

MULTI-BAND SHARED-APERTURE ANTENNA AND COMMUNICATION DEVICE

TECHNICAL FIELD

[0001] This application relates to the field of base station antenna technologies, and in particular, to a multi-band shared-aperture antenna and a communication device.

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BACKGROUND

[0002] In an evolution process of base station antenna networks, a quantity of antenna installation platforms is increasing, and physical space for arranging the antenna installation platforms on a tower is also decreasing. The antenna installation platform is a platform at which an antenna is located. Therefore, a multi-band base station antenna becomes a mainstream of current antenna design. In the case of a limited antenna aperture, it is a trend of antenna technology development to improve integration of antenna frequencies as much as possible. Currently, most 4G multi-band base station antennas have no wide-angle beam scanning capability. However, a 5G MIMO (multiple-in multiple-out, multiple-in multiple-out) array antenna has a flexible 3D-M-MIMO beamforming capability, a wide-angle beam scanning capability, and high spectral efficiency, so that antenna coverage can be effectively improved.

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[0003] In a multi-band array antenna, wide-angle beam scanning is a difficulty and a challenge in array antenna design. Currently, it is still difficult to design an array antenna with cost-effective scanning and multi-frequency coverage, and it is difficult to put the array antenna into large-scale commercial use. Therefore, currently, a phased array antenna and a 5G MIMO antenna that can implement wide-angle beam scanning are still designed in a single-frequency and narrowband form. A newly specified 5G low frequency band cannot support a 5G high rate but can provide good frequency coverage, and therefore is favored by operators. However, there are a plurality of octave bands between the low frequency band and a high frequency band, and it is difficult to integrate the low frequency band into an existing high-frequency antenna. If a base station needs to meet a requirement of the 5G low frequency band, an antenna that meets the requirement of the 5G low frequency band needs to be re-deployed. However, the space on the tower is insufficient and there is no room to re-deploy new antennas. In addition, re-deployment of new antennas requires additional costs. Therefore, currently, it is difficult to design an array antenna that can implement wide-angle beam scanning and support a plurality of frequencies, especially a non-integer frequency ratio in the plurality of frequencies.

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SUMMARY

[0004] This application provides a multi-band shared-aperture antenna and a communication device, so that an antenna array has a strong multi-frequency extension capability, and can maintain a strong wide-angle beam scanning capability in different frequency bands.

5 **[0005]** According to a first aspect, a multi-band shared-aperture antenna is provided. The multi-band shared-aperture antenna includes a plurality of coupled array elements, a frequency combining unit, a low-frequency feed unit, and a high-frequency feed unit.

[0006] Each coupled array element is disposed on a reflection panel.

[0007] The frequency combining unit is connected to the plurality of coupled array elements. The frequency
10 combining unit includes at least one frequency combining layer. Each frequency combining layer includes at least one frequency combiner. Each frequency combiner includes an antenna port, at least one high-frequency port, and at least one low-frequency port. A plurality of high-frequency ports form at least one high-frequency port group, and a plurality of low-frequency ports form at least one low-frequency port group. For each layer, a quantity of high-frequency port groups is not greater than a quantity of frequency combiners, a quantity of low-frequency port groups
15 is less than the quantity of frequency combiners, and the quantity of high-frequency port groups is not less than the quantity of low-frequency port groups.

[0008] When the frequency combining unit includes one frequency combining layer, the antenna port of the frequency combiner is connected to the coupled array element, the plurality of low-frequency ports are connected to the low-frequency feed unit, and the plurality of high-frequency ports are connected to the high-frequency feed unit.

20 **[0009]** When the frequency combining unit includes at least two frequency combining layers, between every two adjacent layers, a plurality of upper-layer low-frequency ports are connected to lower-layer antenna ports, an antenna port of a first-layer frequency combiner is connected to the coupled array element, a plurality of high-frequency ports of the first-layer frequency combiner are connected to the high-frequency feed unit, a plurality of low-frequency ports of a last-layer frequency combiner are connected to the low-frequency feed unit, and a high-frequency
25 port of the last-layer frequency combiner is connected to the high-frequency feed unit.

[0010] The low-frequency feed unit is configured to feed a low-frequency signal.

[0011] The high-frequency feed unit is configured to feed at least one type of frequency signal higher than the low-frequency signal.

[0012] In the foregoing solution, different combinations of low-frequency ports and high-frequency ports are
30 used, so that the antenna has a strong multi-frequency extension capability, and can maintain a strong wide-angle

beam scanning capability in different frequency bands. Because a structure of the feed unit is reconstructed, a quantity of feeding ports is reduced. Therefore, hardware overheads and power consumption are also reduced. In addition, occurrence of grating lobes can also be avoided in a beam scanning process. Moreover, because the structure of the feed unit is reconstructed, the quantity of feeding ports is reduced. Therefore, the hardware overheads and the power consumption are also reduced.

[0013] In a specific implementation solution, the coupled array elements form reconstructed elements of different frequency bands based on different port groups, coupled array elements corresponding to the low-frequency ports in the low-frequency port group jointly form a low-frequency reconstructed element, and coupled array elements corresponding to the high-frequency ports in the high-frequency port group jointly form a high-frequency reconstructed element.

[0014] In the foregoing solution, the low-frequency ports and the high-frequency ports are recombined to form elements with different physical apertures, to improve the wide-angle beam scanning capability in frequency bands. In addition, antenna costs and complexity can be effectively reduced, so that the antenna has a good frequency spread feature, and a solution of constructing a multi-band shared-aperture antenna with an integer ratio and a non-integer frequency ratio is available.

[0015] In a specific implementation solution, a distance d between centers of every two adjacent coupled array elements may satisfy:

$$n_1 * d \leq 0.5 \lambda_1, \text{ where}$$

n_1 is a quantity of high-frequency ports in the high-frequency port group, λ_1 is a wavelength corresponding to a high-frequency signal input by the high-frequency feed unit, and n_1 is a positive integer.

[0016] The distance d between the centers of every two adjacent coupled array elements is determined. In this way, it can be ensured that occurrence of grating lobes is avoided in a beam scanning process in a high frequency band.

[0017] In a specific implementation solution, if a maximum scanning angle of the multi-band shared-aperture antenna is θ_{max} , and the distance d between the centers of every two adjacent coupled array elements may satisfy:

$$n_1 * d \leq \frac{\lambda_1}{1 + \sin \theta_{max}}.$$

[0018] The distance d between the centers of every two adjacent coupled array elements is set. In this way, it can be ensured that occurrence of grating lobes is avoided when there is a strong wide-angle beam scanning capability in a high frequency band.

[0019] In a specific implementation solution, a quantity n_2 of low-frequency ports in the low-frequency port group may satisfy:

$$n_2 * d \leq 0.5 \lambda_2, \text{ where}$$

λ_2 is a wavelength corresponding to a low-frequency signal input by the low-frequency feed unit, n_2 is a positive integer, and d is the distance between the centers of every two adjacent coupled array elements.

[0020] The distance d between the centers of every two adjacent coupled array elements is determined, and the quantity n_2 of low-frequency ports in the low-frequency port group is set. In this way, it can be ensured that occurrence of grating lobes is avoided in a beam scanning process in a low frequency band.

[0021] In a specific implementation solution, if the maximum scanning angle of the multi-band shared-aperture antenna is θ_{max} , the quantity n_2 of low-frequency ports in the low-frequency port group may satisfy:

$$n_2 * d \leq \frac{\lambda_2}{1 + \sin \theta_{max}}.$$

[0022] The quantity n_2 of low-frequency ports in the low-frequency port group is set. In this way, it can be ensured that occurrence of grating lobes is avoided when there is a strong wide-angle beam scanning capability in a low frequency band.

[0023] In a specific implementation solution, phase shift units may further exist on the low-frequency feed unit and the high-frequency feed unit. Each phase shift unit is configured to adjust phase lags/leads of electromagnetic waves radiated by the low-frequency feed unit and the high-frequency feed unit to specified phases corresponding to the coupled array element, and the phase shift unit may be any one or more of the following structures: a digital phase shifter, an analog phase shifter, and a hybrid phase shifter.

[0024] The phase lags/leads of the electromagnetic waves radiated by the low-frequency feed unit and the high-frequency feed unit are adjusted, by using the foregoing various phase shift units, to the specified phases corresponding to the coupled array element, to form beams in different directions, so as to complete beam scanning.

[0025] In a specific implementation solution, the coupled array element includes at least one dipole array element, a polarization direction of the dipole array element is parallel to that of the coupled array element, and coupling capacitors exist on two sides of a tail end of the dipole array element. A direction of the dipole array element is set. In this way, the coupled array element can have a polarization direction in at least one direction, to provide polarization types in more modes.

[0026] In a specific implementation solution, when the coupled array element includes two dipole array elements, the dipole array elements are disposed orthogonally. The dipole array elements are disposed orthogonally,

so that the coupled array elements can have dual polarization features in different directions such as a vertical direction, a horizontal direction, and $\pm 45^\circ$ directions.

[0027] In a specific implementation solution, the frequency combiner may include any one or more of the following structures: a frequency divider, a duplexer, and a filter.

