



(51) International Patent Classification:

H01Q 21/06 (2006.01) H01Q 9/04 (2006.01)
H01Q 25/00 (2006.01) H01Q 1/38 (2006.01)

(21) International Application Number:

PCT/KR2023/019078

(22) International Filing Date:

24 November 2023 (24.11.2023)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

10-2023-0161265 20 November 2023 (20.11.2023) KR

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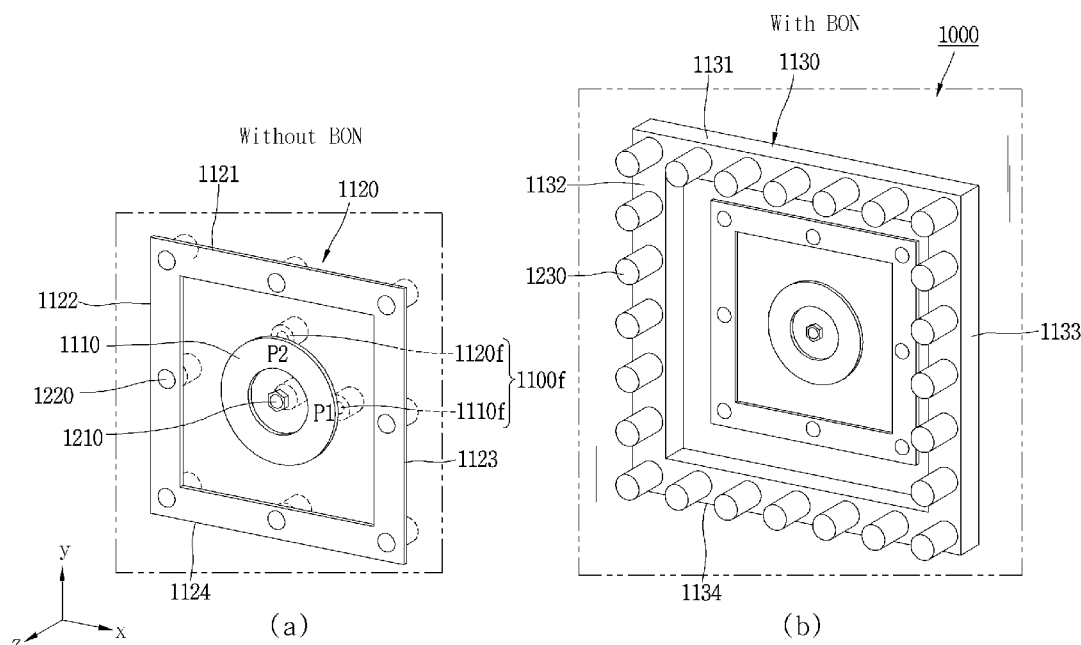
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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST,

(54) Title: ANTENNA MODULE FOR GRATING LOBE MITIGATION AND HIGH GAIN



(57) Abstract: An antenna module may include a first metal patch having a dielectric region therein; a second metal patch surrounding the first metal patch; a feeding structure vertically coupled to the first metal patch at at least one point of the first metal patch; a first vertical structure vertically formed of a metallic material on the inner dielectric region of the first metal patch; and second vertical structures vertically formed of a metallic material at different points of the second metal patch.

SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

Description

Title of Invention: ANTENNA MODULE FOR GRATING LOBE MITIGATION AND HIGH GAIN

Technical Field

- [1] The present disclosure relates to an antenna module for grating lobe mitigation and high gain. One particular implementation relates to an antenna module having a Bed of Nail (BON) structure for grating lobe mitigation and high gain.

Background Art

- [2] In order to increase communication capacity, wireless communication systems require predetermined bandwidths or more. In recent times, researches for methods using millimeter wave (mmWave) frequency bands in 5G and 6G communication systems are ongoing.
- [3] A phased array antenna for mmWave frequency may generally be implemented in a planar layer structure as in a PCB or LTCC technology. The phased array antenna implemented in the planar layer structure may include resonating antenna elements operating in a narrow band, like patch antennas. Therefore, the phased array antenna in the planar layer structure has a difficulty in synthesizing antenna beams in wide frequency bands and implementing constant beamforming performance.
- [4] In the phased array antenna, the number of antenna elements may increase to increase gains of the antenna elements. However, this causes an increase in costs and complexity of a system. In this regard, an antenna gain may be increased by enlarging a spacing between antenna elements to some extents, but a beam steering range without grating lobes is decreased.
- [5] A wide spacing between antenna elements may generally be advantageous in high antenna gain. However, as the spacing between the antenna elements is increased, the grating lobes, as aforementioned, may appear within a beamforming (beam scanning) range.
- [6] To mitigate the grating lobes, nulls of antenna radiation patterns may also be adjacently disposed in a region close to an angle, at which the grating lobes appear, by using active and passive elements of an antenna module. However, a problem of increasing hardware complexity and costs is caused due to the use of more phase shifters to adjust a nulling angle of antenna radiation patterns.
- [7] In order to reduce interference between antenna elements or vary bandwidth characteristics, a Bed of Nail (BON) or Electronic Band Gap (EBG) structure may be employed. However, the BON or EBG structure still has a narrow band characteristic when used to improve beamforming performance. In addition, it is difficult to apply

the BON or EBG structure to a two-dimensional planar array structure other than a one-directional linear array structure.

- [8] Also, to vary antenna beam characteristics, a traveling wave antenna, a dielectric resonator antenna, and the like may be considered. However, it is difficult to implement a grating lobe mitigation structure using the traveling wave antenna and to find or implement a material appropriate for a dielectric resonator in mmwave bands, especially, V bands of 60 GHz or higher.

Disclosure of Invention

Technical Problem

- [9] The present disclosure is directed to solving the aforementioned problems and other drawbacks.
- [10] One aspect of the present disclosure is to implement grating lobe mitigation and high gain in an mmWave antenna module.
- [11] Another aspect of the present disclosure is to implement grating lobe mitigation and high gain without causing an increase in hardware complexity and costs, due to the use of more phase shifters, in an mmWave antenna module.
- [12] Another aspect of the present disclosure is to implement grating lobe mitigation and high gain without causing an increase in power consumption, due to the use of more power amplifiers and phase shifters, in an mmWave antenna module.

Solution to Problem

- [13] To achieve those aspects and other advantages of the present disclosure, an antenna module using a bed of nail (BON) structure having grating lobe mitigation and high gain characteristics may include a first metal patch having a dielectric region therein; a second metal patch surrounding the first metal patch; a feeding structure vertically coupled to the first metal patch at at least one point of the first metal patch; a first vertical structure vertically formed of a metallic material on the inner dielectric region of the first metal patch; and second vertical structures vertically formed of a metallic material at different points of the second metal patch.
- [14] According to an embodiment, the antenna module may further include a third metal structure surrounding the second metal patch, and third vertical structures vertically formed of a metallic material at different points of the third metal structure.
- [15] According an embodiment, the first metal patch may be a circular ring patch in a circular ring shape having inner and outer diameters, and may be disposed on a first surface of a printed circuit board (PCB). The second metal patch may be a square ring patch in a square shape having inner and outer lengths, and may be disposed on the first surface of the PCB. The first vertical structure may be formed to be perpendicular to the first surface and a second surface of the PCB at a center point of the dielectric

region inside the first metal patch. The second vertical structures may be formed to be perpendicular to the first surface and the second surface of the PCB at different points of the second metal patch.

- [16] According to an embodiment, the feeding structure may include a first feeding structure electrically coupled to a first point of the first metal patch to apply a horizontally polarized signal, and a second feeding structure electrically coupled to a second point of the first metal patch to apply a vertically polarized signal.
- [17] According to an embodiment, the second metal patch may include a first sub patch, a second sub patch connected to the first sub patch at one end of the first sub patch, a third sub patch connected to the first sub patch at another end of the first sub patch, and a fourth sub patch connecting the second sub patch and an end portion of the third sub patch.
- [18] According to an embodiment, the second vertical structures may be connected to center points of the first sub patch, the second sub patch, the third sub patch, and the fourth sub patch of the second metal patch. The second vertical structures may be vertically connected to a first connection point between the first sub patch and the second sub patch, a second connection point between the first sub patch and the third sub patch, a third connection point between the second sub patch and the fourth sub patch, and a fourth connection point between the third sub patch and the fourth sub patch.
- [19] According to an embodiment, the third metal structure may be formed as a square ring metal structure formed in a square shape having inner and outer lengths. The third vertical structures may protrude from the third metal structure in a Z-axial direction.
- [20] According to an embodiment, the third metal structure may include a first sub region, a second sub region connected to the first sub region at one end of the first sub region, a third sub region connected to the first sub region at another end of the first sub region, and a fourth sub region connecting the second sub region and an end portion of the third sub region.
- [21] According to an embodiment, the third vertical structures may be configured as a plurality of vertical structures spaced apart from one another respectively on the first sub region, the second sub region, the third sub region, and the fourth sub region of the third metal structure. The third vertical structures may be vertically connected to the third metal structure at a first connection point between the first sub region and the second sub region, a second connection point between the first sub region and the third sub region, a third connection point between the second sub region and the fourth sub region, and a fourth connection point between the third sub region and the fourth sub region.
- [22] According to an embodiment, the antenna module may operate in a first operating

mode of a leaky wave type according to a first spacing a between the third vertical structures adjacent to each other, a second spacing b between the third vertical structures facing each other, and a radius r of the third vertical structures. The first operating mode may be configured to increase the antenna gain and mitigate the grating lobes, as compared to a second operating mode of the antenna module without the third metal structure and the third vertical structures.

- [23] According to an embodiment, the spacing a between the third vertical structures adjacent to each other may have a value greater than a height h in the Z-axial direction of the third vertical structures.
- [24] According to an embodiment, the antenna module may further include a first antenna element to a fourth antenna element disposed adjacent to one another in an X-axial direction. Each of the first antenna element to the fourth antenna element may include the first metal patch, the second metal patch, the third metal structure, the feeding structure, the first vertical structure, the second vertical structure, and the third vertical structure.
- [25] According to an embodiment, the first antenna element and the second antenna element adjacent to the first antenna element in the X-axial direction may be configured to share the third metal structure and the third vertical structures between the first antenna element and the second antenna element.
- [26] According to an embodiment, the antenna module may further include a first antenna element to a sixteenth antenna element disposed adjacent to one another in the X-axial direction and a Y-axial direction. Each of the first antenna element to the sixteenth antenna element may include the first metal patch, the second metal patch, the third metal structure, the feeding structure, the first vertical structure, the second vertical structures, and the third vertical structures.
- [27] According to an embodiment, the first antenna element and the fifth antenna element adjacent to the first antenna element in a Y-axial direction may be configured to share the third metal structure and the third vertical structures between the first antenna element and the fifth antenna element.
- [28] According to an embodiment, a first spacing between the first antenna element and the second antenna element in the X-axial direction may be formed in a range of 0.6 to 0.8 wavelengths of an operating frequency, and A second spacing between the first antenna element and the fifth antenna element in a Y-axial direction may be formed in the range of 0.6 to 0.8 wavelengths of the operating frequency.

Advantageous Effects of Invention

- [29] Hereinafter, technical effects of an antenna module using a BON structure for grating lobe mitigation and high gain will be described, but may not be limited thereto.

- [30] According to an embodiment, in an mmWave antenna module, grating lobe mitigation and high gain can be achieved through a structure surrounding antenna elements.
- [31] According to an embodiment, grating lobe mitigation and high gain can be achieved by using a structure surrounding antenna elements without causing an increase in hardware complexity and costs, due to the use of more phase shifters, in an mmWave antenna module.
- [32] According to an embodiment, grating lobe mitigation and high gain can be achieved by using a structure surrounding antenna elements without causing an increase in power consumption, due to the use of more phase shifters, in an mmWave antenna module.
- [33] According to an embodiment, a broadband two-dimensional array antenna structure can be implemented through a bed of nail (BON) structure surrounding antenna elements.
- [34] According to an embodiment, grating lobes can be mitigated and directivity can be improved by applying broadband array antenna and a high-gain antenna pattern at an extremely high frequency of V band or more.
- [35] According to an embodiment, in an antenna that operates as a dual polarization antenna, grating lobes can be mitigated and a beam-scanning range can be increased.
- [36] According to an embodiment, a unit element and an array antenna of an antenna module can be implemented as low-profile antennas by selectively using a BON structure or adjusting a height of the BON structure according to beam-scanning performance requirements.
- [37] According to an embodiment, since an overall BON structure is integrally manufactured through 3D printing, a separate pin manufacturing process to be individually added is not required, which can facilitate the manufacturing processes and reduce manufacturing costs.
- [38] Further scope of applicability of the present disclosure will become apparent from the foregoing detailed description. It should be understood, however, that the detailed description and specific examples, such as the preferred embodiment of the present disclosure, are given by way of illustration only, since various modifications and alternations within the spirit and scope of the disclosure will be apparent to those skilled in the art.

Brief Description of Drawings

- [39] Figure 1 is a diagram explaining a configuration of a wireless display system according to the present embodiment.
- [40] Figure 2 is a block diagram illustrating detailed configurations of a communication

device and an electronic device.

[41] Figure 3 is a view illustrating an electronic device in accordance with an embodiment of the present disclosure.

[42] Figure 4 is a view illustrating an array antenna of an antenna module according to the present disclosure and regions associated with radiations of the array antenna.

[43] Figure 5 is a graph showing relationship between a steering angle by the array antenna of Figure 4 and an angle at which grating lobes appear.

[44] Figure 6 is a view illustrating a BON structure having characteristics of grating lobe mitigation and high gain according to the present disclosure.

[45] Figure 7 is a graph showing operating modes of a first antenna structure with the BON structure of Figure 6 and a second antenna structure without the BON structure.

[46] Figure 8 is a view illustrating a structure in which an array antenna of the BON structure of Figure 6 is disposed on a PCB.

[47] Figure 9 is a view illustrating unit elements of the array antenna of Figure 6.

