US012388173B2

(12) **United States Patent**
Xing et al.

(10) **Patent No.: US 12,388,173 B2**
(45) **Date of Patent: Aug. 12, 2025**

(54) **ANTENNA**

(71) Applicant: **Shanghai Tianma Microelectronics Co., Ltd.**, Shanghai (CN)

(72) Inventors: **Yifan Xing**, Shanghai (CN); **Zhenyu Jia**, Shanghai (CN); **Xiaonan Han**, Shanghai (CN); **Baiquan Lin**, Shanghai (CN); **Kerui Xi**, Shanghai (CN); **Xiaojun Chen**, Shanghai (CN); **Yingru Hu**, Shanghai (CN); **Shengwei Dai**, Shanghai (CN)

(73) Assignee: **Shanghai Tianma Microelectronics Co., Ltd.**, Shanghai (CN)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 101 days.

(21) Appl. No.: **18/406,402**

(22) Filed: **Jan. 8, 2024**

(65) **Prior Publication Data**

US 2024/0154303 A1 May 9, 2024

(30) **Foreign Application Priority Data**

Apr. 17, 2023 (CN) 202310410534.0

(51) **Int. Cl.**

H01Q 1/52	(2006.01)
H01Q 1/48	(2006.01)
H01Q 1/50	(2006.01)
H01Q 3/36	(2006.01)
H01Q 21/00	(2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 1/523*** (2013.01); ***H01Q 1/48*** (2013.01); ***H01Q 1/50*** (2013.01); ***H01Q 3/36*** (2013.01); ***H01Q 21/0037*** (2013.01); ***H01Q 21/0075*** (2013.01)

(58) **Field of Classification Search**
CPC H01Q 1/523; H01Q 1/48; H01Q 1/50; H01Q 3/36; H01Q 21/0037; H01Q 21/0075
See application file for complete search history.

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

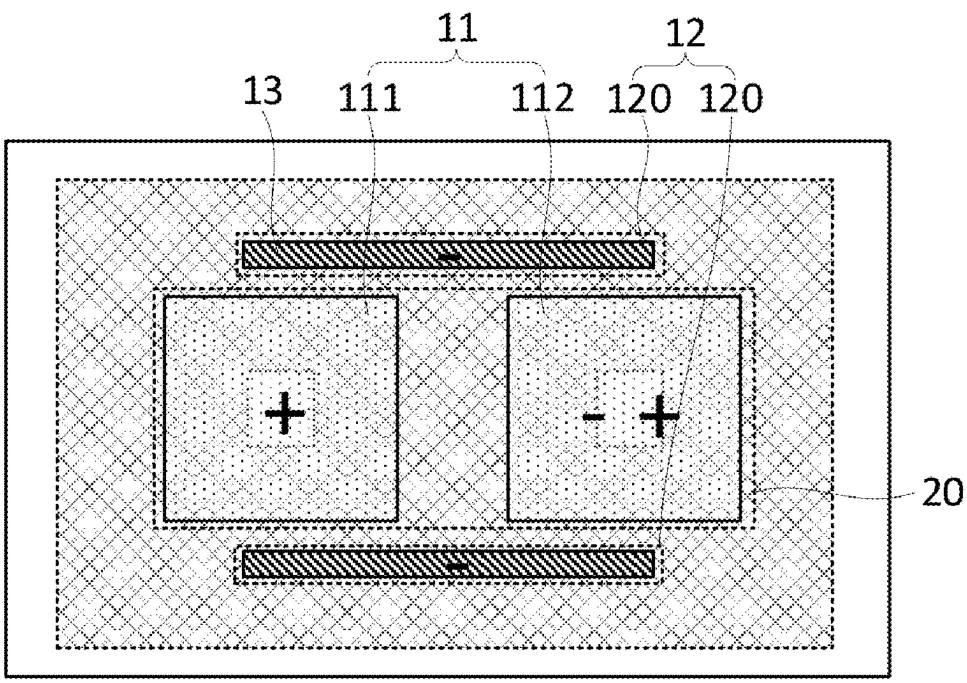
CN	102280695	A	12/2011
CN	107437659	A	12/2017

Primary Examiner — Graham P Smith
(74) *Attorney, Agent, or Firm* — KDW FIRM PLLC

(57) **ABSTRACT**

An antenna is provided in this application. The antenna includes multiple radiating units, at least two adjacent radiating units are correspondingly provided with a respective decoupling structure, the decoupling structure includes two microstrip line units, one microstrip line unit of the two microstrip line units includes at least one microstrip line, and the two microstrip line units are located on two opposite sides of two radiating units in a direction perpendicular to an arrangement direction of two adjacent radiating units. According to the antenna provided in the embodiments of the present disclosure, the decoupling structure composed of the microstrip line are disposed on two sides of the at least two adjacent radiating units, so that an indirect coupling field is formed by the decoupling structure, and the indirect coupling field counteracts a direct coupling field between adjacent radiating units.

20 Claims, 22 Drawing Sheets



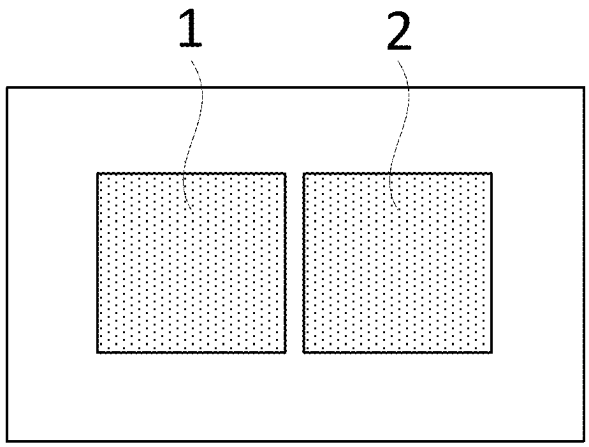


FIG. 1

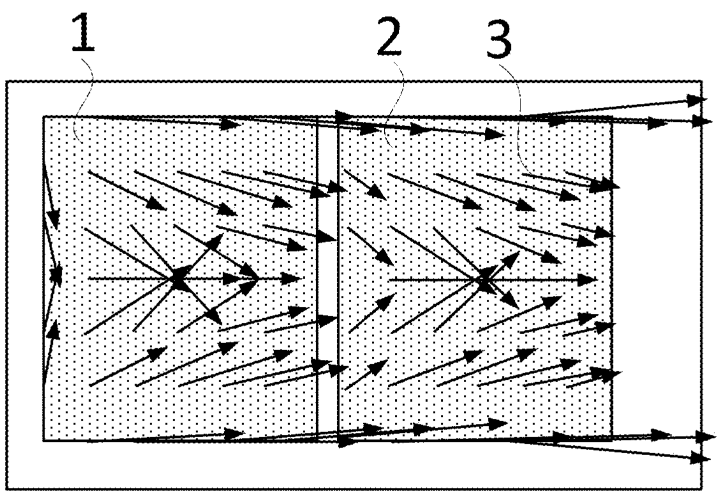


FIG. 2

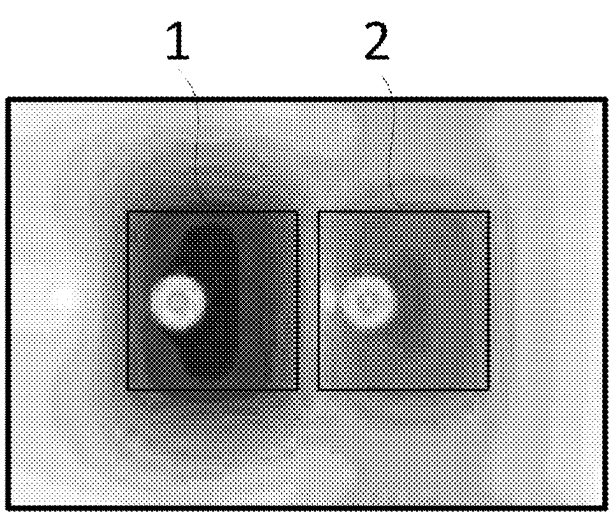


FIG. 3

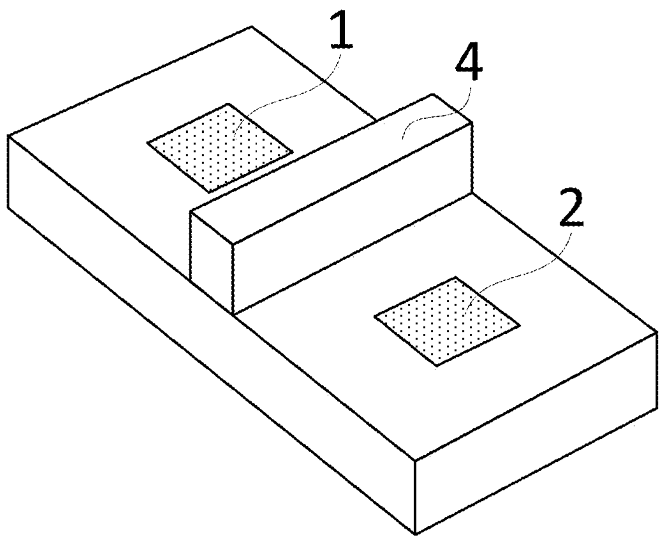

1
4
2

FIG. 4

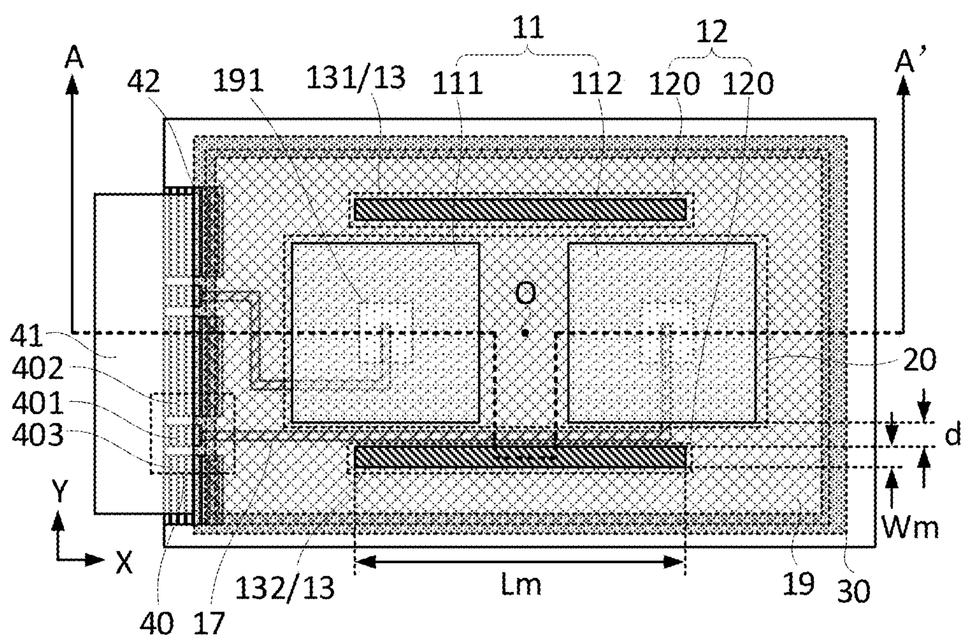

A
A'
11
12
42
191
131/13
111
112
120
120
O
41
402
401
403
20
d
Wm
Y
X
40
17
132/13
Lm
19
30

FIG. 5

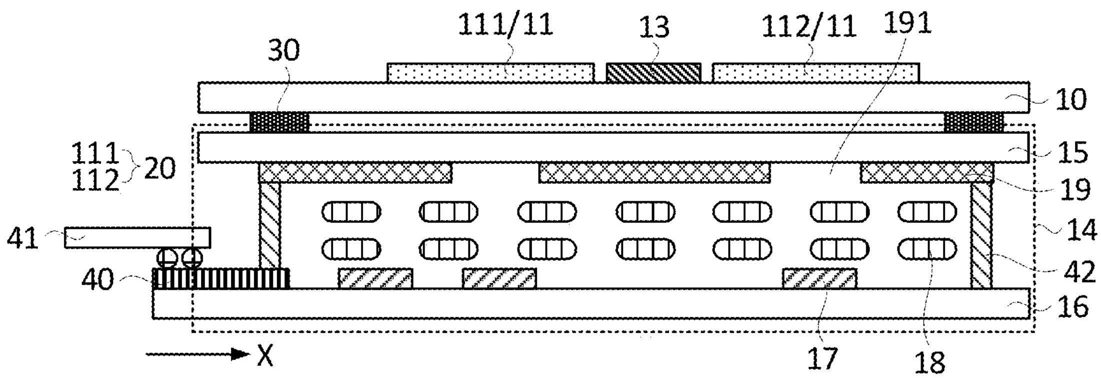

111/11
13
112/11
191
30
10
15
111
112
20
19
14
41
42
40
16
X
17
18

FIG. 6

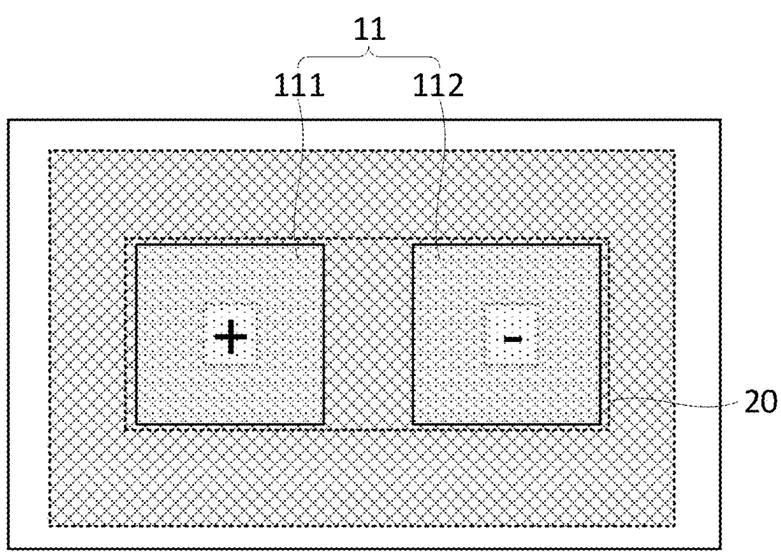

11
111
112
+
-
20

FIG. 7

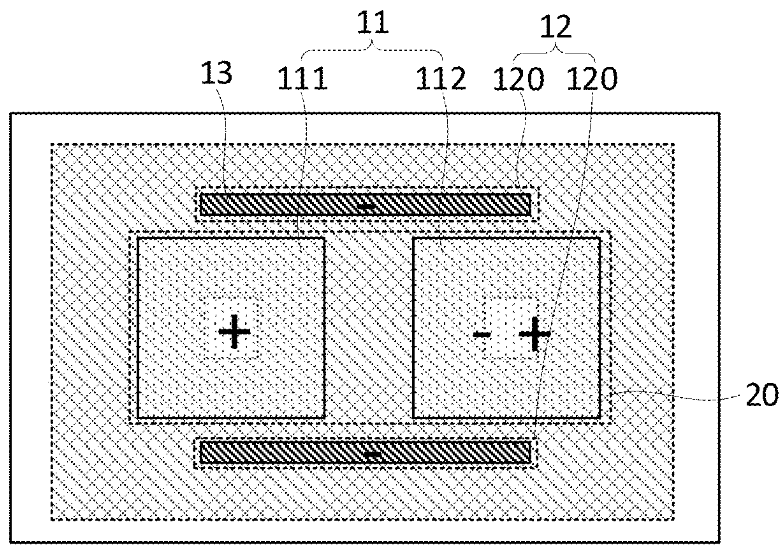


FIG. 8

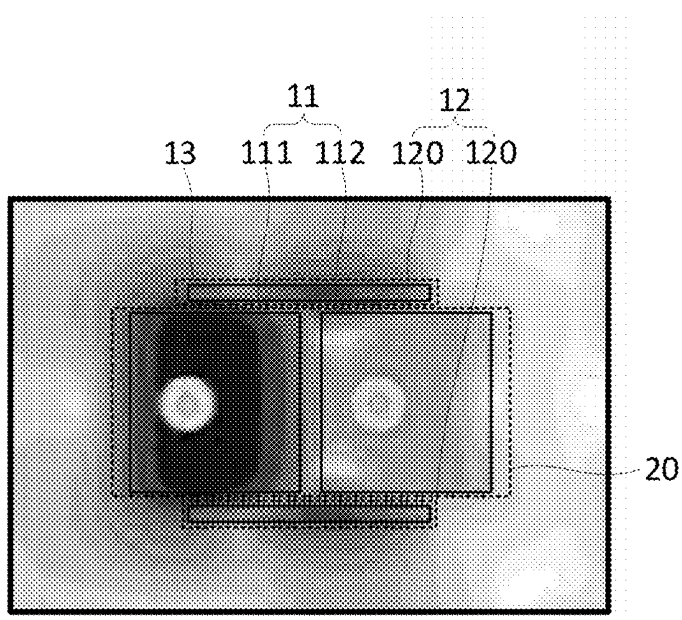
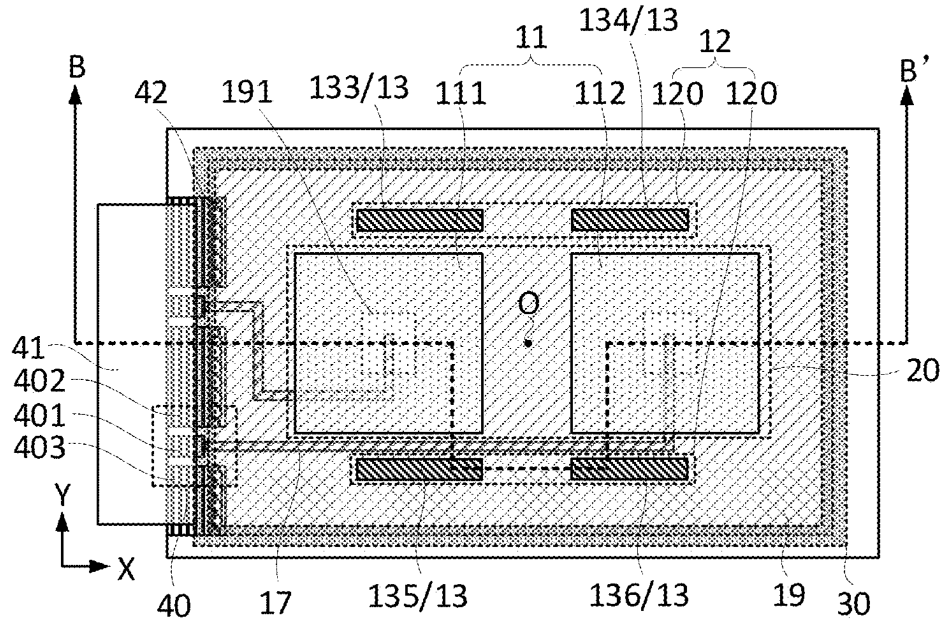
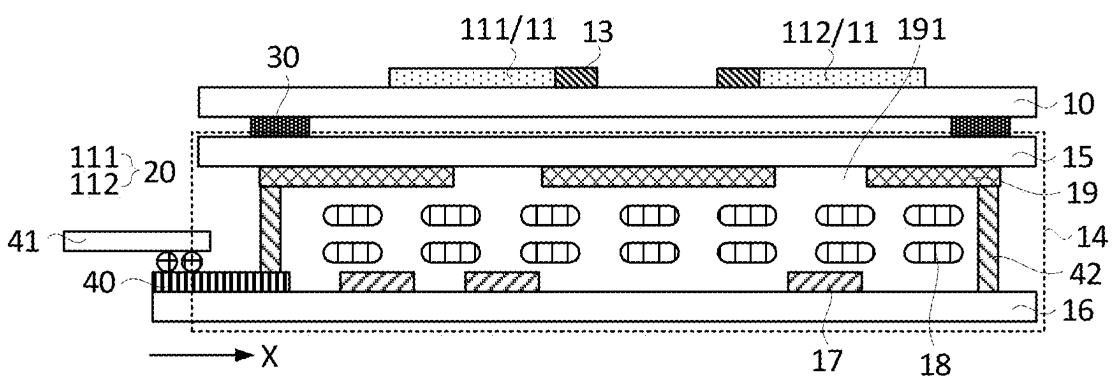


FIG. 9



B
B'
42
191
133/13
111
11
112
134/13
12
120
120
O
41
402
401
403
20
Y
X
40
17
135/13
136/13
19
30

FIG. 10



30
111/11
13
112/11
191
10
15
111
112
20
19
41
14
42
40
16
X
17
18

FIG. 11

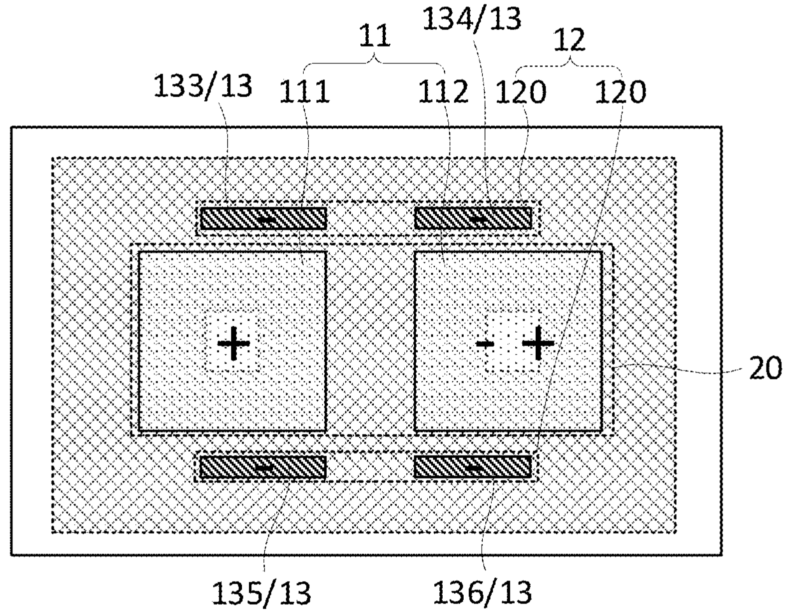

11
134/13
12
133/13
111
112
120
120
20
135/13
136/13

FIG. 12

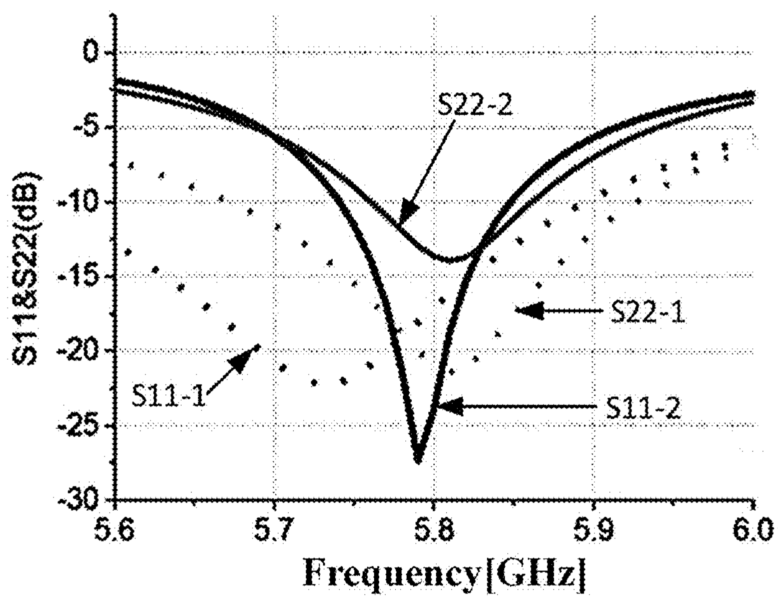

S22-2
S22-1
S11-1
S11-2
S11&S22(dB)
Frequency[GHz]
0
-5
-10
-15
-20
-25
-30
5.6
5.7
5.8
5.9
6.0