5 **[0028]** A quantity of interfaces of the frequency divider, the duplexer, or the filter is set. In this way, quantities of low-frequency and high-frequency ports of the frequency combiner can be extended, and connections can be established in different manners. In addition, the frequency divider is not limited to a dual-frequency type, and a frequency divider of a tri-frequency or multi-frequency type may alternatively be used. This more effectively reduces costs and complexity of the antenna and enables the antenna to have a good frequency spread feature.

10 **[0029]** According to a second aspect, a communication device is provided. The communication device includes any one of the foregoing multi-band shared-aperture antennas. Based on the foregoing design, the antenna has a strong multi-frequency extension capability, and can maintain a strong wide-angle beam scanning capability in different frequency bands. In addition, occurrence of grating lobes can also be avoided in a beam scanning process. Moreover, because a structure of a feed unit is reconstructed, a quantity of feeding ports is reduced. Therefore, hardware
15 overheads and power consumption can also be reduced.

BRIEF DESCRIPTION OF DRAWINGS

[0030] FIG. 1 is a schematic diagram of a structure of a base station;

[0031] FIG. 2a and FIG. 2b are schematic diagrams of a multi-band shared-aperture antenna designed in an overlap-coaxial manner;

20 **[0032]** FIG. 2c and FIG. 2d are schematic diagrams of a multi-band shared-aperture antenna designed in an overlap-interleave manner;

[0033] FIG. 2e is a schematic diagram of a feeding structure corresponding to structures shown in FIG. 2a to FIG. 2d;

[0034] FIG. 2f is a schematic diagram of a multi-band shared-aperture antenna designed by using a reflection
25 panel separation technology;

[0035] FIG. 2g is a schematic diagram of a multi-band shared-aperture antenna designed by using a broadband unit sharing technology;

[0036] FIG. 2h is a schematic diagram of a feeding structure corresponding to a structure shown in FIG. 2g;

[0037] FIG. 2i is a schematic diagram of a multi-band shared-aperture antenna designed by using a tightly

coupled phased array technology;

- [0038]** FIG. 2j is a schematic diagram of isolation of a structure shown in FIG. 2i in different frequency bands;
- [0039]** FIG. 2k is a schematic diagram of a feeding structure corresponding to the structure shown in FIG. 2i;
- [0040]** FIG. 3a is a schematic diagram of a multi-band shared-aperture antenna;
- 5 **[0041]** FIG. 3b is a schematic diagram of a structure of a multi-band shared-aperture antenna including phase shift units;
- [0042]** FIG. 4a is a principle diagram of beamforming of an analog phase shifter;
- [0043]** FIG. 4b is a principle diagram of beamforming of a digital phase shifter;
- [0044]** FIG. 4c is a principle diagram of beamforming of a hybrid phase shifter;
- 10 **[0045]** FIG. 5a to FIG. 5d are schematic diagrams of a dual-band antenna;
- [0046]** FIG. 6 is a schematic diagram of a tri-band antenna;
- [0047]** FIG. 7a to FIG. 7i are schematic diagrams of a multi-band shared-aperture antenna of a planar array type;
- [0048]** FIG. 8a is a schematic diagram of periodically arranged array elements;
- [0049]** FIG. 8b is a schematic diagram of aperiodically arranged array elements;
- 15 **[0050]** FIG. 8c is a schematic diagram of arranged array elements including dummy elements;
- [0051]** FIG. 9a and FIG. 9b are schematic diagrams of dual-polarized coupled array elements;
- [0052]** FIG. 10 is a schematic diagram of a quad-band single-polarized planar array;
- [0053]** FIG. 11 is a schematic diagram of a reflective array antenna;
- [0054]** FIG. 12 is a schematic diagram of an intelligent reflector surface; and
- 20 **[0055]** FIG. 13 is a schematic diagram of a reflection element.

DESCRIPTION OF EMBODIMENTS

- [0056]** To make the objectives, technical solutions, and advantages of this application clearer, the following further describes this application in detail with reference to the accompanying drawings.
- [0057]** The following explains words related to or possibly related to this application.
- 25 **[0058]** 1. "At least one" means one or more, that is, includes one, two, three, or more.
- [0059]** 2. "A plurality of" means two or more, that is, includes two, three, four, or more.
- [0060]** 3. A connection refers to coupling, including a direct connection or an indirect connection through another component to implement an electrical connection.
- [0061]** 4. A grating lobe refers to a lobe, other than a main lobe, generated when elements of an array antenna

are superposed in a same direction in a plurality of directions when a spacing between the elements is large enough.

[0062] 5. A phased array radar (phased array radar, PAR) uses a large quantity of individually controlled small antenna elements to form an antenna array. Each antenna element is controlled by an independent phase shift switch. A phase transmitted by each antenna element is controlled, so that beams with different phases can be combined.

5 Electromagnetic waves transmitted by antenna elements of a phased array are combined into a mostly straight radar main lobe according to an interference principle.

[0063] 6. A microwave wireless energy transmission technology is a mode of energy transmission, and has a good application prospect in fields such as satellite energy transmission, directional energy weapons, biomedicine, and two-site power transmission. A receive antenna and a rectifier circuit in the microwave wireless energy transmission technology are two key research technical points.

10 **[0064]** 7. A retrodirective antenna is an antenna array, and specifically refers to an antenna that preferentially returns power to a source direction when the antenna receives a signal in a direction of arrival.

[0065] 8. A tightly coupled phased array (tightly coupled phased array, TCPA) is an array antenna for improving a bandwidth of a phased array through strong coupling between elements.

15 **[0066]** 9. "Co-planar" means that a same aperture is used by antennas for different frequency bands for operation. Compared with non-co-planar antennas, for co-planar antennas, a plurality of antennas with different frequencies and polarization features can be appropriately designed to fall within a same aperture. In addition to maintaining a compact antenna structure, the co-planar antennas have multi-frequency and multi-polarization operation performance, and are a development trend of future antennas.

20 **[0067]** To facilitate understanding of a multi-band shared-aperture antenna provided in embodiments of this application, an application scenario of the multi-band shared-aperture antenna is first described. The multi-band shared-aperture antenna provided in embodiments of this application is applicable to a mobile communication system. The mobile communication system herein includes but is not limited to: a global system for mobile communications (global system for mobile communications, GSM) system, a code division multiple access (code division multiple access, CDMA) system, a wideband code division multiple access (wideband code division multiple access, WCDMA) system, a general packet radio service (general packet radio service, GPRS) system, a long term evolution (long term evolution, LTE) system, an LTE frequency division duplex (frequency division duplex, FDD) system, an LTE time division duplex (time division duplex, TDD) system, a universal mobile telecommunications system (universal mobile telecommunications system, UMTS), a worldwide interoperability for microwave access (worldwide interoperability for microwave Access, WiMAX) communication system, a 5th generation (5th generation, 5G) system or a new radio (new radio, NR) system, a future 6th generation (6th generation, 6G) system, or the like.

[0068] For example, the multi-band shared-aperture antenna in this application may be further applied to the field of phased array radars. The multi-band shared-aperture antenna is used as a phased array antenna of a phased array radar. This can improve a radar scanning angle, improve scanning flexibility, and improve performance.

[0069] The multi-band shared-aperture antenna in this application may be further applied to the field of microwave wireless energy transmission. The multi-band shared-aperture antenna is used as a receive antenna for microwave wireless energy transmission, to provide a reflector function and connect to a microwave rectifier circuit to receive and convert energy. In this way, reflector surface features of other frequency bands can be reconstructed without affecting reception features of energy transmission frequency bands, and advantages of a reflection reconstructed element array/reflector antenna are considered while wireless energy transmission is implemented.

[0070] The multi-band shared-aperture antenna design in this application may be further applied to the field of retrodirective antennas. An operation mode of the retrodirective antenna determines that an array antenna needs to have a wide beam scanning angle and a wide frequency bandwidth. However, system complexity and costs are greatly increased due to a radio frequency transceiver component with a large beam of a conventional retrodirective antenna, and application of the retrodirective antenna is limited. This application may be extended to an antenna array of a retrodirective antenna. The multi-band shared-aperture antenna in the foregoing embodiment is used as an array antenna, to implement a multi-band retrodirective antenna and extend a bandwidth. A coupler may be further loaded on the multi-band shared-aperture antenna, a coupled array element on the multi-band shared-aperture antenna is connected to an absorbing load, and an interference signal is automatically tracked and aligned through coupler calibration, to reduce an array RCS (radar cross-section, radar cross-section), and improving signal security.

[0071] The multi-band shared-aperture antenna provided in embodiments of this application may also be applied to a wireless network system. The multi-band shared-aperture antenna may be applied to a base station subsystem (base station subsystem, BBS), a terrestrial radio access network (UMTS terrestrial radio access network, UTRAN), a UMTS (universal mobile telecommunications system, universal mobile telecommunications system), or an evolved terrestrial radio access network (evolved universal terrestrial radio access, E-UTRAN), and is further configured to provide cell coverage of a radio signal to establish a connection between UE and a radio frequency end of a wireless network.