[48] Figure 10 is a view illustrating an antenna module configured as an array antenna according to presence or absence of a BON structure.

[49] Figures 11a and 11b are views illustrating radiation patterns of unit elements and array structure of an antenna module according to presence or absence of a BON structure.

Mode for the Invention

[50] Description will now be given in detail according to one or more embodiments disclosed herein, with reference to the accompanying drawings. For the sake of brief description with reference to the drawings, the same or equivalent components may be provided with the same or similar reference numbers, and description thereof will not be repeated. In general, a suffix such as "module" and "unit" may be used to refer to elements or components. Use of such a suffix herein is merely intended to facilitate description of the specification, and the suffix itself is not intended to give any special meaning or function. In describing the present disclosure, if a detailed explanation for a related known function or construction is considered to unnecessarily divert the gist of the present disclosure, such explanation has been omitted but would be understood by those skilled in the art. The accompanying drawings are used to help easily understand the technical idea of the present disclosure and it should be understood that the idea of the present disclosure is not limited by the accompanying drawings. The idea of the present disclosure should be construed to extend to any alterations, equivalents and substitutes besides the accompanying drawings.

[51] It will be understood that although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These

terms are generally only used to distinguish one element from another.

[52] It will be understood that when an element is referred to as being "connected with" another element, the element can be connected with the another element or intervening elements may also be present. In contrast, when an element is referred to as being "directly connected with" another element, there are no intervening elements present.

[53] A singular representation may include a plural representation unless it represents a definitely different meaning from the context.

[54] Terms such as "include" or "has" are used herein and should be understood that they are intended to indicate an existence of several components, functions or steps, disclosed in the specification, and it is also understood that greater or fewer components, functions, or steps may likewise be utilized.

[55] Electronic devices presented herein may be implemented using a variety of different types of terminals. Examples of such devices include cellular phones, smart phones, laptop computers, digital broadcasting terminals, personal digital assistants (PDAs), portable multimedia players (PMPs), navigators, slate PCs, tablet PCs, ultra books, wearable devices (for example, smart watches, smart glasses, head mounted displays (HMDs)), and the like.

[56] By way of non-limiting example only, further description will be made with reference to particular types of mobile terminals. However, such teachings apply equally to other types of terminals, such as those types noted above. In addition, these teachings may also be applied to stationary terminals such as digital TV, desktop computers, digital signages, and the like.

[57] A description will now be given in detail of specific embodiments of the present disclosure, together with drawings.

[58] FIG. 1 is a diagram schematically illustrating an example of an entire wireless (AV) system including a video display device according to one embodiment of the present disclosure.

[59] As illustrated in FIG. 1, an image display device 100 according to one embodiment of the present disclosure is connected to the wireless AV system (or a broadcasting network) and an Internet network. The image display device 100 may be, for example, a network TV, a smart TV, a hybrid broadcast broadband TV (HBBTV), or the like.

[60] The image display device 100 may be wirelessly connected to the wireless AV system (or the broadcasting network) via a wireless interface or wirelessly or wiredly connected to the Internet network via an Internet interface. In relation to this, the image display device 100 may be configured to be connected to a server or another electronic device via a wireless communication system. As an example, the image display device 100 needs to provide an 802.11ay communication service operating in a millimeter wave (mmWave) band to transmit or receive large-capacity data at a high speed.

- [61] The mmWave band may be any frequency band in a range of 10 GHz to 300 GHz. In this disclosure, the mmWave band may include an 802.11ay band of a 60 GHz band. In addition, the mmWave band may include a 5G frequency band of a 28 GHz band or the 802.11ay band of the 60 GHz band. The 5G frequency band may be set to about 24 to 43 GHz band and the 802.11ay band may be set to 57 to 70 GHz or 57 to 63 GHz band, but are not limited thereto.
- [62] The image display device 100 may wirelessly transmit or receive data to/from an electronic device in a periphery of the image display device 100, e.g., a set-top box or another electronic device via the wireless interface. As an example, the image display device 100 may transmit or receive wireless AV data to/from a set-top box or another electronic device, e.g., a mobile terminal arranged in front of or below the image display device 100.
- [63] The image display device 100 includes, for example, a wireless interface 101b, a section filter 102b, an application information table (AIT) filter 103b, an application data processing unit 104b, a data processing unit 111b, a media player 106b, an Internet protocol processing unit 107b, an Internet interface 108b, and a runtime module 109b.
- [64] Through a broadcast interface that is the wireless interface 101b, AIT data, real-time broadcast content, application data, and a stream event are received. The real-time broadcast content may be referred to as linear audio/video (A/V) content.
- [65] The section filter 102b performs section filtering on four types of data received through the wireless interface 101b to transmit the AIT data to the AIT filter 103b, the linear A/V content to the data processing unit 111b, and the stream events and the application data to the application data processing unit 104b.
- [66] Non-linear A/V content and the application data are received through the Internet interface 108b. The non-linear A/V content may be, for example, a content on demand (COD) application. The non-linear A/V content is transmitted to the media player 106b, and the application data is transmitted to the runtime module 109b.
- [67] Further, the runtime module 109b includes, for example, an application manager and a browser as illustrated in FIG. 1. The application manager controls a life cycle of an interactive application using, for example, the AIT data. In addition, the browser performs, for example, a function of displaying and processing the interactive application.
- [68] Hereinafter, a communication module having an antenna for providing a wireless interface in an electronic device such as the above-described image display device will be described in detail. In relation to this, the wireless interface for communication between electronic devices may be a WiFi wireless interface, but is not limited thereto. As an example, a wireless interface supporting the 802.11ay standard may be provided

for high-speed data transmission between electronic devices.

- [69] The 802.11ay standard is a successor standard for raising a throughput for the 802.11ad standard to 20 Gbps or greater. An electronic device supporting an 802.11ay wireless interface may be configured to use a frequency band of about 57 to 64 GHz. The 802.11ay wireless interface may be configured to provide backward compatibility for an 802.11ad wireless interface. The electronic device providing the 802.11ay wireless interface may be configured to provide coexistence with a legacy device using the same band.
- [70] In relation to a wireless environment for the 802.11ay standard, it may be configured to provide a coverage of 10 meters or longer in an indoor environment, and 100 meters or longer in an outdoor environment with a line of sight (LOS) channel condition.
- [71] The electronic device supporting the 802.11ay wireless interface may be configured to provide visual reality (VR) headset connectivity, support server backups, and support cloud applications that require low latency.
- [72] An ultra-short range (USR) communication scenario, i.e., a near field communication scenario which is a use case of the 802.11ay wireless interface, is a model for fast large-capacity data exchange between two terminals. The USR communication scenario may be configured to require low power consumption of less than 400 mW, while providing a fast link setup within 100 msec, transaction time within 1 second, and a 10 Gbps data rate at a very close distance of less than 10 cm.
- [73] As the use case of the 802.11ay wireless interface, the 8K UHD Wireless Transfer at Smart Home Usage Model may be taken into account. In the Smart Home Usage Model, a wireless interface between a source device and a sink device may be taken into consideration to stream 8K UHD content at home. In relation to this, the source device may be one of a set-top box, a Blue-ray player, a tablet PC, and a smart phone and the sink device may be one of a smart TV and a display device, but are not limited thereto. In relation to this, the wireless interface may be configured to transmit uncompressed 8K UHD streaming data (60 fps, 24 bits per pixel, at least 4:2:2) with a coverage of less than 5 m between the source device and the sink device. To do so, the wireless interface may be configured such that data is transmitted between electronic devices at a speed of at least 28 Gbps.
- [74] In order to provide such a wireless interface, embodiments related to an array antenna operating in a mmWave band and an electronic device including the array antenna will be described with reference to the accompanying drawings. It will be apparent to those skilled in the art that the present disclosure may be embodied in other specific forms without departing from the spirit or essential characteristics thereof.
- [75] FIG. 2 illustrates a detailed configuration of electronic devices configured to support a wireless interface according to the present disclosure. FIG. 2 illustrates a block

diagram of an access point 110 (generally, a first wireless node) and an access terminal 120 (generally, a second wireless node) in a wireless communication system. The access point 110 is a transmitting entity for downlink transmission and a receiving entity for uplink transmission. The access terminal 120 is a transmitting entity for uplink transmission and a receiving entity for downlink transmission. As used herein, the "transmitting entity" is an independently operating apparatus or device capable of transmitting data through a wireless channel, and the "receiving entity" is an independently operating apparatus or device capable of receiving data through a wireless channel.

[76] Referring to FIGS. 1 and 2, the set-top box (STB) of FIG. 1 may be the access point 110, and an electronic device, that is, the image display device 100 of FIG. 1 may be the access terminal 120, but are not limited thereto. Accordingly, it should be understood that the access point 110 may alternatively be an access terminal, and the access terminal 120 may alternatively be an access point.

[77] To transmit data, the access point 110 includes a transmission (TX) data processor 220, a frame builder 222, a TX processor 224, a plurality of transceivers 226-1 to 226-N, and a plurality of antennas 230-1 to 230-N. The access point 110 also includes a controller 234 configured to control operations of the access point 110.

[78] To transmit data, the access point 110 includes a transmission (TX) data processor 220, a frame builder 222, a TX processor 224, a plurality of transceivers 226-1 to 226-N, and a plurality of antennas 230-1 to 230-N. The access point 110 also includes a controller 234 configured to control operations of the access point 110.

[79] During operation, the TX data processor 220 receives data (e.g., data bits) from a data source 215, and processes the data for transmission. For example, the TX data processor 220 may encode data (e.g., data bits) into encoded data, and modulate the encoded data into data symbols. The TX data processor 220 may support different modulation and coding schemes (MCSs). For example, the TX data processor 220 may encode data at any one of a plurality of different coding rates (e.g., using low-density parity check (LDPC) encoding). In addition, the TX data processor 220 may modulate the encoded data using any one of a plurality of different modulation schemes including, but not limited to, BPSK, QPSK, 16QAM, 64QAM, 64APSK, 128APSK, 256QAM, and 256APSK.

[80] The controller 234 may transmit, to the TX data processor 220, a command for specifying an MCS to be used (e.g., based on channel conditions for downlink transmission). The TX data processor 220 may encode and modulate the data received from the data source 215 according to the specified MCS. It needs to be recognized that the TX data processor 220 may perform additional processing on the data, such as data scrambling and/or other processing. The TX data processor 220 outputs the data

symbols to the frame builder 222.

- [81] The frame builder 222 constructs a frame (also referred to as a packet) and inserts the data symbols into a data payload of the frame. The frame may include a preamble, a header, and a data payload. The preamble may include a short training field (STF) sequence and a channel estimation (CE) sequence to assist the access terminal 120 in receiving the frame. The header may include information regarding data in a payload, such as a length of the data and an MCS used to encode and modulate the data. Based on this information, the access terminal 120 may demodulate and decode the data. The data in the payload may be partitioned among a plurality of blocks, and each block may contain a part of the data and a guard interval (GI) to assist the receiver in phase tracking. The frame builder 222 outputs the frame to the TX processor 224.
- [82] The TX processor 224 processes the frame for transmission on downlink. For example, the TX processor 224 may support different transmission modes, e.g., an orthogonal frequency-division multiplexing (OFDM) transmission mode and a single-carrier (SC) transmission mode. In this example, the controller 234 may transmit, to the TX processor 224, a command for specifying a transmission mode to be used, and the TX processor 224 may process the frame for transmission according to the specified transmission mode. The TX processor 224 may apply a spectrum mask to the frame so that a frequency configuration of a downlink signal complies with particular spectrum requirements.
- [83] The TX processor 224 may support multiple-input-multiple-output (MIMO) transmission. In these aspects, the access point 110 may include a plurality of antennas 230-1 to 230-N and a plurality of transceivers 226-1 to 226-N (e.g., one for each antenna). The TX processor 224 may perform spatial processing on incoming frames and provide a plurality of transmission frame streams to a plurality of antennas. The transceivers 226-1 to 226-N receive and process (e.g., convert to analog, amplify, filter, and frequency up-convert) each of the transmission frame streams to generate transmission signals for transmission through the antennas 230-1 to 230-N.
- [84] To transmit data, the access terminal 120 includes a TX data processor 260, a frame builder 262, a TX processor 264, a plurality of transceivers 266-1 to 266-M, and a plurality of antennas 270-1 to 270-M (e.g., one antenna per transceiver). The access terminal 120 may transmit data to the access point 110 on uplink and/or transmit the data to another access terminal (e.g., for peer-to-peer communication). The access terminal 120 also includes a controller 274 configured to control operations of the access terminal 120.
- [85] The transceivers 266-1 to 266-M receive and process (e.g., convert to analog, amplify, filter, and frequency up-convert) an output from the TX processor 264 for transmission via one or more of the antennas 270-1 to 270-M. For example, the

transceiver 266-1 may up-convert the output from the TX processor 264 into a transmission signal having a frequency in a 60 GHz band. Accordingly, the antenna module described herein may be configured to perform a beamforming operation in the 60 GHz band, for example, in a band of about 57 to 63 GHz. In addition, the antenna module may be configured to support MIMO transmission while performing beamforming in the 60 GHz band.