FIG. 13

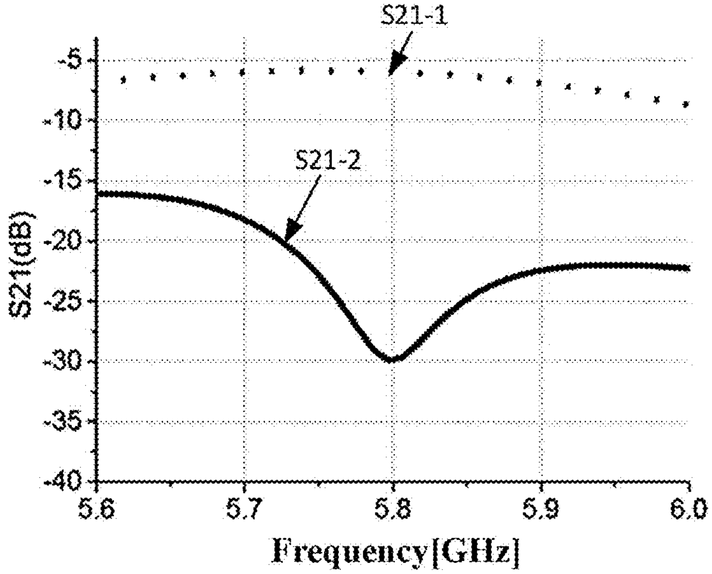

S21-1
S21-2
-5
-10
-15
-20
-25
-30
-35
-40
S21(dB)
5.6
5.7
5.8
5.9
6.0
Frequency[GHz]