[0072] The multi-band shared-aperture antenna in embodiments may alternatively be disposed in a radio access network device to implement signal receiving and sending. Specifically, the radio access network device may include but is not limited to a base station 100 shown in FIG. 1. The base station 100 may be a base transceiver station (base transceiver station, BTS) in a GSM or CDMA system, or may be a NodeB (NodeB, NB) in a WCDMA system, or may be an evolved NodeB (evolved NodeB, eNB or eNodeB) in an LTE system, or may be a radio controller in a

cloud radio access network (cloud radio access network, CRAN) scenario, or the base station 100 may be a relay station, an access point, a vehicle-mounted device, a wearable device, a base station in a 5G network, a base station in a future evolved PLMN network, or the like, for example, a new radio base station. This is not limited in embodiments of this application. The base station 100 may provide wireless cell signal coverage, and serve a terminal device in one or more cells.

[0073] FIG. 1 shows a possible structure of a base station 100. The base station 100 of this structure may include a base station antenna 101, a transceiver (Transceiver, TRX) 102, and a baseband processing unit 103. The TRX 102 is connected to an antenna port of the base station antenna 101, so that the antenna port may be configured to receive a to-be-sent signal sent by the TRX 102 and radiate the to-be-sent signal through a radiating element of the base station antenna 101, or send a received signal received by the radiating element to the TRX 102. The TRX 102 may be a remote radio unit (radio remote unit, RRU), and the baseband processing unit 103 may be a baseband unit (baseband unit, BBU).

[0074] The baseband unit may be configured to process a to-be-sent baseband optical signal and transmit the to-be-sent baseband optical signal to the RRU, or receive and process a received baseband signal sent by the RRU (that is, a baseband signal obtained by converting a received radio frequency signal received by the base station antenna 101 by the RRU in a signal receiving process). The RRU may convert the to-be-transmitted baseband optical signal sent by the BBU into a to-be-sent radio frequency signal (including performing necessary signal processing on the baseband signal, for example, signal amplification). Then, the RRU may send the to-be-sent radio frequency signal to the base station antenna 101 through an antenna port, so that the radio frequency signal is radiated through the base station antenna 101, or the RRU may receive a received radio frequency signal sent through an antenna port of the base station antenna 101, convert the received radio frequency signal into a received baseband signal, and send the received baseband signal to the BBU.

[0075] The base station antenna 101 may include an array antenna 1011, a feed network 1012, and an antenna port 1013. The array antenna 1011 may include radiating elements arranged according to a geometric rule, and is configured to receive and/or radiate a radio wave. An output end of the feed network 1012 is connected to the array antenna 1011, and is configured to feed each radiating element in the array antenna 1011, so that the array antenna 1011 radiates a plurality of beams, where different beams may cover different ranges. The feed network 1012 may include a phase shifter, configured to change a radiation direction of a beam radiated by the array antenna 1011. The feed network 1012 may include a vertical-dimensional feed network and a horizontal-dimensional feed network. The vertical-dimensional feed network may be configured to adjust a beam width and a vertical-dimensional beam direction of a beam, and the horizontal-dimensional feed network may be configured to perform horizontal-

dimensional beamforming on a transmitted signal, and change a beam width, a shape, and a beam direction of a beam. An input end of the feed network 1012 is connected to the antenna port 1013 to form a transmit-receive channel. Each antenna port 1013 corresponds to one transmit-receive channel, and the antenna port 1013 may be connected to the TRX 102.

5 **[0076]** In some embodiments, each base station antenna 101 may have a plurality of antenna ports 1013, and each base station antenna 101 may have a plurality of TRXs 102. Each antenna port 1013 is connected to one TRX 102. The baseband processing unit 103 may be connected to one or more TRXs 102.

[0077] Currently, a communication base station needs to implement full-band coverage of 2G, 3G, 4G, and 5G. Therefore, an antenna needs to have radiating elements matching different frequency bands. A current antenna mainly
10 includes but is not limited to the following structures to implement multi-band beam scanning:

[0078] Structure 1: Multi-band shared-aperture antenna designed by using an overlap-coaxial (overlap-coaxial) method

[0079] FIG. 2a is a front view of a multi-band shared-aperture antenna designed by using an overlap-coaxial method, and FIG. 2b is a top view of the multi-band shared-aperture antenna designed by using the overlap-coaxial
15 method. A low-frequency array element 2011 uses a bowl-shaped element, and includes two pairs of dipoles. The bowl-shaped element is hollowed out in the middle, and is configured to place a high-frequency array element 2012. Herein, the high-frequency array element 2012 in the bowl is referred to as an inner-bowl element, and a remaining high-frequency array element 2012 outside the bowl is referred to as an outer-bowl element. An aperture of the low-frequency array element 2011 is greater than that of the high-frequency array element 2012. The high-frequency array
20 elements 2012 inside and outside the bowl form dual-polarized elements by using conventional crossed dipoles.

[0080] Structure 2: Multi-band shared-aperture antenna designed by using an overlap-interleave (overlap-interleave) method

[0081] FIG. 2c is a front view of a multi-band shared-aperture antenna designed by using an overlap-interleave method, and FIG. 2d is a top view of the multi-band shared-aperture antenna designed by using the overlap-interleave
25 method. The multi-band antenna is formed by using a low-frequency array element 2021 and a high-frequency array element 2022 in a staggered cross manner. FIG. 2e is a schematic diagram of a feeding structure corresponding to structures shown in FIG. 2a to FIG. 2d. A base station antenna may include a low-frequency array element and a high-frequency array element. The low-frequency array element is configured to receive a signal f_L sent by a low-frequency feed network, and the high-frequency array element is configured to receive a signal f_H sent by a high-frequency feed network.
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[0082] Structure 3: Multi-band shared-aperture antenna designed by using a reflection panel separation technology

[0083] FIG. 2f is a schematic diagram of a multi-band shared-aperture antenna designed by using a reflection panel separation technology. The multi-band shared-aperture antenna includes a low-frequency array element 2031 and a high-frequency array element 2032. A radiation structure of the low-frequency array element 2031 is transparent to the low-frequency array element 2031, is used as a part of the low-frequency array element 2031, and is also used as a radiation field of the high-frequency array element 2032.

[0084] Structure 4: Multi-band shared-aperture antenna designed by using a broadband unit sharing technology

[0085] FIG. 2g is a schematic diagram of a multi-band shared-aperture antenna designed by using a broadband unit sharing technology. The multi-band shared-aperture antenna includes a broadband antenna element 2051, and a same broadband antenna element 2051 is shared in a plurality of bands. FIG. 2h is a schematic diagram of a feeding structure corresponding to a structure shown in FIG. 2g. The antenna may include a broadband antenna element. The broadband antenna element is configured to receive a signal f_L sent by a low-frequency feed network and a signal f_H sent by a high-frequency feed network.

[0086] Structure 5: Multi-band shared-aperture antenna designed by using a tightly coupled phased array technology

[0087] FIG. 2i is a schematic diagram of a multi-band shared-aperture antenna designed by using a tightly coupled phased array technology. A tightly coupled phased array includes a plurality of tightly coupled elements 2061. Usually, an electrical size of each tightly coupled element 2061 of the tightly coupled phased array is small. To implement separate beamforming in different frequency bands, input ports of array elements are separately connected to output ports of phase shifters with different frequencies by using a frequency division network, to implement a coplanar array. FIG. 2j is a schematic diagram of isolation of a structure shown in FIG. 2i in different frequency bands. FIG. 2k is a schematic diagram of a feeding structure corresponding to the structure shown in FIG. 2i. A base station antenna may include a tightly coupled element 2061. Each tightly coupled element 2061 is configured to receive a signal f_L sent by a low-frequency feed network and a signal f_H sent by a high-frequency feed network.

[0088] In the foregoing structures 1 and 2, radiation interference is generated between the high-frequency array element and the low-frequency array element. Because different types of high-frequency array elements and low-frequency array elements are required, costs are also increased. In addition, because the high-frequency array element and the low-frequency array element are disposed, it is difficult to extend another frequency band. In the foregoing structure 3, the high-frequency array element and the low-frequency array element are in a hierarchical three-

dimensional structure, the structure is complex, costs are high, and practical application is difficult. In the foregoing structure 4, during broadband design, it is difficult to implement wide-angle beam scanning in a high frequency band within a bandwidth range. However, during narrowband design, frequency extension cannot be performed. In the foregoing structure 5, because a size of the tightly coupled element is less than that of a conventional antenna element, a scale of a feeding port is large, and costs are increased with an increase in a quantity of phase shifters or baseband processing modules. In addition, isolation in a low frequency band is poor.

[0089] In conclusion, currently, it is still difficult to provide a multi-band shared-aperture antenna that can support multi-band extension, especially a non-integer frequency ratio in a plurality of frequencies, and can implement wide-angle beam scanning without generating grating lobes, meet low costs, and have good isolation in frequency bands.

[0090] In view of the foregoing problem, embodiments of this application provide a multi-band shared-aperture antenna. Different frequency bands are designed on coupled array elements of a same aperture. Therefore, the antenna has a co-planar structure, so that the antenna has a strong multi-frequency extension capability, and can maintain a strong wide-angle beam scanning capability in different frequency bands. In addition, occurrence of grating lobes can also be avoided in a beam scanning process. In addition, because a structure of a feed unit is reconstructed, a quantity of feeding ports is reduced. Therefore, hardware overheads and power consumption are also reduced.