- [86] In relation to this, the antennas 270-1 to 270-M and the transceivers 266-1 to 266-M may be implemented in an integrated form on a multi-layer circuit substrate. To do so, among the antennas 270-1 to 270-M, an antenna configured to operate with vertical polarization may be vertically arranged inside the multi-layer circuit substrate.
- [87] To receive data, the access point 110 includes a reception (RX) processor 242 and an RX data processor 244. During operation, the transceivers 226-1 to 226-N receive a signal (e.g., from the access terminal 120) and spatially process (e.g., frequency down-convert, amplify, filter, and digitally convert) the received signal.
- [88] The RX processor 242 receives outputs from the transceivers 226-1 through 226-N and processes the outputs to recover data symbols. For example, the access point 110 may receive data from a frame (e.g., from the access terminal 120). In this example, the RX processor 242 may detect a start of the frame using a short training field (STF) sequence in a preamble of the frame. The RX processor 242 may also use the STF for automatic gain control (AGC) adjustment. The RX processor 242 may also perform channel estimation (e.g., using a channel estimation (CE) sequence in the preamble of the frame), and perform channel equalization on the received signal based on the channel estimation.
- [89] The RX data processor 244 receives data symbols from the RX processor 242 and an indication of a corresponding MSC scheme from the controller 234. The RX data processor 244 demodulates and decodes the data symbols, recovers the data according to the indicated MSC scheme, and stores and/or outputs the recovered data (e.g., data bits) to a data sink 246 for additional processing.
- [90] The access terminal 120 may transmit the data using an orthogonal frequency-division multiplexing (OFDM) transmission mode or a single-carrier (SC) transmission mode. In this case, the RX processor 242 may process the received signal according to a selected transmission mode. In addition, as described above, the TX processor 264 may support MIMO transmission. In this case, the access point 110 includes the antennas 230-1 to 230-N and the transceivers 226-1 to 226-N (e.g., one for each antenna). Accordingly, the antenna module described herein may be configured to perform a beamforming operation in the 60 GHz band, for example, in a band of about 57 to 63 GHz. In addition, the antenna module may be configured to support MIMO transmission while performing beamforming in the 60 GHz band.

- [91] In relation to this, the antennas 230-1 to 230-M and the transceivers 226-1 to 226-M may be implemented in an integrated form on a multi-layer circuit substrate. To do so, among the antennas 230-1 to 230-M, an antenna configured to operate with vertical polarization may be vertically arranged inside the multi-layer circuit substrate.
- [92] Meanwhile, each transceiver receives and processes (e.g., frequency down-converts, amplifies, filters, and digitally converts) a signal from each antenna. The RX processor 242 may perform spatial processing on the outputs from the transceivers 226-1 to 226-N to recover the data symbols.
- [93] The access point 110 also includes a memory 236 coupled to the controller 234. The memory 236 may store commands that, when executed by the controller 234, cause the controller 234 to perform one or more of the operations described herein. Similarly, the access terminal 120 also includes a memory 276 coupled to the controller 274. The memory 276 may store commands that, when executed by the controller 274, cause the controller 274 to perform one or more of the operations described herein.
- [94] FIG. 3 is a view illustrating an electronic device in accordance with an embodiment of the present disclosure. The electronic device 200 may include a display panel 260, a first antenna module 300, and a second antenna module 310. The electronic device 200 may perform wireless communication with the communication device 100 disposed apart therefrom by a predetermined distance L2 in a direction of a specific angle α .
- [95] Each of the first antenna module 300 and the second antenna module 310 may include 32 antennas, but this is merely an example. Monopole antennas 306, 308 may be disposed on both side surfaces of the first antenna module 300 and the second antenna module 310. A monopole antenna 316 may be disposed at a bottom portion of the first antenna module 300. A second monopole antenna 318 may be disposed at a bottom portion of the second antenna module 310.
- [96] The first antenna module 300 and the second antenna module 310 may be disposed below the display panel 260.
- [97] In the first antenna module 300, a plurality of first antenna patches 304, a plurality of monopole antennas 306, and a plurality of dipole antennas 308 may be disposed on a first substrate 302.
- [98] The first substrate 302 may be vertically disposed. A length of the first substrate 302 in a left-right direction X may be larger than that in a top-down direction Y. A front surface of the first substrate 302 may face forward, similar to a front surface of the display panel 260.
- [99] As illustrated in FIG. 3, the plurality of first antenna patches 304 may be arranged in a row in a horizontal direction, and may be arranged in a plurality of rows in a top-down direction Y.
- [100] The plurality of first antenna patches 304 may be arranged on a front surface of the

first substrate 302.

- [101] The plurality of monopole antennas 306 may include a plurality of left monopole antennas disposed at a left side end of the first substrate 302 and a plurality of right monopole antennas disposed at a right side end of the first substrate 302. The plurality of dipole antennas 308 may include a plurality of lower dipole antennas disposed at a lower end of the first substrate 302.
- [102] The first antenna module 300 may be closer to one side end 262 between the one side end 262 and the other side end 264 of the display panel 260. The first antenna module 300 may be a right antenna module closer to a right side end between a left side end and the right side end of the display panel 260. The first antenna module 300 may be disposed to be biased toward the right of the display device 20.
- [103] The first antenna module 300 may further include a first cover in FIG. 4, which covers the first substrate 302, the plurality of first antenna patches 304, the plurality of monopole antennas 306, and the plurality of dipole antennas 308. The first substrate 302, the plurality of first antenna patches 304, and the plurality of monopole antennas 306 may be located inside the first cover, and may be protected by the first cover.
- [104] At least one antenna included in the second antenna module 310 may have a vertically polarized characteristic in which an electric field is formed in a Y-axis direction, which is a top-down direction Y corresponding to a width of the second substrate 312. In the second antenna module 310, a plurality of first antenna patches 314, a plurality of monopole antennas 316, and a plurality of dipole antennas 318 may be disposed on the second substrate 312. The plurality of second monopole antennas 318 may have vertical polarization characteristics in which an electric field is formed in the Y-axis direction, which is the top-down direction Y.
- [105] The second substrate 312 may be vertically disposed. A length of the second substrate 312 in a left-right direction X may be larger than that in a top-down direction Y. A front surface of the second substrate 312 may face forward, similar to a front surface of the display panel 260.
- [106] As illustrated in FIG. 3, the plurality of second antenna patches 314 may be arranged in a row in a horizontal direction, and may be arranged in a plurality of rows in a top-down direction Y.
- [107] The plurality of second antenna patches 314 may be arranged on a front surface of the second substrate 312.
- [108] The monopole antenna 316 is an antenna having a vertical straight or spiral conductor that operates as a half of a dipole antenna. A plurality of monopole antennas 316 may be provided on the second substrate 312. The plurality of monopole antennas 316 may be disposed closer to an edge between the center and the edge of the second substrate 312.

- [109] The plurality of monopole antennas 316 may include a plurality of left dipole antennas disposed at a left side end of the second substrate 312 and a plurality of right monopole antennas disposed at a right side end of the second substrate 312. The plurality of monopole antennas 318 may include a plurality of lower monopole antennas disposed at a lower end of the second substrate 312.
- [110] The second antenna module 310 may be closer to the other side end 264 between the one side end 262 and the other side end 264 of the display panel 260. The second antenna module 310 may be a left antenna module closer to a left side end between the left side end and the right side end of the display panel 260. The second antenna module 310 may be disposed to be biased toward the left of the display device 20.
- [111] The second antenna module 310 may further include a second cover 202, which covers the second substrate 312, the plurality of second antenna patches 314, the plurality of monopole antennas 316, and the plurality of monopole antennas 318. The second substrate 312, the plurality of second antenna patches 316, a plurality of monopole antennas 316, and a plurality of second monopole antennas 318 may be located inside the second cover, and may be protected by the second cover.
- [112] Hereinafter, an antenna module having grating lobe mitigation and high gain characteristics according to the present disclosure will be described. In this regard, the antenna module having the grating lobe mitigation and high gain characteristics may be applied to the plurality of first antenna patches 304 of the first antenna module 300 of FIG. 3. The antenna module having the grating lobe mitigation and high gain characteristics may be applied to the plurality of second antenna patches 314 of the second antenna module 310 of FIG. 3. In the meantime, the antenna module having the grating lobe mitigation and high gain characteristics may be applied to an arbitrary mobile electronic device, not being limited to a stationary electronic device.
- [113] The antenna module having the grating lobe mitigation and high gain characteristics according to the present disclosure may be proposed to achieve those following aspects. One aspect of the present disclosure is to implement grating lobe mitigation and high gain in an mmWave antenna module. Another aspect of the present disclosure is to implement grating lobe mitigation and high gain without causing an increase in hardware complexity and costs, due to the use of more phase shifters, in an mmWave antenna module. Another aspect of the present disclosure is to implement grating lobe mitigation and high gain without causing an increase in power consumption, due to the use of more power amplifiers and phase shifters, in an mmWave antenna module.
- [114] Meanwhile, in order to mitigate grating lobes, an Electronic Band Gap (EBG) structure or a Bed of Nail (BON) structure may be used as a passive element, without using an active element. The BON structure may be disposed between adjacent antenna elements of an array antenna to surround the antenna elements. The EBG

structure may be formed inside and/or outside an antenna element to prevent interference between antenna elements or change bandwidth characteristics. The EBG structure can be used in the EBG mode or leaky mode. The mode depends on the operation frequency at which the BON structure with given dimension is used.

[115] In this regard, FIG. 4 is a view illustrating an array antenna of an antenna module according to the present disclosure and regions associated with radiations of the array antenna.

[116] Referring to FIG. 4, an array antenna 1100 may include a plurality of antennas disposed with being spaced apart from one another by predetermined spacings. A first region R1 in which the array antenna 1100 is allowed to radiate a radio signal at a predetermined angle corresponds to a fields allowed sector. A second region R2 in which a radio signal radiated by the array antenna 1100 is redirected to a different direction corresponds to a fields redirection sector. The first region R1 may be defined as a region that is within a predetermined length L_{a1} and a predetermined angle θ_{a1} from a center point of the array antenna 1100. The second region R2 may be defined as a region that has the predetermined length L_{a1} and predetermined angle θ_{a1} or more from the center point.

[117] Meanwhile, FIG. 5 is a graph showing relationship between a steering angle by the array antenna of FIG. 4 and an angle at which grating lobes appear. Referring to FIGS. 4 and 5, an angle θ_b at which grating lobes appear according to a spacing d between antenna elements of the array antenna 1100 and a steering angle θ_a of the array antenna 1100 are illustrated.

[118] In this regard, as the spacing d between the antenna elements of the array antenna 1100 increases, the angle θ_b at which the grating lobes appear is formed close to 0 degree. For example, when the spacing d between the antenna elements is 0.8 wavelengths (λ) and the steering angle θ_a is 60 degrees, the angle θ_b at which the grating lobe appears has a value close to -20 degrees. When the spacing d between the antenna elements is 0.6 wavelengths (λ) and the steering angle θ_a is 60 degrees, the angle θ_b at which the grating lobes appear has a value close to -55 degrees. On the other hand, when the spacing d between the antenna elements is 0.52λ and the steering angle θ_a is 60 degrees, the grating lobes do not appear.

[119] However, interference between antenna elements may increase as the antenna elements of the array antenna 1100 are disposed adjacent to each other. Also, the antenna elements may increase in size in order to maintain predetermined levels or more of reflection loss, gain, and efficiency characteristics in broad bands. As a result, it may be difficult to maintain the spacing d between the adjacent antenna elements of the array antenna 1100 to a predetermined level or less.

[120] FIG. 5 showing the grating lobe appearance angle as a function of main lobe

direction is for an array antenna without any grating lobe mitigation structures. FIG. 5 illustrates possible limitations regarding grating lobes for traditional array structures. When the BON structure operates in the leaky mode, the field redirection and allowed sectors may be re-defined.

- [121] Hereinafter, an antenna module of a BON structure having grating lobe mitigation and high gain characteristics according to the present disclosure will be described. An antenna module according to the present disclosure may be designed in a BON structure capable of being implemented even in a millimeter band, especially, V band of 60 GHz or more.
- [122] The antenna module using the BON structure can be implemented to achieve a high antenna gain and mitigate grating lobes, during beam-scanning, in a two-dimensional region in the X-axial direction and Y-axial direction. In this regard, a first spacing between adjacent antenna elements in the X-axial direction may be in the range of 0.6 to 0.8 wavelength of the operating frequency. The second spacing between adjacent antenna elements in the Y-axial direction may be in the range of 0.6 to 0.8 wavelength of the operating frequency. The first spacing and the second spacing between the adjacent antenna elements may be applied to spacings between arbitrary adjacent antenna elements in the X-axial direction or the Y-axial direction.
- [123] In this regard, FIG. 6 is a view illustrating a BON structure having characteristics of grating lobe mitigation and high gain according to the present disclosure. (a) of FIG. 6 is a front view on a XY plane of a BON structure 1200. (b) of FIG. 6 is a lateral view on the XZ plane of the BON structure 1200.
- [124] Referring to FIG. 6, the BON structure 1200 may include a metal structure 1200a and vertical structures 1230. The metal structure 1200a may be disposed on a PCB configuring an antenna module. The vertical structures 1230 may include, on the XY plane, upper vertical structures 1230a disposed on an upper region of the metal structure 1200a, and lower vertical structures 1230b disposed on a lower region of the metal structure 1200a.
- [125] Each of the upper vertical structures 1230a may be formed in a cylindrical shape having a predetermined diameter r . Each of the lower vertical structures 1230b may be formed in a cylindrical shape having the predetermined diameter r . The upper vertical structures 1230a may be provided in plurality spaced apart from one another by predetermined spacing a in an X-axial direction. The lower vertical structures 1230b may be provided in plurality spaced apart from one another by the predetermined spacing a in the X-axial direction. The upper vertical structures 1230a and the lower vertical structures 1230b may be provided in plurality spaced apart from each other by a predetermined spacing b in a Y-axial direction. In this regard, the spacing b in the Y-axial direction may be set to be longer than the spacing a in the X-axial direction.