FIG. 14

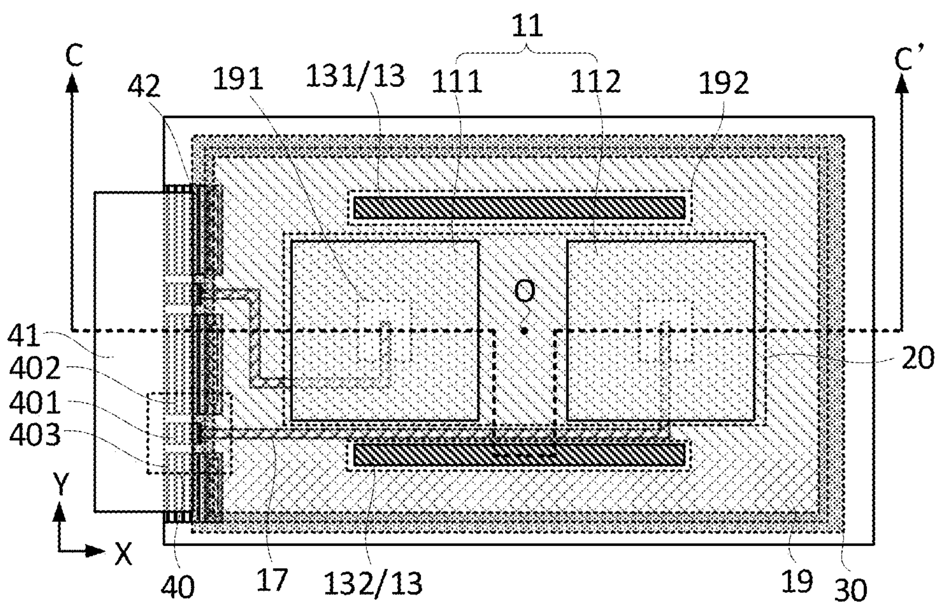

11
C
C'
42
191
131/13
111
112
192
O
41
402
401
403
20
Y
X
40
17
132/13
19
30

FIG. 15

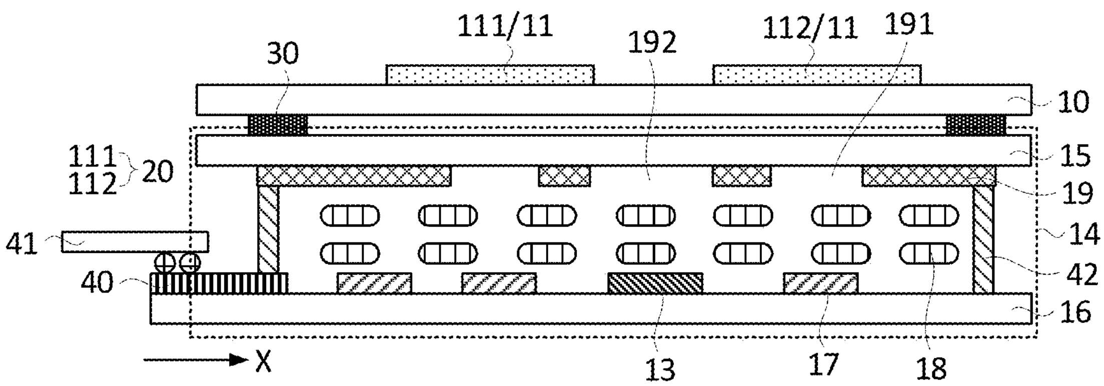


FIG. 16

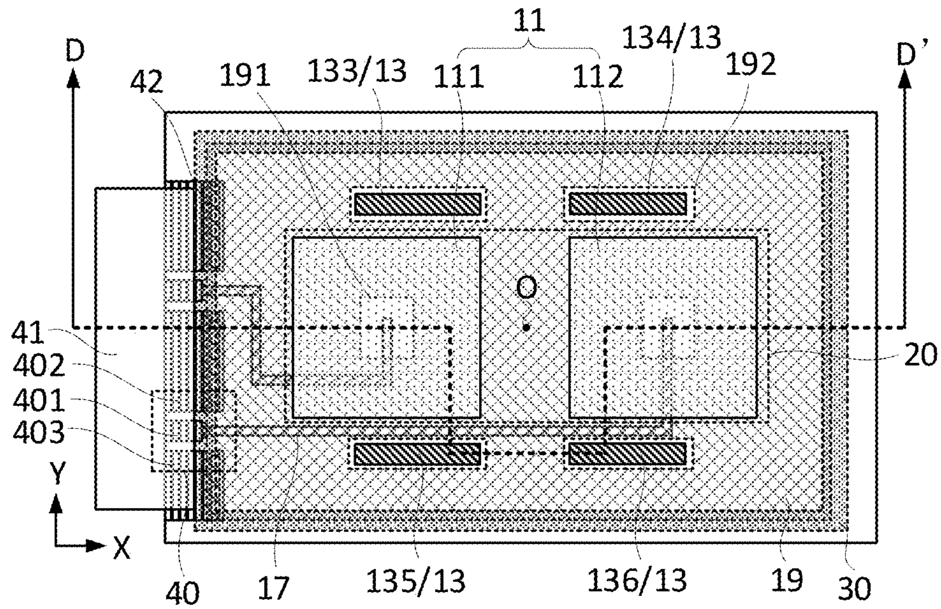


FIG. 17

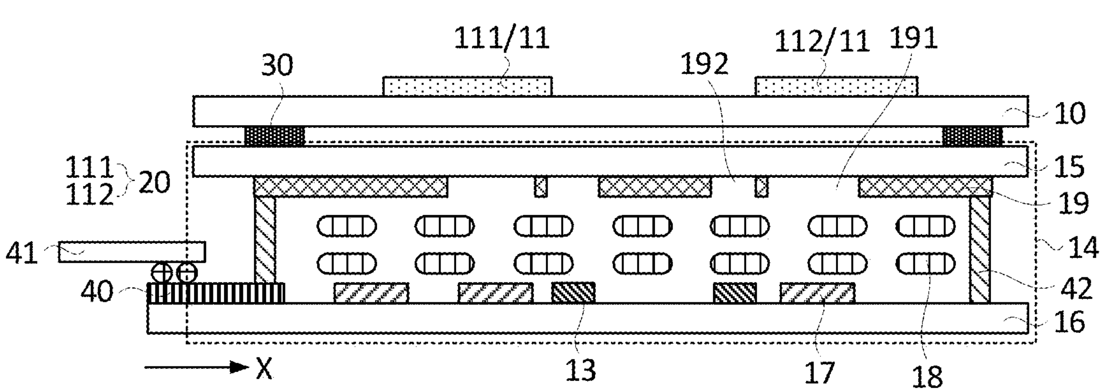


FIG. 18

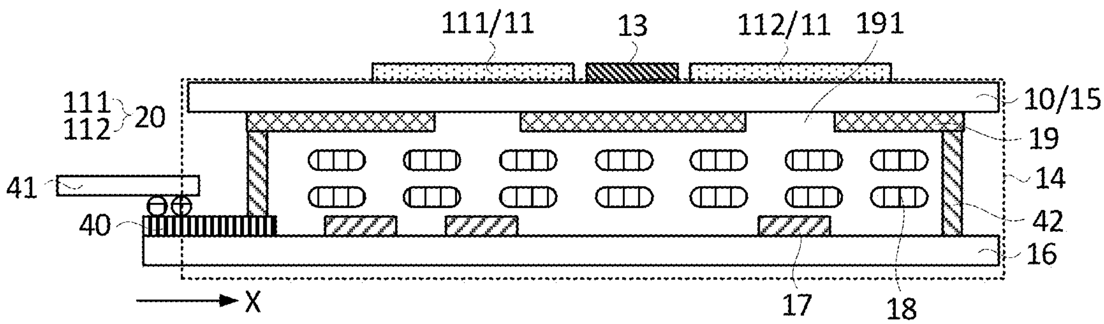


FIG. 19

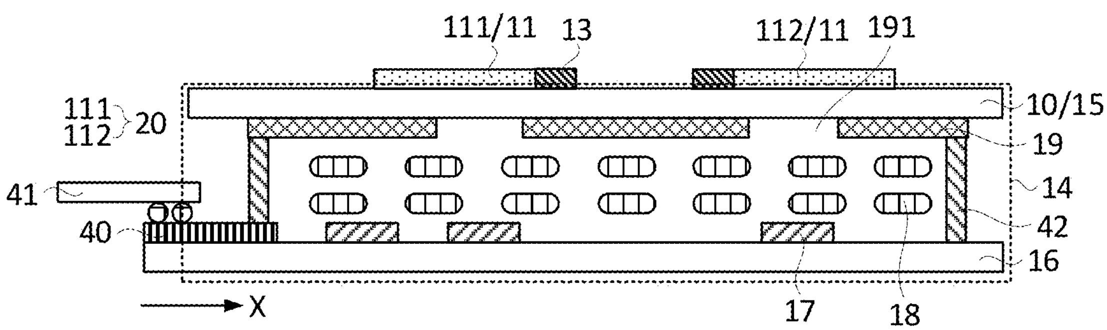


FIG. 20

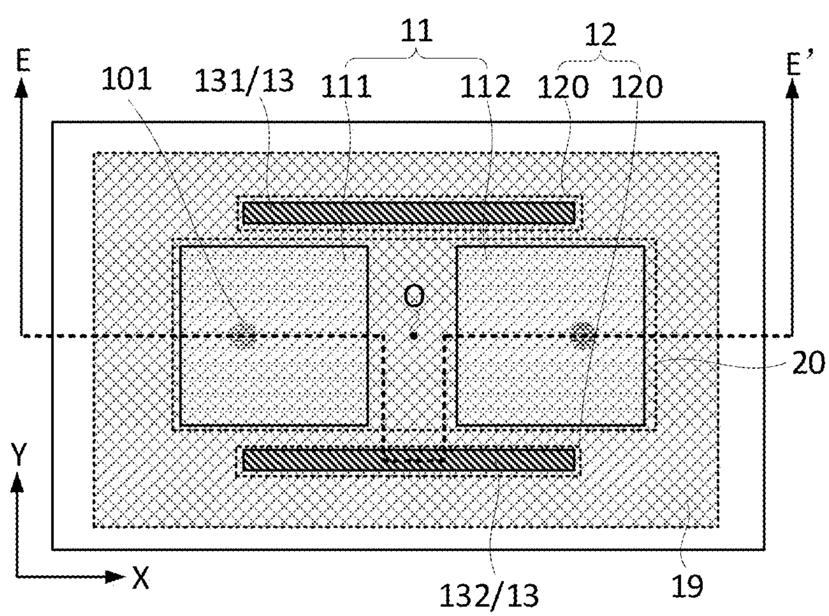


FIG. 21

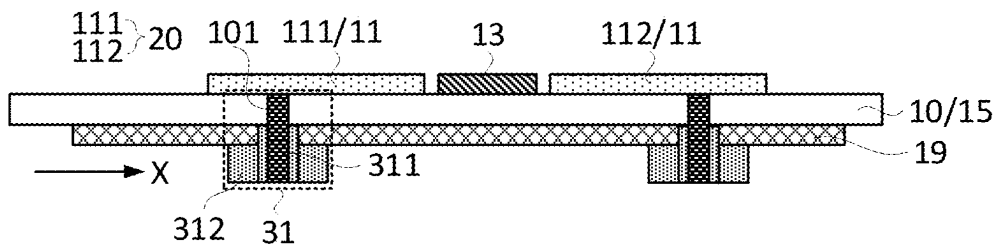


FIG. 22

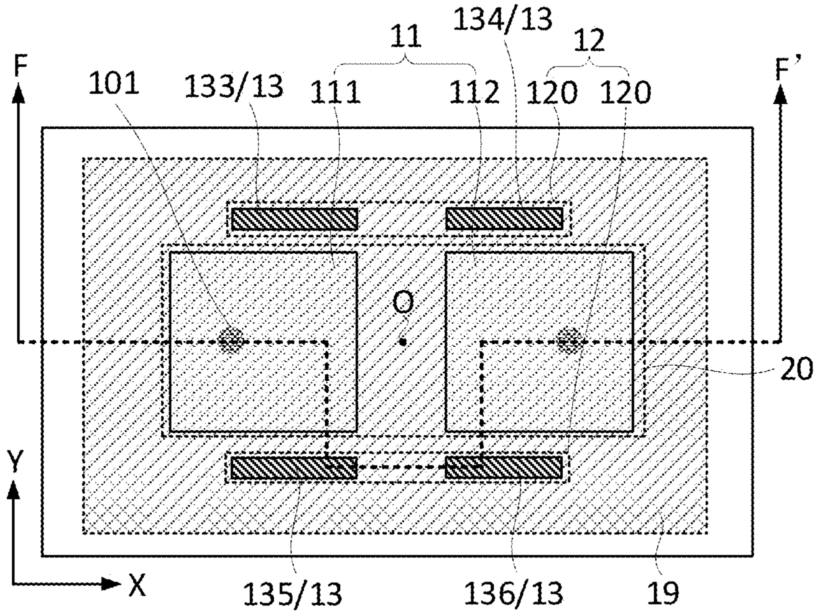


FIG. 23

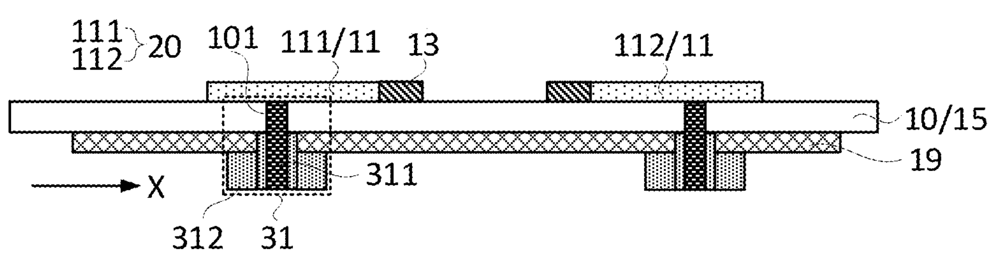


FIG. 24

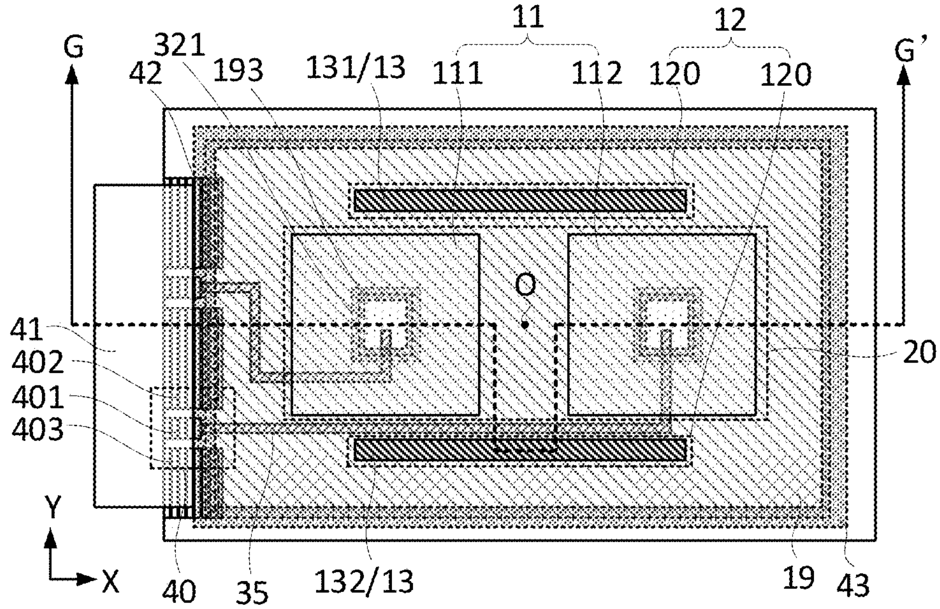


FIG. 25

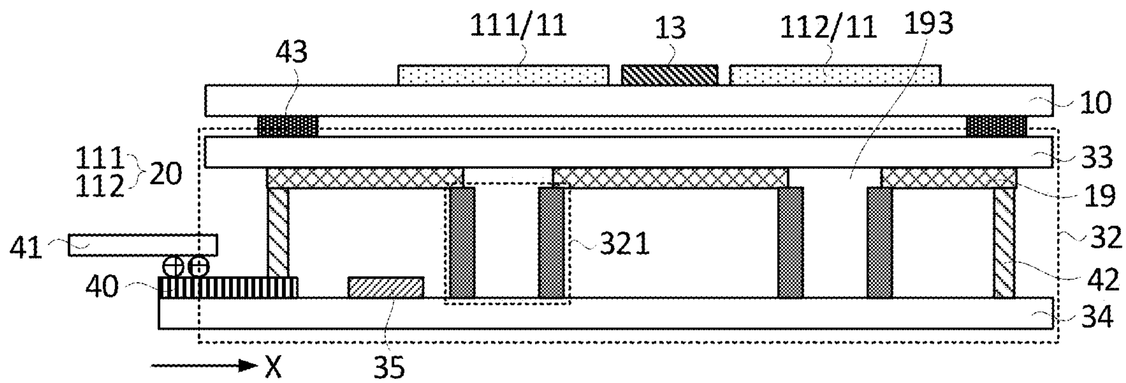


FIG. 26

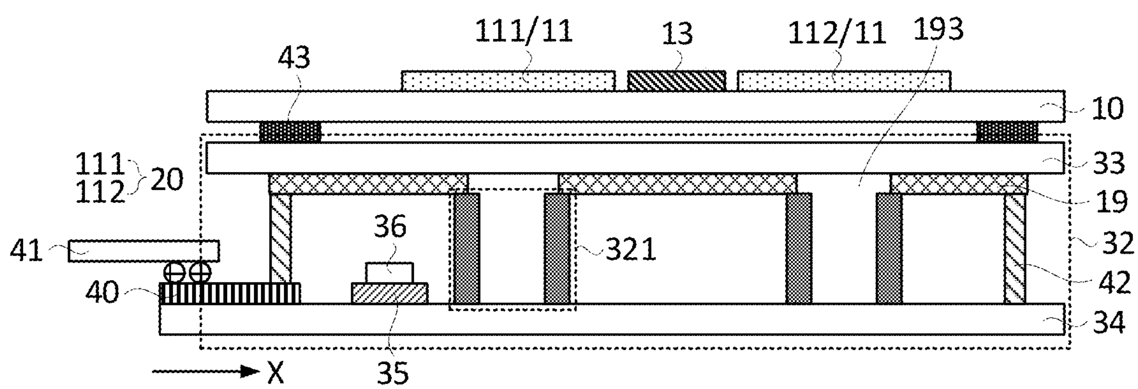


FIG. 27

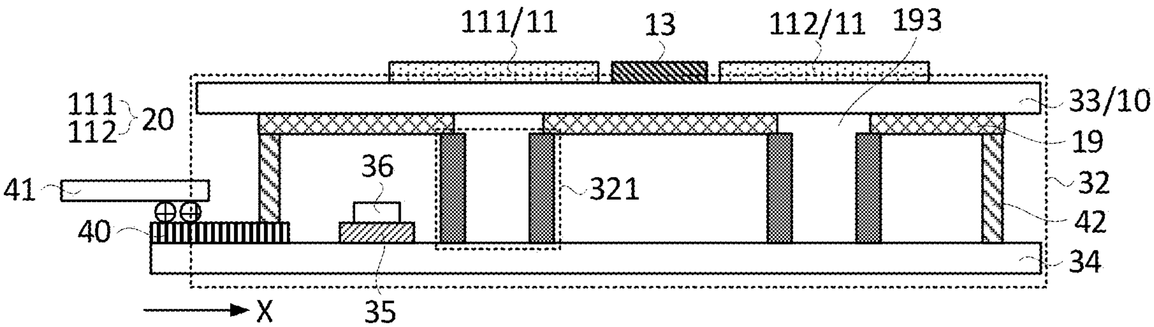


FIG. 28

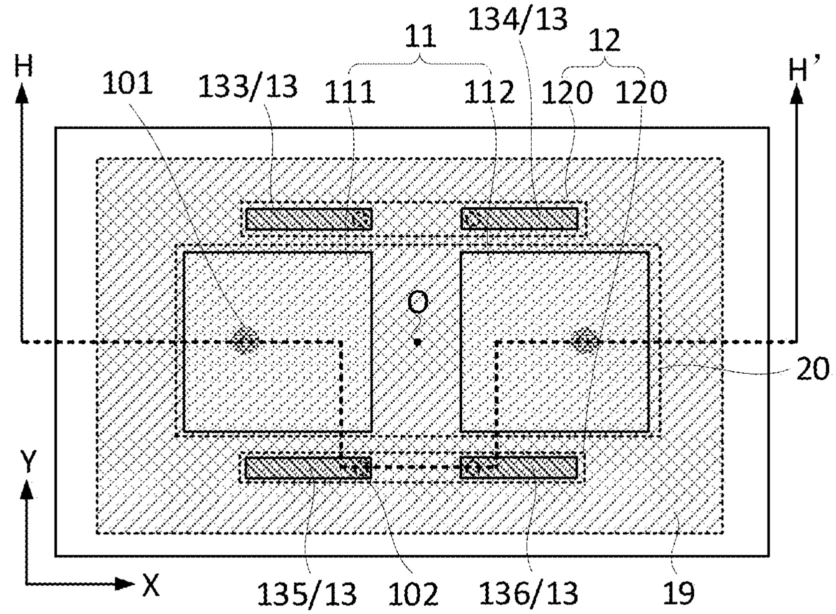


FIG. 29

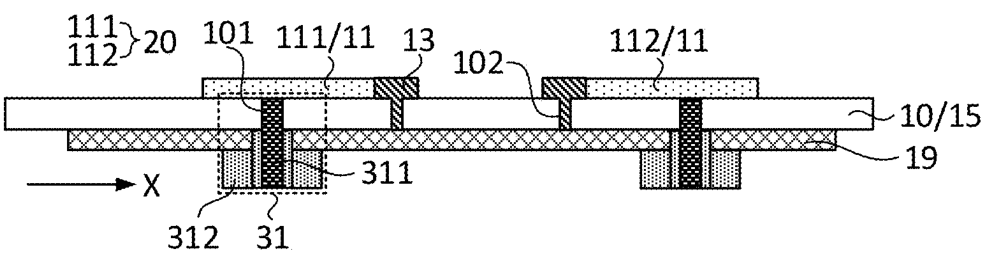


FIG. 30

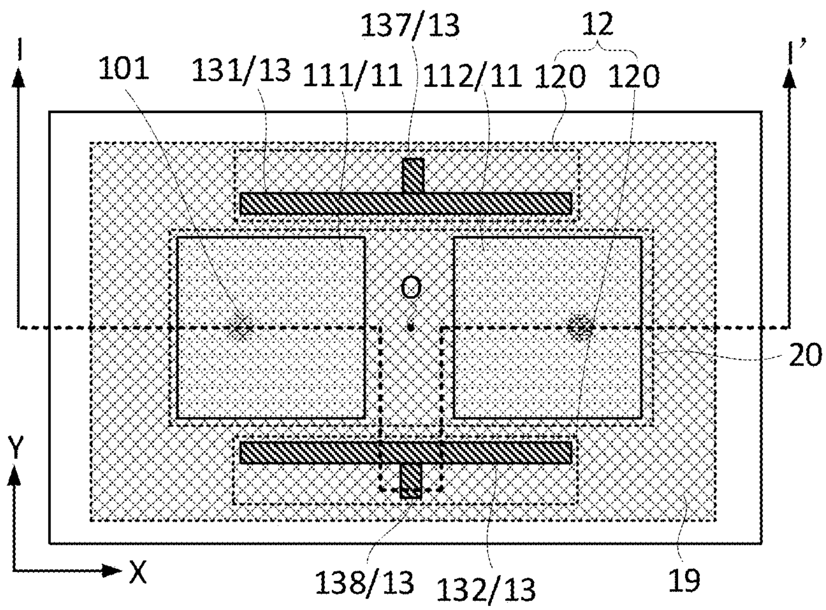

137/13
12
I
I'
101
131/13
111/11
112/11
120
120
O
20
Y
X
138/13
132/13
19

FIG. 31

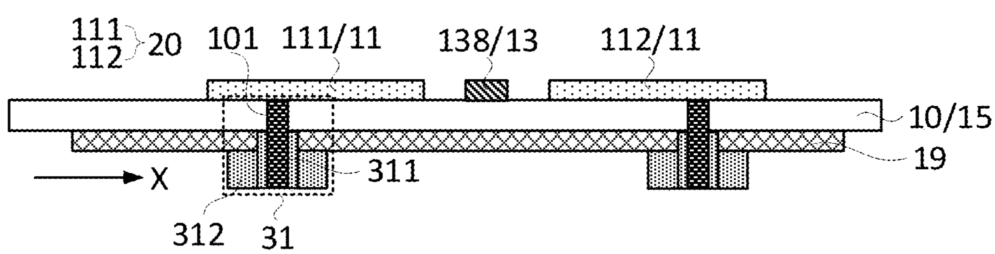

111
112
20
101
111/11
138/13
112/11
10/15
19
X
311
312
31

FIG. 32

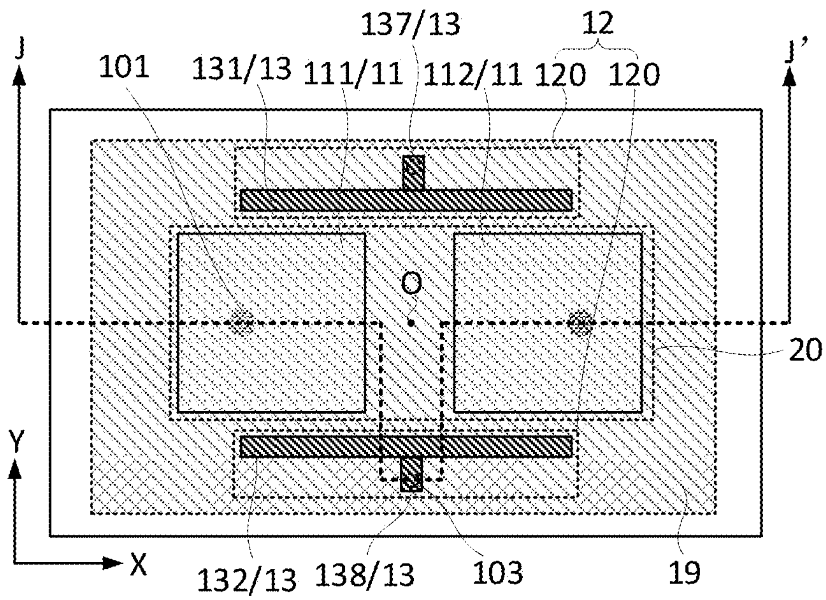

137/13
12
J
J'
101
131/13
111/11
112/11
120
120
O
20
Y
X
132/13
138/13
103
19

FIG. 33

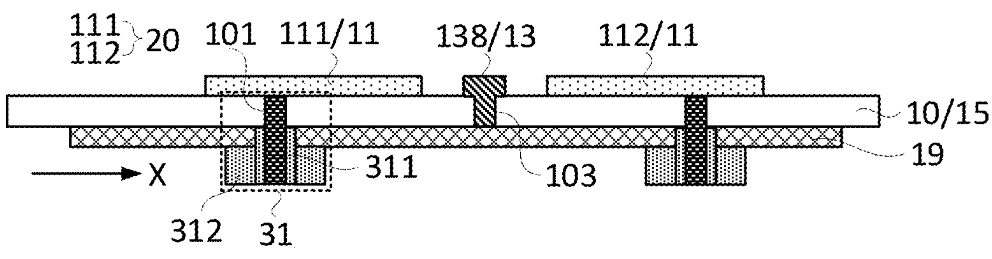

111
112
20
101
111/11
138/13
112/11
10/15
19
X
311
103
312
31

FIG. 34

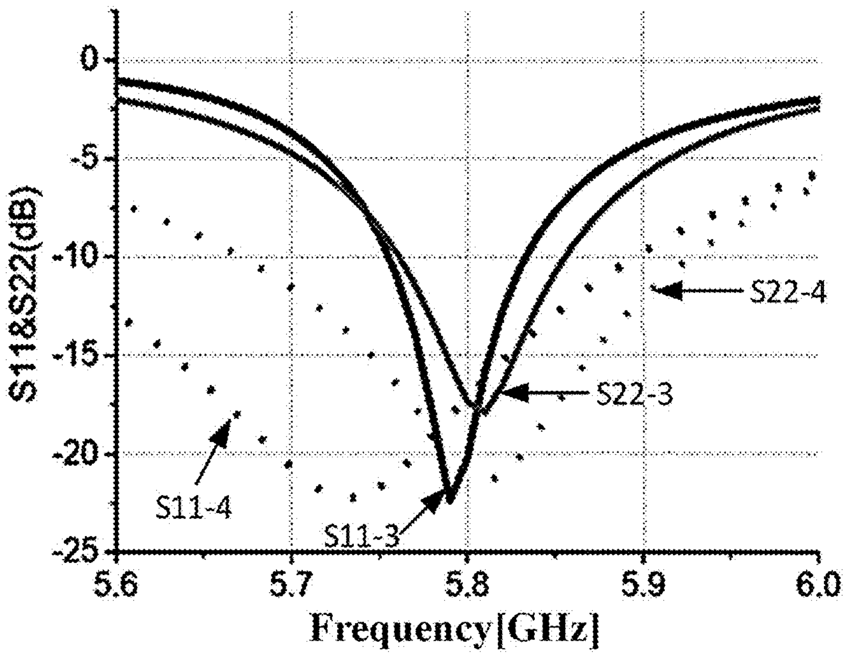

0
-5
-10
-15
-20
-25
S11&S22(dB)
5.6
5.7
5.8
5.9
6.0
Frequency[GHz]
S22-4
S22-3
S11-4
S11-3

FIG. 35

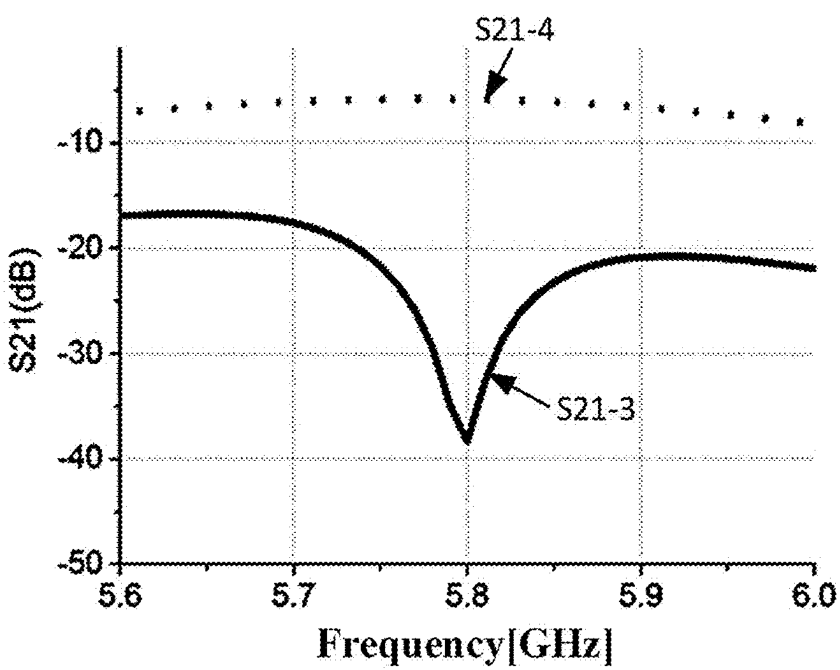

S21-4
-10
-20
-30
-40
-50
S21(dB)
5.6
5.7
5.8
5.9
6.0
Frequency[GHz]
S21-3

FIG. 36

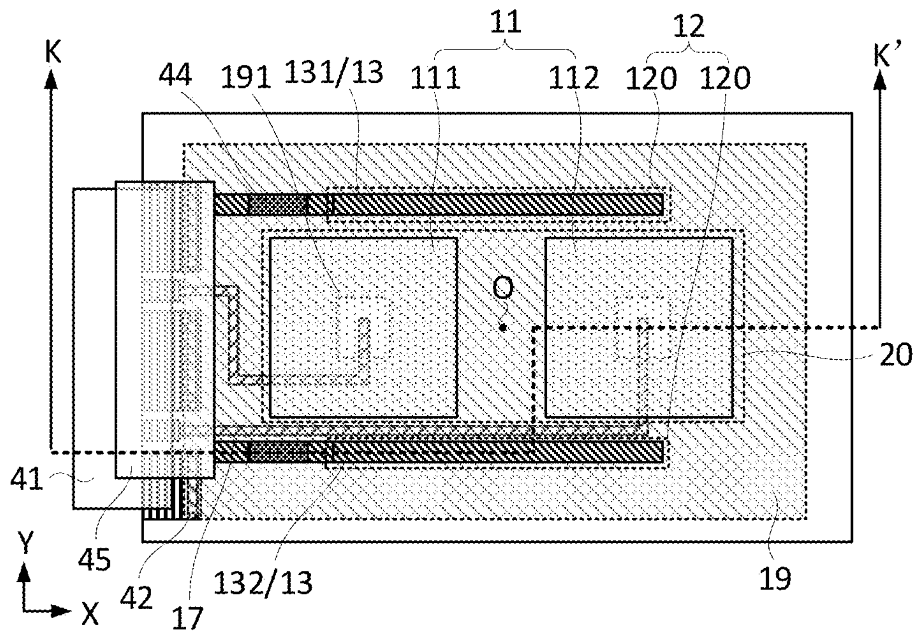

11
12
K
K'
44
191
131/13
111
112
120
120
O
20
41
45
42
17
132/13
19
Y
X

FIG. 37

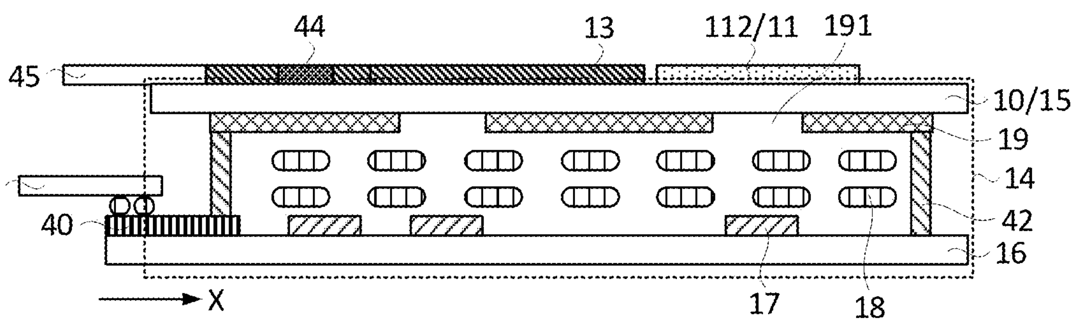
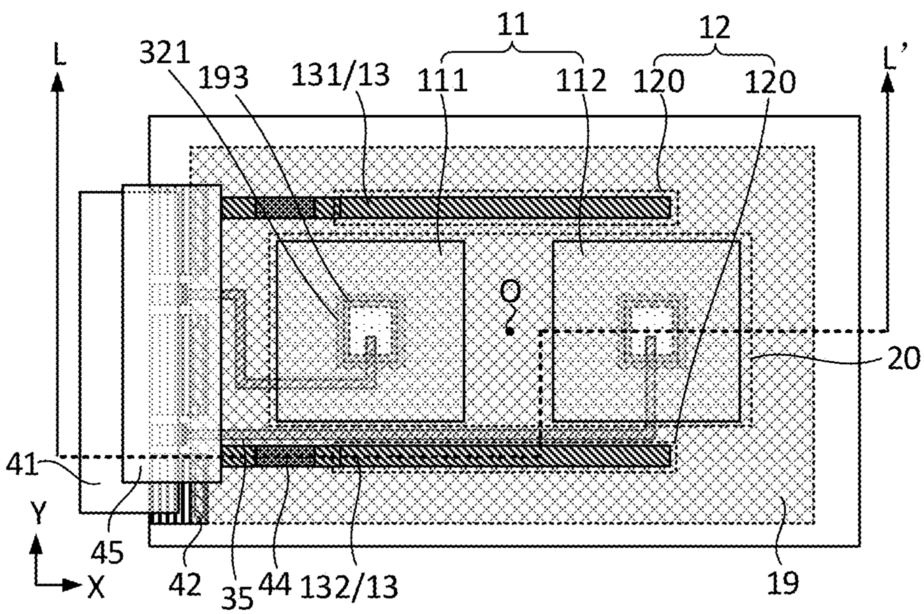
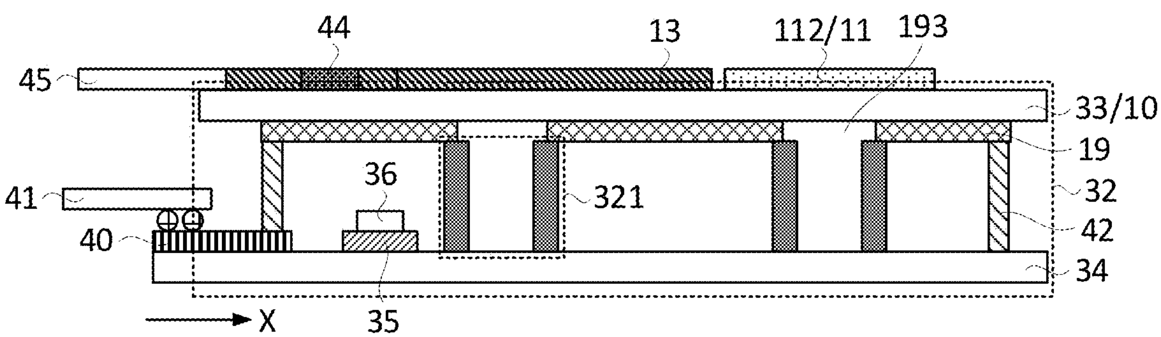