[0091] The multi-band shared-aperture antenna provided in embodiments of this application can meet the following conditions: An operating bandwidth exceeds a bandwidth of 10:1, and a full-band voltage standing wave ratio is less than 2. The following describes in detail a structure shown in FIG. 3a. FIG. 3a is a schematic diagram of a structure of a multi-band shared-aperture antenna according to this application. The multi-band shared-aperture antenna 101 may include a plurality of coupled array elements 301, and each coupled array element 301 is disposed on a reflection panel 302.

[0092] The frequency combining unit 303 is connected to the plurality of coupled array elements 301. The frequency combining unit 303 includes at least one frequency combining layer 304. Each frequency combining layer 304 includes at least one frequency combiner 305. Each frequency combiner 305 includes an antenna port 306, at least one high-frequency port 307, and at least one low-frequency port 308. The high-frequency port 307 forms at least one high-frequency port group, and the low-frequency port 308 forms at least one low-frequency port group. For each layer, a quantity of high-frequency port groups is not greater than a quantity of frequency combiners 305, a quantity of low-frequency port groups is less than the quantity of frequency combiners 305, and the quantity of high-frequency port groups is not less than the quantity of low-frequency port groups.

[0093] When the frequency combining unit 303 includes one frequency combining layer 304, the antenna port

306 of the frequency combiner 305 is connected to the coupled array element 301, a plurality of low-frequency ports 308 are connected to a low-frequency feed unit 309, and a plurality of high-frequency ports 307 are connected to a high-frequency feed unit 310.

[0094] When the frequency combining unit 303 includes at least two frequency combining layers 304, between every two adjacent layers, an upper-layer low-frequency port 308 is connected to a lower-layer antenna port 306, an antenna port 306 of a first-layer frequency combiner 305 is connected to the coupled array element 301, a high-frequency port 307 of the first-layer frequency combiner 305 is connected to the high-frequency feed unit 310, a low-frequency port 308 of a last-layer frequency combiner 305 is connected to the low-frequency feed unit 309, and a high-frequency port 307 of the last-layer frequency combiner 305 is connected to the high-frequency feed unit 310.

[0095] The low-frequency feed unit 309 is configured to feed a low-frequency signal.

[0096] The high-frequency feed unit 310 is configured to feed at least one type of frequency signal higher than the low-frequency signal.

[0097] In some embodiments, the coupled array elements 301 form reconstructed elements of different frequency bands based on different port groups. Coupled array elements 301 corresponding to the low-frequency port 308 in the low-frequency port group jointly form a low-frequency reconstructed element 311, and coupled array elements 301 corresponding to the high-frequency port 307 in the high-frequency port group jointly form a high-frequency reconstructed element 312.

[0098] In the foregoing manner, different frequency bands may be appropriately designed in a same coupled array element 301 to form a co-planar structure, and elements with different physical apertures are formed through flexible reconstruction of the coupled array elements 301, to improve a wide-angle beam scanning capability in frequency bands. In addition, antenna costs and complexity can be effectively reduced, so that the base station antenna 101 has a good frequency spread feature, and a solution of constructing a multi-band shared-aperture antenna with an integer ratio and a non-integer frequency ratio is available. In addition, after reconstruction of the coupled array elements 301, isolation of an array antenna can meet a requirement, and a quantity of feeding ports can be reduced during beam scanning.

[0099] In some embodiments, phase shift units 313 further exist on the low-frequency feed unit 309 and the high-frequency feed unit 310.

[00100] FIG. 3b is a schematic diagram of a structure of a multi-band shared-aperture antenna including phase shift units. Each phase shift unit 313 is configured to adjust phase lags/leads of electromagnetic waves radiated by the low-frequency feed unit 309 and the high-frequency feed unit 310 to specified phases corresponding to the coupled array element, and the phase shift unit 313 is any one or more of the following structures: a digital phase shifter, an

analog phase shifter, and a hybrid phase shifter. The phase lags/leads of the electromagnetic waves radiated by the low-frequency feed unit and the high-frequency feed unit are adjusted, by using the foregoing various phase shift units, to the specified phases corresponding to the coupled array element, to form beams in different directions, so as to complete beam scanning.

5 **[00101]** Specifically, the phase shift unit 313 is configured to adjust a weighting coefficient of each antenna element in an antenna array, to generate a directional beam. This is referred to as beamforming. Beamforming technologies are mainly based on three technical solutions: analog beamforming (analog beamforming, ABF), digital beamforming (digital beamforming, DBF), and hybrid beamforming (hybrid-digital precoding beamforming, HBF). For brief description, the following describes the foregoing three beamforming methods by using an example in which
10 beam scanning is performed in a one-dimensional array to implement beamforming. It should be noted that this application is not limited to one-dimensional beam scanning. Through appropriate reconstruction of coupled array elements and appropriate layout of feed units, two-dimensional beam scanning may alternatively be performed in the antenna array in a two-dimensional plane, and a directional beam can be generated by adjusting a weighting coefficient of each element in the antenna array.

15 **[00102]** The analog phase shifter corresponds to an analog beamforming technology. FIG. 4a is a principle diagram of beamforming of the analog phase shifter. Phase shifters are mainly classified into a phase shifter that changes a physical length and a phase shifter that changes a dielectric constant. The analog phase shifter is located at a back end of the antenna and usually can continuously adjust phases. The analog phase shifter applies a weight to an analog signal. At a transmit end, after a digital signal passes through a DAC, the digital signal is first decomposed into
20 a plurality of analog signals by a power divider, and then beamforming is performed on the analog signals by using the analog phase shifter. At a receive end, analog signals received by a plurality of antennas are combined and then sent to the DAC by using the phase shifter.

[00103] The digital phase shifter corresponds to a digital beamforming technology. FIG. 4b is a principle diagram of beamforming of the digital phase shifter. The digital phase shifter is used to apply a weight including an amplitude and a phase to a front end of a baseband signal. To be specific, at a transmit end, the digital phase shifter is located
25 before a DAC, and at a receive end, the digital phase shifter is located after an ADC. A quantity of antenna arrays is in one-to-one correspondence to a quantity of radio frequency (RF) chains. To be specific, each RF chain requires an independent set of a DAC/an ADC, a frequency mixer, a filter, and a power amplifier. The quantity of radio frequency chains increases with an increase in a quantity of ports.

30 **[00104]** The hybrid phase shifter corresponds to a hybrid beamforming technology. FIG. 4c is a principle diagram of beamforming of the hybrid phase shifter. The hybrid phase shifter integrates features of the digital and analog phase

shifters, achieves a balance between a quantity of radio frequency channels, costs, performance, and system design complexity, and implements a phase encoding function by cascading digital-to-analog converters. The hybrid phase shifter can effectively reduce a quantity of radio frequency channels, and balance costs and beam scanning performance.

5 **[00105]** In some embodiments, the frequency combiner 305 includes any one or more of the following structures: a frequency divider, a duplexer, and a filter.

[00106] In addition, the frequency divider is not limited to a dual-frequency type, and a frequency divider of a tri-frequency or multi-frequency type may alternatively be used.

[00107] To be specific, there may be ports of other frequency bands, other than the low-frequency port 308 and the high-frequency port 307, on the frequency combiner 305. Quantities of interfaces of the frequency divider, the duplexer, and the filter are set. In this way, a quantity of low frequency and high-frequency ports of the frequency combiner can be extended, and connections can be established in different manners. This more effectively reduces costs and complexity of the antenna and enables the antenna to have a good frequency spread feature. A person skilled in the art should know a combiner structure and a specific connection manner between the ports of the other frequency bands, other than the low-frequency port and the high-frequency port, on the frequency combiner 305. Details are not described herein.

[00108] In some embodiments, a distance d between centers of every two adjacent coupled array elements 301 may satisfy: $n_1 * d \leq 0.5 \lambda_1$, where λ_1 is a wavelength corresponding to a high-frequency signal input by the high-frequency feed unit 310, and n_1 is a positive integer. The distance d between the centers of every two adjacent coupled array elements is determined. In this way, occurrence of grating lobes can be avoided in a beam scanning process in a high frequency band.

[00109] In some embodiments, if a maximum scanning angle of the multi-band shared-aperture antenna 101 is θ_{max} , the distance d between the centers of every two adjacent coupled array elements 301 may satisfy: $n_1 * d \leq \frac{\lambda_1}{1 + \sin \theta_{max}}$. The distance d between the centers of every two adjacent coupled array elements is set. In this way, occurrence of grating lobes can be avoided when there is a strong wide-angle beam scanning capability in a high frequency band.

[00110] Specifically, during beam scanning, a spacing between the low-frequency and high-frequency reconstructed elements satisfies the following formula:

$D \leq \frac{\lambda}{1 + \sin \theta_{max}}$, where λ is a wavelength corresponding to a signal, and θ_{max} is the maximum scanning angle for beam scanning.

[00111] Therefore, when the coupled array elements 301 are arranged, the distance d between the centers of the coupled array elements 301 needs to be set based on the spacing D between the reconstructed elements and the quantity n_1 of high-frequency ports in the high-frequency port group.