- [126] Meanwhile, a first antenna structure having a BON structure may operate in a different operating mode from a second antenna structure without the BON structure. In this regard, FIG. 7 is a graph showing operating modes of a first antenna structure with the BON structure of FIG. 6 and a second antenna structure without the BON structure.
- [127] Referring to FIGS. 4, 6, and 7, an antenna module having a BON structure 1200 may be implemented as an array antenna having antenna elements disposed in at least one axial direction. The antenna module having the BON structure 1200 may operate in a first operating mode that is a leaky mode of a leaky wave type. An antenna module without the BON structure may operate in a second operating mode that is a propagation mode of a propagation wave type.
- [128] The antenna module operating in the first operating mode may be configured to perform beamforming (beam scanning) by a predetermined angle at an f_p frequency or more. The antenna module operating in the second operating mode may be configured to perform beamforming (beam scanning) by a predetermined angle at an f_p frequency or less. Therefore, a frequency gap between a first operating band of the antenna module having the BON structure 1200 and a second operating band of the antenna module without the BON structure may be expressed as a value of $f_p - f_{c1}$. Therefore, the antenna module having the BON structure 1200 may operate at a higher frequency band, by the frequency gap, than the antenna module without the BON structure. The BON structure 1200 according to the present disclosure may be referred to an EBG structure because of operating as a structure having the gap of the frequency band.
- [129] In a propagation mode, surface waves are prevented from radiating. In this case beam scanning is still possible, but altering the beam-scanning region is very limited. In the propagation mode, a wide frequency band can be synthesized, in which the grating lobe is prevented from appearing for a suitable inter-element distance. However, the beam scanning range cannot be altered. The leaky mode is operated from above the frequencies of f_p . The antenna array structure with The BON operates within the leaky-mode region.
- [130] Meanwhile, a beamforming angle (beam scanning angle) q of the antenna module may be expressed by Equation 1 below. In this regard, β denotes a propagation constant of a radio signal radiated by the antenna module. Here, k_0 denotes a wave number of a radio signal in the air radiated by the antenna module, c denotes speed of light, and λ_g denotes a guided wavelength of the antenna module.
- [131] Also, β_p denotes a propagation constant of a radio signal radiated by the antenna module having the BON structure 1200. The propagation constant β_p may be determined by the diameter r of the BON structure 1200, and the X-axial spacing a and the Y-axial spacing b between the vertical structures 1230. Therefore, a predetermined

range of a beam scanning angle may be adjusted for each frequency by varying the diameter r of the BON structure 1200, and the X-axial spacing a and the Y-axial spacing b between the vertical structures 1230. When the predetermined range of the beam scanning angle increases, the second region R2 as the fields redirection section of FIG. 4 may be adjusted.

[132] [Math.1]

$$\theta = \sin^{-1} \frac{\beta}{k_0},$$

$$\beta_p = \left(\frac{2\pi}{\lambda_g} \right)^2 = \left(\frac{2\pi f_p}{c_0} \right)^2 = \frac{2\pi/s^2}{\ln \frac{s}{2\pi r} + F(u)},$$

where, $s = \sqrt{ab}$, $u = a/b$, and

$$F(u) = -\frac{\ln u}{2} + \sum_{n=1}^{\infty} \left(\frac{\coth(\pi n u) - 1}{n} \right) + \frac{\pi u}{6}$$

[133] Meanwhile, the antenna module having the BON structure according to the present disclosure may be configured as an array antenna including a plurality of antenna elements. In this regard, FIG. 8 is a view illustrating a structure in which the array antenna with the BON structure of FIG. 6 is disposed on a PCB. (a) of FIG. 8 shows a first PCB 1010a on which the antenna module having the BON structure is implemented as an array antenna having a plurality of antenna elements. The array antenna disposed on the first PCB 1010a may be implemented as a 4x4 array antenna. (b) of FIG. 8 shows a second PCB 1020 on which the BON structure 1200 is formed to correspond to the antenna elements of (a) of FIG. 8. A metal structure 1130 having a plurality of grids that form the BON structure 1200 may be a 4x4 BON structure corresponding to the antenna or a 5x5 BON structure as illustrated. When the metal structure 1130 is configured as the 5x5 BON structure, grating lobes by antenna elements disposed on a boundary region can be reduced.

[134] (c) of FIG. 8 shows a first PCB 1010a implemented as the array antenna having the plurality of antenna elements of (a) of FIG. 8, and a second PCB 1010b having the BON structure 1200 to correspond to the antenna elements of (a) of FIG. 8. The array antenna that has the BON structure 1200 to correspond to the antenna elements constitutes the antenna module 1000. Referring to (b) and (c) of FIG. 8, the BON structure 1200 may have third vertical structures 1230 disposed between the metal structures 1130 having the plurality of grids.

[135] In this regard, a third metal structure 1130 of the BON structure 1200 may be disposed on a second surface as a rear surface of the PCB 1010. The plurality of antenna elements may be disposed on a first surface as a front surface of the PCB 1010. A feeding structure for feeding each of the plurality of antenna elements may be

disposed inside the PCB 1010.

- [136] Meanwhile, FIG. 9 is a view illustrating unit elements of the array antenna of FIG. 6. (a) of FIG. 9 shows a unit element without the BON structure, and (b) of FIG. 9 shows a unit element with the BON structure. In this regard, FIG. 9 is an enlarged view of the unit element in the antenna module in FIG. 8.
- [137] Hereinafter, the antenna module having the BON structure according to the present disclosure will be described with reference to FIGS. 6, 8, and 9.
- [138] The unit element of the antenna module 1000 having the BON structure may include a first metal patch 1110, a second metal patch 1120, a feeding structure 1100f, a first vertical structure 1210, and second vertical structures 1220. The unit element of the array antenna 1000 having the BON structure may further include a third metal structure 1130, and third vertical structures 1230.
- [139] A dielectric region may be defined inside the first metal patch 1110. The first metal patch 1110 may be a circular ring patch in a circular ring shape having inner and outer diameters, and may be disposed on the first surface of the PCB 1010. The second metal patch 1120 may be formed to surround the first metal patch 1110. The second metal patch 1120 may be a square patch in a square shape having inner and outer lengths, and may be disposed on the first surface of the PCB 1010.
- [140] The third metal patch 1130 may be formed to surround the second metal patch 1120. The third metal structure 1130 may be a square ring metal structure formed in a square shape having inner and outer lengths. The third metal structure 1130 may be disposed on the first surface as the front surface of the PCB 1010 or on the second surface as the rear surface of the PCB 1010.
- [141] The feeding structure 1100f may be vertically coupled to the first metal patch 1110 at at least one point of the first metal patch 1110. The feeding structure 1100f may be capacitively coupled to the ring-shaped first metal patch 1110 without being directly connected. To this end, a substrate may be disposed between the feeding structure 1100f and the ring-shaped first metal patch 1110. The feeding structure 1100f may include a first feeding structure 1110f and a second feeding structure 1120f.
- [142] The first feeding structure 1110f may be electrically coupled to a first point P1 of the first metal patch 1110 to apply a horizontally polarized signal. The antenna module 1000 having the first metal patch 1110 coupled to the first feeding structure 1110f may be configured to radiate the horizontally polarized signal.
- [143] The second feeding structure 1120f may be electrically coupled to a second point P2 of the first metal patch 1110 to apply a vertically polarized signal. The antenna module 1000 having the first metal patch 1110 coupled to the second feeding structure 1120f may be configured to radiate the vertically polarized signal. Therefore, the grating lobes can be mitigated and the beam scanning range can be enlarged in the antenna

module that operates as a dual-polarization antenna applying the horizontally and vertically polarized signals. The first and second points P1, P2 are dented as ports for the antenna module, and they can be used to interpret their feeding locations as well.

- [144] Meanwhile, the antenna module 1000 using the BON structure may include a plurality of vertical structures formed in a Z-axial direction. The antenna module 1000 having the BON structure may include a first vertical structure 1210, and second vertical structures 1220. The first vertical structure 1210 and the second vertical structures 1220 may be configured as a plurality of metal patches disposed in the Z-axial direction. The plurality of metal patches configuring the first vertical structure 1210 may be electrically connected in the Z-axial direction by vertical vias. The plurality of metal patches configuring the second vertical structures 1220 may be electrically connected in the Z-axial direction by the vertical vias. As the first vertical structure 1210 and the second vertical structures 1220 are configured as the plurality of metal patches, the PCB 1010 may also be implemented as a multi-layered substrate. The antenna module 1000 having the BON structure may further include third vertical structures 1230.
- [145] The first vertical structure 1210 may be vertically formed of a metallic material in the dielectric region inside the first metal patch 1110. The first vertical structure 1210 may be formed in the Z-axial direction to be perpendicular to the XY plane of the PCB 1010. The first vertical structure 1210 may be formed to be perpendicular to the first surface and the second surface of the PCB 1010 at a center point of the dielectric region inside the first metal patch 1110. The first surface and the second surface of the PCB 1010 may correspond to the front surface and the rear surface of the PCB, respectively. The second vertical structures 1220 may be vertically formed of a metallic material at different points of the second metal patch 1120. The second vertical structures 1220 may be formed in the Z-axial direction to be perpendicular to the XY plane of the PCB 1010. The second vertical structures 1220 may be formed to be perpendicular to the first surface and the second surface of the PCB 1010 at the different points of the second metal patch 1120.
- [146] The third vertical structures 1230 may be vertically formed of a metallic material at different points of the third metal patch 1130. The third vertical structures 1230 may be formed in the Z-axial direction to be perpendicular to the XY plane of the PCB 1010. The third vertical structures 1230 may be formed to be perpendicular to the first surface and the second surface of the PCB 1010 at the different points of the third metal structure 1130. The third vertical structures 1230 may protrude from the third metal structure 1130 in the Z-axial direction.
- [147] In this regard, the third vertical structures 1230 may be fixed by screws to specific points of the unit antenna element or the third metal structure 1130 of the array

antenna. A height h of each of the third vertical structures 1230 may be adjusted by varying a height of the screw, thereby tuning electrical performance. Accordingly, in the BON structure including the third vertical structures 1230, the electrical characteristic for each frequency can be tuned by adjusting the protruded height of each screw.

- [148] Meanwhile, the metal patches and metal structures of the antenna module 1000 having the BON structure may be formed in a closed-loop shape, such as a circular ring structure or a square ring structure. In this regard, the first metal patch 1110 may be configured as a circular ring patch in a circular ring shape. The second metal patch 1120 may be configured as a square ring patch in a square shape. The second metal structure 1130 may be configured as a square ring metal structure in a square shape.
- [149] The second metal patch 1120 may include a first sub patch 1121 to a fourth sub patch 1124. The first sub patch 1121 may define an upper region of the second metal patch 1120 disposed on the XY plane. The second sub patch 1122 may define one side (left) region of the second metal patch 1120 disposed on the XY plane. The third sub patch 1123 may define another side (right) region of the second metal patch 1120 disposed on the XY plane. The fourth sub patch 1124 may define a lower region of the second metal patch 1120 disposed on the XY plane.
- [150] The second sub patch 1122 may be connected to the first sub patch 1121 at one end of the first sub patch 1121. The third sub patch 1123 may be connected to the first sub patch 1121 at another end of the first sub patch 1121. The fourth sub patch 1124 may connect an end portion of the second sub patch 1122 and an end portion of the third sub patch 1123. The fourth sub patch 1124 may connect a lower end of the second sub patch 1122 and a lower end of the third sub patch 1123.
- [151] The third metal patch 1130 may include a first sub region 1131 to a fourth sub region 1134. The first sub region 1131 may define an upper region of the third metal structure 1130 disposed on the XY plane. The second sub region 1132 may define one side (left) region of the third metal patch 1130 disposed on the XY plane. The third sub region 1133 may define another side (right) region of the third metal patch 1130 disposed on the XY plane. The fourth sub region 1134 may define a lower region of the third metal patch 1130 disposed on the XY plane.
- [152] The second sub region 1132 may be connected to the first sub region 1131 at one end of the first sub region 1131. The third sub region 1133 may be connected to the first sub region 1131 at another end of the first sub region 1131. The fourth sub region 1134 may connect an end portion of the second sub region 1132 and an end portion of the third sub region 1133. The fourth sub region 1134 may connect a lower end of the second sub region 1132 and a lower end of the third sub region 1133.
- [153] Meanwhile, each of the second and third vertical structures 1220 and 1230 of the

antenna module 1000 having the BON structure may be provided in plurality to mitigate grating lobes and perform gain optimization. The second vertical structures 1220 may be connected to center points of the first sub patch 1121, the second sub patch 1122, the third sub patch 1123, and a fourth sub patch 1124 of the second metal patch 1120. The second vertical structures 1220 may be vertically connected to the second metal patch 1120 at a first connection point between the first sub patch 1121 and the second sub patch 1122. The second vertical structures 1220 may be vertically connected to the second metal patch 1120 at a second connection point between the first sub patch 1121 and the third sub patch 1123. The second vertical structures 1220 may be vertically connected to the second metal patch 1120 at a third connection point between the second sub patch 1122 and the third sub patch 1123. The second vertical structures 1220 may be vertically connected to the second metal patch 1120 at a fourth connection point between the third sub patch 1123 and the fourth sub patch 1124.

[154] The third vertical structures 1230 may be configured as a plurality of vertical structures that are spaced apart by predetermined spacings in the X-axial direction within the first sub region 1131 of the third metal structure 1130. The third vertical structures 1230 may be configured as a plurality of vertical structures that are spaced apart by predetermined spacings in the Y-axial direction within the second sub region 1132 of the third metal structure 1130. The third vertical structures 1230 may be configured as a plurality of vertical structures that are spaced apart by predetermined spacings in the Y-axial direction within the third sub region 1132 of the third metal structure 1130. The third vertical structures 1230 may be configured as a plurality of vertical structures that are spaced apart by predetermined spacings in the X-axial direction within the fourth sub region 1134 of the third metal structure 1130.

[155] The third vertical structures 1230 may be vertically connected to the third metal structure 1130 at a first connection point between the first sub region 1131 and the second sub region 1132. The second vertical structures 1220 may be vertically connected to the third metal structure 1130 at a second connection point between the first sub region 1131 and the third sub region 1133. The second vertical structures 1220 may be vertically connected to the third metal structure 1130 at a third connection point between the second sub region 1132 and the third sub region 1133. The second vertical structures 1220 may be vertically connected to the third metal structure 1130 at a fourth connection point between the third sub region 1133 and the fourth sub region 1134.

[156] Meanwhile, the antenna module 1000 having the BON structure according to the present disclosure may operate in a first operating mode of a leaky wave type. In this regard, the antenna module 1000 may operate in the first operating mode of the leaky wave type according to a first spacing a between the third vertical structures 1230

adjacent to each other, a second spacing b between the third vertical structures 1230 facing each other, and a radius r of the third vertical structures 1230. In the first operating mode of the leaky wave type, an antenna gain can increase and grating lobes can be mitigated, as compared to a second operating mode of the antenna module without the third metal structure and the third vertical structures. Also, the first spacing a , the second spacing b and the radius may be used to alter the radiation pattern of the antenna module 1000 having the BON structure.