44
13
112/11
191
45
10/15
19
41
14
40
42
16
X
17
18

FIG. 38



L
321
193
131/13
11
111
112
12
120
120
L'
O
20
41
Y
X
45
42
35
44
132/13
19

FIG. 39



44
13
112/11
193
45
33/10
19
36
41
321
32
42
40
34
X
35

FIG. 40

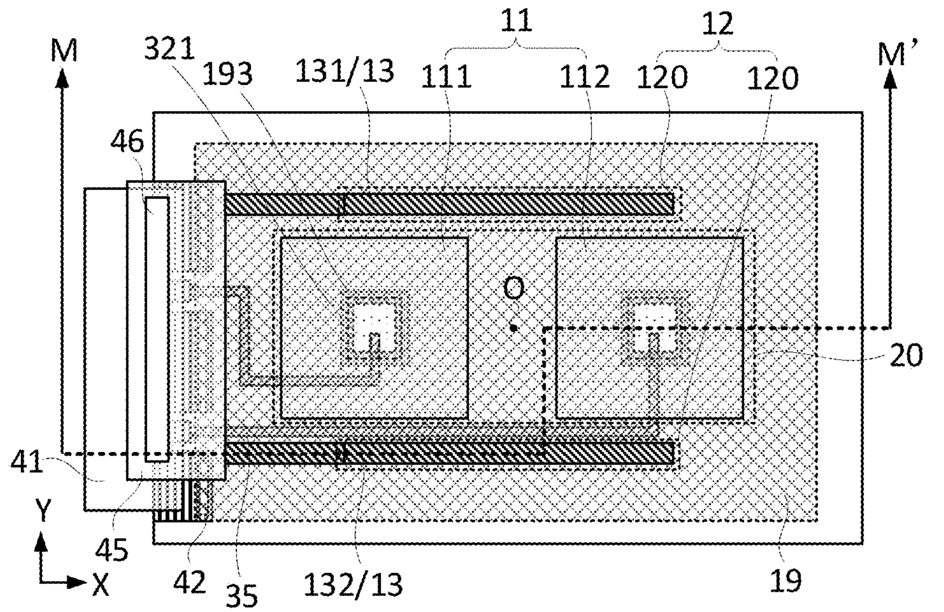

11
12
M
321
193
131/13
111
112
120
120
M'
46
O
20
41
Y
45
X
42
35
132/13
19

FIG. 41

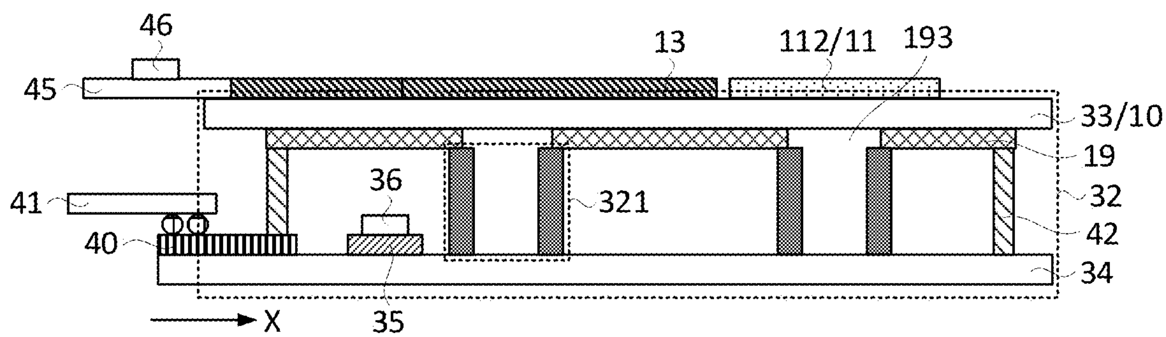

46
13
112/11
193
45
33/10
19
36
41
321
32
42
40
34
X
35

FIG. 42

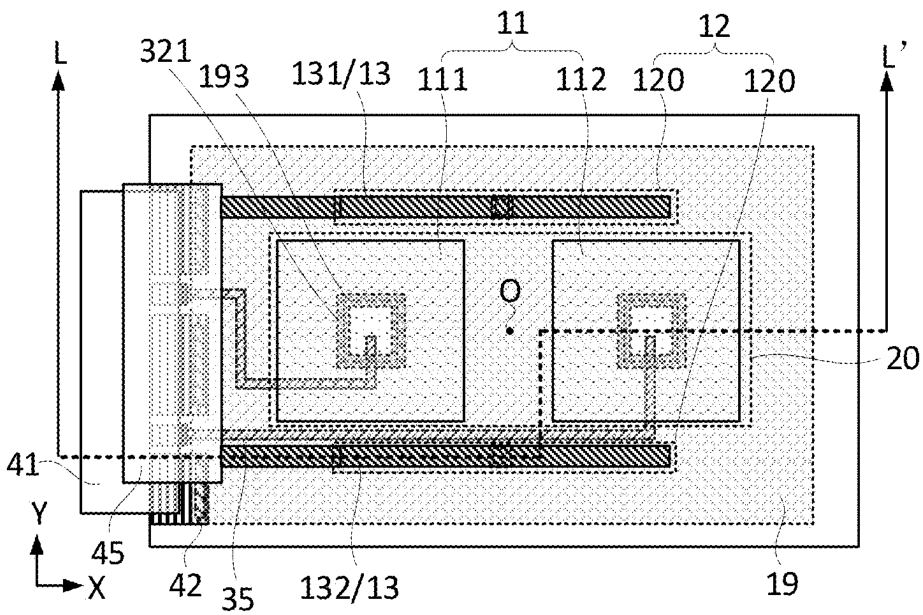

11
12
L
L'
321
193
131/13
111
112
120
120
O
20
41
Y
X
45
42
35
132/13
19

FIG. 43

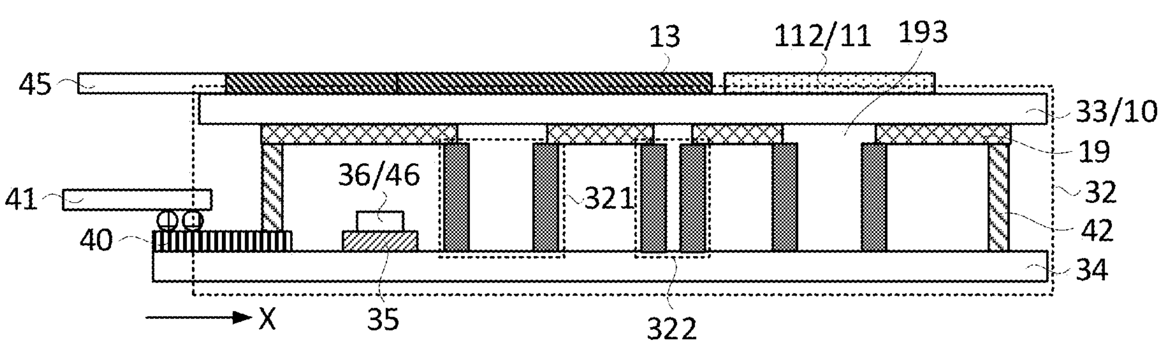

13
112/11
193
45
33/10
19
36/46
321
32
41
42
40
34
X
35
322

FIG. 44

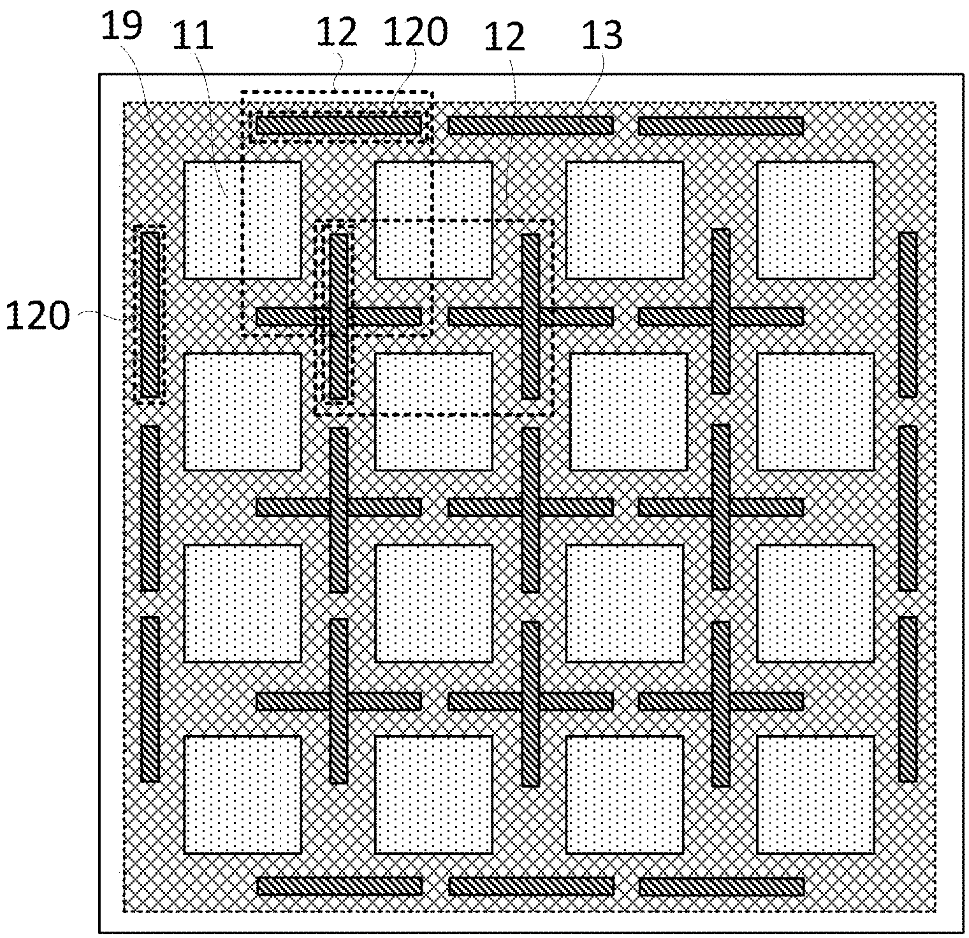


FIG. 45

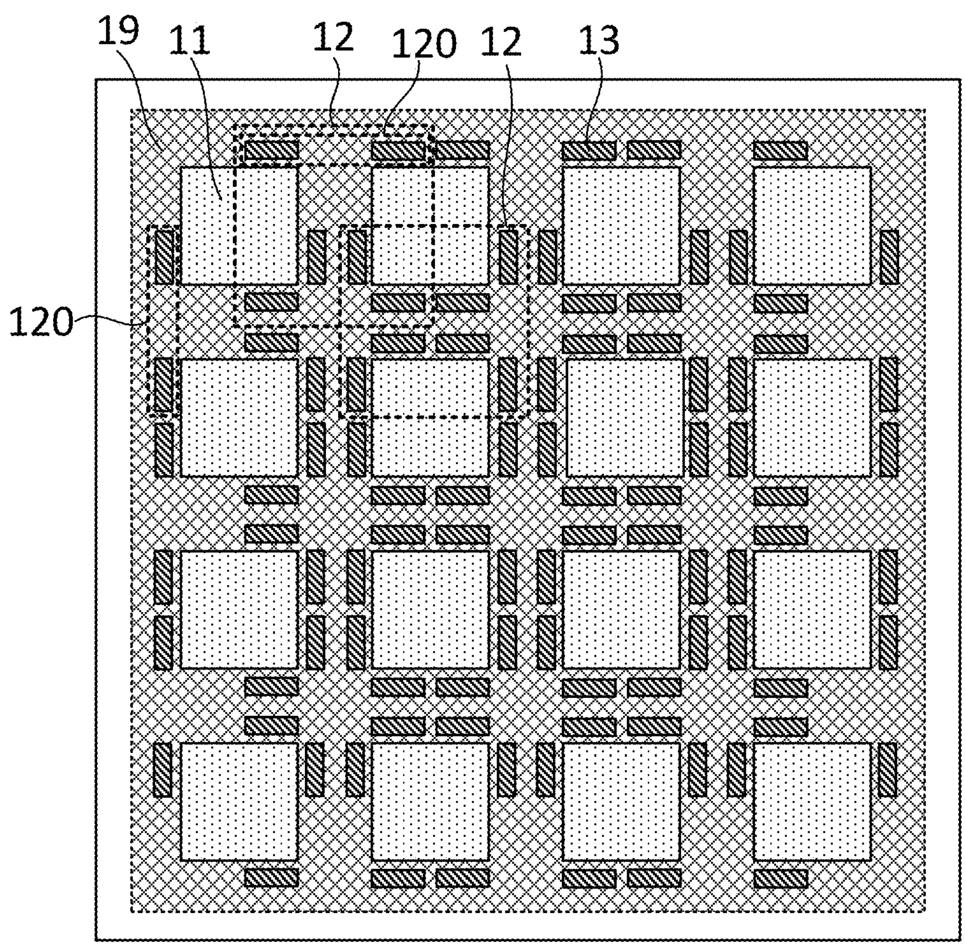


FIG. 46

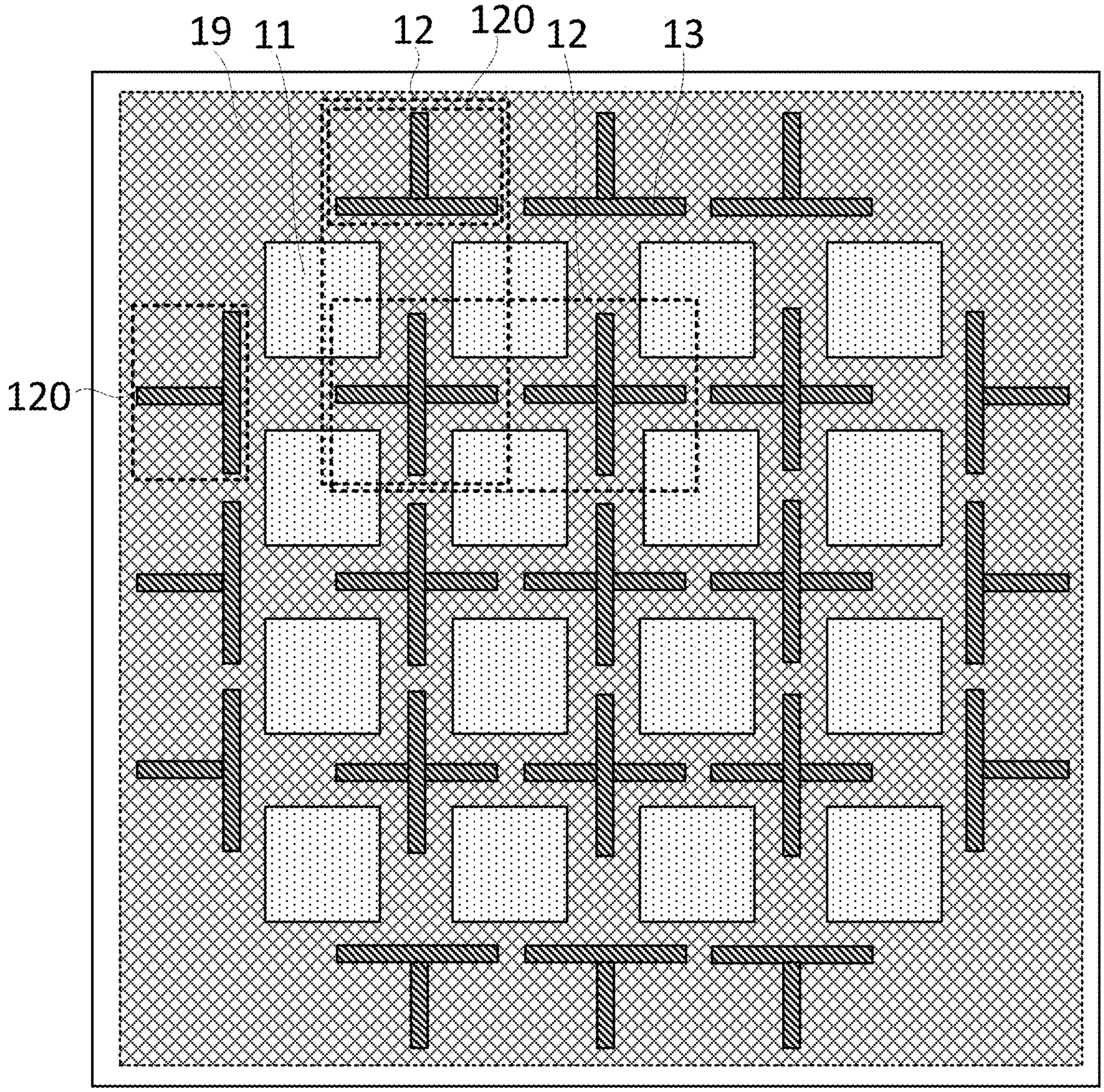


FIG. 47

ANTENNA

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims the priority of Chinese Patent Application No. 202310410534.0, filed on Apr. 17, 2023, the disclosure of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present disclosure relates to the field of communication technologies, and in particular to, an antenna.

BACKGROUND

With the gradual evolution of communication systems, antennas have gained more and more widespread applications. A phased array antenna is used as an example, in the related art, the phased array antenna includes multiple radiating units, and the multiple radiating units are configured to radiate out phase-shifted radio frequency signals to form a beam having a main lobe direction.

Radiating units in the related art are typically deployed on a same side of a substrate by using a metal film forming technology. As the miniaturization demand of the antennas is raised, on the basis of not degrading the performance of the antennas and the radiation performance, the multiple radiating units need to be densely arranged on a substrate with a smaller size. The mutual coupling between the radiating units may cause many negative effects on the antenna system performance of the multiple radiating units, such as radiation pattern distortion, radiation performance deterioration, input impedance and radiation impedance change, and antenna radiation efficiency reduction. Therefore, the reduction of mutual coupling effects between the radiating units and the improvement of isolation between the radiating units are one of important problems to be solved as the integration of the antennas increases and the miniaturization of the antennas advances.

SUMMARY

The present disclosure provides an antenna. The antenna includes a first substrate, multiple radiating units and at least one decoupling structure. The multiple radiating units are arranged in an array on a side of the first substrate. At least two adjacent radiating units among the multiple radiating units constitute one radiating unit group, and the radiating unit group includes a first radiating unit and a second radiating unit disposed adjacent to each other. The at least one decoupling structure is disposed in correspondence with the radiating unit group, one decoupling structure of the at least one decoupling structure includes two microstrip line units, and one microstrip line unit of the two microstrip line units includes at least one microstrip line. The first radiating unit and the second radiating unit are disposed on a same layer and arranged in a first direction. In a second direction, the two microstrip line units are located on two opposite sides of the radiating unit group, respectively, and a vertical projection of one microstrip line unit of the two microstrip line units on the first substrate and a vertical projection of other microstrip line unit of the two microstrip line units on the first substrate are symmetrically disposed about a center point of a vertical projection of the radiating unit group on the first substrate. The second direction intersects the first direction.

It should be understood that the contents described in this section are not intended to identify key or critical features of the embodiments of the present disclosure, nor intended to limit the scope of the present disclosure. Other features of the present disclosure will be readily understood from the following description.

BRIEF DESCRIPTION OF DRAWINGS

In order to more clearly explain the technical schemes in embodiments of the present disclosure, the drawings used for describing the embodiments will be briefly introduced below. Obviously, the drawings in the following description are some embodiments of the present disclosure. For those of ordinary skill in the art, other drawings may also be obtained without creative labor according to these drawings.

FIG. **1** is a schematic structural diagram of an antenna in the related art;

FIG. **2** is a schematic diagram of an electric field distribution of an antenna of FIG. **1**;

FIG. **3** is a schematic diagram of an electric field strength distribution of an antenna of FIG. **1**;

FIG. **4** is a schematic structural diagram of another antenna in the related art;

FIG. **5** is a schematic structural diagram of an antenna according to an embodiment of the present disclosure;

FIG. **6** is a schematic cross-sectional structural diagram of FIG. **5** taken along a direction of A-A';

FIG. **7** is a schematic diagram of a mutual coupled electric field of an antenna in the related art;

FIG. **8** is a schematic diagram of a mutual coupled electric field of an antenna according to an embodiment of the present disclosure;

FIG. **9** is a schematic diagram of an electric field strength distribution of an antenna according to an embodiment of the present disclosure;

FIG. **10** is a schematic structural diagram of another antenna according to an embodiment of the present disclosure;

FIG. **11** is a schematic cross-sectional structural diagram of FIG. **10** taken along a direction of B-B';

FIG. **12** is a schematic diagram of a mutual coupled electric field of another antenna according to an embodiment of the present disclosure;

FIG. **13** is a schematic diagram of simulation results of an antenna according to an embodiment of the present disclosure;

FIG. **14** is a schematic diagram of simulation results of another antenna according to an embodiment of the present disclosure;

FIG. **15** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **16** is a schematic cross-sectional structural diagram of FIG. **15** taken along a direction of C-C';

FIG. **17** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **18** is a schematic cross-sectional structural diagram of FIG. **17** taken along a direction of D-D';

FIG. **19** is a schematic cross-sectional structural diagram of an antenna according to an embodiment of the present disclosure;

FIG. **20** is schematic cross-sectional structural diagram of another antenna according to an embodiment of the present disclosure;

FIG. **21** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **22** is a schematic cross-sectional structural diagram of FIG. **21** taken along a direction of E-E';

FIG. **23** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **24** is a schematic cross-sectional structural diagram of FIG. **23** taken along a direction of F-F';

FIG. **25** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **26** is a schematic cross-sectional structural diagram of FIG. **25** taken along a direction of G-G';

FIG. **27** is a schematic cross-sectional structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **28** is a schematic cross-sectional structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **29** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **30** is a schematic cross-sectional structural diagram of FIG. **30** taken along a direction of H-H';

FIG. **31** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **32** is a schematic cross-sectional structural diagram of FIG. **31** taken along a direction of I-I';

FIG. **33** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **34** is a schematic cross-sectional structural diagram of FIG. **33** taken along a direction of J-J';

FIG. **35** is a schematic diagram of simulation results of still another antenna according to an embodiment of the present disclosure;

FIG. **36** is a schematic diagram of simulation results of still another antenna according to an embodiment of the present disclosure;

FIG. **37** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **38** is a schematic cross-sectional structural diagram of FIG. **37** taken along a direction of K-K';

FIG. **39** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **40** is a schematic cross-sectional structural diagram of FIG. **39** taken along a direction of L-L';

FIG. **41** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **42** is a schematic cross-sectional structural diagram of FIG. **41** taken along a direction of M-M';

FIG. **43** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **44** is a schematic cross-sectional structural diagram of FIG. **43** taken along a direction of N-N';

FIG. **45** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure;

FIG. **46** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure; and

FIG. **47** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

In order that schemes of the present disclosure may be better understood by those skilled in the art, the technical schemes in embodiments of the present disclosure will be described clearly and completely below in conjunction with the drawings in the embodiments of the present disclosure. Apparently, the described embodiments are merely part of the embodiments of the present disclosure, rather than all of the embodiments of the present disclosure. All other embodiments obtained by those of ordinary skill in the art based on the embodiments of the present disclosure without requiring creative efforts shall all fall within the scope of protection of the present disclosure.

The terms "first," "second," and the like in the Description and claims of the present disclosure, and in the foregoing drawings, are used for distinguishing between similar objects and not necessarily for describing a particular order or sequential order. It should be understood that the data so used may be interchanged under appropriate circumstances so that the embodiments of the present disclosure described herein are capable of being implemented in sequences other than those illustrated or described herein. Furthermore, the terms "include" and "have", as well as any variations thereof, are intended to cover a non-exclusive inclusion. For example, a process, a method, a system, a product, or an apparatus that includes a series of steps or units is not limited to those steps or units explicitly listed, but may include other steps or units not explicitly listed, or may include other steps or units inherent to such process, method, product, or apparatus.

The conventional antenna with multiple radiating units is usually not highly integrated and not compact in structure. A spacing between adjacent radiating units is set to be greater than or equal to 0.5λ (λ is an operating wavelength) and less than a maximum wavelength of grating lobes that occur, that is, a spacing d between adjacent radiating units, the spacing d satisfies $d<\lambda/(1+\sin\theta)$, where θ is a designed maximum scan angle. An antenna with an operating wavelength of 6 GHz is used as an example, the spacing between adjacent radiating units is greater than or equal to 0.5λ(~25 mm), so that the isolation between adjacent radiating units may be ensured to satisfy the performance requirement of the antenna.

With the improvement of high integration and miniaturization of the antenna, the spacing between adjacent radiating units needs to be greatly compressed.

FIG. **1** is a schematic structural diagram of an antenna in the related art, FIG. **2** is a schematic diagram of an electric field distribution of an antenna of FIG. **1**, and FIG. **3** is a schematic diagram of an electric field strength distribution of an antenna of FIG. **1**.

As shown in FIG. **1**, the antenna includes a radiating unit **1** and a radiating unit **2** disposed adjacent to each other.

The inventors have found that in case that a spacing between the radiating unit **1** and the radiating unit **2** becomes less than 0.5λ, when the radiating unit **1** is operated and the radiating unit **2** is not operated, that is, when only the radiating unit **1** is fed, the radiating unit **1** radiates a radio frequency signal outwardly. At this time, an electric field formed by the antenna may be represented by the distribution of an electric field line **3** in FIG. **2**, and the distribution of an electric field intensity may be represented by the grayscale distribution in FIG. **3**. In FIG. **3**, the stronger the electric field intensity, the deeper the grayscale color.

As can be seen from the distribution of the electric field line **3** in FIG. **2** and the distribution of the electric field intensity in FIG. **3**, when a distance between the radiating unit **1** and the radiating unit **2** is less than 0.5λ, a coupled electric field with greater intensity may be formed on the radiating unit **2** when the radiating unit **1** is fed. Similarly, when the radiating unit **2** is fed, a coupled electric field with greater intensity may also be formed on the radiating unit **1**. The mutual coupling between radiating units may have many negative effects on the performance of the antenna having the multiple radiating units, such as radiation pattern distortion, radiation performance deterioration, input impedance and radiation impedance change, and antenna radiation efficiency reduction. Therefore, the improvement of the isolation between radiating units is an urgent problem to be solved for the antenna with the high integration.

FIG. **4** is a schematic structural diagram of another antenna in the related art. As shown in FIG. **4**, the inventors have further found that, in order to reduce the mutual coupling effect between the radiating unit **1** and the radiating unit **2** and to improve the isolation between the radiating unit **1** and the radiating unit **2**, a vertical retaining wall **4** may be inserted between the radiating unit **1** and the radiating unit **2**. However, the vertical barrier **4** needs to occupy a large space between the radiating unit **1** and the radiating unit **2**, which is unfavorable to the high integration of the antenna and the miniaturization design of the antenna. Moreover, the vertical retaining wall **4** is also difficult in the manufacturing process and the packaging process.