[00112] Optionally, if the quantity of high-frequency ports in the high-frequency port group is 1, a spacing d_1 that is set between centers of high-frequency reconstructed elements 312 is the same as the distance d between the centers of the coupled array elements 301.

[00113] If the quantity of high-frequency ports in the high-frequency port group is m , the distance d that is set between the centers of the coupled array element 301 is equal to a spacing D between the high-frequency reconstructed elements 312 divided by m .

[00114] In some other embodiments, a quantity n_2 of low-frequency ports 308 in the low-frequency port group satisfies:

$$n_2 * d \leq 0.5 \lambda_2.$$

[00115] λ_2 is a wavelength corresponding to a low-frequency signal input by the low-frequency feed unit, d is the distance between the centers of every two adjacent coupled array elements, and n_2 is a positive integer. The distance d between the centers of every two adjacent coupled array elements is determined, and the quantity n_2 of low-frequency ports in the low-frequency port group is set. In this way, it can be ensured that occurrence of grating lobes is avoided in a beam scanning process in a low frequency band.

[00116] In some other embodiments, if the maximum scanning angle of the multi-band shared-aperture antenna is θ_{max} , the quantity n_2 of low-frequency ports in the low-frequency port group satisfies:

$$n_2 * d \leq \frac{\lambda_2}{1 + \sin \theta_{max}}.$$

The quantity n_2 of low-frequency ports in the low-frequency port group is set. In this

way, it can be ensured that occurrence of grating lobes is avoided when there is a strong wide-angle beam scanning capability in a low frequency band.

[00117] Specifically, after the coupled array elements 301 are arranged, the distance d between the centers of the coupled array elements 301 is determined, and a spacing d_2 between centers of low-frequency reconstructed elements 311 is determined based on the wavelength λ_2 corresponding to the low-frequency signal input by the low-frequency feed unit 309 and a known value of d .

[00118] The quantity of low-frequency ports 308 in the low-frequency port group is the spacing d_2 between the centers of the low-frequency reconstructed elements 311. In this case, the quantity of low-frequency ports 308 in the low-frequency port group needs to satisfy:

$$n_2 * d_2 \leq \frac{\lambda_2}{1 + \sin \theta_{max}}, \text{ so that the low-frequency reconstructed element 311 does not generate grating lobes}$$

5 even when the maximum scanning angle θ_{max} is satisfied (a spacing between the low-frequency reconstructed elements 311 is less than $\frac{\lambda_2}{(1 + \sin \theta_{max}) * \text{Quantity } n_2 \text{ of low-frequency ports}}$).

[00119] In some embodiments of this application, after reconstruction of the coupled array elements 301 on the multi-band shared-aperture antenna, an integer frequency ratio between a high frequency and a low frequency may be satisfied, and no grating lobe is generated during beam scanning at the high frequency and the low frequency. In the
10 following embodiments, a beam scanning angle of the multi-band shared-aperture antenna satisfies that scanning is performed at maximum scanning angles of $\pm 60^\circ$ without generating grating lobes.

[00120] FIG. 5a is a schematic diagram of a dual-band antenna. The coupled array element 301 in the figure is configured to connect to the antenna port of the frequency combiner 305, the high-frequency port of each frequency combiner 305 is connected to the high-frequency feed unit 310, and two low-frequency ports 308 as a group are
15 connected to the low-frequency feed unit 309. A high frequency is f_H , a low frequency is f_L , and $f_H : f_L$ is 2:1. The low-frequency reconstructed element 311 is reconstructed by using two coupled array elements 301, and the high-frequency reconstructed element 312 includes one coupled array element 301, to implement a dual-band antenna with a frequency ratio of 2:1. A spacing d_1 between centers of reconstructed high-frequency reconstructed elements 312 and a spacing d_2 between centers of reconstructed low-frequency reconstructed elements 311 both satisfy a condition
20 that no grating lobe is generated during beam scanning.

[00121] In some embodiments of this application, after reconstruction of the coupled array elements 301 on the multi-band shared-aperture antenna, a non-integer frequency ratio between a high frequency and a low frequency may be further satisfied, and no grating lobe is generated during beam scanning at the high frequency and the low frequency.

[00122] Example 1: FIG. 5b is a schematic diagram of a dual-band antenna. The low-frequency reconstructed
25 element 311 is reconstructed by using five coupled array elements 301, and the high-frequency reconstructed element 312 is reconstructed by using two coupled array elements 301, to implement a dual-band antenna with a frequency ratio of 2.5:1. A spacing d_1 between centers of reconstructed high-frequency reconstructed elements 312 and a spacing d_2 between centers of reconstructed low-frequency reconstructed elements 311 both satisfy a condition that no grating lobe is generated during beam scanning.

[00123] Example 2: FIG. 5c is a schematic diagram of a dual-band antenna. The low-frequency reconstructed element 311 is reconstructed by using three coupled array elements 301, and the high-frequency reconstructed element 312 is reconstructed by using two coupled array elements 301, to implement a dual-band antenna with a frequency ratio of 1.5:1. A spacing d1 between centers of reconstructed high-frequency reconstructed elements 312 and a spacing d2 between centers of reconstructed low-frequency reconstructed elements 311 both satisfy a condition that no grating lobe is generated during beam scanning.

[00124] In addition, coupled array element reconstruction may be further performed with reference to an integer ratio and a non-integer ratio, to implement a dual-band antenna. As shown in FIG. 5d, some low-frequency reconstructed elements 311 are reconstructed by using four coupled array elements 301, some other low-frequency reconstructed elements 311 are reconstructed by using three coupled array elements 301, and the high-frequency reconstructed element 312 is reconstructed by using two coupled array elements 301. A spacing d1 between centers of reconstructed high-frequency reconstructed elements 312, a spacing d21 (four coupled array elements) between centers of reconstructed low-frequency reconstructed elements 311, and a spacing d22 (three coupled array elements) between centers of the reconstructed low-frequency reconstructed elements 311 all satisfy a condition that no grating lobe is generated during beam scanning.

[00125] Provided that reconstruction of the coupled array elements 301 satisfies a prerequisite that no grating lobe is generated during scanning, adjacent coupled array elements may be randomly combined within a spacing range for the condition that no grating lobe is generated during beam scanning, and a quantity of reconstructing coupled array elements is not limited in a same frequency. In other words, on the prerequisite that no grating lobe is generated during scanning, a quantity of low-frequency ports in the low-frequency port group may be randomly set. This is not limited herein.

[00126] In some embodiments, the high-frequency feed unit 310 is configured to feed at least two types of frequency signals higher than the low-frequency signal to the high-frequency port group of the frequency combiner. For example, in this embodiment, the high-frequency feed unit 310 is configured to feed two types of frequency signals higher than the low-frequency signal. The following uses an example in which a signal with a highest frequency is a high-frequency signal f_H , a signal with a second highest frequency is an intermediate-frequency signal f_M , and the low-frequency signal is f_L . FIG. 6 is a schematic diagram of a tri-band antenna. The low-frequency reconstructed element 311 is reconstructed by using four coupled array elements 301, an intermediate-frequency reconstructed element 314 is reconstructed by using two coupled array elements 301, and the high-frequency reconstructed element 312 includes one coupled array element 301. A spacing d1 between centers of reconstructed

high-frequency reconstructed elements 312, a spacing d_2 between centers of reconstructed low-frequency reconstructed elements 311, and a spacing d_3 between centers of intermediate-frequency reconstructed elements 314 all satisfy a condition that no grating lobe is generated during beam scanning.

[00127] In addition, similarly, the design solution of this application may be extended to a quad-band antenna or even an N-band antenna, where N is a positive integer, and one coupled array element 301 is shared in a plurality of bands to form a co-planar array. Therefore, directivity patterns of frequency bands in the multi-band shared-aperture antenna are well consistent, and an ultra-wideband flexible reconstruction capability and frequency extension can be implemented. In addition, the condition that no grating lobe is generated during scanning is still satisfied at different frequencies, to provide an equivalent wide-angle beam scanning capability. Through reconstruction of the coupled array element 301, for the array antenna, a quantity of active channels and complexity can be effectively reduced, complexity of a feed network and antenna costs are reduced, and finally, comprehensive competitiveness of the antenna is improved.

[00128] In some embodiments, to improve a radiation effect of the antenna, a manner of reconstructing the array antenna may not be limited to reconstruction and frequency extension of the one-dimensional coupled array element 301 described above, and may alternatively be reconstruction of the coupled array element 301 in a two-dimensional plane. FIG. 7a is a schematic diagram of a dual-band antenna of a planar array type. On the array antenna, coupled array elements are usually combined and arranged in a two-dimensional planar array type. Two rows of coupled array elements 301 in FIG. 7a are used as an example. The coupled array element 301 is configured to connect to the antenna port of the frequency combiner 305, the high-frequency port of each frequency combiner 305 is connected to the high-frequency feed unit 310, and four low-frequency ports 308 as a group are connected to the low-frequency feed unit 309. A high frequency is f_H , and a low frequency is f_L . FIG. 7b is a schematic connection diagram of the low-frequency reconstructed elements. The low-frequency reconstructed element 311 is reconstructed by using 2*2 coupled array elements 301. FIG. 7c is a schematic connection diagram of the high-frequency reconstructed elements. The high-frequency reconstructed element 312 includes one coupled array element 301. A spacing d_1 between centers of the reconstructed high-frequency reconstructed elements 312 and a spacing d_2 between centers of the reconstructed low-frequency reconstructed elements 311 both satisfy the condition that no grating lobe is generated during beam scanning. A quantity of channels for feeding ports is effectively reduced, to reduce costs.