[157] The antenna module 1000 in the first operating mode may be configured such that the first spacing a between the adjacent third vertical structures 1230 has a value greater than a Z-axial height h of the third vertical structures 1230. Radiation patterns radiated from the antenna module 1000 may be limited within a predetermined region by the Z-axial height h of the third vertical structures 1230. Accordingly, the radiation patterns radiated from the antenna module 1000 may further be limited within a predetermined angular range. Therefore, the antenna module 1000 having the third vertical structures 1230 can mitigate grating lobes outside the predetermined angular range. Also, in the antenna module 1000 having the third vertical structures 1230, directivity can be improved within the predetermined angular range, thereby increasing the antenna gain.

[158] Meanwhile, the antenna module 1000 having the BON structure according to the present disclosure may be implemented as an array antenna. In this regard, FIG. 10 is a view illustrating an antenna module configured as an array antenna according to presence or absence of a BON structure. (a) of FIG. 10 is a perspective view of an antenna module including a plurality of antenna elements without a BON structure. (b) of FIG. 10 is a perspective view of an antenna module including a plurality of antenna elements with a BON structure. Referring to FIG. 10, antenna elements adjacent to each other among the plurality of antenna elements may be spaced apart from each other by a first spacing in the X-axial direction. The antenna elements adjacent to each other among the plurality of antenna elements may be spaced apart from each other by a second spacing in the Y-axial direction. To implement the same beamforming (beam scanning) range in the X-axial direction and the Y-axial direction, the first spacing and the second spacing may be set to be the same value d . The first spacing and the second spacing may be set to 0.6 wavelengths to implement the beamforming (beam scanning) range to a predetermined angle or more, but may not be limited thereto, and may vary depending on applications.

[159] Hereinafter, the antenna module having the BON structure capable of being implemented as an array antenna will be described with reference to FIGS. 8 to 10. The antenna module 1000 may have a one-dimensional array antenna structure or a two-dimensional array antenna structure.

- [160] The antenna module 1000 having the one-dimensional antenna structure may include a first antenna element EL1 to a fourth antenna element EL4 that are disposed adjacent to one another in the X-axial direction. Each of the first antenna element EL1 to the fourth antenna element EL4 may include a first metal patch 1110, a second metal patch 1120, a third metal structure 1130, a feeding structure 1100f, a first vertical structure 1210, second vertical structures 1220, and third vertical structures 1230.
- [161] The first antenna element EL1 and the second antenna element EL2 adjacent to the first antenna element EL1 in the X-axial direction may be configured to share the third metal structure 1130 and the third vertical structures 1230. The third metal structure 1130 and the third vertical structures 1230 may be disposed between the first antenna element EL1 and the second antenna element EL2. The second antenna element EL2 and the third antenna element EL3 adjacent to the second antenna element EL2 in the X-axial direction may be configured to share the third metal structure 1130 and the third vertical structures 1230. The third metal structure 1130 and the third vertical structures 1230 may be disposed between the second antenna element EL2 and the third antenna element EL3. The third antenna element EL3 and the fourth antenna element EL4 adjacent to the third antenna element EL3 in the X-axial direction may be configured to share the third metal structure 1130 and the third vertical structures 1230. The third metal structure 1130 and the third vertical structures 1230 may be disposed between the third antenna element EL3 and the fourth antenna element EL4.
- [162] The antenna module 1000 having the two-dimensional antenna structure may include a first antenna element EL1 to a sixteenth antenna element EL16 that are disposed adjacent to one another in the X-axial direction and the Y-axial direction. Each of the first antenna element EL1 to the sixteenth antenna element EL16 may include a first metal patch 1110, a second metal patch 1120, a third metal structure 1130, a feeding structure 1100f, a first vertical structure 1210, second vertical structures 1220, and third vertical structures 1230.
- [163] The first antenna element EL1 and the fifth antenna element EL5 adjacent to the first antenna element EL1 in the Y-axial direction may be configured to share the third metal structure 1130 and the third vertical structures 1230. The third metal structure 1130 and the third vertical structures 1230 may be disposed between the first antenna element EL1 and the fifth antenna element EL5. The fifth antenna element EL5 and the ninth antenna element EL9 adjacent to the fifth antenna element EL5 in the Y-axial direction may be configured to share the third metal structure 1130 and the third vertical structures 1230. The third metal structure 1130 and the third vertical structures 1230 may be disposed between the fifth antenna element EL5 and the ninth antenna element EL9. The ninth antenna element EL9 and the thirteenth antenna element EL13 adjacent to the ninth antenna element EL9 in the Y-axial direction may be configured

to share the third metal structure 1130 and the third vertical structures 1230. The third metal structure 1130 and the third vertical structures 1230 may be disposed between the ninth antenna element EL9 and the thirteenth antenna element EL13.

[164] The structure configured to share the third metal structure 1130 and the third vertical structures 1230 may be applied to the second and sixth antenna elements EL2 and EL6. The structure configured to share the third metal structure 1130 and the third vertical structures 1230 may be applied to the third and seventh antenna elements EL3 and EL7. The structure configured to share the third metal structure 1130 and the third vertical structures 1230 may be applied to the fourth and eighth antenna elements EL4 and EL8. Similarly, the structure configured to share the third metal structure 1130 and the third vertical structures 1230 may be applied to any antenna elements adjacent to each other in the X-axial direction or the Y-direction.

[165] Meanwhile, the antenna module 1000 having the BON structure according to the present disclosure may operate in an operating mode of a leaky wave type to mitigate grating lobes and optimize antenna gain. FIGS. 11a and 11b are views illustrating radiation patterns of unit element and array structure of an antenna module according to presence or absence of a BON structure. FIG. 11a illustrates the radiation patterns of the unit element of the antenna module in a band of 71 GHz according to the presence or absence of the BON structure. FIG. 11b illustrates the radiation patterns of the array structure of the antenna module in the band of 71 GHz according to the presence or absence of the BON structure.

[166] Referring to FIG. 11a, a radiation pattern RP1 of a unit element with the BON structure has a higher antenna gain within a predetermined angular range than a radiation pattern RP1a of a unit element without the BON structure. For example, the radiation pattern RP1 of the unit element with the BON structure has a higher antenna gain within a range of 60 degrees or 75 degrees. On the other hand, the radiation pattern RP1 of the unit element with the BON structure has a lower antenna gain out of the range of 60 degrees or 75 degrees, to mitigate grating lobes. The radiation pattern RP1 is a radiation pattern of the antenna module 1000 with the BON structure in FIG. 9(b). The radiation pattern RP1a is a radiation pattern of the antenna module without the BON structure in FIG. 9(a). In this regard, the radiation pattern RP1a has lower gain and lower half-power beamwidth compared to the radiation pattern RP1.

[167] Referring to FIG. 11b, a radiation pattern RP2 of a unit element with the BON structure has a higher antenna gain at a beam scanning angle than a radiation pattern RP2a of a unit element with the BON structure. For example, the radiation pattern RP2 of the unit element with the BON structure has a higher antenna gain within a range of about -45 degrees (315 degrees) that is a beam scanning angle. On the other hand, the radiation pattern RP2 of the unit element with the BON structure has a lower antenna

gain at about 60 degrees, to mitigate grating lobes. The radiation pattern of FIG. 11b is the radiation pattern of the array antenna, which is obtained with the structure shown in FIG. 10(b). The radiation pattern of FIG. 11b is also obtainable with the structure shown in FIG. 8 (c).

[168] Therefore, the antenna module having the BON structure according to the present disclosure may be applied to a high-gain antenna element using a PCB technology. The antenna module having the BON structure according to the present disclosure may be used for a planar phased array design. In this regard, a distance between antenna elements may increase, grating lobes may appear, and beam widths may differently change over a broad band. To solve those problems, the BON structures of FIGS. 6, 8, and 9 can be configured to increase the beam width of the antenna element and decrease a value of grating lobe relative to a main lobe during beam scanning, thereby mitigating the grating lobes.

[169] The BON structure may be attached to a PCB having an array antenna by using screws as illustrated in FIG. 6. Therefore, the antenna module having the BON structure has a structure that can be manufactured by a 3D printer. Depending on an application, an array antenna may be implemented without the BON structure when a beamforming angle is limited to a predetermined range. However, as illustrated in FIG. 5, the grating lobes may appear within a predetermined angular range during beamforming. Therefore, since the grating lobes appear within the predetermined angular range, a range of beam scanning angle is substantially reduced, and a beam scanning loss increases.

[170] To solve the problem, the antenna module using the BON structure according to the present disclosure reduces beam scanning angle errors and increases antenna gains at the beam scanning angles. The antenna module using the BON structure according to the present disclosure can control grating lobes to be less than a predetermined level at a specific angle by mitigating the grating lobes. Therefore, in the antenna module using the BON structure, the range of beam scanning angle substantially increases and the beam scanning loss is reduced.

[171] Meanwhile, the first spacing in the X-axial direction between the adjacent antenna elements in the antenna module 1000 using the BON structure according to the present disclosure may be in a range of 0.6 to 0.8 wavelengths of an operating frequency. The second spacing in the Y-axial direction between the adjacent antenna elements in the antenna module 1000 using the BON structure may be in the range of 0.6 to 0.8 wavelengths of the operating frequency.

[172] Therefore, the antenna module 1000 using the BON structure can be implemented to achieve a high antenna gain and mitigate grating lobes, during beam-scanning, in a two-dimensional region in the X-axial direction and Y-axial direction. In this regard,

the first spacing between the first antenna element EL1 and the second antenna element EL2 may be in the range of 0.6 to 0.8 wavelength of the operating frequency. In the first spacing between the first antenna element EL1 and the second antenna element EL5 may be in the range of 0.6 to 0.8 wavelength of the operating frequency. Similarly, the first spacing and the second spacing between the adjacent antenna elements may be applied to spacings between arbitrary adjacent antenna elements in the X-axial direction or the Y-axial direction.

- [173] The forgoing description has been given of the antenna module using the BON structure for grating lobe mitigation and high gain. Technical effects of the antenna module using the BON structure for the grating lobe mitigation and high gain may be summarized as follows, but may not be limited thereto.
- [174] Hereinafter, technical effects of an antenna module using a BON structure for grating lobe mitigation and high gain will be described, but may not be limited thereto.
- [175] According to an embodiment, in an mmWave antenna module, grating lobe mitigation and high gain can be achieved through a structure surrounding antenna elements.
- [176] According to an embodiment, grating lobe mitigation and high gain can be achieved by using a structure surrounding antenna elements without causing an increase in hardware complexity and costs, due to the use of more phase shifters, in an mmWave antenna module.
- [177] According to an embodiment, grating lobe mitigation and high gain can be achieved using a structure surrounding antenna elements without causing an increase in power consumption, due to the use of more phase shifters, in an mmWave antenna module.
- [178] According to an embodiment, a broadband two-dimensional array antenna structure can be implemented through a bed of nail (BON) structure surrounding antenna elements.
- [179] According to an embodiment, grating lobes can be mitigated and directivity can be improved by applying broadband array antenna and a high-gain antenna pattern at an extremely high frequency of V band or more.
- [180] According to an embodiment, in an antenna that operates as a dual polarization antenna, grating lobes can be mitigated and a beam-scanning range can be increased.
- [181] According to an embodiment, a unit element and an array antenna of an antenna module can be implemented as low-profile antennas by selectively using a BON structure or adjusting a height of the BON structure according to beam-scanning performance requirements.
- [182] According to an embodiment, since an overall BON structure is integrally manufactured through 3D printing, a separate pin manufacturing process to be individually added is not required, which can facilitate the manufacturing processes and reduce

manufacturing costs.

[183] Further scope of applicability of the present disclosure will become apparent from the foregoing detailed description. It should be understood, however, that the detailed description and specific examples, such as the preferred embodiment of the present disclosure, are given by way of illustration only, since various modifications and alternations within the spirit and scope of the disclosure will be apparent to those skilled in the art.

[184] Further scope of applicability of the present disclosure will become apparent from the following detailed description. It should be understood, however, that the detailed description and specific examples, such as the preferred implementation of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will be apparent to those skilled in the art. Therefore, the detailed description should not be limitedly construed in all of the aspects, and should be understood to be illustrative. Therefore, all changes and modifications that fall within the metes and bounds of the claims, or equivalents of such metes and bounds are therefore intended to be embraced by the appended claims.

Claims

- [Claim 1] An antenna module for grating lobe mitigation and high gain, the antenna module comprising:
a first metal patch having a dielectric region therein;
a second metal patch formed to surround the first metal patch;
a third metal structure formed to surround the second metal patch;
a feeding structure vertically coupled to the first metal patch at at least one point of the first metal patch;
a first vertical structure vertically formed of a metallic material at the inner dielectric region of the first metal patch;
second vertical structures vertically formed of a metallic material at different points of the second metal patch; and
third vertical structures vertically formed of a metallic material at different points of the third metal structure.
- [Claim 2] The antenna module of claim 1, wherein the first metal patch is a circular ring patch in a circular ring shape having inner and outer diameters, and is disposed on a first surface of a printed circuit board (PCB),
the second metal patch is a square ring patch in a square shape having inner and outer lengths, and is disposed on the first surface of the PCB,
the first vertical structure is formed to be perpendicular to the first surface and a second surface of the PCB at a center point of the dielectric region inside the first metal patch, and
the second vertical structures are formed to be perpendicular to the first surface and the second surface of the PCB at different points of the second metal patch.
- [Claim 3] The antenna module of claim 2, wherein the feeding structure comprises:
a first feeding structure electrically coupled to a first point of the first metal patch to apply a horizontally polarized signal; and
a second feeding structure electrically coupled to a second point of the first metal patch to apply a vertically polarized signal.
- [Claim 4] The antenna module of claim 3, wherein the second metal patch comprises a first sub patch, a second sub patch connected to the first sub patch at one end of the first sub patch, a third sub patch connected to the first sub patch at another end of the first sub patch, and a fourth sub patch connecting the second sub patch and an end portion of the

third sub patch.