Based on the above-described technical problem, an embodiment of the present disclosure provides an antenna. The antenna includes a first substrate, multiple radiating units and at least one decoupling structure. The multiple radiating units are arranged in an array on a side of the first substrate. At least two adjacent radiating units among the multiple radiating units constitute one radiating unit group, and the radiating unit group includes a first radiating unit and a second radiating unit disposed adjacent to each other. The at least one decoupling structure is disposed in correspondence with the radiating unit group, one decoupling structure of the at least one decoupling structure includes two microstrip line units, and one microstrip line unit of the two microstrip line units includes at least one microstrip line. The first radiating unit and the second radiating unit are disposed on a same layer and arranged in a first direction. In a second direction, the two microstrip line units are located on two opposite sides of the radiating unit group, respectively, and a vertical projection of one microstrip line unit of the two microstrip line units on the first substrate and a vertical projection of other microstrip line unit of the two microstrip line units on the first substrate are symmetrically disposed about a center point of a vertical projection of the radiating unit group on the first substrate. The second direction intersects the first direction.

According to the above-described technical schemes, when any one of the radiating units is in operation, a parasitic electric field may be formed on the decoupling structure, and the parasitic electric field may be coupled on another radiating unit to form a compensation electric field, so as to counteract the coupled electric field formed by the coupling of the operating radiating units on the radiating units, thereby reducing the mutual coupling between adjacent radiating units, improving the isolation between adjacent radiating units, and further solving a problem that the antenna in which the radiating units are closely placed may have strong mutual coupling between adjacent radiating units, which is conductive to improving the integration of the antenna. Moreover, the parasitic electric field on the decoupling structure also couples to the operating radiating units so as to form a positive electric field enhancement, thereby enhancing the primary electric field on the operating radiating units and improving the radiation efficiency of the antenna. In addition, the decoupling structure is composed of the microstrip line, is simple in structure, may be prepared directly by using the mature panel process, and is easy to implement.

The above is the core idea of the present disclosure, and the technical schemes of the embodiments of the present disclosure will be described clearly and completely in connection with the accompanying drawings in the embodiments of the present disclosure below.

FIG. **5** is a schematic structural diagram of an antenna according to an embodiment of the present disclosure. FIG. **6** is a schematic cross-sectional structural diagram of FIG. **5** taken along a direction of A-A'. As shown in FIGS. **5** and **6**, the antenna provided in the embodiments of the present disclosure includes a first substrate **10**, multiple radiating units **11** and at least one decoupling structure **12**. The multiple radiating units **11** are arranged in an array on a side of the first substrate **10**. At least two adjacent radiating units **11** constitute one radiating unit group **20**, and the radiating unit group includes a first radiating unit **111** and a second radiating unit **112** disposed adjacent to each other. The decoupling structure **12** is disposed in correspondence with the radiating unit group **20**, and the decoupling structure **12** includes two microstrip line units **120**, and one microstrip line unit of the two microstrip line units **120** includes at least one microstrip line **13**. The first radiating unit **111** and the second radiating unit **112** are disposed on a same layer and arranged in a first direction X. In a second direction Y, the two microstrip line units **120** are located on two opposite sides of the radiating unit group **20**, respectively, and a vertical projection of one microstrip line unit **20** in the two microstrip line units **120** on the first substrate **10** and a vertical projection of another microstrip line unit **20** in the two microstrip line units **120** on the first substrate **10** are symmetrically disposed about a center point O of a vertical projection of the radiating unit group **20** on the first substrate **10**. The second direction Y intersects the first direction X.

Specifically, as shown in FIGS. **5** and **6**, the radiating unit **11** is used for transmitting and receiving a signal, and the first substrate **10** is configured to support the radiating unit **11**. The first substrate **10** is provided with at least two radiating units **11**, and the at least two radiating units **11** may be located on a same film layer and arranged in an array.

When the antenna is in operation, different signals may be transmitted to different radiating units **11**, respectively, so as to enable the multiple radiating units **11** to transmit and receive signals independently. For example, signals of different frequencies may be transmitted to different radiating units **11**, respectively, so as to enable the multi-band communication. The different radiating units **11** may operate individually, simultaneously, or alternately to satisfy various functional requirements of the antenna, which is not specifically limited in the embodiments of the present disclosure.

Further, the first substrate **10** may be made of a material having a smaller dielectric constant (Dk) and a smaller dissipation factor (DF). The smaller the dielectric constant of the first substrate **10** is, the smaller the dissipation factor of the first substrate **10** to the radio frequency signal is. Similarly, the smaller the dissipation factor of the first substrate **10** is, the smaller the dissipation factor caused by the first substrate **10** on the radio frequency signal is. For example, the dielectric constant of the first substrate **10** may satisfy Dk≤5, and the dissipation factor may satisfy DF≤0.07, so that the first substrate **10** causes a small dissipation factor for the radio frequency signal, thereby being conductive to improving the radiation efficiency of the antenna.

Based on the above requirements for the dielectric constant of the first substrate **10** and the dissipation factor of the first substrate **10**, the first substrate **10** may be selected from a glass substrate or a printed circuit board (PCB), so that the antenna has the relatively high radiation efficiency.

Further, the thinner a thickness of the first substrate **10** is, the smaller the dissipation factor of the radio frequency signal on the first substrate **10** is. In this embodiment, the thickness h of the first substrate **10** may be set to satisfy 0.3 mm≤h≤1.1 mm. The use of the thinner first substrate **10** can reduce the dissipation factor of the radio frequency signal and improve the radiation efficiency of the antenna. It should be understood that within the above thickness range, a smaller dissipation factor may be obtained by selecting the first substrate **10** of 0.3 mm. If the first substrate **10** is further thinned, then the first substrate **10** is liable to be damaged, which is detrimental to the support performance of the first substrate **10**.

Further, any two adjacent radiating units **11** may constitute one radiating unit group **20**. For example, as shown in FIGS. **5** and **6**, the radiating unit group **20** includes the first radiating unit **111** and the second radiating unit **112** disposed adjacent to each other.

As described above, when a distance between the first radiating unit **111** and the second radiating unit **112** is small, the first radiating unit **111** and the second radiating unit **112** are coupled to each other to cause problems such as radiation pattern distortion, radiation performance deterioration, input impedance and radiation impedance change, and antenna radiation efficiency reduction.

Specifically, FIG. **7** is a schematic diagram of a mutual coupled electric field of an antenna in the related art. As shown in FIG. **7**, when the first radiating unit **111** and the second radiating unit **112** are not correspondingly provided with the decoupling structure, there exist only direct coupling fields formed by the coupling between the first radiating unit **111** and the second radiating unit **112**, and no other coupling field exists. For example, when only the first radiating unit **111** is fed, the coupled electric field directly generated by the first radiating unit **111** on the second radiating unit **112** is the direct coupling field.

A direction of a current induced by the direct coupling field to the first radiating unit **111** is opposite to a direction of a current induced by the direct coupling field to the second radiating unit **112**. Therefore, the coupling causes a polarity inversion of the electric field. As shown in FIG. **7**, if a positive electric field is applied to the first radiating unit **111**, then a negative electric field may be coupled to the second radiating unit **112**, and the negative electric field may affect the radiation performance of the second radiating unit **112**.

With continued reference to FIGS. **5** and **6**, in this embodiment, at least one radiating unit group **20** is correspondingly provided with a respective decoupling structure **12**. The decoupling structure **12** includes two microstrip line units **120**, one microstrip line unit of the two microstrip line units **120** consists of at least one microstrip line **13**. Moreover, if an arrangement direction of the first radiating unit **111** and the second radiating unit **112** is the first direction X, then in the second direction Y intersecting the first direction X, the two microstrip line units **120** are respectively located on two opposite sides of the radiating unit group **20**, that is, an arrangement direction of the two microstrip line units **120** intersects the arrangement direction of the first radiating unit **111** and the second radiating unit **112**. FIGS. **5** and **6** show an example in which the first direction X is perpendicular to the second direction Y.

FIG. **8** is a schematic diagram of a mutual coupled electric field of an antenna according to an embodiment of the present disclosure. As shown in FIG. **8**, the decoupling structure **12** is provided for the radiating unit group **20**, an indirect coupling field is formed on the first radiating unit **111** and the second radiating unit **112** in addition to the above-described direct coupling field. For example, when only the first radiating unit **111** is fed, the coupled electric field indirectly generated on the second radiating unit **112** by the first radiating unit **111** through the decoupling structure **12** is the indirect coupling field.

As such, in addition to the direct coupling field having an effect on the induced currents on the first radiating unit **111** and the second radiating unit **112**, the indirect coupling field also has an effect on the induced currents on the first radiating unit **111** and the second radiating unit **112**. Therefore, the induced currents on the first radiating unit **111** and the second radiating unit **112** may be considered to be a superposition of currents generated by the direct coupling field and the indirect coupling field.

Specifically, with continued reference to FIG. **8**, as previously described, if a positive electric field is applied to the first radiating unit **111**, then the first radiating unit **111** may be directly coupled to the second radiating unit **112** to form a negative electric field, and this negative electric field may affect the radiation performance of the second radiating unit **112**. Moreover, the first radiating unit **111** is coupled to the microstrip line **13** in the two microstrip line units **120** to form the parasitic electric field. Since the polarity inversion is formed by the coupling, if the first radiating unit **111** is the positive electric field, then the parasitic electric field formed by coupling on the microstrip line **13** is the negative electric field.

Further, as shown in FIG. **8**, the negative electric field on the microstrip line **13** is coupled to the second radiating unit **112** to form a compensation electric field, since the polarity inversion is formed by the coupling, the compensation electric field is the positive electric field, the positive electric field compensates for the negative electric field formed by the directly coupling of the first radiating unit **111** to the second radiating unit **112** so as to counteract at least a part of the negative electric field formed by the directly coupling of the first radiating unit **111** to the second radiating unit **112**, thereby reducing the mutual coupling between the first radiating unit **111** and the second radiating unit **112**, improving the isolation between the first radiating unit **111** and the second radiating unit **112**, and further solving a problem that the antenna in which the radiating units **11** are closely placed may have strong mutual coupling between adjacent radiating units **11**, which is conductive to improving the integration of the antenna.

Moreover, as shown in FIG. **8**, the negative electric field formed by the coupling of the first radiating unit **111** on the microstrip lines **13** in the two microstrip line units **120** is also negatively fed back to the first radiating unit **111**, and a feedback enhancement electric field is formed in the coupling of the first radiating unit **111**. Since the polarity inversion is formed by the coupling, the feedback enhancement electric field is the positive electric field, thereby forming a positive electric field enhancement on the first radiating unit **111**, which can enhance a primary electric field on the first radiating unit **111** and improve the radiation efficiency of the first radiating unit **111**.

Further, with continued reference to FIG. **5**, a vertical projection of one microstrip line unit of the two microstrip line units **120** on the first substrate **10** and a vertical projection of other microstrip line unit of the two microstrip line units **120** on the first substrate **10** are symmetrically disposed about the center point O of the vertical projection of the radiating unit group **20** on the first substrate **10**, so that parasitic electric fields formed on the two microstrip line units **120** contribute symmetrical electric field compensations to the first radiating unit **111** and the second radiating unit **112**, thereby avoiding the introduction of new additional coupled electric fields which is detrimental to the decoupling effect of the decoupling structure **12**.

The center point O of the vertical projection of the radiating unit group **20** on the first substrate **10** is a geometric center of the vertical projection of the radiating unit group **20** on the first substrate **10**. As shown in FIG. **5**, that the vertical projection of the one microstrip line unit of the two microstrip line units **120** on the first substrate **10** and the vertical projection of the other microstrip line unit of the two microstrip line units **120** on the first substrate **10** are symmetrically disposed about the center point O of the vertical projection of the radiating unit group **20** on the first substrate **10** may be: a straight line passing through a center point O and extending in first direction X is used as a first symmetry axis, the vertical projection of the one microstrip unit of the two microstrip units **120** on first substrate **10** and the vertical projection of the another microstrip unit of the two microstrip line units **120** on the first substrate **10** are symmetrically disposed about the first symmetry axis, and moreover, a straight line passing through the center point O and extending in the second direction Y is used as a second symmetry axis, a vertical projection of each microstrip line unit **120** on the first substrate **10** is symmetrical about the second symmetry axis, with such arrangement, the parasitic electric fields formed on the two microstrip units **120** contribute symmetrical electric field compensations to the first radiating unit **111** and the second radiating unit **112**, thereby avoiding the introduction of new additional coupled electric fields which is detrimental to the decoupling effect of the decoupling structure **12**.

FIG. **9** is a schematic diagram of an electric field strength distribution of an antenna according to an embodiment of the present disclosure. In FIG. **9**, a darker gray color indicates a stronger electric field intensity.

As shown in FIG. **9**, when the distance between the first radiating unit **111** and the second radiating unit **112** is less than 0.5λ, the decoupling structure **12** is provided. In case that the first radiating unit **111** is operated and the second radiating unit **112** is not operated, that is, only the first radiating unit **111** is fed, the first radiating unit **111** is coupled to the microstrip line **13** in the two microstrip line units **120** to form the parasitic electric field, and the parasitic electric field on the microstrip line **13** is coupled to the second radiating unit **112** to form the compensation electric field, so as to counteract at least a part of the coupled electric field formed by the directly coupling of the first radiating unit **111** to the second radiating unit **112**. As can be seen from FIG. **3**, the intensity of the coupled electric field formed on the second radiating unit **112** is greatly reduced, thereby reducing the mutual coupling between the first radiating unit **111** and the second radiating unit **112**, improving the isolation between the first radiating unit **111** and the second radiating unit **112**, and further solving the problem that the antenna in which the radiating units **11** are closely placed may have strong mutual coupling between adjacent radiating units **11**, which is conductive to improving the integration of the antenna.

Moreover, with continued reference to FIG. **9**, the parasitic electric field formed by coupling the first radiating unit **111** on the microstrip line **13** in the two microstrip line units **120** is also negatively fed back to the first radiating unit **111**, and a feedback enhancement electric field is formed by coupling the first radiating unit **111**, thereby achieving an electric field enhancement by coupling the first radiating unit **111**. As can be seen from FIG. **3**, the primary electric field on the first radiating unit **111** is enhanced, thereby being conductive to improving the radiation efficiency of the first radiating unit **111**.

It should be noted that the length and width of the microstrip line **13** in the microstrip line unit **120** and the spacing between the microstrip line **13** and the corresponding radiating unit **11** may be optimized for the operating frequency of the antenna, the impedance matching requirement, and the requirements of the radiation performance and loss.

Here, as shown in FIG. **5**, a length Lm of the microstrip line **13**, a width Wm of the microstrip line **13** and a spacing d between the microstrip line **13** and the adjacent radiating unit **11** can be adjusted so that the influence of the electric field generated by the operating radiating unit **11** on the electric field of the adjacent radiating unit **11** can be minimized.

Specifically, for the length Lm of the microstrip line **13**, the inventors have found that the length Lm of the microstrip line **13** is related to the operating frequency of the antenna, and the length Lm of the microstrip line **13** may be set to be on the same order of magnitude as the operating wavelength of the antenna, so as to achieve the better antenna radiation performance. For example, if the decoupling structure **12** is applied to a millimeter-wave antenna, then the length Lm of the microstrip line **13** is on the order of millimeters; if the decoupling structure **12** is applied to a centimeter-wave antenna, then the length Lm of the microstrip line **13** is on the order of centimeters.

Moreover, the length Lm of the microstrip line **13** is also related to the optimum decoupling frequency range, the optimum decoupling frequency range of the decoupling structure **12** moves to a high frequency as the length Lm of the microstrip line **13** becomes shorter, and the decoupling effect of the decoupling structure **12** is better. Therefore, if it is necessary to reduce the mutual coupling effect of the high frequency range, the length Lm of the microstrip line **13** may be set relatively short; and if it is necessary to reduce the mutual coupling effect of the low frequency range, then the length Lm of the microstrip line **13** may be set relatively long.

For the width Wm of the microstrip line **13**, the inventors have found that the width Wm of the microstrip line **13** is inversely proportional to the isolation, that is, the larger the width Wm of the microstrip line **13** is, the worse the isolation effect between the decoupling structure **12** and adjacent radiating units **11** is, and the smaller the width Wm of the microstrip line **13** is, the better the isolation effect between the decoupling structure **12** and adjacent radiating units **11** is.

Moreover, the width Wm of the microstrip line **13** is also related to the optimum decoupling frequency range. The larger the width Wm of the microstrip line **13** is, the optimum decoupling frequency range of the decoupling structure **12** moves toward the low frequency. The smaller the width Wm of the microstrip line **13** is, the optimum decoupling frequency range of the decoupling structure **12** moves toward the high frequency. Therefore, if it is necessary to reduce the mutual coupling effect of the high frequency range, the width Wm of the microstrip line **13** may be set to be relatively narrow. If it is necessary to reduce the mutual coupling effect of the low frequency range, the width Wm of the microstrip line **13** may be set to be relatively wide.

For the spacing d between the microstrip line **13** and the adjacent radiating unit **11**, the inventors have found that the smaller the spacing d between the microstrip line **13** and the adjacent radiating unit **11** is, the better the decoupling effect of the decoupling structure **12** is.

Optionally, the spacing d between the microstrip line **13** and the adjacent radiating unit **11** may be set in the range of 3 μm to 10 μm. At this time, the field strength of the parasitic electric field formed by the coupling of the first radiating unit **111** on the microstrip line **13** is sufficient to counteract the coupled electric field formed by the coupling of the first radiating unit **111** on the second radiating unit **112**, so that the decoupling structure **12** achieves the optimal decoupling effect.

Optionally, the spacing d between the microstrip line **13** and the adjacent radiating unit **11** is not limited to the above-described range. In view of the ease of the manufacturing process, the spacing d between the microstrip line **13** and the adjacent radiating unit **11** can be set larger. For example, the spacing d between the microstrip line **13** and the adjacent radiating unit **11** may be set in the range of 8 μm to 20 μm, so as to reduce the difficulty of the manufacturing process of the antenna and achieve the better decoupling effect of the decoupling structure **12**.

It can be understood from the above description that the isolation effect of the decoupling structure **12** may be adjusted by adjusting the length Lm and the width Wm of the microstrip line **13** and the spacing d between the microstrip line **13** and the adjacent radiating unit **11** in a coordinated manner. Since the large setting of the width Wm of the microstrip line **13** can be detrimental to the improvement of the isolation, the required decoupling frequency range can be acquired mainly by adjusting the length Lm of the microstrip line **13**. Moreover, the field strength of the parasitic electric field formed on the microstrip line **13** can be roughly adjusted by adjusting the length Lm of the microstrip line **13** and the spacing d between the microstrip line **13** and the adjacent radiating unit **11**, further, the field strength of the parasitic electric field formed on the microstrip line **13** is finely adjusted by adjusting the width Wm of the microstrip line **13**, so that the field strength of the parasitic electric field formed on the microstrip line **13** by the coupling of the first radiating unit **111** on the microstrip line **13** is sufficient to counteract the coupled electric field formed on the second radiating unit **112** by the coupling of the first radiating unit **111** on the second radiating unit **112**, whereby the decoupling structure **12** is enabled to achieve the good decoupling effect.

In this embodiment, the width Wm of the microstrip line **13** may be set in the range of a few microns to a few hundred microns. The width Wm of the microstrip line **13** being less than or equal to 100 μm may enable the isolation of the antenna to be increased by 10 dB or more without adversely affecting the radiation efficiency of the antenna. Therefore, the decoupling structure **12** just occupies a space less than hundred microns in width, and the spacing between adjacent radiating units **11** can be greatly reduced. An antenna with an operating wavelength of 6 GHz is used as an example, in case that the decoupling structure **12** is not provided, the spacing between adjacent radiating units **11** is required to be greater than or equal to 0.5λ (~25 mm) so as to ensure the isolation, and in case that the decoupling structure **12** is provided, the spacing between adjacent radiating units **11** can be reduced from ~25 mm to 1 mm-2 mm in a case of ensuring the isolation, thereby facilitating the high integration and the miniaturized design of the antenna.

Moreover, the decoupling structure **12** is composed of the microstrip line **13**. The decoupling structure **12** is simple in structure, may be prepared directly by using the mature panel process, and is easy to implement.

In conclusion, according to the antenna provided in embodiments of the present disclosure, the decoupling structure composed of the microstrip line is disposed on two sides of at least two adjacent radiating units. When any one of the radiating units is in operation, a parasitic electric field may be formed on the decoupling structure, and the parasitic electric field may be coupled on another radiating unit to form a compensation electric field, so as to counteract the coupled electric field formed by the direct coupling of the operating radiating units on the another radiating unit, thereby reducing the mutual coupling between adjacent radiating units, improving the isolation between adjacent radiating units, and further solving a problem that the antenna in which the radiating units are closely placed may have strong mutual coupling between adjacent radiating units, which is conductive to improving the integration of the antenna. Moreover, the parasitic electric field on the decoupling structure also couples to the operating radiating units so as to form a positive electric field enhancement, thereby enhancing the primary electric field on the operating radiating units and improving the radiation efficiency of the antenna. In addition, the decoupling structure is composed of the microstrip line, is simple in structure, may be prepared directly by using the mature panel process, and is easy to implement.

With continued reference to FIGS. **5** and **6**, optionally, the one microstrip line unit of the two microstrip line units **120** includes a first microstrip line **131**, and the other microstrip line unit of the two microstrip line units **120** includes a second microstrip line **132**. The first microstrip line **131** and the second microstrip line **132** each extend in the arrangement direction of the first radiating unit **111** and the second radiating unit **112**. A vertical projection of the first microstrip line **131** on the first substrate **10** and a vertical projection of the second microstrip line **132** on the first substrate **10** are symmetrically disposed about the center point O of the vertical projection of the radiating unit group **20** on the first substrate **10**.

Specifically, as shown in FIGS. **5** and **6**, in the two microstrip line units **120** of the decoupling structure **12**, one microstrip line unit **120** is composed of the first microstrip line **131**, and the other microstrip line unit **120** is composed of the second microstrip line **132**, that is, the decoupling structure **12** is composed of only the two microstrip lines **13**, i.e., the first microstrip line **131** and the second microstrip line **132**. The structure is simple, and the preparation process is easy to be implemented.

Further, as shown in FIG. **5**, the first microstrip line **131** and the second microstrip line **132** each extend in the arrangement direction of the first radiating unit **111** and the second radiating unit **112** (the first direction X in the drawings), and the first microstrip line **131** and the second microstrip line **132** are arranged in a direction intersecting the arrangement direction of the first radiating unit **111** and the second radiating unit **112** (the second direction Y in the drawings). The first microstrip line **131** and the second microstrip line **132** are respectively located on two opposite sides of the radiating unit group **20**, and the vertical projection of the first microstrip line **131** on the first substrate **10** and the vertical projection of the second microstrip line **132** on the first substrate **10** are symmetrically disposed about the center point O of the vertical projections of the radiating unit group **20** on the first substrate **10**.