[00129] In addition, the foregoing reconstruction manner of the array antenna is not limited to the one-dimensional and two-dimensional reconstruction described above, and may alternatively be of a conformal planar antenna array type. FIG. 7d is a schematic diagram of an antenna of a conformal planar array type. FIG. 7e is a schematic diagram of antenna feeding of the conformal planar array type. A specific reconstruction manner of coupled

array elements on a conformal plane is based on a same concept as the foregoing reconstruction manner, and details are not described herein again.

[00130] In some embodiments, array element reconstruction may be performed on a single-polarized planar array. A single-polarized reconstruction manner may include the following manners:

5 **[00131]** Manner 1: FIG. 7f is a schematic diagram of a planar array formed by reconstructing coupled array elements in a horizontal direction. In the left part of the figure, the low-frequency reconstructed element 311 is horizontally reconstructed by using two coupled array elements 301 in the horizontal direction, and the high-frequency reconstructed element 312 includes one coupled array element 301, to reconstruct a dual-band antenna in the horizontal direction. In the middle part of the figure, the low-frequency reconstructed element 311 is vertically reconstructed by using two coupled array elements 301 in the horizontal direction, and the high-frequency reconstructed element 312 includes one coupled array element 301, to reconstruct a dual-band antenna in a vertical direction. In the right part of the figure, the low-frequency reconstructed element 311 is vertically and horizontally reconstructed by using 2*2 coupled array elements 301 in the horizontal direction, and the high-frequency reconstructed element 312 includes one coupled array element 301, to reconstruct a dual-band antenna in the vertical and horizontal directions.

[00132] Manner 2: FIG. 7g is a schematic diagram of a planar array formed by reconstructing coupled array elements in a vertical direction. In the left part of the figure, the low-frequency reconstructed element 311 is horizontally reconstructed by using two coupled array elements 301 in the vertical direction, and the high-frequency reconstructed element 312 includes one coupled array element 301, to reconstruct a dual-band antenna in a horizontal direction. In the middle part of the figure, the low-frequency reconstructed element 311 is vertically reconstructed by using two coupled array elements 301 in the vertical direction, and the high-frequency reconstructed element 312 includes one coupled array element 301, to reconstruct a dual-band antenna in the vertical direction. In the right part of the figure, the low-frequency reconstructed element 311 is vertically and horizontally reconstructed by using 2*2 coupled array elements 301 in the vertical direction, and the high-frequency reconstructed element 312 includes one coupled array element 301, to reconstruct a dual-band antenna in the vertical and horizontal directions.

[00133] Manner 3: FIG. 7h is a schematic diagram of a planar array with a non-integer ratio that is formed by reconstructing coupled array elements in a horizontal direction. In the left part of the figure, the low-frequency reconstructed element 311 is horizontally reconstructed by using three coupled array elements 301 in the horizontal direction, and the high-frequency reconstructed element 312 is horizontally reconstructed by using two coupled array elements 301 in the horizontal direction, to reconstruct a dual-band antenna in the horizontal direction. In the right part of the figure, the low-frequency reconstructed element 311 is vertically and horizontally reconstructed by using

3*3 coupled array elements 301 in the horizontal direction, and the high-frequency reconstructed element 312 is vertically and horizontally reconstructed by using 2*2 coupled array elements 301 in the horizontal direction, to reconstruct a dual-band antenna in the vertical and horizontal directions.

[00134] Manner 4: FIG. 7i is a schematic diagram of a tri-band planar array formed by reconstructing coupled array elements in a horizontal direction. In the left part of the figure, the low-frequency reconstructed element 311 is horizontally reconstructed by using four coupled array elements 301 in the horizontal direction, the intermediate-frequency reconstructed element 314 is horizontally reconstructed by using two coupled array elements 301 in the horizontal direction, and the high-frequency reconstructed element 312 includes one coupled array element 301 in the horizontal direction, to reconstruct a tri-band antenna in the horizontal direction. In the middle part of the figure, the low-frequency reconstructed element 311 is horizontally and vertically reconstructed by using 2*4 coupled array elements 301 in the horizontal direction, the intermediate-frequency reconstructed element 314 is horizontally and vertically reconstructed by using 2*2 coupled array elements 301 in the horizontal direction, and the high-frequency reconstructed element 312 includes one coupled array element 301 in the horizontal direction, to reconstruct a tri-band antenna in vertical and horizontal directions. In the right part of the figure, the low-frequency reconstructed element 311 is horizontally and vertically reconstructed by using 4*4 coupled array elements 301 in the horizontal direction, the intermediate-frequency reconstructed element 314 is horizontally and vertically reconstructed by using 2*2 coupled array elements 301 in the horizontal direction, and the high-frequency reconstructed element 312 includes one coupled array element 301 in the horizontal direction, to reconstruct a tri-band antenna in the vertical and horizontal directions.

[00135] After periodic reconstruction of the coupled array elements 301, a reconstructed planar array is a periodic array. If aperiodic reconstruction is performed on the coupled array elements 301, a reconstructed array is equivalent to a sparse array. Specifically, flexible arrangement may be performed according to a requirement of the array antenna. Optionally, the coupled array elements 301 may be periodically or aperiodically arranged on the planar array.

[00136] Manner 1: The planar array uses periodic arrangement. FIG. 8a is a schematic diagram of periodically arranged array elements. Reconstruction of coupled array elements 301 is performed in one frequency band (this is similar to other frequency bands). Different excitation values may be configured for ports connected to the reconstructing coupled array elements 301, to finally implement a directivity pattern feature of specific performance. The left part of the figure is a schematic diagram of reconstruction of the coupled array elements 301, the middle part of the figure is a schematic diagram of distribution of reconstructed equivalent antenna elements, and the right part of the figure is a schematic diagram of distribution of excitation amplitudes. Different patterns are used to represent different excitation amplitudes.

[00137] Manner 2: The planar array uses aperiodic arrangement. As shown in FIG. 8b, the left part of the figure is a schematic diagram of reconstruction of coupled array elements 301, the middle part of the figure is a schematic diagram of distribution of reconstructed equivalent antenna elements, and the right part of the figure is a schematic diagram of distribution of excitation amplitudes.

5 **[00138]** Manner 3: A dummy element (dummy) area may be configured on a planar array, to implement a sparse array. As shown in FIG. 8c, each reconstructed element may be reconstructed by using a same quantity or different quantities of coupled array elements 301. For a sparse array antenna, algorithm optimization may be performed on array performance. The left part of the figure is a schematic diagram of reconstruction of coupled array elements 301. Dummy elements shown in dashed boxes may be disposed in the planar array, and feeding configuration is not
10 performed on the dummy elements, to implement an equivalent sparse array. The middle part of the figure is a schematic diagram of distribution of a reconstructed equivalent array. The right part of the figure is a schematic diagram of distribution of amplitudes of the equivalent array.

[00139] In some embodiments, the coupled array element 301 includes at least one dipole array element.

[00140] A polarization direction of the dipole array element is parallel to that of the coupled array element 301,
15 and coupling capacitors exist on two sides of a tail end of the dipole array element. A direction of the dipole array element is set. In this way, the coupled array element can have a polarization direction in at least one direction, to provide polarization types in more modes.

[00141] In the foregoing embodiment, coupled array elements 301 that are all in a single polarization direction are provided. Optionally, the multi-band shared-aperture antenna may further support a multi-polarization direction.
20 The dipole array elements are disposed orthogonally, so that the coupled array elements can have dual polarization features in different directions such as the vertical direction, the horizontal direction, and $\pm 45^\circ$ directions.

[00142] When the coupled array element 301 is designed in a dual-polarized form, and the coupled array element 301 includes two dipole array elements, the dipole array elements are disposed orthogonally. Orthogonal disposition manners include but are not limited to the following manners for the coupled array element 301:

25 **[00143]** Manner 1: The two dipole array elements are designed in the vertical and horizontal directions. As shown in FIG. 9a, in the left part of the figure, the low-frequency reconstructed element 311 is horizontally reconstructed by using two coupled array elements 301 including dipole array elements in the vertical and horizontal directions, and the high-frequency reconstructed element 312 includes a coupled array element 301 including dipole array elements in the vertical and horizontal directions. In the middle part of the figure, the low-frequency reconstructed element 311
30 is vertically reconstructed by using two coupled array elements 301 including dipole array elements in the vertical and horizontal directions, and the high-frequency reconstructed element 312 includes a coupled array element 301

including dipole array elements in the vertical and horizontal directions. In the right part of the figure, the low-frequency reconstructed element 311 is vertically and horizontally reconstructed by using 2*2 coupled array elements 301 including dipole array elements in the vertical and horizontal directions, and the high-frequency reconstructed element 312 includes one coupled array element 301 including dipole array elements in the vertical and horizontal directions.