[Claim 5] The antenna module of claim 4, wherein the second vertical structures are connected to center points of the first sub patch, the second sub patch, the third sub patch, and the fourth sub patch of the second metal patch, and

the second vertical structures are vertically connected to a first connection point between the first sub patch and the second sub patch, a second connection point between the first sub patch and the third sub patch, a third connection point between the second sub patch and the fourth sub patch, and a fourth connection point between the third sub patch and the fourth sub patch.

[Claim 6] The antenna module of claim 3, wherein the third metal structure is formed as a square ring metal structure formed in a square shape having inner and outer lengths, and
the third vertical structures protrude from the third metal structure in a Z-axial direction.

[Claim 7] The antenna module of claim 5, wherein the third metal structure comprises a first sub region, a second sub region connected to the first sub region at one end of the first sub region, a third sub region connected to the first sub region at another end of the first sub region, and a fourth sub region connecting the second sub region and an end portion of the third sub region.

[Claim 8] The antenna module of claim 7, wherein the third vertical structures are configured as a plurality of vertical structures spaced apart from one another respectively on the first sub region, the second sub region, the third sub region, and the fourth sub region of the third metal structure, and

the third vertical structures are vertically connected to the third metal structure at a first connection point between the first sub region and the second sub region, a second connection point between the first sub region and the third sub region, a third connection point between the second sub region and the fourth sub region, and a fourth connection point between the third sub region and the fourth sub region.

[Claim 9] The antenna module of claim 6, wherein the antenna module operates in a first operating mode of a leaky wave type according to a first spacing a between the third vertical structures adjacent to each other, a second spacing b between the third vertical structures facing each other, and a radius r of the third vertical structures, and

the first operating mode is configured to increase the antenna gain and mitigate the grating lobes, as compared to a second operating mode of the antenna module without the third metal structure and the third vertical structures.

[Claim 10] The antenna module of claim 9, wherein the spacing a between the third vertical structures adjacent to each other has a value greater than a height h in the Z-axial direction of the third vertical structures.

[Claim 11] The antenna module of claim 3, further comprising a first antenna element to a fourth antenna element disposed adjacent to one another in an X-axial direction, and
each of the first antenna element to the fourth antenna element comprises the first metal patch, the second metal patch, the third metal structure, the feeding structure, the first vertical structure, the second vertical structures, and the third vertical structures.

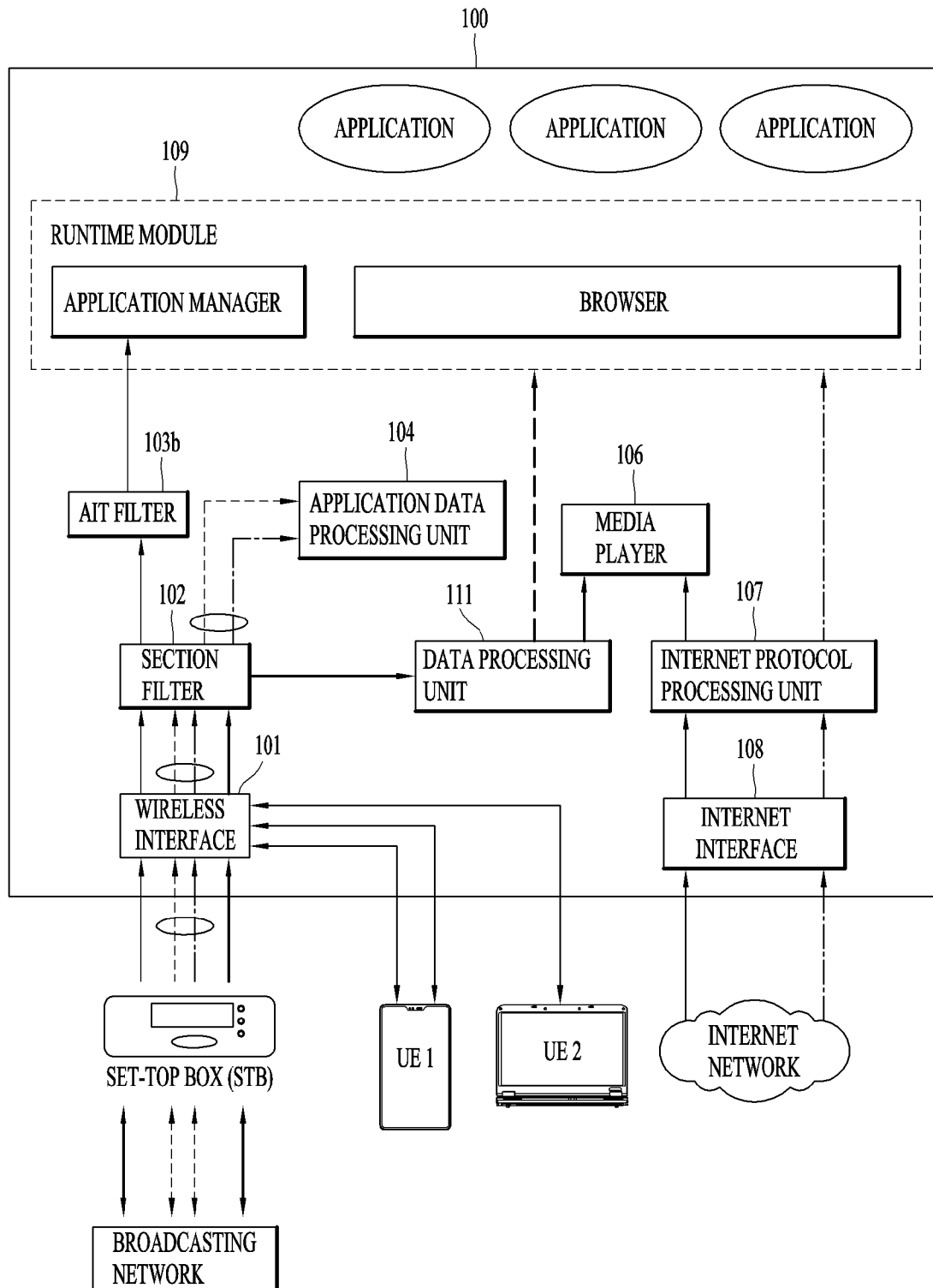
[Claim 12] The antenna module of claim 11, wherein the first antenna element and the second antenna element adjacent to the first antenna element in the X-axial direction are configured to share the third metal structure and the third vertical structures between the first antenna element and the second antenna element.

[Claim 13] The antenna module of claim 12, further comprising a first antenna element to a sixteenth antenna element disposed adjacent to one another in the X-axial direction and a Y-axial direction, and
each of the first antenna element to the sixteenth antenna element comprises the first metal patch, the second metal patch, the third metal structure, the feeding structure, the first vertical structure, the second vertical structures, and the third vertical structures.

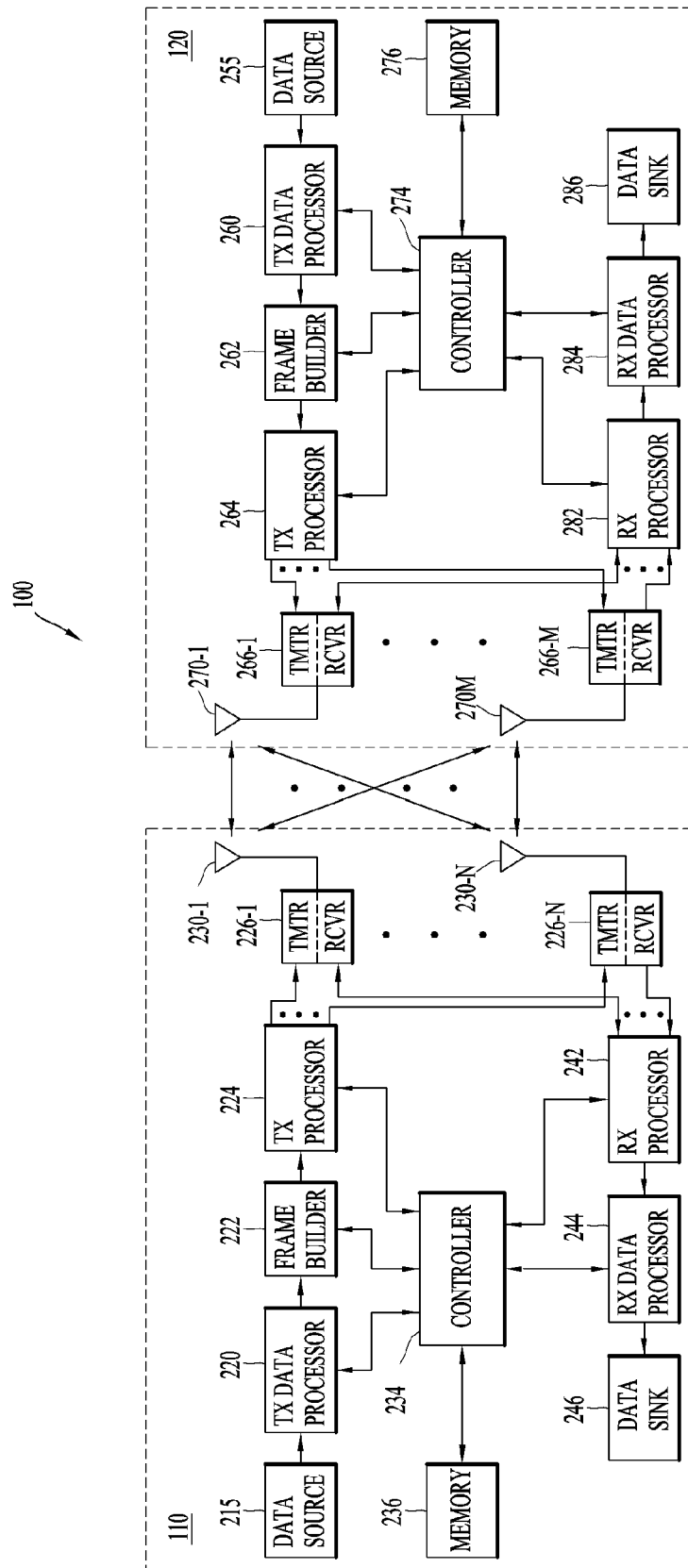
[Claim 14] The antenna module of claim 13, wherein the first antenna element and the fifth antenna element adjacent to the first antenna element in a Y-axial direction are configured to share the third metal structure and the third vertical structures between the first antenna element and the fifth antenna element.

[Claim 15] The antenna module of claim 12, wherein a first spacing between the first antenna element and the second antenna element in the X-axial direction is formed in a range of 0.6 to 0.8 wavelengths of an operating frequency, and
a second spacing between the first antenna element and the fifth antenna element in a Y-axial direction is formed in the range of 0.6 to 0.8 wavelengths of the operating frequency.

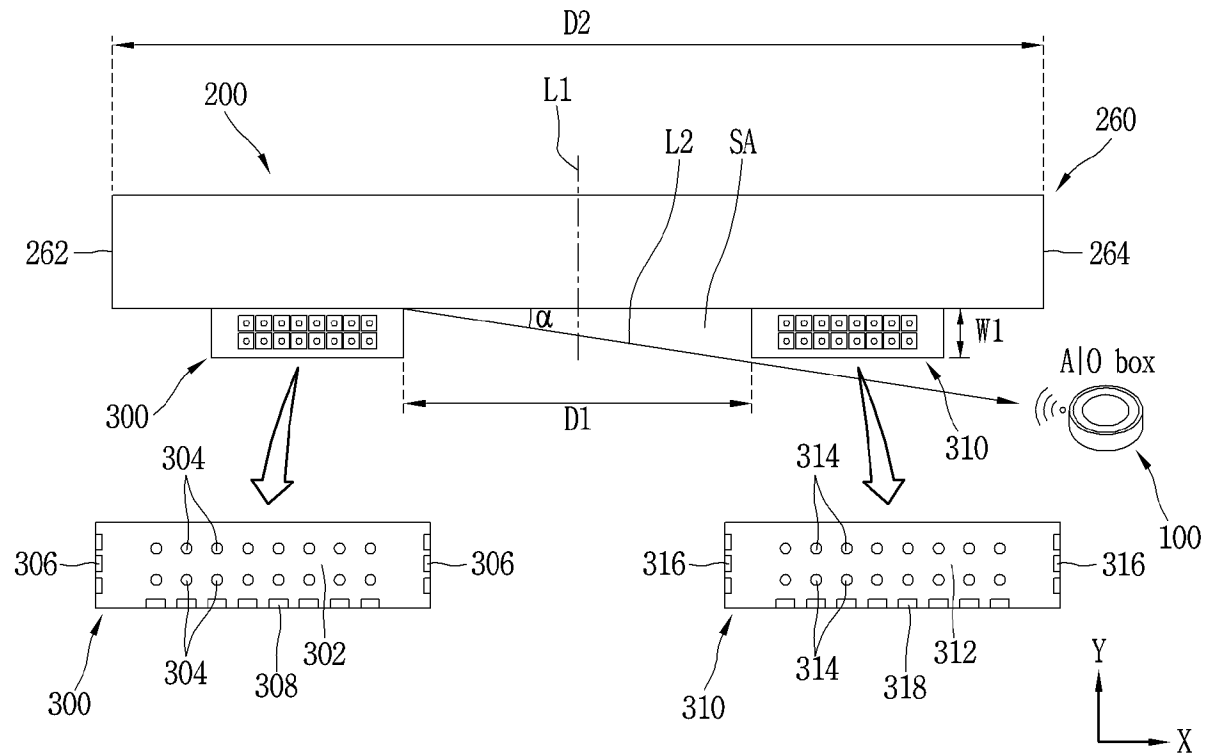
[Fig. 1]