Exemplarily, as shown in FIG. **5**, the straight line passing through the center point O and extending in first direction X is used as the first symmetry axis, the vertical projection of the first microstrip line **131** on the first substrate **10** and the vertical projection of the second microstrip line **132** on the first substrate **10** are symmetrically disposed about the first symmetry axis, and moreover, the straight line passing through the center point O and extending in the second direction Y is used as the second symmetry axis, a vertical projection of the first microstrip line **131** on the first substrate **10** is symmetrical about the second symmetry axis, and a vertical projection of the second microstrip line **132** on the first substrate **10** is symmetrical about the second symmetry axis.

With such arrangement, when the first radiating unit **111** is fed, the first radiating unit **111** is coupled to the first microstrip line **131** and the second microstrip line **132** to form parasitic electric fields, the parasitic electric fields on the first microstrip line **131** and the second microstrip line **132** are coupled to the second radiating unit **112** to form the compensation electric field, so as to counteract at least a part of the coupled electric field formed by the directly coupling of the first radiating unit **111** to the second radiating unit **112**. Similarly, when the second radiating unit **112** is fed, the second radiating unit **112** is coupled to the first microstrip line **131** and the second microstrip line **132** to form parasitic electric fields, the parasitic electric fields on the first microstrip line **131** and the second microstrip line **132** are coupled to the first radiating unit **111** to counteract at least a part of the coupled electric field formed by direct coupling of the second radiating unit **112** to the first radiating unit **111**. As a result, the first microstrip line **131** and the second microstrip line **132** are provided so that the mutual coupling between the first radiating unit **111** and the second radiating unit **112** is reduced, the isolation between the first radiating unit **111** and the second radiating unit **112** is improved, thereby solving the problem that the antenna in which the radiating units **11** are closely placed may have strong mutual coupling between adjacent radiating units **11**, which is conductive to improving the integration of the antenna.

Moreover, the parasitic electric field formed on the first microstrip line **131** and the second microstrip line **132** is also negatively fed back to the feeding radiating unit **11**, and a feedback enhancement electric field is formed by coupling the operating radiating unit **11**, thereby forming a positive electric field enhancement on the feeding radiating unit **11**, which is conductive to improving the radiation efficiency of the antenna.

It should be noted that a length of the first microstrip line **131** and a length of the second microstrip line **132** may be optimized for the operation frequency of the antenna, impedance matching requirements, and radiation performances and loss requirements, so as to minimize the mutual coupling effect between adjacent radiating units **11**.

The inventors have found that, in the second direction Y, the first microstrip line **131** at least partially overlaps with the first radiating unit **111**, and the first microstrip line **131** at least partially overlaps with the second radiating unit **112**. Similarly, in the second direction Y, the second microstrip line **132** at least partially overlaps with the first radiating unit **111**, and the second microstrip line **132** at least partially overlaps with the second radiating unit **112**, so that the decoupling structure **12** can achieve the better decoupling effect.

Further, in the first direction X, the length of the first microstrip line **131** is less than or equal to the sum of the length of the first radiating unit **111** and the length of the second radiating unit **112**. Similarly, the length of the second microstrip line **132** is less than or equal to the sum of the length of the first radiating unit **111** and the length of the second radiating unit **112**, so that the decoupling structure **12** can achieve the better decoupling effect.

FIG. **10** is a schematic structural diagram of another antenna according to an embodiment of the present disclosure, and FIG. **11** is a schematic cross-sectional structural diagram of FIG. **10** taken along a direction of B-B'. As shown in FIGS. **10** and **11**, optionally, one microstrip line unit of the two microstrip line units **120** includes a third microstrip line **133** and a fourth microstrip line **134** arranged in the first direction X, and the third microstrip line **133** and the fourth microstrip line **134** are insulated from each other. The other microstrip line unit **120** of the two microstrip line units **120** includes a fifth microstrip line **135** and a sixth microstrip line **136** arranged in the first direction, and the fifth microstrip line **135** and the sixth microstrip line **136** are insulated from each other. The third microstrip line **133**, the fourth microstrip line **134**, the fifth microstrip line **135** and the sixth microstrip line **136** extend in the first direction X. The third microstrip line **133** and the fifth microstrip line **135** at least partially overlap with the first radiating unit **111** in the second direction Y, and the fourth microstrip line **134** and the sixth microstrip line **136** at least partially overlap with the second radiating unit **112** in the second direction Y.

Specifically, as shown in FIGS. **10** and **11**, in the two microstrip line units **120** of the decoupling structure **12**, one microstrip line unit **120** is composed of a third microstrip line **133** and a fourth microstrip line **134** which are insulated from each other, and the other microstrip line unit **120** is composed of a fifth microstrip line **135** and a sixth microstrip line **136** which are insulated from each other, that is, the decoupling structure **12** is composed of four microstrip lines **13**, namely, the third microstrip line **133**, the fourth microstrip line **134**, the fifth microstrip line **135** and the sixth microstrip line **136**.

Further, as shown in FIG. **10**, the third microstrip line **133**, the fourth microstrip line **134**, the fifth microstrip line **135** and the sixth microstrip line **136** each extend in the arrangement direction of the first radiating unit **111** and the second radiating unit **112** (the first direction X in the drawings), and the third microstrip line **133** and the fifth microstrip line **135** are arranged in a direction intersecting the arrangement direction of the first radiating unit **111** and the second radiating unit **112** (the second direction Y in the drawings), and the fourth microstrip line **134** and the sixth microstrip line **136** are arranged in a direction intersecting the arrangement direction of the first radiating unit **111** and the second radiating unit **112** (the second direction Y in the drawings). The third microstrip line **133** and the fifth microstrip line **135** may be located on two opposite sides of the first radiating unit **111**, the fourth microstrip line **134** and the sixth microstrip line **136** may be located on two opposite sides of the second radiating unit **112**, respectively, and a vertical projection of the third microstrip line **133** on the first substrate **10**, a vertical projection of the fourth microstrip line **134** on the first substrate **10**, a vertical projection of the fifth microstrip line **135** on the first substrate **10**, and a vertical projection of the sixth microstrip line **136** on the first substrate **10** are symmetrically disposed about the center point O of the vertical projection of the radiating unit group **20** on the first substrate **10**.

Exemplarily, as shown in FIG. **10**, the straight line passing through the center point O and extending in first direction X is used as the first symmetry axis, a vertical projection of the third microstrip line **133** on the first substrate **10** and a vertical projection of the fifth microstrip line **135** on the first substrate **10** are symmetrically disposed about the first symmetry axis, and a vertical projection of the fourth microstrip line **134** on the first substrate **10** and a vertical projection of the sixth microstrip line **136** on the first substrate **10** are symmetrically disposed about the first symmetry axis, and moreover, the straight line passing through the center point O and extending in the second direction Y is used as the second symmetry axis, a vertical projection of the third microstrip line **133** on the first substrate **10** and a vertical projection of the fourth microstrip line **134** on the first substrate **10** are symmetrical about the second symmetry axis, and a vertical projection of the fifth microstrip line **135** on the first substrate **10** and a vertical projection of the sixth microstrip line **136** on the first substrate **10** are symmetrical about the second symmetry axis.

FIG. **12** is a schematic diagram of a mutual coupled electric field of another antenna according to an embodiment of the present disclosure. As shown in FIG. **12**, in this embodiment, when the first radiating unit **111** is fed, a primary electric field is formed on the first radiating unit **111** (for example, the primary electric field in FIG. **12** is a positive electric field), and the first radiating unit **111** is coupled on the third microstrip line **133**, the fourth microstrip line **134**, the fifth microstrip line **135** and the sixth microstrip line **136** to form parasitic electric fields (for example, the parasitic electric fields in FIG. **12** are the negative electric fields).

The electric field strength on the microstrip line **13** is concentrated at a position close to the middle of the microstrip line **13**. Therefore, in the second direction Y, the fourth microstrip line **134** and the sixth microstrip line **136** are set to at least partially overlap with the second radiating unit **112**, that is, the fourth microstrip line **134** and the sixth microstrip line **136** are located on two opposite sides of the second radiating unit **112**, respectively, so that positions of the strongest strength of the parasitic electric fields on the fourth microstrip line **134** and the sixth microstrip line **136** are located on two opposite sides of the second radiating unit **112**, respectively, and further parasitic electric fields on the fourth microstrip line **134** and the sixth microstrip line **136** may be coupled to the second radiating unit **112** to form a compensation electric field that is stronger and more symmetrical with respect to the center position of the second radiating unit **112** (for example, the compensation electric field in FIG. **12** is the positive electric field), thereby being able to better counteract the coupled electric field formed by the directly coupling of the first radiating unit **111** to the second radiating unit **112** (for example, the coupled electric field in FIG. **12** is the negative electric field). Similarly, when the second radiating unit **112** is fed, the second radiating unit **112** may be coupled on the third microstrip line **133**, the fourth microstrip line **134**, the fifth microstrip line **135** and the sixth microstrip line **136** to form parasitic electric fields, the third microstrip line **133** and the fifth microstrip line **135** are set to at least partially overlap with the first radiating unit **111** in the second direction Y, that is, the third microstrip line **133** and the fifth microstrip line **135** are located on two opposite sides of the first radiating unit **111**, respectively, so that positions of the strongest strength of the parasitic electric fields on the third microstrip line **133** and the fifth microstrip line **135** are located on two opposite sides of the first radiating unit **111**, and further parasitic electric fields on the third microstrip line **133** and the fifth microstrip line **135** may be coupled to the first radiating unit **111** to form a compensation electric field that is stronger and more symmetrical with respect to the center position of the first radiating unit **111**, thereby being able to better counteract the coupled electric field formed by the directly coupling of the second radiating unit **112** to the first radiating unit **111**

As a result, the third microstrip line **133**, the fourth microstrip line **134**, the fifth microstrip line **135** and the sixth microstrip line **136** are provided so that the mutual coupling between the first radiating unit **111** and the second radiating unit **112** is reduced, the isolation between the first radiating unit **111** and the second radiating unit **112** is improved, and thereby solving the problem that the antenna in which the radiating units **11** are closely placed may have strong mutual coupling between adjacent radiating units **11**, which is conductive to improving the integration of the antenna.

Moreover, the third microstrip line **133** and the fifth microstrip line **135** at least partially overlap with the first radiating unit **111** in the second direction Y, that is, the third microstrip line **133** and the fifth microstrip line **135** are located on two opposite sides of the first radiating unit **111**, respectively. When the first radiating unit **111** is fed, positions at which a strength of the parasitic electric fields on the third microstrip line **133** and the fifth microstrip line **135** is strongest are located on two opposite sides of the first radiating unit **111**, and further parasitic electric fields on the third microstrip line **133** and the fifth microstrip line **135** may be coupled to the first radiating unit **111** to form a feedback enhancement electric field on the first radiating unit **111** that is stronger and more symmetrical with respect to the center position of the first radiating unit **111**, thereby forming the better forward electric field enhancement to the first radiating unit **111**, which is conductive to improving the radiation efficiency of the antenna.

Similarly, the fourth microstrip line **134** and the sixth microstrip line **136** are at least partially overlapped with the second radiating unit **112** in the second direction Y, that is, the fourth microstrip line **134** and the sixth microstrip line **136** are located on two opposite sides of the second radiating unit **112**, respectively. When the second radiating unit **112** is fed, positions at which a strength of the parasitic electric fields on the fourth microstrip line **134** and the sixth microstrip line **136** is strongest are located on two opposite sides of the second radiating unit **112**, and further parasitic electric fields on the fourth microstrip line **134** and the sixth microstrip line **136** may be coupled to the second radiating unit **112** to form a feedback enhancement electric field on the second radiating unit **112** that is stronger and more symmetrical with respect to the center position of the second radiating unit **112**, thereby forming the better forward electric field enhancement to the second radiating unit **112**, which is conductive to improving the radiation efficiency of the antenna.

FIG. **13** is a schematic diagram of simulation results of an antenna according to an embodiment of the present disclosure, an example in which the first radiating unit **111** is operated and the second radiating unit **112** is not operated, that is, only the first radiating unit **111** is fed is used as an example in FIG. **13** for description. A curve S**11**-**1** represents that a return loss of the first radiating unit **111** in case that the decoupling structure **12** is not provided, a curve S**22**-**1** represents that a return loss of the second radiating unit **112** in case that the decoupling structure **12** is not provided, a curve S**11**-**2** represents that a return loss of the first radiating unit **111** in case that the decoupling structure **12** is provided, and the curve S**22**-**2** represents that a return loss of the second radiating unit **112** in case that the decoupling structure **12** is provided.

As shown in FIGS. **10** to **13**, in case that the decoupling structure **12** provided in the embodiments of the present disclosure is provided, the return loss of the first radiating unit **111** in an operating bandwidth range becomes smaller, which indicates that the radiation performance of the first radiating unit **111** is effectively improved. The return loss of the second radiating unit **112** in the operating bandwidth range becomes larger, which indicates that the influence of the electric field of the first radiating unit **111** on the second radiating unit **112** becomes smaller, and the isolation between the first radiating unit **111** and the second radiating unit **112** is effectively improved.

FIG. **14** is a schematic diagram of simulation results of another antenna according to an embodiment of the present disclosure, an example in which the first radiating unit **111** is operated, and the second radiating unit **112** is not operated, that is, only the first radiating unit **111** is fed is used as an example in FIG. **14** for description. A curve S**21**-**1** represents that an insertion loss of the first radiating unit **111** in case that the decoupling structure **12** is not provided, and a curve S**21**-**2** represents that an insertion loss of the first radiating unit **111** in case that the decoupling structure **12** is provided. As shown in FIGS. **10** to **12** and **14**, in case that the decoupling structure **12** provided in the embodiments of the present disclosure is provided, the insertion loss of the first radiating unit **111** in the operating bandwidth range becomes smaller, which indicates that the radiation efficiency of the first radiating unit **111** is effectively improved.

With continued reference to FIGS. **10** to **12**, it should be noted that a spacing between two microstrip lines **13** in a same microstrip line unit **120** may be set according to a size of the radiating unit **11**, where the larger the size of the radiating unit **11** is, the larger the spacing between the two microstrip lines **13** in the same microstrip line unit **120** may be set, otherwise, the smaller the size of the radiating unit **11** is, the smaller the spacing between the two microstrip lines **13** in the same microstrip line unit **120** may be set, which is not specifically limited in the embodiments of the present disclosure.

With continued reference to FIGS. **6** and **11**, optionally, the microstrip line **13** and the radiating unit **11** are disposed on a same layer.

As described above, the smaller the spacing d between the microstrip line **13** and the radiating unit **11** is, the better the decoupling effect of the decoupling structure **12** is. Therefore, in this embodiment, the microstrip line **13** and the radiating unit **11** are disposed on the same layer so that a smaller spacing between the microstrip line **13** and the radiating unit **11** may be obtained, thereby obtaining the better decoupling effect.

Moreover, the microstrip line **13** and the radiating unit **11** are disposed on the same film layer, so that the provision of one metal layer may be reduced, thereby achieving the purpose of reducing the production cost and reducing the thickness of the substrate. Moreover, the microstrip line **13** may be made of the same material as the radiating unit **11**, so that the microstrip line **13** and the radiating unit **11** may be prepared in a same process, thereby shortening the process time.

With continued reference to FIGS. **5**, **6**, **10** and **11**, optionally, the antenna provided in the embodiments of the present disclosure further includes a liquid crystal phase shifter **14** located on a side of the first substrate **10** facing away from the multiple radiating units **11**, the liquid crystal phase shifter **14** includes a second substrate **15** and a third substrate **16** disposed opposite to each other, and the third substrate **16** is located on a side of the second substrate **15** facing away from the multiple radiating units **11**. The liquid crystal phase shifter **14** further includes a delay line **17**, a liquid crystal layer **18** and a ground metal layer **19**. The liquid crystal layer **18** is located between the second substrate **15** and the third substrate **16**, the delay line **17** is located between the third substrate **16** and the liquid crystal layer **18**, and the ground metal layer **19** is located between the second substrate **15** and the liquid crystal layer **18**. The ground metal layer **19** includes a first hollow portion **191**, and one radiating unit of the radiating units **11** covers the first hollow portion **191** in a thickness direction of the first substrate **10**.

As shown in FIGS. **5**, **6**, **10** and **11**, the delay line **17** is configured to transmit a radio frequency signal, and the radio frequency signal may be provided by a feed source such as a radio frequency integrated circuit or a radio frequency chip.

Exemplarily, as shown in FIGS. **5**, **6**, **10** and **11**, a feed structure **40** may be connected at one end of the delay line **17**, the feed structure **40** may be bound to a flexible printed circuit (FPC) **41**, and the radio frequency chip may be bound and connected to the flexible printed circuit **41** so that the delay line **17** receives a radio frequency signal provided by the radio frequency chip through the flexible printed circuit **41**.

With continued reference to FIGS. **5**, **6**, **10** and **11**, the feed structure **40** may include a feed segment **401**, a first ground segment **402** and a second ground segment **403**. The feed segment **401** is located between the first ground segment **402** and the second ground segment **403**, and the feed segment **401** is connected to the delay line **17** for transmitting a radio frequency signal to the delay line **17**. The feed segment **401**, the first ground segment **402** and the second ground segment **403** constitute a coplanar waveguide (CPW) structure, and the coplanar waveguide structure has features of small volume, light weight and planar structure so that the coplanar waveguide structure has advantages of being convenient for obtaining a linear polarization operation, a circular polarization operation, a dual polarization operation, and a multi-band operation, moreover, the coplanar waveguide structure, as a microwave planar transmission structure with superior performance and convenient processing, has the performance advantages over microstrip lines in a millimeter wave frequency band.

It should be noted that a feeding manner of the delay line **17** is not limited to the above-described embodiments, and in other embodiments, the delay line **17** may be fed in other manners, for example, the radio frequency chip is directly disposed on the third substrate **16** so as to be directly connected to the delay line **17**, which is not specifically limited in the embodiments of the present disclosure.

With continued reference to FIGS. **5**, **6**, **10** and **11**, a radio frequency signal on the delay line **17** is transmitted in the liquid crystal layer **18** between the delay line **17** and the ground metal layer **19**. Voltage signals are applied to the delay line **17** and the ground metal layer **19**, respectively, so that an electric field may be formed between the delay line **17** and the ground metal layer **19**. The electric field may drive liquid crystal molecules in the liquid crystal layer **18** to deflect, thereby changing a dielectric constant of the liquid crystal layer **18**. The change of the dielectric constant of the liquid crystal layer **18** may shift the phase of the radio frequency signal transmitted on the delay line **17**, thereby changing the phase of the radio frequency signal and achieving the phase shift function of the radio frequency signal. It should be understood that the voltage signal on the delay line **17** and the ground metal layer **19** is controlled, so that a deflection angle of liquid crystal molecules in the liquid crystal layer **18** may be controlled, further the phase adjusted during the phase shift of the radio frequency signal may be controlled, and finally a beam pointing of a radio frequency signal transmitted by the antenna may be controlled.

With continued reference to FIG. **5**, FIG. **6**, FIG. **10** and FIG. **11**, a first hollow portion **191** is disposed on the ground metal layer **19**. In the thickness direction of the first substrate **10**, an overlapping region exists between the radiating unit **11**, the first hollow portion **191** and the delay line **17**. The liquid crystal layer **18** between the delay line **17** and the ground metal layer **19** shifts the phase of the radio frequency signal, that is, after the phase of the radio frequency signal is changed, the shifted radio frequency signal is coupled to the radiating unit **11** at the first hollow portion **191** of the ground metal layer **19**, so that the radiating unit **11** radiates the signal outwardly.

The delay line **17** may be disposed in correspondence with the radiating unit **11**. For example, the delay line **17** is disposed in one-to-one correspondence with the radiating unit **11**, and radiating units **11** corresponding to different delay lines **17** are disposed insulated from each other. At this time, different voltage signals may be applied to the different delay lines **17** to enable liquid crystal molecules at corresponding positions of different delay lines **17** to have different deflection angles, so that the dielectric constants of the liquid crystal layer **18** at each position are different, further, phases of radio frequency signals at the positions of different delay lines **17** are adjusted, and finally, different beam pointings of different radio frequency signals are achieved.

It should be noted that materials of the radiating unit **11**, the delay line **17** and the ground metal layer **19** may be selected from, but not limited to, low-impedance materials such as copper, silver, silver alloy, and copper alloy, so as to effectively reduce the energy loss caused by the high resistance, thereby improving the radiation efficiency of the antenna.

Further, a thickness of the radiating unit **11**, a thickness of the delay line **17** and a thickness of the ground metal layer **19** may be set in the range of 1 μm to 3 μm, so that the thickness of the radiating unit **11**, the delay line **17** and the ground metal layer **19** is relatively thin, thereby facilitating the lightweight design of the antenna. Moreover, the radio frequency signal flows through the surface of the metal layer at a certain depth, the certain depth is the skin depth. Therefore, the radiating unit **11**, the delay line **17** and the ground metal layer **19** may have the above-described thickness range, so that the thickness of the radiating unit **11**, the delay line **17** and the ground metal layer **19** is greater than or equal to the skin depth, thereby avoiding the energy loss caused by the radio frequency signal penetrating through the metal structures such as the delay line **17** and the ground metal layer **19**.

With continued reference to FIGS. **5**, **6**, **10** and **11**, a support structure **42** may also be disposed between the second substrate **15** and the third substrate **16**, the support structure **42** is configured to support the second substrate **15** and the third substrate **16**, thereby providing the accommodation space for the liquid crystal layer **18**. The support structure **42** may be a rubber frame and the like, which is not limited in the embodiments of the present disclosure.

FIG. **15** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure, FIG. **16** is a schematic cross-sectional structural diagram of FIG. **15** taken along a direction of C-C', FIG. **17** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure, and FIG. **18** is a schematic cross-sectional structural diagram of FIG. **17** taken along a direction of D-D'. As shown in FIGS. **15** to **18**, optionally, the microstrip line **13** and the delay line **17** are disposed on a same layer. The ground metal layer **19** includes a second hollow portion **192**, and the second hollow portion **192** covers one microstrip line of the at least one microstrip line **13** in the thickness direction of the first substrate **10**.

As shown in FIGS. **15** to **18**, the microstrip line **13** and the delay line **17** are disposed on the same film layer, so that the provision of one metal layer may be reduced thereby achieving the purpose of reducing the production cost and reducing the thickness of the substrate. Moreover, the microstrip line **13** may be made of the same material as the delay line **17**, so that the microstrip line **13** and the delay line **17** may be manufactured in the same process, thereby shortening the process time.

Moreover, a second hollow portion **192** corresponding to the microstrip line **13** is disposed on the ground metal layer **19**, and an overlapping region exists between the second hollow portion **192** and the microstrip line **13** in the thickness direction of the first substrate **10**, thereby avoiding the ground metal layer **19** from shielding the microstrip line **13** and affecting the electric field coupling between the radiating unit **11** and the microstrip line **13**, and ensuring the decoupling effect between the microstrip line **13** and the adjacent radiating unit **11**.