[00144] Manner 2: The two dipole array elements are designed in the $\pm 45^\circ$ directions. As shown in FIG. 9b, in the left part of the figure, the low-frequency reconstructed element 311 is horizontally reconstructed by using two coupled array elements 301 including dipole array elements in the $\pm 45^\circ$ directions, and the high-frequency reconstructed element 312 includes one coupled array element 301 including dipole array elements in the $\pm 45^\circ$ directions. In the middle part of the figure, the low-frequency reconstructed element 311 is vertically reconstructed by using two coupled array elements 301 including dipole array elements in the $\pm 45^\circ$ directions, and the high-frequency reconstructed element 312 includes one coupled array element 301 including dipole array elements in the $\pm 45^\circ$ directions. In the right part of the figure, the low-frequency reconstructed element 311 is vertically and horizontally reconstructed by using 2*2 coupled array elements 301 including dipole array elements in the $\pm 45^\circ$ directions, and the high-frequency reconstructed element 312 includes one coupled array element 301 including dipole array elements in $\pm 45^\circ$ directions.

[00145] In addition, this application provides an example of a quad-band antenna. FIG. 10 is a schematic diagram of a quad-band single-polarized planar array. The figure includes 12*12 coupled array elements 301, a physical aperture of the coupled array element 301 is 19 mm×19 mm, and an array element spacing is also 19 mm. The coplanar array antenna includes Band 3, Band 41, Band 42, and an LAA band. A standing wave bandwidth of the quad-band antenna can reach 1.5 GHz to 6 GHz. According to the multi-band shared-aperture antenna provided in this application, a physical aperture of each reconstructed element in an operating frequency band corresponding to the reconstructed element can satisfy a condition that no grating lobe is generated during $\pm 60^\circ$ scanning, a quantity of feeding ports of the antenna can be reduced, and isolation of the reconstructed element can be improved. In this way, an appropriate quantity of channels is maintained for each frequency band, the quantity of feeding ports of the antenna is reduced, costs are reduced, and comprehensive competitiveness of the antenna is improved. Specifically, according to an array scanning formula without grating lobes, a spacing between coupled array elements is approximately $0.5\lambda_{LAA}$. If the spacing between coupled array elements 301 is set to $0.5\lambda_{LAA}$, reconstruction of the coupled array elements 301 may not be performed at a highest frequency of the LAA band. The coupled array element 301 is an antenna element of the LAA band. A maximum of four coupled array elements 301 may be used for reconstruction at 3.5 G (Band 42), a maximum of nine coupled array elements 301 may be used for reconstruction at 2.6 G (Band 41),

and a maximum of 16 coupled array elements 301 may be used for reconstruction at 1.7 G (Band 3). The quantity of feeding ports can be reduced by using the foregoing antenna structure, and the costs can be reduced. Within a range of a maximum quantity of reconstructable coupled array elements, reconstructed elements that are of different frequency bands and that include different antenna elements are flexibly disposed.

5 **[00146]** Optionally, as shown in the following Table 1, a lower frequency indicates a larger quantity of reconstructable coupled array elements and a more flexible reconstruction manner. Dark parts in Table 1 indicate reconstruction scales of coupled array elements that can be selected for different frequency bands. When a spacing between reconstructing antenna elements does not exceed about 0.5 time a wavelength of a corresponding frequency band after reconstruction, beam scanning angles of ± 60 degrees can be satisfied without grating lobes during scanning.

10 In addition, due to different reconstruction manners, a quantity of reconstructing antenna elements that may be designed on the array antenna varies. For the foregoing 12*12 array antenna, a minimum of 144 reconstructing antenna elements in the LAA band may be designed on the array antenna, a minimum of 36 reconstructing antenna elements in Band 42 may be designed on the array antenna, a minimum of 16 reconstructing antenna elements in Band 42 may be designed on the array antenna, and nine reconstructing antenna elements in Band 3 are designed on the array

15 antenna. As shown in the following Table 2, compared with a conventional quad-band antenna array, the quad-band antenna provided in this application may operate in different frequency bands, to reduce the quantity of feeding ports and reduce the costs.

[00147] The quantity of feeding ports can be reduced by 144–9 for Band 3, the quantity of feeding ports can be reduced by 144–16 for Band 41, and the quantity of feeding ports can be reduced by 144–36 for Band 42. Therefore,

20 compared with a quantity of feeding ports in a conventional solution, for the quad-band antenna with 12×12 coupled

array elements, the quantity of feeding ports in this solution is reduced by $64.4\% \left(\frac{576 - 205}{576} \right)$. This effectively reduces antenna complexity and the quantity of feeding ports for beamforming. A large-scale sparse antenna array may be reconstructed by flexibly adjusting a quantity of coupled array elements of each reconstructed element, to implement an antenna array with higher performance or a special requirement.

Table 1

Spacing between coupled array elements = 19 mm	Size of a reconstructing antenna element (unit: wavelength of a corresponding frequency band)					Maximum quantity of reconstructable antenna elements	Quantity of reconstructing antenna elements corresponding to the maximum quantity of reconstructable antenna elements
Reconstruction scale	1×1	2×2	3×3	4×4	5×5		
Frequency							
Band 3 (f_0)	0.11×0.11	0.23×0.23	0.34×0.34	0.46×0.46	0.57×0.57	4×4=16	3×3=9
Band 41 ($1.44f_0$)	0.16×0.16	0.33×0.33	0.49×0.49	0.66×0.66	0.82×0.82	3×3=9	4×4=16
Band 42 ($1.94f_0$)	0.22×0.22	0.44×0.44	0.69×0.69	0.89×0.89	1.11×1.11	2×2=4	6×6=36
LAA ($3.06f_0$)	0.35×0.35	0.70×0.70	1.05×1.05	1.39×1.39	1.74×1.74	1×1=1	12×12=144

Table 2

Comparison between quantity of feeding ports			
Frequency	Quantity of feeding ports in the conventional solution	Quantity of feeding ports in this application	The quantity of feeding ports is reduced by 64.4%.
Band 3 (f_0)	144	9	
Band 41 ($1.44f_0$)	144	16	
Band 42 ($1.94f_0$)	144	36	
LAA ($3.06f_0$)	144	144	
Total	576	205	

5 **[00148]** According to the multi-band shared-aperture antenna provided in this application, the coupled array elements are reconstructed based on the tightly coupled phased array technology, and the coupled array elements are flexibly reconstructed to elements of physical apertures in different frequency bands, to implement a multi-band coplanar antenna array, share an aperture for different frequency ratios, and implement a wide-angle beam scanning capability in the frequency bands. In addition, antenna costs and complexity can be effectively reduced, and a strong multi-frequency extension capability can be provided, to construct a solution with an integer frequency ratio and a

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non-integer frequency ratio. Compared with port isolation between conventional tightly coupled elements, port isolation between reconstructed elements is improved by at least 6 dB after reconstruction. Because the multi-band shared-aperture antenna is designed in a co-planar form and shares a same coupled array element, the multi-band shared-aperture antenna has good manufacturability, directivity patterns of frequency bands are well consistent, and an equivalent beam scanning angle can be maintained in different frequency bands, to resolve a problem that grating lobes are generated due to an excessively large spacing. This further reduces the quantity of feeding ports and the costs.

[00149] In some embodiments, the multi-band shared-aperture antenna in this application may be further applied to design of a reflective array antenna. FIG. 11 is a schematic diagram of a reflective array antenna. The reflective array antenna includes a feed 1101 and a reflector surface 1102. The reflector surface 1102 is generally of a planar structure. Elements arranged in a plane that are irradiated by the feed 1101 are configured to enable the antenna to have a parabolic feature. A main principle is to adjust element structure sizes on the reflector surface 1102 at different locations, so that the reflector surface 1102 of the antenna has phase delays of different values, and a beam focus and a direction of the antenna can be adjusted through accurate design. However, a conventional reflective array antenna has a narrowband feature. In addition, because a spatial phase delay difference varies with a frequency, a bandwidth of a reflective array antenna formed by conventional microstrip patch elements is less than 5%, and there is a disadvantage that it is difficult to maintain a high gain bandwidth.

[00150] The reflector surface 1102 may be designed as an intelligent reflector surface (intelligent reflector surface, IRS). As shown in FIG. 12, the intelligent reflector surface IRS includes:

an IRS controller 1201, configured to receive reflection amplitude/phase shift information; a control circuit board 1202, triggered by the IRS controller 1201 and responsible for adjusting a reflection amplitude/phase shift of each reflection element 1204; and a copper plate 1203, configured to avoid signal energy leakage. A PIN diode is embedded in the reflection element 1204, and a bias voltage of the reflection element 1204 is controlled by using a DC feeder. The PIN diode switches between "on" and "off" states, to generate a phase difference of π . In addition, to effectively control a reflection amplitude, a variable resistance load may be applied to design of the reflection element 1204, and different parts of incident signal energy are consumed by changing a resistance value in each reflection element 1204, to implement a controllable reflection amplitude within [0,1]. However, limited by a form of a patch element, a bandwidth of the intelligent reflector surface is low. If the multi-band shared-aperture antenna design in this application is applied to the reflection element, each reflection element 1204 of the reflector surface may be equivalent to a coupled array element. FIG. 13 is a schematic diagram of a reflection element. A diode, an MEMS (micro-electro-mechanical system, micro-electro-mechanical system) switch, or the like is loaded on each patch

element, to adjust and control a reflected beam at an operating working frequency. After a patch element 1301 is connected to a load and reconstruction and combination are performed, a control diode 1302 is loaded to equivalently extend a physical aperture of an element of a reflective array antenna, to add a new frequency to the reflector surface. In this way, a multi-frequency shared-aperture reflector surface feature is implemented, and bandwidth extension is implemented for the reflective array antenna. Alternatively, an absorbing resistor 1303 may be further loaded on a reconstructed element, to generate a wave-absorbing feature in a specific frequency band, reduce a radar scattering interface, implement a stealth feature of a reflective array, and improve security.

