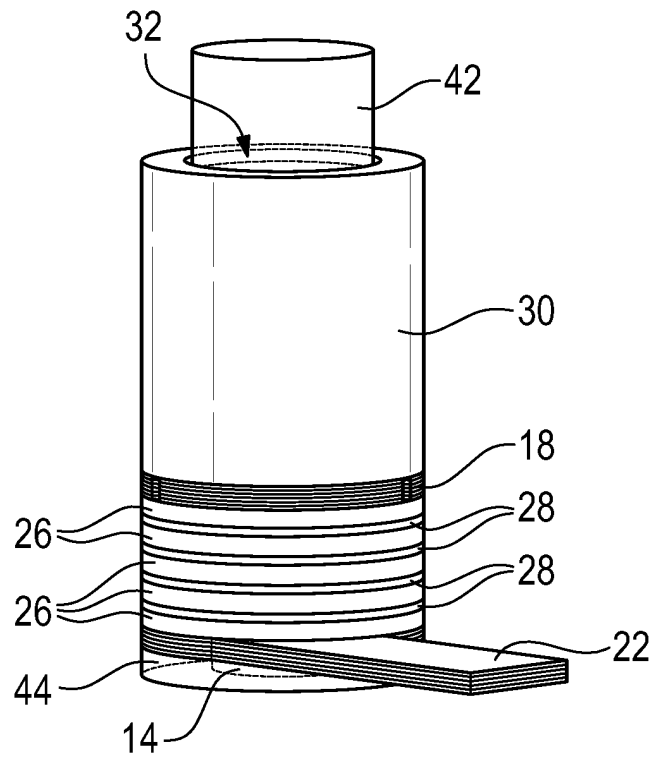


Fig. 4

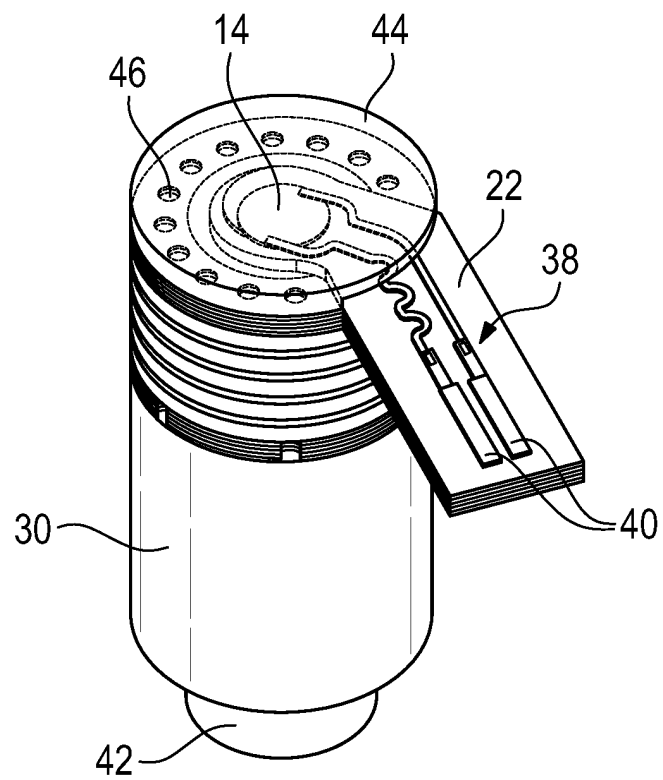
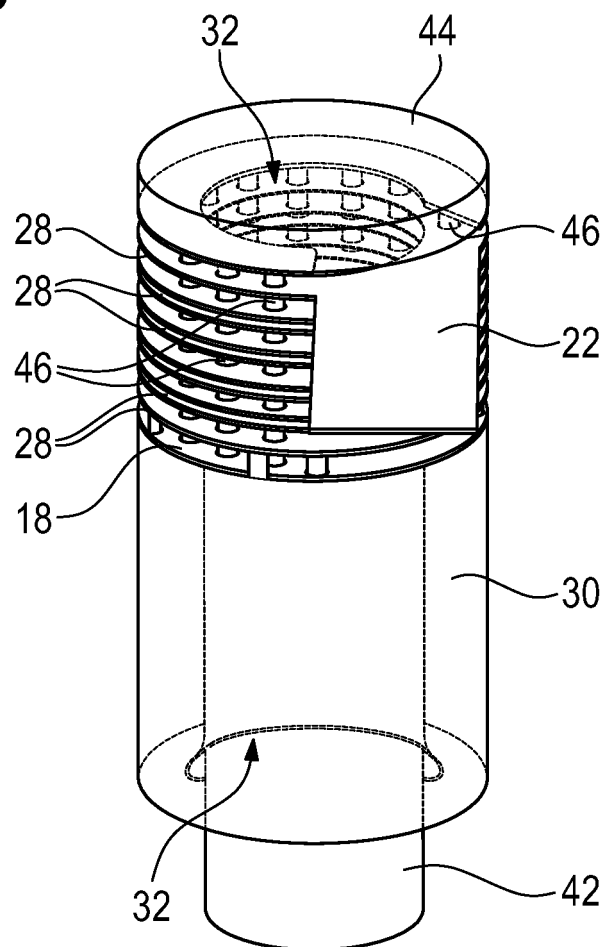


Fig. 5





EUROPEAN SEARCH REPORT

Application Number

EP 21 20 6066

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2021/126353 A1 (LEE HONG SEOK [KR] ET AL) 29 April 2021 (2021-04-29) * paragraphs [0043], [0045], [0055], [0056] * * figures 1, 3, 6 *	1-3, 6-10, 12, 14, 15	INV. H01Q1/38 H01Q1/52 H01Q13/06 H01Q21/06 H01Q21/28 H01Q3/26
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TECHNICAL FIELDS SEARCHED (IPC)

H01Q

The present search report has been drawn up for all claims

1

Place of search

The Hague

Date of completion of the search

19 April 2022

Examiner

Mitchell-Thomas, R

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 21 20 6066

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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