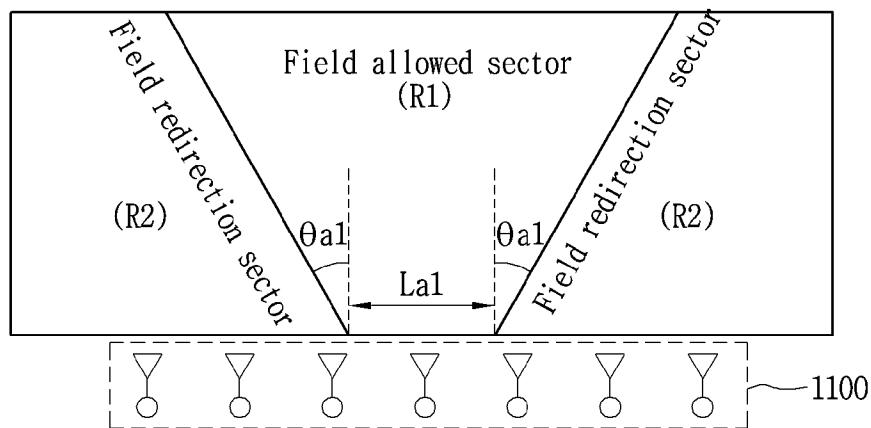
[Fig. 2]



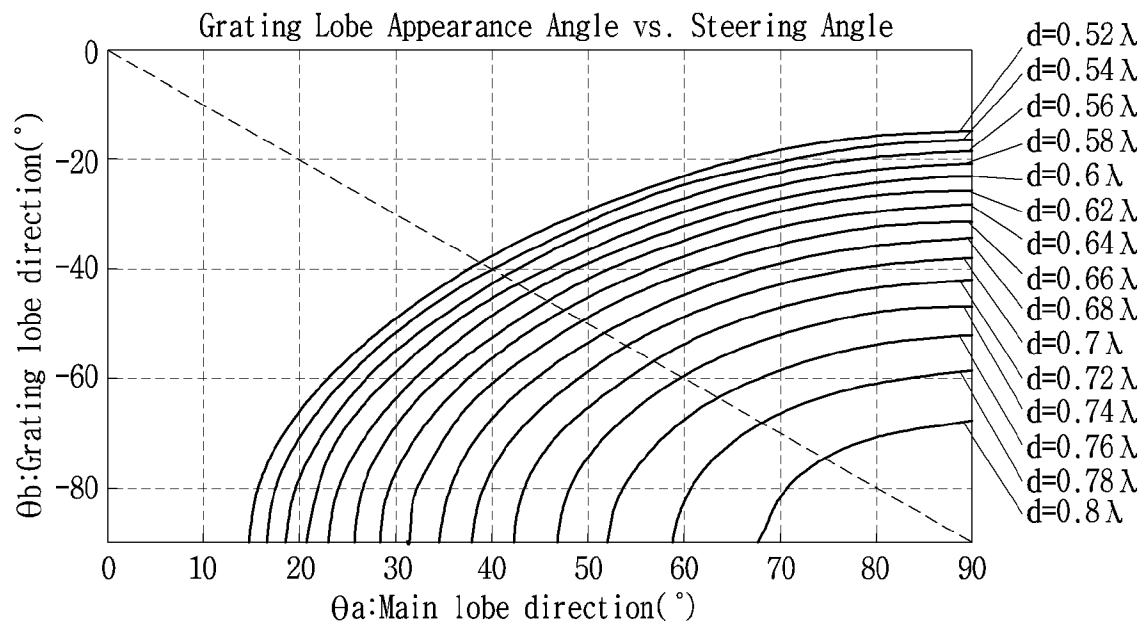
[Fig. 3]



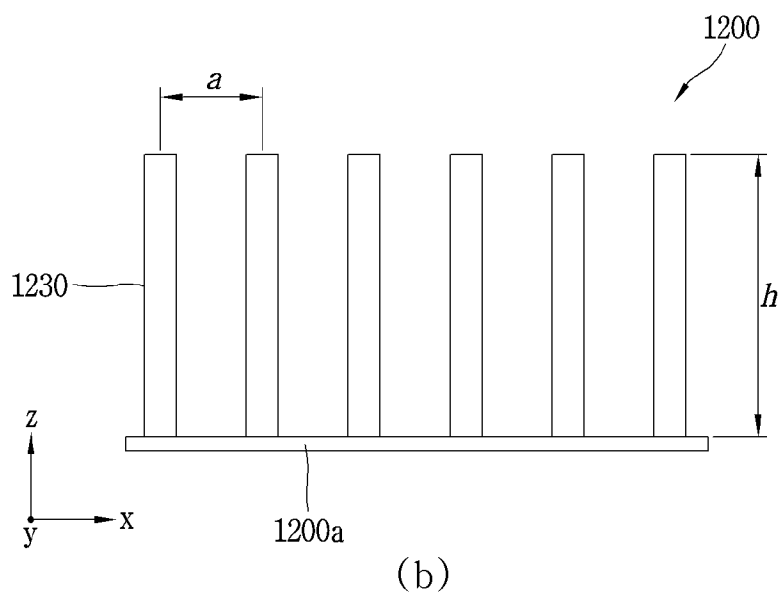
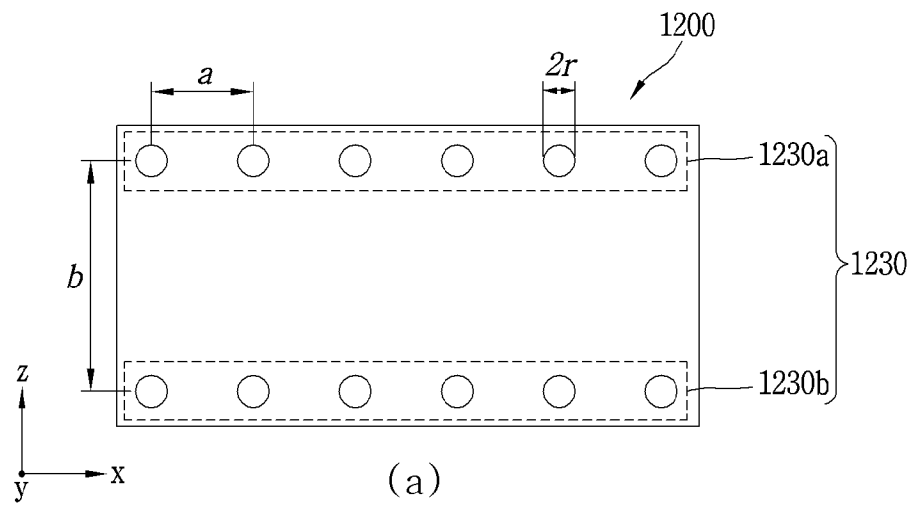
[Fig. 4]



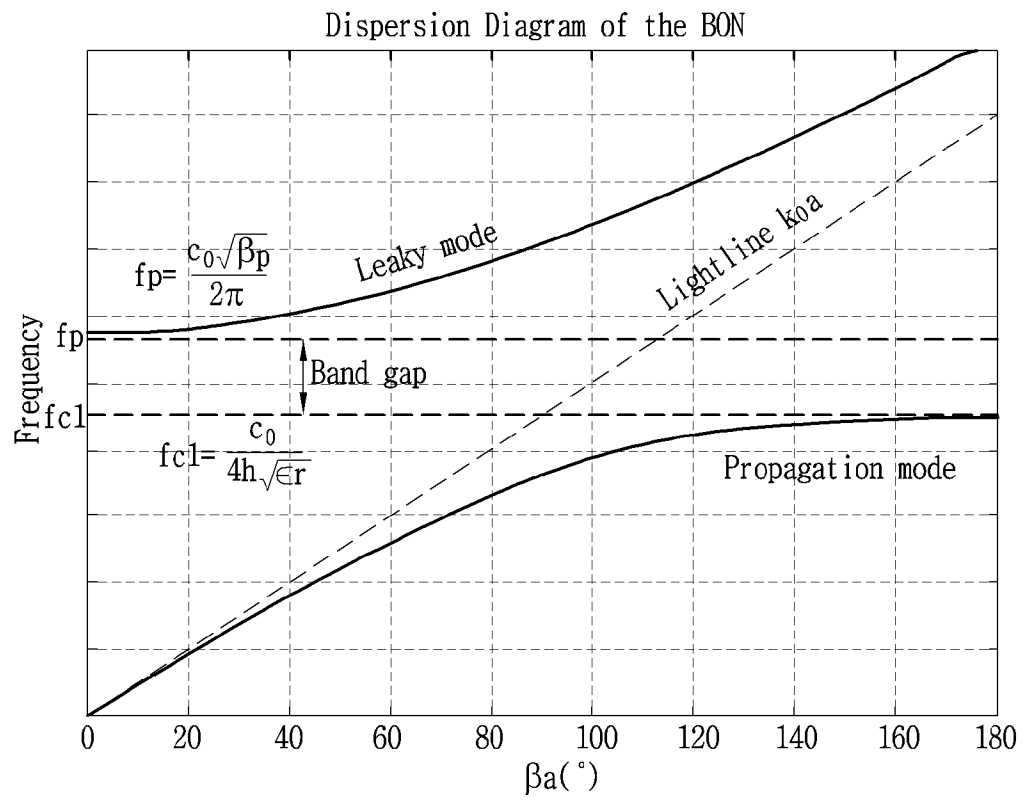
[Fig. 5]



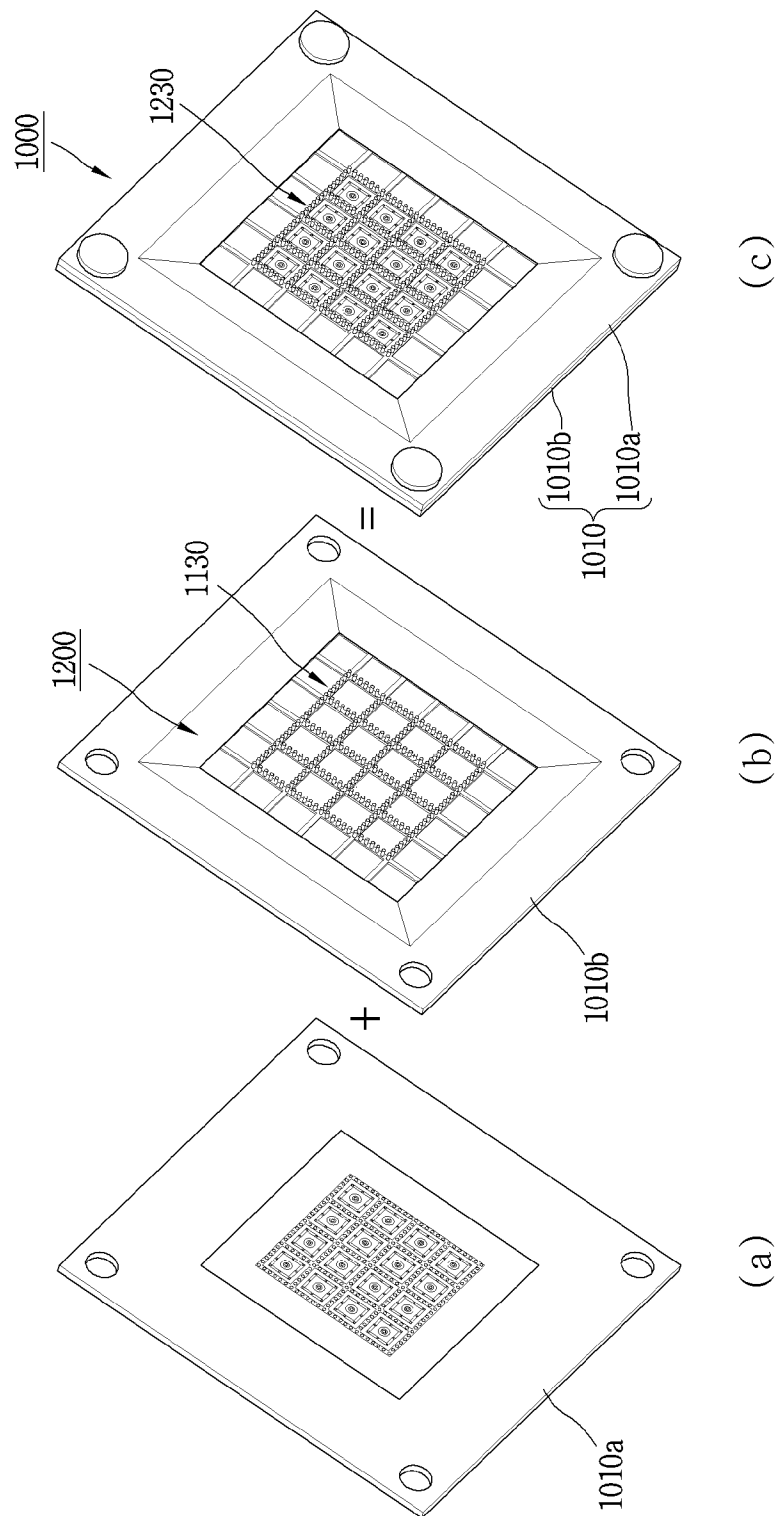
[Fig. 6]