[00151] In addition, an embodiment of this application further provides a communication device. The communication device includes any one of the foregoing multi-band shared-aperture antennas. In the foregoing design, the communication device including the multi-band shared-aperture antenna has a strong multi-frequency extension capability, and can maintain a strong wide-angle beam scanning capability in different frequency bands. In addition, occurrence of grating lobes can also be avoided in a beam scanning process. Moreover, because a structure of a feed unit is reconstructed, a quantity of feeding ports is reduced. Therefore, hardware overheads and power consumption can also be reduced.

[00152] In the solutions of this application, according to the multi-band shared-aperture antenna and the communication device provided in this application, coupled array elements are reconstructed based on a tightly coupled phased array technology, and the coupled array elements are flexibly reconstructed to elements of physical apertures in different frequency bands, to implement a multi-band co-planar antenna array, share an aperture for different frequency ratios, and implement a wide-angle beam scanning capability in the frequency bands. In addition, antenna costs and complexity can be effectively reduced, and a strong multi-frequency extension capability can be provided, to construct a solution with an integer frequency ratio and a non-integer frequency ratio. Compared with port isolation between conventional tightly coupled elements, port isolation between reconstructed elements is improved by at least 6 dB after reconstruction. Because the multi-band shared-aperture antenna is designed in a co-planar form and shares a same coupled array element, the multi-band shared-aperture antenna has good manufacturability, directivity patterns of frequency bands are well consistent, and an equivalent beam scanning angle can be maintained in different frequency bands, to resolve a problem that grating lobes are generated due to an excessively large spacing. This further reduces a quantity of feeding ports and the costs.

[00153] A person skilled in the art should understand that embodiments of this application may be provided as a method, a system, or a computer program product. Therefore, this application may use a form of hardware only embodiments, software only embodiments, or embodiments with a combination of software and hardware. Moreover, this application may use a form of a computer program product that is implemented on one or more computer-usable

storage media (including but not limited to a disk memory, a CD-ROM, an optical memory, and the like) that include computer-usable program code.

[00154] This application is described with reference to a flowchart and/or a block diagram of a method, a device (system), and a computer program product according to this application. It should be understood that computer program instructions may be used to implement each process and/or each block in the flowcharts and/or the block diagrams and a combination of a process and/or a block in the flowcharts and/or the block diagrams. These computer program instructions may be provided for a general-purpose computer, a dedicated computer, an embedded processor, or a processor of any other programmable data processing device to generate a machine, so that the instructions executed by a computer or a processor of any other programmable data processing device generate an apparatus for implementing a specific function in one or more processes in the flowcharts and/or in one or more blocks in the block diagrams.

[00155] These computer program instructions may be stored in a computer-readable memory that can instruct the computer or any other programmable data processing device to work in a specific manner, so that the instructions stored in the computer-readable memory generate an artifact that includes an instruction apparatus. The instruction apparatus implements a specific function in one or more processes in the flowcharts and/or in one or more blocks in the block diagrams.

[00156] These computer program instructions may alternatively be loaded onto a computer or another programmable data processing device, so that a series of operations and steps are performed on the computer or the another programmable device, to generate computer-implemented processing. Therefore, the instructions executed on the computer or the another programmable device provide steps for implementing a specific function in one or more procedures in the flowcharts and/or in one or more blocks in the block diagrams.

[00157] It is clearly that, a person skilled in the art can make various modifications and variations to this application without departing from the scope of this application. In this way, this application is intended to cover these modifications and variations of this application provided that they fall within the scope of the claims of this application and their equivalent technologies.

CLAIMS

What is claimed is:

1. A multi-band shared-aperture antenna, comprising a plurality of coupled array elements, a frequency combining unit, a low-frequency feed unit, and a high-frequency feed unit, wherein

each coupled array element is disposed on a reflection panel;

the frequency combining unit is connected to the plurality of coupled array elements; the frequency combining unit comprises at least one frequency combining layer; each frequency combining layer comprises at least one frequency combiner; each frequency combiner comprises an antenna port, at least one high-frequency port, and at least one low-frequency port; a plurality of high-frequency ports form at least one high-frequency port group, and a plurality of low-frequency ports form at least one low-frequency port group; and for each layer, a quantity of high-frequency port groups is not greater than a quantity of frequency combiners, a quantity of low-frequency port groups is less than the quantity of frequency combiners, and the quantity of high-frequency port groups is not less than the quantity of low-frequency port groups;

when the frequency combining unit comprises one frequency combining layer, the antenna port of the frequency combiner is connected to the coupled array element, the plurality of low-frequency ports are connected to the low-frequency feed unit, and the plurality of high-frequency ports are connected to the high-frequency feed unit;

when the frequency combining unit comprises at least two frequency combining layers, between every two adjacent layers, a plurality of upper-layer low-frequency ports are connected to lower-layer antenna ports, an antenna port of a first-layer frequency combiner is connected to the coupled array element, a plurality of high-frequency ports of the first-layer frequency combiner are connected to the high-frequency feed unit, a plurality of low-frequency ports of a last-layer frequency combiner are connected to the low-frequency feed unit, and a high-frequency port of the last-layer frequency combiner is connected to the high-frequency feed unit;

the low-frequency feed unit is configured to feed a low-frequency signal; and

the high-frequency feed unit is configured to feed at least one type of frequency signal higher than the low-frequency signal.

2. The multi-band shared-aperture antenna according to claim 1, wherein the coupled array elements form reconstructed elements of different frequency bands based on different port groups, coupled array elements corresponding to the low-frequency ports in the low-frequency port group jointly form a low-frequency reconstructed element, and coupled array elements corresponding to the high-frequency ports in the high-frequency port group jointly form a high-frequency reconstructed element.

3. The multi-band shared-aperture antenna according to claim 1 or 2, wherein a distance d between centers of every two adjacent coupled array elements satisfies:

$$n_1 * d \leq 0.5 \lambda_1, \text{ wherein}$$

n_1 is a quantity of high-frequency ports in the high-frequency port group, λ_1 is a wavelength corresponding to a high-frequency signal input by the high-frequency feed unit, and n_1 is a positive integer.

4. The multi-band shared-aperture antenna according to claim 3, wherein if a maximum scanning angle of the multi-band shared-aperture antenna is θ_{max} , the distance d between the centers of every two adjacent coupled array elements satisfies:

$$n_1 * d \leq \frac{\lambda_1}{1 + \sin \theta_{max}}.$$

5. The multi-band shared-aperture antenna according to any one of claims 1 to 4, wherein a quantity n_2 of low-frequency ports in the low-frequency port group satisfies:

$$n_2 * d \leq 0.5 \lambda_2, \text{ wherein}$$

λ_2 is a wavelength corresponding to a low-frequency signal input by the low-frequency feed unit, n_2 is a positive integer, and d is the distance between the centers of every two adjacent coupled array elements.

6. The multi-band shared-aperture antenna according to claim 5, wherein if the maximum scanning angle of the multi-band shared-aperture antenna is θ_{max} , the quantity n_2 of low-frequency ports in the low-frequency port group satisfies:

$$n_2 * d \leq \frac{\lambda_2}{1 + \sin \theta_{max}}.$$

7. The multi-band shared-aperture antenna according to any one of claims 1 to 6, wherein phase shift units further exist on the low-frequency feed unit and the high-frequency feed unit; and

each phase shift unit is configured to adjust phase lags/leads of electromagnetic waves radiated by the low-frequency feed unit and the high-frequency feed unit to specified phases corresponding to the coupled array element, and the phase shift unit is any one or more of the following structures: a digital phase shifter, an analog phase shifter, and a hybrid phase shifter.

8. The multi-band shared-aperture antenna according to any one of claims 1 to 7, wherein the coupled array element comprises at least one dipole array element, a polarization direction of the dipole array element is parallel to that of the coupled array element, and coupling capacitors exist on two sides of a tail end of the dipole array element.

9. The multi-band shared-aperture antenna according to claim 8, wherein when the coupled array element comprises two dipole array elements, the dipole array elements are disposed orthogonally.

10. The multi-band shared-aperture antenna according to any one of claims 1 to 9, wherein the frequency combiner comprises any one or more of the following structures: a frequency divider, a duplexer, and a filter.

5 11. A communication device, comprising the multi-band shared-aperture antenna according to any one of claims 1 to 10.