With continued reference to FIG. **5**, FIG. **6**, FIG. **10**, FIG. **11**, and FIG. **15** to FIG. **18**, optionally, the first substrate **10** and the second substrate **15** are bonded by the first bonding adhesive **30**, and a gap exists between the first bonding adhesive **30** and the radiating unit **11** in the thickness direction of the first substrate **10**.

As shown in FIG. **5**, FIG. **6**, FIG. **10**, FIG. **11**, and FIG. **15** to FIG. **18**, in this embodiment, the second substrate **15** of the liquid crystal phase shifter **14** is a separate substrate different from the first substrate **10**. In the process of preparing the antenna, the radiating unit **11** may be formed on the first substrate **10**, the ground metal layer **19** may be formed on the second substrate **15**, and the first substrate **10** and the second substrate **15** are bonded by the first bonding adhesive **30**, so that the preparation of the radiating unit **11** and the ground metal layer **19** may be achieved without providing the double-sided conductive metal layer on one substrate, thereby reducing the difficulty of the production process and improving the production efficiency.

Further, since a dielectric constant of the first bonding adhesive **30** is greater than a dielectric constant of the air, the first bonding adhesive **30** is set to not overlap with the radiation unit **11** in the thickness direction of the first substrate **10**, so that the dielectric loss of the radio frequency signal between the first substrate **10** and the second substrate **15** may be reduced, thereby facilitating the improvement of the radiation efficiency of the antenna.

A specific setting shape of the first bonding adhesive **30** may be a character rectangular shape as shown in FIGS. **5**, **6**, **10**, **11**, and **15** to **18**, but is not limited thereto. In other embodiments, the setting range of the first bonding adhesive **30** may be adjusted according to actual requirements.

It should be noted that, the smaller a thickness of the first bonding adhesive **30** is, the smaller the dissipation factor of the radio frequency signal between the first substrate **10** and the second substrate **15** is, thereby facilitating the improvement of the radiation efficiency of the antenna. However, if the thickness of the first bonding adhesive **30** is too small, the firmness of the adhesion of the first bonding adhesive **30** is affected, and thus the thickness of the first adhesive **30** may be set according to the material of the first bonding adhesive **30**.

For example, when the first bonding adhesive **30** is a frame adhesive, the thickness of the first bonding adhesive **30** may be set to be about hundred micrometers, that is, the thickness of the first bonding adhesive **30** may be set to be in the range of 100 μm to 1000 μm. The first bonding adhesive **30** may be made to have a relatively thin thickness while ensuring the firmness of the adhesion between the first substrate **10** and the second substrate **15**, so that the dissipation factor of the first bonding adhesive **30** to the radio frequency signal is relatively small, and the radiation efficiency of the antenna is favorably improved.

FIG. **19** is a schematic cross-sectional structural diagram of an antenna according to an embodiment of the present disclosure, and FIG. **20** is schematic cross-sectional structural diagram of another antenna according to an embodiment of the present disclosure. As shown in FIGS. **19** and **20**, optionally, the first substrate **10** and the second substrate **15** are a same substrate.

The antenna structure shown in FIG. **19** differs from the antenna structure shown in FIG. **6** in that the first substrate **10** and the second substrate **15** share the same substrate. Similarly, the antenna structure shown in FIG. **20** differs from the antenna structure shown in FIG. **11** in that the first substrate **10** and the second substrate **15** share the same substrate. Therefore, the explanation of the structure and terminology identical to or corresponding to the above-described embodiments is not described herein.

As shown in FIGS. **19** and **20**, in this embodiment, the first substrate **10** and the second substrate **15** are provided as the same substrate, so that the overall thickness of the substrate may be reduced, thereby facilitating the light-weight design of the antenna. Moreover, the dissipation factor of the radio frequency signal on the substrate may be reduced and the radiation efficiency of the antenna can be improved.

FIG. **21** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure, FIG. **22** is a schematic cross-sectional structural diagram of FIG. **21** taken along a direction of E-E', FIG. **23** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure, and FIG. **24** is a schematic cross-sectional structural diagram of FIG. **23** taken along a direction of F-F'. As shown in FIGS. **21** to **24**, optionally, the antenna provided in the embodiments of the present disclosure further includes a ground metal layer **19** and a coaxial cable interface **31**. The ground metal layer **19** is located on a side of the first substrate **10** facing away from the radiating unit **11**, and the ground metal layer **19** at least partially overlaps with the radiating unit **11** in a thickness direction of the first substrate **10**. The coaxial cable interface **31** is located on a side of the ground metal layer **19** facing away from the radiating unit **11**, and the first substrate **10** includes a first through hole **101**, and the coaxial cable interface **31** is connected to the radiating unit **11** through the first through hole **101**.

Specifically, as shown in FIGS. **21**-**24**, the coaxial cable interface **31** may include, but is not limited to, an inner conductive core **311** in the middle and an outer insulating sheath **312** outside the inner conductive core **311**.

The inner conductive core **311** of the coaxial cable interface **31** is electrically connected to the radiating unit **11** through the first through hole **101** on the first substrate **10**, and the coaxial cable interface **31** may enable the coaxial feeding of the radiating unit **11** through an externally connected radio frequency integrated circuit, so that a radio frequency electromagnetic field is excited between the radiating unit **11** and the ground metal layer **19**, and the radio frequency electromagnetic field radiates outwards through the radiating unit **11**.

With continued reference to FIGS. **21** to **24**, it should be noted that the inner conductive core **311** of the coaxial cable interface **31** is separated from the ground metal layer **19** by the outer insulating sheath **312** of the coaxial cable interface **31** so as to ensure the insulation between the inner conductive core **311** of the coaxial cable interface **31** and the ground metal layer **19**.

Further, when the first substrate **10** is a glass substrate, the first through hole **101** may be implemented by a single-substrate glass perforation technology. Moreover, the radiating unit **11** and the ground metal layer **19** may be prepared by a double-sided film forming process using a low temperature chemical vapor deposition (CVD) technology, but is not limited thereto.

FIG. **25** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure, and FIG. **26** is a schematic cross-sectional structural diagram of FIG. **25** taken along a direction of G-G'. As shown in FIGS. **25** and **26**, optionally, the antenna provided in the embodiments of the present disclosure further includes a waveguide structure **32** located on a side of the first substrate **10** facing away from the radiating unit **11**. The waveguide structure **32** includes a fourth substrate **33** and a fifth substrate **34** disposed opposite to each other, and the fifth substrate **34** is located on a side of the fourth substrate **33** facing away from the radiating unit **11**. The waveguide structure **32** includes a hollow waveguide tube **321** and a ground metal layer **19**. The hollow waveguide tube **321** is located between the fourth substrate **33** and the fifth substrate **34**, and the ground metal layer **19** is located between the fourth substrate **33** and the hollow waveguide tube **321**. The ground metal layer **19** includes a third hollow portion **193**, one radiating unit of the radiating units **11** covers the third hollow portion **193** in a thickness direction of the first substrate, and the hollow waveguide tube **321** at least partially overlaps with the third hollow portion **193** in the thickness direction of the first substrate. The hollow waveguide tube **321** is configured to feed the radio frequency signal provided by a feed source to the radiating units **11**.

Specifically, as shown in FIGS. **25** and **26**, a feed wire **35** may be disposed on the fifth substrate **34**, and the feeding wire **35** is configured to transmit a radio frequency signal supplied from the feed source, where the feed source may be the radio frequency integrated circuit or a radio frequency chip, which is not specifically limited in the embodiments of the present disclosure.

Exemplarily, as shown in FIGS. **25** and **26**, a feed structure **40** may be connected to one end of the feeding wire **35**, the feed structure **40** may be bound to a flexible printed circuit (FPC) **41**, and the radio frequency chip may be bound and connected to the flexible printed circuit **41** so that the feed wire **35** is configured to receive a radio frequency signal provided by the radio frequency chip through the flexible printed circuit **41**.

Optionally, as shown in FIGS. **25** and **26**, the feed structure **40** may include a feed segment **401**, a first ground segment **402** and a second ground segment **403**. The feed segment **401** is located between the first ground segment **402** and the second ground segment **403**, the feed segment **401** is connected to the delay line **17** for transmitting a radio frequency signal to the delay line **17**. The feed segment **401**, the first ground segment **402** and the second ground segment **403** constitute a coplanar waveguide (CPW) structure. The Coplanar waveguide structure has the characteristics of a small volume, a light weight and a planar structure, so that the coplanar waveguide structure has the advantages of being convenient for obtaining a linear polarization operation, a circular polarization operation, a dual polarization operation, a multi-band operation, moreover, the coplanar waveguide structure, as a microwave planar transmission structure with superior performance and convenient processing, has the performance advantage over microstrip lines in a millimeter-wave band.

It should be noted that the feeding manner of the feed wire **35** is not limited to the above-described embodiments, and in other embodiments, the feed wire **35** may be fed in other manners.

Exemplarily, FIG. **27** is a schematic cross-sectional structural diagram of still another antenna according to an embodiment of the present disclosure.

The antenna structure shown in FIG. **27** differs from the antenna structure shown in FIG. **26** in that an antenna feed radio-frequency chip **36** is directly disposed on the fifth substrate **34**, so that the antenna feed radio-frequency chip **36** may be directly connected to the feed wire **35** so as to achieve the feeding of the radio-frequency signal, and the explanation of the structure and terminology identical to or corresponding to the above-described embodiments is not described herein.

With continued reference to FIGS. **25** and **26**, along the thickness direction of the first substrate **10**, the feed wire **35** at least partially overlaps with the hollow waveguide tube **321** to feed the radio frequency signal transmitted by the feed wire **35** into the hollow waveguide tube **321**.

The hollow waveguide tube **321** is a metal tube structure having a hollow cavity, and the electromagnetic energy may be guided and propagated in the inner space of the hollow waveguide tube **321**, and the metal tube wall may prevent the leakage of electromagnetic energy to outside, and therefore the signal transmission may be achieved with extremely low loss.

With continued reference to FIGS. **25** and **26**, the ground metal layer **19** is provided with a third hollow portion **193**, an overlapping region exists between the radiating unit **11**, the third hollow portion **193** and the hollow waveguide tube **321** in the thickness direction of the first substrate **10**, and the radio frequency signal transmitted by the hollow waveguide tube **321** is coupled to the radiating unit **11** through the third hollow portion **193** of the ground metal layer **19** so that the radiating unit **11** radiates the signal outwardly, thereby achieving the waveguide feed to the radiating unit **11**.

The material of the tube wall of the hollow waveguide tube **321** may be selected from, but not limited to, low-impedance material such as copper, so as to effectively reduce the energy loss caused by too high resistance, thereby improving the radiation efficiency of the antenna.

Further, the thickness of the tube wall of the hollow waveguide tube **321** may be set in the range of 1 μm to 3 μm, so that the thickness of the tube wall of the hollow waveguide tube **321** is relatively thin, thereby facilitating the reduction of the occupied space of the hollow waveguide tube **321**. Moreover, the thickness of the hollow waveguide tube **321** may be made to be greater than or equal to the skin depth, thereby avoiding the energy loss caused by the penetration of the radio frequency signal through the tube wall of the hollow waveguide tube **321**.

With continued reference to FIG. **25**, the hollow waveguide tube **321** may be a rectangular waveguide tube so as to implement the signal transmission in a transverse electric (TE) mode or transverse magnetic (TM) mode, but is not limited to.

It should be noted that the height of the hollow waveguide tube **321** may be set according to the operating wavelength of the antenna. For example, the height of the hollow waveguide tube **321** may be set to be in the same order of magnitude as the operating wavelength of the antenna to achieve the better signal transmission performance. For example, if the hollow waveguide tube **321** is applied to a millimeter-wave antenna, then the height of the hollow waveguide tube **321** may be on the order of millimeters. If the hollow waveguide tube **321** is applied to a centimeter wave antenna, then the height of the hollow waveguide tube **321** may be on the order of centimeters.

Moreover, the diameter of the hollow waveguide tube **321** may be set according to the operating wavelength (operating frequency) of the antenna, which is not specifically limited in the embodiments of the present disclosure.

With continued reference to FIGS. **25** to **27**, a support structure **42** may also be disposed between the fourth substrate **33** and the fifth substrate **34**, the support structure **42** is configured to support the fourth substrate **33** and the fifth substrate **34**, thereby providing the accommodation space for the hollow waveguide tube **321**. The support structure **42** may be made of a material such as a resin to provide the good support performance, which is not limited in the embodiments of the present disclosure.

With continued reference to FIGS. **25** to **27**, optionally, the first substrate **10** and the fourth substrate **33** are bonded by the second bonding adhesive **43**, and a gap exists between the second bonding adhesive **43** and the radiating unit **11** in the thickness direction of the first substrate **10**.

As shown in FIGS. **25** to **27**, in this embodiment, the fourth substrate **33** of the waveguide structure **32** is a separate substrate different from the first substrate **10**. In a process of preparing the antenna, the radiating unit **11** may be formed on the first substrate **10**, the ground metal layer **19** may be formed on the fourth substrate **33**, and the first substrate **10** and the fourth substrate **33** may be adhered to each other by the second bonding adhesive **43**, so that the preparation of the radiating unit **11** and the ground metal layer **19** may be achieved without disposing the double-sided conductive metal layer on one substrate, thereby reducing the difficulty of the production process and improving the production efficiency.

Further, since the dielectric constant of the second bonding adhesive **43** is greater than the dielectric constant of the air, no overlapping exists between the second bonding adhesive **43** and the radiating unit **11** in the thickness direction of the first substrate **10**, so that the dielectric loss of the radio frequency signal between the first substrate **10** and the fourth substrate **33** may be reduced, thereby facilitating the improvement of the radiation efficiency of the antenna.

The specific setting shape of the second bonding adhesive **43** may be a character rectangular shape as shown in FIGS. **25** to **27**, but is not limited thereto. In other embodiments, the setting range of the second bonding adhesive **43** may be adjusted according to actual requirements.

It should be noted that, the smaller the thickness of the second bonding adhesive **43** is, the smaller the dissipation factor of the radio frequency signal between the first substrate **10** and the fourth substrate **33** is, thereby facilitating the improvement of the radiation efficiency of the antenna. However, the thickness of the second bonding adhesive **43** is too small, which affects the firmness of the adhesion of the second bonding adhesive **43**. Therefore, the thickness of the second bonding adhesive **43** may be set according to the material of the second bonding adhesive **43**.

For example, when the second bonding adhesive **43** is a frame adhesive, the thickness of the second bonding adhesive **43** may be set to be about hundred microns, that is, the thickness of the second bonding adhesive **43** may be set to be in the range of 100 μm to 1000 μm, so that the second bonding adhesive **43** may have a relatively thin thickness while ensuring the firmness of the adhesion between the first substrate **10** and the fourth substrate **33**, so that the dissipation factor of the second bonding adhesive **43** to the radio frequency signal is relatively small, thereby improving the radiation efficiency of the antenna.

FIG. **28** is a schematic cross-sectional structural diagram of still another antenna according to an embodiment of the present disclosure. As shown in FIG. **28**, optionally, the first substrate **10** and the fourth substrate **33** are a same substrate.

As shown in FIG. **28**, in this embodiment, the first substrate **10** and the fourth substrate **33** are provided as the same substrate, so that the overall thickness of the substrate may be reduced thereby facilitating the lightweight design of the antenna. Meanwhile, the dissipation factor of the radio frequency signal on the substrate may be reduced and the radiation efficiency of the antenna can be improved.

The antenna structure shown in FIG. **28** differs from the antenna structure shown in FIG. **27** in that the first substrate **10** and the fourth substrate **33** share the same substrate, and the explanation of the structure and terminology identical to or corresponding to the above-described embodiments is not described herein.

FIG. **29** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure, and FIG. **30** is a schematic cross-sectional structural diagram of FIG. **30** taken along a direction of H-H'. As shown in FIGS. **4** to **30**, optionally, the microstrip line **13** is floated, or the microstrip line **13** is grounded.

Exemplarily, as shown in FIGS. **4** to **28**, the microstrip line **13** may be disposed in a floating manner, that is, the microstrip line **13** is not electrically connected to any signal line, and the microstrip line **13** is not connected to any signal. With such arrangement, the connection structure of the microstrip line **13** is simple and is easy to implement. Moreover, the microstrip line **13** is connected to other structures without punching a hole in the first substrate **10**, and the liquid crystal leakage caused by punching the liquid crystal box may be avoided in the scheme of adopting the liquid crystal phase shifter **14**.

In other embodiments, as shown in FIGS. **29** and **30**, the microstrip line **13** may also be grounded. The microstrip line **13** is grounded so that the microstrip line **13** is not susceptible to the electrostatic accumulation of the external environment, so that the phase shift or frequency shift of the radio frequency signal may be avoided, and the parasitic electric field formed on the microstrip line **13** is more stable, whereby the compensation for the direct coupling field between the adjacent radiating units **11** is more stable, and thus the decoupling effect is more stable.

It should be noted that, in the antenna structure provided in any one of the above-described embodiments, the microstrip line **13** may be grounded to make the antenna operate more stable, which may be set by those skilled in the art according to actual requirements, and will not be described in detail herein.

With continued reference to FIGS. **29** and **30**, optionally, the antenna provided in the embodiments of the present disclosure further includes a ground metal layer **19**, the ground metal layer **19** is located on a side of the first substrate **10** facing away from the radiating unit **11**, and the ground metal layer **19** at least partially overlaps with the radiating unit **11** in the thickness direction of the first substrate **10**. The first substrate **10** includes a second through hole **102**, the second through hole **102** at least partially overlaps with the microstrip line **13** in the thickness direction of the first substrate **10**, and the microstrip line **13** is connected to the ground metal layer **19** through the second through hole **102**.

Specifically, as shown in FIGS. **29** and **30**, the microstrip line **13** can be electrically connected to the ground metal layer **19** through the second through hole **102** in the first substrate **10** to achieve the ground arrangement of the microstrip line **13**, whereby there is no need to an additional interface of the microstrip line **13** for grounding, and the structure is simpler. Moreover, when the first substrate **10** is the glass substrate, the second through hole **102** may be achieved by the single-substrate glass perforation technology, and the process is easy to achieve.

It should be noted that a diameter of the second through hole **102** may also be simulated and optimized for the operating frequency of the antenna, impedance matching requirements, and radiation performance and loss requirements. For example, the diameter of the second through hole **102** may be set to be on the same order of magnitude as the operating wavelength of the antenna to achieve the better decoupling effect. For example, if the decoupling structure **12** is applied to the millimeter-wave antenna, then the second through hole **102** may be on the order of millimeters. If the decoupling structure **12** is applied to the centimeter-wave antenna, then the second through hole **102** is on the order of centimeters.

FIG. **31** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure, and FIG. **32** is a schematic cross-sectional structural diagram of FIG. **31** taken along a direction of I-I'. As shown in FIGS. **31** and **32**, optionally, a first drainage microstrip line **137** is disposed on a side of the first microstrip line **131** facing away from the radiating unit group **20**, the first drainage microstrip line **137** extends in the second direction Y, and one end of the first drainage microstrip line **137** is connected to the first microstrip line **131** at a center position of the first microstrip line **131**. A second drainage microstrip line **138** is disposed on a side of the second microstrip line **132** facing away from the radiating unit group **20**, the second drainage microstrip line **138** extends in the second direction Y, and one end of the second drainage microstrip line **138** is connected to the second microstrip line **132** at a center position of the second microstrip line **132**. A vertical projection of the first drainage microstrip line **137** on the first substrate **10** and a vertical projection of the second drainage microstrip line **138** on the first substrate **10** are symmetrically disposed about the center point O of the vertical projection of the radiating unit group **20** on the first substrate **10**.

Specifically, as shown in FIGS. **31** and **32**, in the two microstrip line units **120** of the decoupling structure **12**, one microstrip line unit **120** is composed of a first microstrip line **131** and a first drainage microstrip line **137**, and the other microstrip line unit **120** is composed of a second microstrip line **132** and a second drainage microstrip line **138**, that is, the decoupling structure **12** is composed of four microstrip lines **13**, namely, the first microstrip line **131**, the first drainage microstrip line **137**, the second microstrip line **132** and the second drainage microstrip line **138**.

As shown in FIGS. **31** and **32**, both the first drainage microstrip line **137** and the second drainage microstrip line **138** extend in the second direction Y, and one end of the first drainage microstrip line **137** is connected to the first microstrip line **131** at the center position of the first microstrip line **131**, and one end of the second drainage microstrip line **138** is connected to the second microstrip line **132** at the center position of the second microstrip line **132**, so that the vertical projection of the one microstrip line unit of the two microstrip line units **120** on the first substrate **10** and the vertical projection of the other microstrip line unit of the two microstrip line units **120** on the first substrate **10** are symmetrically disposed about the center point O of the vertical projection of the radiating unit group **20** on the first substrate **10**, so that the parasitic electric fields formed on the two microstrip line units **120** are symmetrical to the electric field compensation contributions of the first radiating unit **111** and the second radiating unit **112**, thereby avoiding the introduction of new additional coupled electric fields and preventing the decoupling effect of the decoupling structure **12**.

Moreover, the first drainage microstrip line **137** may serve as the drainage function. One end of the first drainage microstrip line **137** is disposed to be connected to the first microstrip line **131** at the center position of the first microstrip line **131** to form a T-shaped microstrip line structure, so that the induced charge on the first microstrip line **131** is concentrated at a connection point between the first drainage microstrip line **137** and the first microstrip line **131**, that is, the current density at the connection point between the first drainage microstrip line **137** and the first microstrip line **131** is maximum, whereby the parasitic electric field strength at the connection point of the first drainage microstrip line **137** and the first microstrip line **131** is maximum, and further, in the first direction X, the parasitic electric field formed on the microstrip line unit **120** in which the first drainage microstrip line **137** and the first microstrip line **131** are located is made symmetrical to the electric field compensation contribution of the first radiating unit **111** and the second radiating unit **112**, thereby improving the decoupling effect of the decoupling structure **12**.

Similarly, the second drainage microstrip line **138** may also serve as the drainage function. One end of the second drainage microstrip line **138** is disposed to be connected to the second microstrip line **132** at the center of the second microstrip line **132** to form a T-shaped microstrip line structure, so that the induced charge on the second microstrip line **132** is concentrated at the connection point of the second drainage microstrip line **138** and the second microstrip line **132**, that is, the current density at the connection point of the second drainage microstrip line **138** and the second microstrip line **132** is maximum, whereby the parasitic electric field strength at the connection point of the second drainage microstrip line **138** and the second microstrip line **132** is maximum, and further, in the first direction X, the parasitic electric field formed on the microstrip line unit **120** in which the second drainage microstrip line **138** and the second microstrip line **132** are located is symmetrical to the electric field compensation contribution of the first radiating unit **111** and the second radiating unit **112**, thereby improving the decoupling effect of the decoupling structure **12**.