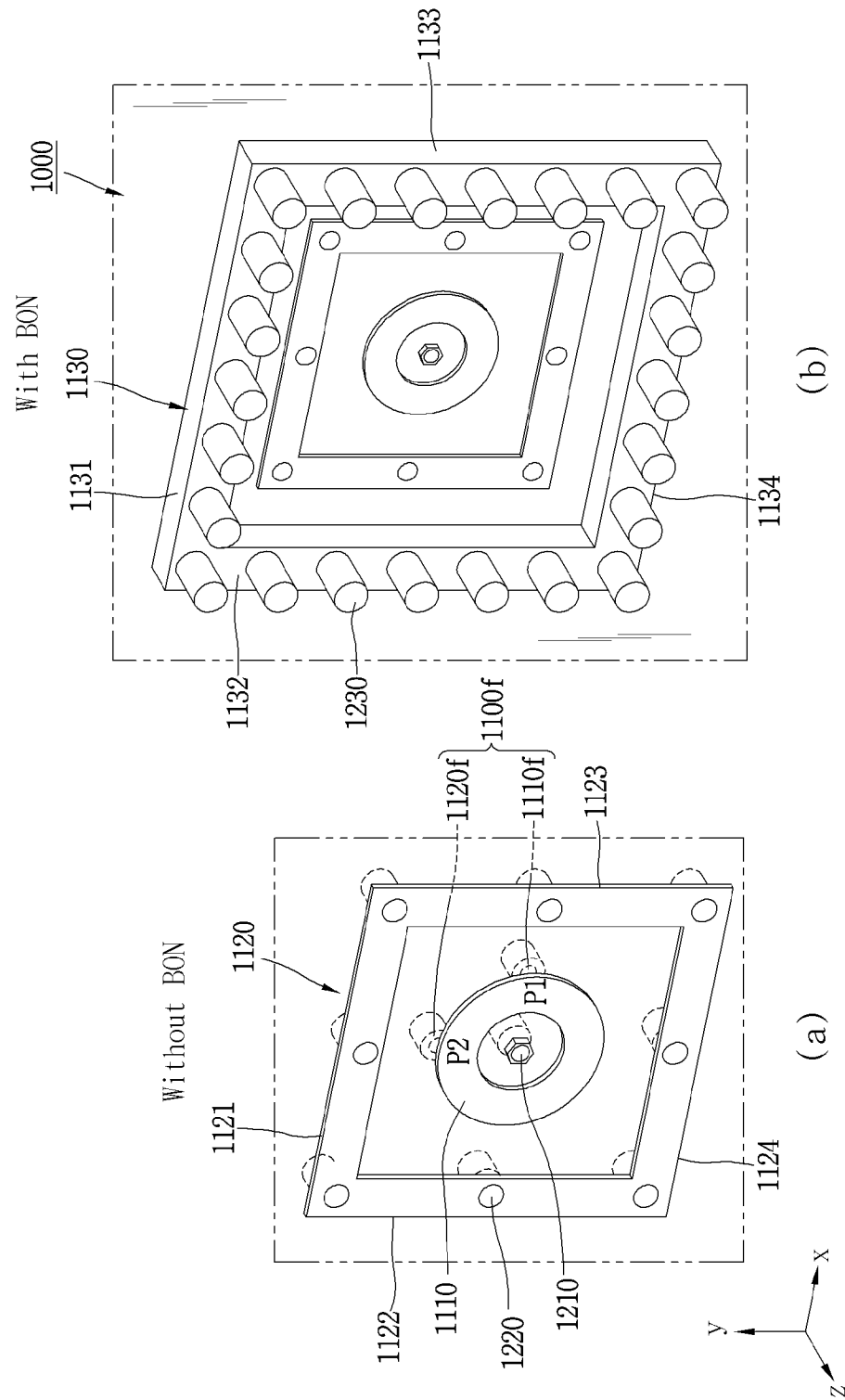
[Fig. 7]



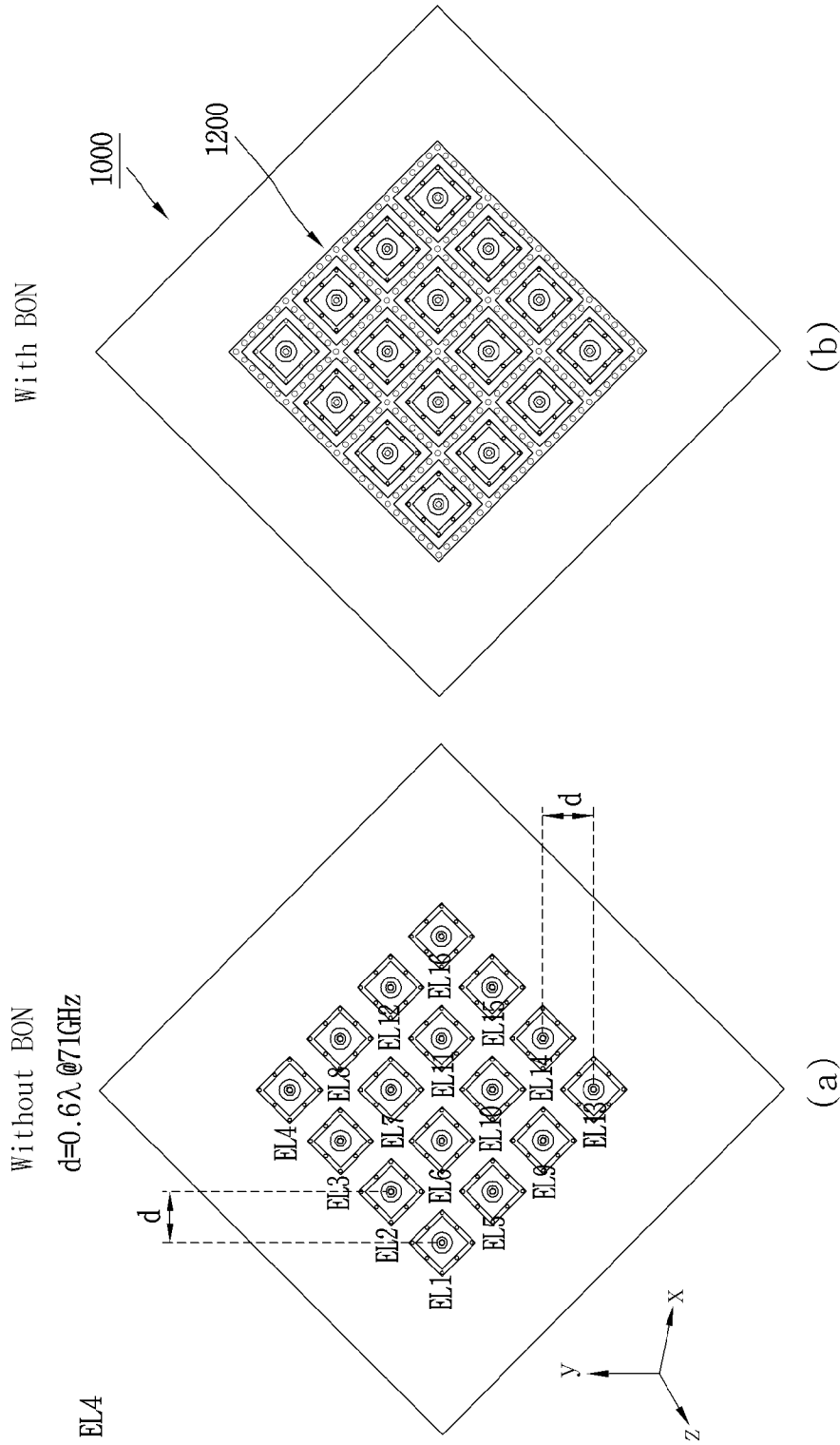
[Fig. 8]



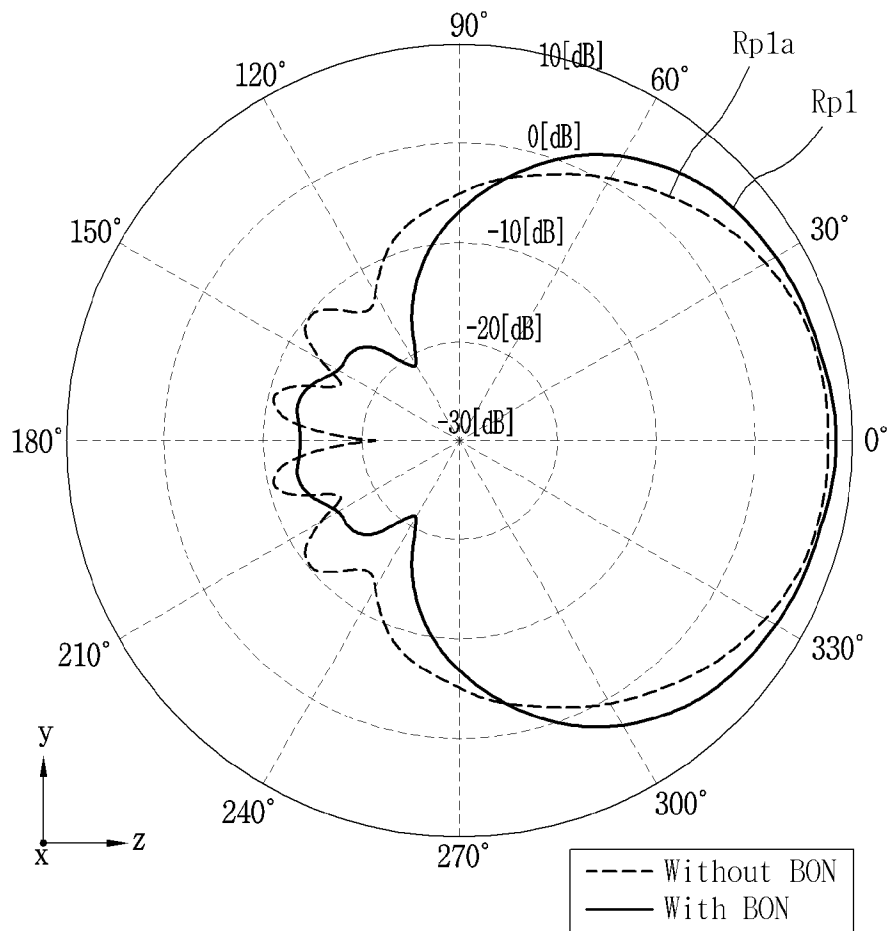
[Fig. 9]



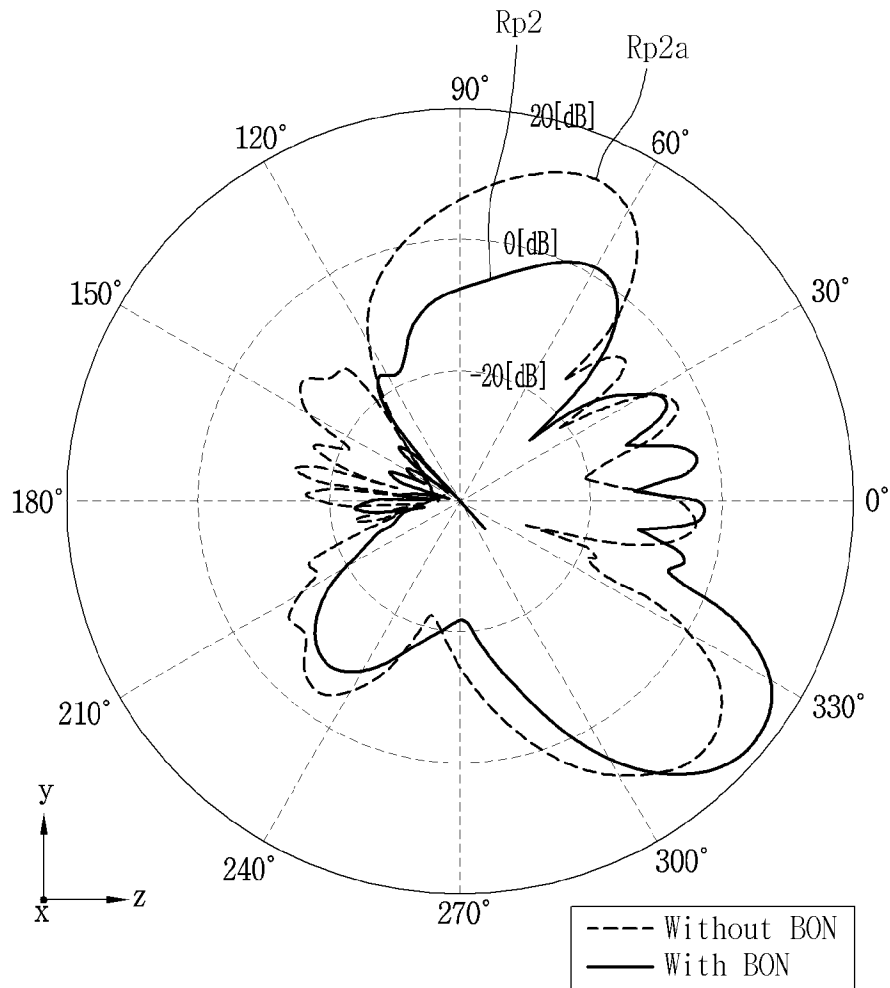
[Fig. 10]



[Fig. 11a]



[Fig. 11b]



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2023/019078

A. CLASSIFICATION OF SUBJECT MATTER**H01Q 21/06**(2006.01)i; **H01Q 25/00**(2006.01)i; **H01Q 9/04**(2006.01)i; **H01Q 1/38**(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01Q 21/06(2006.01); H01Q 1/38(2006.01); H01Q 1/50(2006.01); H01Q 9/04(2006.01)

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: antenna, metal, patch, feeding, vertical structure

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2007-0052587 A1 (DAJUN CHENG) 08 March 2007 (2007-03-08) paragraphs [0012]-[0024] and figures 1-3, 7	1-15
A	US 2020-0287287 A1 (SONY CORPORATION) 10 September 2020 (2020-09-10) paragraphs [0034]-[0036] and figures 1-2	1-15
A	CN 105375105 A (722 RESEARCH INSTITUTE OF CHINA SHIPBUILDING INDUSTRY CORPORATION) 02 March 2016 (2016-03-02) claims 1-10 and figures 1-6	1-15
A	US 2010-0090903 A1 (WOO-JIN BYUN et al.) 15 April 2010 (2010-04-15) claims 1-9 and figures 1-4	1-15
A	US 2003-0052825 A1 (BARSUR RAMA RAO et al.) 20 March 2003 (2003-03-20) claims 1-10 and figures 2-4	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

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“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

12 August 2024

Date of mailing of the international search report

12 August 2024

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2023/019078

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				WO	2008-069493	A1	12 June 2008
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				WO	03-026069	A2	27 March 2003
				WO	03-026069	A3	11 March 2004