FIG. **33** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure, and FIG. **34** is a schematic cross-sectional structural diagram of FIG. **33** taken along a direction of J-J'. As shown in FIGS. **33** and **34**, optionally, the first drainage microstrip **137** is grounded, and the second drainage microstrip **138** is grounded.

Specifically, as shown in FIGS. **33** and **34**, as previously described, when the T-type microstrip line structure is energized, the induced charge is concentrated at the connection point of the first drain microstrip line **137** and the first microstrip line **131**, and at the connection point of the second drain microstrip line **138** and the second microstrip line **132**, that is, the current density at the connection point of the first drain microstrip line **137** and the first microstrip line **131** is maximum, and the parasitic electric field strength at the connection point of the second drain microstrip line **138** and the second microstrip line **132** is maximum.

In this embodiment, the first drain microstrip **137** and the second drain microstrip **138** are grounded to avoid the excessive current density at the connection point of the first drain microstrip **137** and the first microstrip **131** and at the connection point of the second drain microstrip **138** and the second microstrip **132**, or to avoid the secondary coupling field causing damage to the indirect coupling field due to the accumulating polarization of electric charges at the connection point of the first drainage microstrip line **137** and the first microstrip line **131**, and at the connection point of the second drainage microstrip line **138** and the second microstrip line **132**, thereby ensuring the decoupling effect.

With continued reference to FIGS. **33** and **34**, optionally, a ground metal layer **19** is disposed on a side of the first substrate **10** facing away from the radiating unit **11**. The first substrate **10** further includes third through holes **103**, at least one third through hole **103** at least partially overlaps with the first drainage microstrip line **137** in the thickness direction of the first substrate **10**, and at least one third through hole **103** at least partially overlaps with the second drainage microstrip line **138**, so that the first drainage microstrip line **137** and the second drainage microstrip line **138** are connected to the ground metal layer **19** through the third through holes **103**, thereby enabling the ground arrangement of the first drainage microstrip line **137** and the second drainage microstrip line **138**. When the T-shaped microstrip line structure is energized, the first drain microstrip line **137** and the second drain microstrip line **138** function as drainage, so that the induced charge flows to the ground metal layer **19** through the first drain microstrip line **137** and the second drain microstrip line **138**, thereby avoiding the secondary coupling field causing damage to the indirect coupling field due to the accumulating polarization of electric charges at the connection point of the first drainage microstrip line **137** and the first microstrip line **131**, and at the connection point of the second drainage microstrip line **138** and the second microstrip line **132**, and ensuring the decoupling effect.

Moreover, the first drainage microstrip **137** and the second drainage microstrip **138** are not additionally provided with an interface for grounding, and the structure is simple. When the first substrate **10** is a glass substrate, the third through hole **103** may be implemented by a single-substrate glass perforation technology, and the process is easy to achieve.

It should be noted that a diameter of the third through hole **103** may also be simulated and optimized for the operation frequency of the antenna, impedance matching requirements, and radiation performance and loss requirements. For example, the diameter of the third through hole **103** may be set to be on the same order of magnitude as the operating wavelength of the antenna to achieve the better decoupling effect. For example, if the decoupling structure **12** is applied to the millimeter-wave antenna, then the third through hole **103** may be on the order of millimeters. If the decoupling structure **12** is applied to the centimeter-wave antenna, then the third through hole **103** is on the order of centimeters.

FIG. **35** is a schematic diagram of simulation results of still another antenna according to an embodiment of the present disclosure, an example in which the first radiating unit **111** is operated and the second radiating unit **112** is not operated, that is, only the first radiating unit **111** is fed is used in FIG. **35** for description. A curve S**11-3** represents that a return loss of the first radiating unit **111** in case that the decoupling structure **12** is provided, a curve S**22-3** represents a return loss of the second radiating unit **112** in case that the decoupling structure **12** is provided, a curve S**11-4** represents a return loss of the first radiating unit **111** in case that the decoupling structure **12** is not provided, and a curve S**22-4** represents a return loss of the second radiating unit **112** in case that the decoupling structure **12** is not provided.

As shown in FIG. **35**, after the decoupling structure **12** provided in the embodiments of the present disclosure is provided, the return loss of the first radiating unit **111** in the operating bandwidth range does not become larger, which indicates that the radiation performance of the first radiating unit **111** is not affected. The return loss of the second radiating unit **112** in the operating bandwidth range becomes larger, which indicates that the influence of the electric field of the first radiating unit **111** on the second radiating unit **112** becomes smaller, and the isolation between the first radiating unit **111** and the second radiating unit **112** is effectively improved.

FIG. **36** is a schematic diagram of simulation results of still another antenna according to an embodiment of the present disclosure, an example in which the first radiating unit **111** is operated, and the second radiating unit **112** is not operated, that is, only the first radiating unit **111** is fed in FIG. **36** for description. A curve S**21-3** represents that an insertion loss of the first radiating unit **111** in case that the decoupling structure **12** is provided, and a curve S**21-4** represents that an insertion loss of the first radiating unit **111** in case that the decoupling structure **12** is not provided. As shown in FIGS. **33**, **34** and **36**, in case that the decoupling structure **12** provided in the embodiments of the present disclosure is provided, the insertion loss of the first radiating unit **111** in the operating bandwidth range becomes smaller, which indicates that the radiation efficiency of the first radiating unit **111** is effectively improved.

FIG. **37** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure, FIG. **38** is a schematic cross-sectional structural diagram of FIG. **37** taken along a direction of K-K', FIG. **39** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure, and FIG. **40** is a schematic cross-sectional structural diagram of FIG. **39** taken along a direction of L-L'. As shown in FIGS. **37** to **40**, optionally, the antenna provided in the embodiments of the present disclosure further includes at least one impedance matching unit **44**. The at least one impedance matching unit **44** is connected to the at least one microstrip line **13** in one-to-one correspondence. One impedance matching unit of the at least one impedance matching unit **44** includes at least one of a resistor, a capacitor or an inductor.

Specifically, as shown in FIGS. **37** to **40**, each microstrip line **13** is correspondingly connected with an impedance matching unit **44**. As described above, the radiating unit **11** is coupled to the microstrip line **13** to form a parasitic electric field when the radiating unit **11** is fed, and the impedance matching unit **44** is configured to adjust the load of the microstrip line **13**. The difference in the load of the microstrip line **13** can adjust the difficulty degree of the parasitic electric field radiation on the microstrip line **13**. In this manner, the intensity of the compensation electric field formed by coupling the parasitic electric field on the microstrip line **13** on the adjacent radiating unit **11** can be adjusted, so that the intensity of the compensation electric field matches the intensity of the coupled electric field formed by direct coupling on the radiating unit **11**, thereby just counteracting the coupled electric field formed by direct coupling on the radiating unit **11**, and minimizing the influence of the electric field generated by the operating radiating unit **11** on the electric field of the adjacent radiating unit **11**.

Further, the impedance matching unit **44** may include at least one of a resistor, a capacitor or an inductor. For example, the impedance matching unit **44** may be an RLC circuit, specifically a circuit structure in which a resistor, a series of inductors, and a parallel capacitor are connected. The resistor may employ a variable resistor, and/or the capacitor may employ a variable capacitor and the like to achieve the flexible adjustment of the load, thereby achieving the dynamic compensation of the mutual coupled electric field between adjacent radiating units **11**, so as to improve the stability of the indirect coupling field and ensure the decoupling effect.

With continued reference to FIGS. **37** to **40**, the impedance matching unit **44** may be electrically connected to the control flexible circuit board **45**, whereby the respective control integrated circuit is bound and connected to the control flexible circuit board **45**, so as to enable the control integrated circuit to transmit a load control signal to the impedance matching unit **44** through the control flexible circuit board **45**, adjust the load size of the impedance matching unit **44**, and further, dynamically adjust in the control integrated circuit for the coupling between different radiating units **11**, and integrate the compensation algorithm and the optimization algorithm to optimize the decoupling effect.

It should be noted that in the antenna structure provided in any one of the above-described embodiments, the microstrip lines **13** may be correspondingly connected so as to dynamically compensate the mutual coupled electric field between adjacent radiating units **11**, improve the stability of the indirect coupled electric field, and ensure the decoupling effect, which may be set by those skilled in the art according to actual requirements, and will not be described in detail herein.

FIG. **41** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure, FIG. **42** is a schematic cross-sectional structural diagram of FIG. **41** taken along a direction of M-M', FIG. **43** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure, and FIG. **44** is a schematic cross-sectional structural diagram of FIG. **43** taken along a direction of N-N'. As shown in FIGS. **41** to **44**, optionally, the antenna provided in the embodiments of the present disclosure further includes a radio frequency chip **46**, the radio frequency chip **46** is electrically connected to the microstrip line **13** or is coupled to the microstrip line **13**. The radio frequency chip **46** is configured to apply an additional radio frequency signal to the microstrip line **13**.

Specifically, as shown in FIGS. **41** and **44**, the antenna is further provided with a radio frequency chip **46**, the radio frequency chip **46** may apply an additional radio frequency signal to the microstrip line **13** to form an extra additional electric field on the microstrip line **13**, the additional electric field, after being superimposed with the parasitic electric field formed on the microstrip line **13**, is coupled to form the compensation electric field on the radiating unit **11** so as to compensate for the coupled electric field formed by the direct coupling on the radiating unit **11**. The intensity of the additional electric field, the waveform, and the like may be finely adjusted by the radio frequency chip **46** so as to match the intensity of the compensation electric field with the intensity of the coupled electric field formed by the direct coupling on the radiating unit **11**, thereby just counteracting the coupled electric field formed by the direct coupling on the radiating unit **11**, and achieving the optimal decoupling effect.

For example, if a strong compensation electric field is required to counteract the coupled electric field formed by the direct coupling on the radiating unit **11**, then an additional electric field capable of forming a positive electric field enhancement for the parasitic electric field may be superimposed on the microstrip line **13** by the radio frequency chip **46**. If a weaker compensation electric field is required to counteract the coupled electric field formed by the direct coupling on the radiating unit **11**, then an additional electric field capable of forming a reverse electric field attenuation to the parasitic electric field may be superimposed on the microstrip line **13** by the radio frequency chip **46**.

For another example, the waveform of the additional radio frequency signal may be adjusted by the radio frequency chip **46** to adjust the maximum radiation direction of the superimposed electric field on the microstrip line **13**, so that the parasitic electric field on the microstrip line **13** may be superimposed with the additional electric field and then shifted to the desired radiation direction.

With the above-described technical schemes, the coupling between different radiating units **11** can be dynamically adjusted in the radio frequency chip **46**, and the compensation algorithm and the optimization algorithm can be integrated to optimize the decoupling effect.

With continued reference to FIGS. **41** and **42**, the microstrip line **13** may be electrically connected to the control flexible circuit board **45**, whereby the radio frequency chip **46** is bound and connected to the control flexible circuit board **45**, so as to enable the radio frequency chip **46** to transmit an additional radio frequency signal to the microstrip line **13** through the control flexible circuit board **45**, and adjust the additional electric field on the microstrip line **13**, and at this time, the radio frequency chip **46** is electrically connected to the microstrip line **13**, and the coupling between different radiating units **11** can be dynamically adjusted in the radio frequency chip **46**, and the compensation algorithm and the optimization algorithm may be integrated to optimize the decoupling effect.

With continued reference to FIGS. **43** and **44**, the radio frequency chip **46** may be provided on the fifth substrate **34**. The radio frequency chip **46** may transmit an additional radio frequency signal to the microstrip line **13** through an additional hollow waveguide **322** to adjust an additional electric field on the microstrip line **13**, and in this manner, the radio frequency chip **46** is coupled to the microstrip line **13**, so that the coupling between different radiating units **11** can be dynamically adjusted in the radio frequency chip **46**, and the compensation algorithm and the optimization algorithm may be integrated to optimize the decoupling effect.

With continued reference to FIGS. **41** and **42**, the radio frequency chip **46** may be a different chip from the antenna feed radio frequency chip **36**, the antenna feed radio frequency chip **36** is configured to supply a radio frequency signal to the radiating unit **11**, and the radio frequency chip **46** is configured to supply an additional radio frequency signal to the microstrip line **13**, so that the above-described functions may be achieved by using a low-cost radio frequency chip.

With continued reference to FIGS. **43** and **44**, the radio frequency chip **46** may also be the same chip as the antenna feed radio frequency chip **36**, that is, a single chip may be used to simultaneously provide radio frequency signals to the radiating unit **11** and additional radio frequency signals to the microstrip line **13**, thereby reducing the space occupied by the radio frequency chip and facilitating the high integration and the miniaturization design of the antenna.

It should be noted that the regulation of the parasitic electric field on the microstrip line **13** is not limited to the above-described embodiments. In other embodiments, the parasitic electric field on the microstrip line **13** may be regulated by connecting the microstrip line **13** to an externally mounted independent liquid crystal phase shifter. For example, a radio frequency connector such as an SMA interface or an SMP interface may be connected to one end of the microstrip line **13**. A corresponding radio frequency connector is also disposed on the liquid crystal cell of the externally mounted liquid crystal phase shifter to achieve the connection between the microstrip line **13** and the externally mounted liquid crystal phase shifter, and further the parasitic electric field on the microstrip line **13** is regulated by the externally mounted liquid crystal phase shifter to optimize the decoupling effect, which is not specifically limited in this embodiment of the present disclosure.

FIG. **45** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure, FIG. **46** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure, and FIG. **47** is a schematic structural diagram of still another antenna according to an embodiment of the present disclosure. As shown in FIGS. **45** to **47**, optionally, in any one row of radiating units **11**, any two radiating units **11** disposed adjacent to each other are correspondingly provided with a respective decoupling structure **12**. In any one column of radiating units **11**, any two radiating units **11** disposed adjacent to each other are correspondingly provided with a respective decoupling structure **12**.

Exemplarily, FIG. **45** shows a two-dimensional layout structure of a decoupling structure **12** composed of two microstrip lines **13** in an array of radiating units, FIG. **46** shows a two-dimensional layout structure of a decoupling structure **12** composed of four microstrip lines **13** in an array of radiating units, and FIG. **47** shows a two-dimensional layout structure of a decoupling structure **12** composed of a T-shaped microstrip line structure in an array of radiating units. As shown in FIG. **45** to **47**, the antenna may be provided with multiple radiating units **11** arranged in an array. In each row of radiating units **11**, any two adjacent radiating units **11** are correspondingly provided with a respective decoupling structure **12**, and in each column of radiating units **11**, any two adjacent radiating units **11** are correspondingly provided with a respective decoupling structure **12**, so that a direct coupling field between any two adjacent radiating units **11** can be compensated and counteracted to reduce the mutual coupling between any two adjacent radiating units **11**, the isolation between any adjacent radiating units **11** is improved, and further a problem that the antenna in which the radiating units **11** are closely placed may have strong mutual coupling between adjacent radiating units is solved, which is conductive to improving the integration of the antenna.

It should be noted that the number and layout of the radiating units **11** may be set according to actual requirements, which is not limited in the embodiments of the present disclosure.

With continued reference to FIGS. **45** and **47**, optionally, at least one microstrip line **13** is shared between any two adjacent rows of radiating units **11**, and at least one microstrip line **13** is shared between any two adjacent columns of radiating units **11**.

Exemplarily, FIG. **45** shows a two-dimensional layout structure of a decoupling structure **12** composed of two microstrip lines **13** in an array of radiating units, where decoupling structures **12** provided correspondingly to any two adjacent rows of radiating units **11** may share at least one microstrip line unit **120**, so that the space occupied by the decoupling structure **12** between the two adjacent rows of radiating units **11** may be reduced, thereby facilitating the high integration and the miniaturization design of the antenna while ensuring the isolation. Similarly, the decoupling structure **12** provided correspondingly to any two adjacent columns of radiating units **11** may share at least one microstrip line unit **120**, so that the space occupied by the decoupling structure **12** between the two adjacent columns of radiating units **11** may be reduced, thereby facilitating the high integration and the miniaturization design of the antenna while ensuring the isolation.

FIG. **47** shows a two-dimensional layout structure of a decoupling structure **12** having a T-shaped microstrip line structure in an array of radiating units, where decoupling structure **12** provided correspondingly to any two adjacent rows of radiating units **11** may share at least one microstrip line **13**, so that the space occupied by the decoupling structure **12** between the two adjacent rows of radiating units **11** may be reduced, thereby facilitating the high integration and the miniaturization design of the antenna while ensuring the isolation. Similarly, the decoupling structure **12** provided correspondingly to any two adjacent columns of radiating units **11** may also share at least one microstrip line **13**, so that the space occupied by the decoupling structure **12** between the two adjacent columns of radiating units **11** may be reduced, thereby facilitating the high integration and the miniaturization design of the antenna while ensuring the isolation.

It should be noted that the two-dimensional layout structure of the decoupling structure **12** in the radiating unit array is not limited to the above-described embodiments. In other embodiments, the decoupling structure **12** may adopt other layout structures in the radiating unit array, which is not specifically limited in the embodiments of the present disclosure.

The antenna according to the embodiments of the present disclosure may be an antenna of a type such as a liquid crystal antenna and a phased array antenna, but is not limited thereto. It should be understood that, in any antenna having multiple radiating units, the decoupling structure provided in any one of the embodiments of the present disclosure may be used to reduce the mutual coupling between adjacent radiating units, improve the isolation between radiating units, and further solve a problem that the antenna in which the radiating units are closely placed may have strong mutual coupling between adjacent radiating units, which is conductive to improving the integration of the antenna.

The above implementations should not be construed as limiting the protection scope of the present disclosure. It should be understood by those skilled in the art that various modifications, combinations, sub-combinations and substitutions may be made depending on design requirements and other factors. Any modification, equivalent replacement, and improvement made within the spirit and principle of the present disclosure should be included within the protection scope of the present disclosure.

What is claimed is:

1. An antenna, comprising a first substrate, a plurality of radiating units and at least one decoupling structure, wherein,

the plurality of radiating units are arranged in an array on a side of the first substrate;

at least two adjacent radiating units among the plurality of radiating units constitute one radiating unit group, and the radiating unit group comprises a first radiating unit and a second radiating unit disposed adjacent to each other;

the at least one decoupling structure is disposed in correspondence with the radiating unit group, one decoupling structure of the at least one decoupling structure comprises two microstrip line units, and one microstrip line unit of the two microstrip line units comprises at least one microstrip line;

the first radiating unit and the second radiating unit are disposed on a same layer and arranged in a first direction;

in a second direction, the two microstrip line units are located on two opposite sides of the radiating unit group, respectively, and a vertical projection of one microstrip line unit of the two microstrip line units on the first substrate and a vertical projection of other microstrip line unit of the two microstrip line units on the first substrate are symmetrically disposed about a center point of a vertical projection of the radiating unit group on the first substrate; and

the second direction intersects the first direction.

2. The antenna of claim **1**, wherein,

the one microstrip line unit of the two microstrip line units comprises a first microstrip line, and the other microstrip line unit of the two microstrip line units comprises a second microstrip line;

the first microstrip line and the second microstrip line extend in an arrangement direction of the first radiating unit and the second radiating unit; and

a vertical projection of the first microstrip line on the first substrate and a vertical projection of the second microstrip line on the first substrate are symmetrically disposed about the center point of the vertical projection of the radiating unit group on the first substrate.

3. The antenna of claim 1, wherein,

the one microstrip line unit of the two microstrip line units comprises a third micro strip line and a fourth microstrip line arranged in the first direction, and the third microstrip line and the fourth microstrip line are insulated from each other; the other microstrip line unit of the two microstrip line units comprises a fifth microstrip line and a sixth microstrip line arranged in the first direction, and the fifth microstrip line and the sixth microstrip line are insulated from each other;

the third microstrip line, the fourth microstrip line, the fifth microstrip line and the sixth microstrip line extend in the first direction; and

the third microstrip line and the fifth microstrip line at least partially overlaps with the first radiating unit in the second direction, and the fourth microstrip line and the sixth microstrip line at least partially overlaps with the second radiating unit in the second direction.

4. The antenna of claim 1, wherein the at least one microstrip line and the plurality of radiating units are disposed on a same layer.

5. The antenna of claim 1, wherein,

the antenna further comprises a liquid crystal phase shifter located on a side of the first substrate facing away from the plurality of radiating units, the liquid crystal phase shifter comprises a second substrate and a third substrate disposed opposite to each other, and the third substrate is located on a side of the second substrate facing away from the plurality of radiating units;

the liquid crystal phase shifter further comprises a delay line, a liquid crystal layer and a ground metal layer;

the liquid crystal layer is located between the second substrate and the third substrate, the delay line is located between the third substrate and the liquid crystal layer, and the ground metal layer is located between the second substrate and the liquid crystal layer; and

the ground metal layer comprises a first hollow portion, and one radiating unit of the plurality of radiating units cover the first hollow portion in a thickness direction of the first substrate.

6. The antenna of claim 5, wherein,

the at least one microstrip line and the delay line are disposed on a same layer; and

the ground metal layer comprises a second hollow portion, and the second hollow portion covers one microstrip line of the at least one microstrip line in the thickness direction of the first substrate.

7. The antenna of claim 5, wherein,

the first substrate and the second substrate are bonded by a first bonding adhesive; and

a gap exists between the first bonding adhesive and the plurality of radiating units in the thickness direction of the first substrate.

8. The antenna of claim 5, wherein the first substrate and the second substrate are a same substrate.

9. The antenna of claim 1, wherein,

the antenna further comprises a ground metal layer and a coaxial cable interface;

the ground metal layer is located on a side of the first substrate facing away from the plurality of radiating units, and the ground metal layer at least partially overlaps with the plurality of radiating units in a thickness direction of the first substrate; and

the coaxial cable interface is located on a side of the ground metal layer facing away from the plurality of radiating units, the first substrate comprises a first through hole, and the coaxial cable interface is connected to the plurality of radiating units through the first through hole.

10. The antenna of claim 1, wherein,

the antenna further comprises a waveguide structure located on a side of the first substrate facing away from the plurality of radiating units, the waveguide structure comprises a fourth substrate and a fifth substrate disposed opposite to each other, and the fifth substrate is located on a side of the fourth substrate facing away from the plurality of radiating units;

the waveguide structure comprises a hollow waveguide tube and a ground metal layer;

the hollow waveguide tube is located between the fourth substrate and the fifth substrate, and the ground metal layer is located between the fourth substrate and the hollow waveguide tube;

the ground metal layer comprises a third hollow portion, one radiating unit of the plurality of radiating units covers the third hollow portion in a thickness direction of the first substrate, and the hollow waveguide tube at least partially overlaps with the third hollow portion in the thickness direction of the first substrate; and

the hollow waveguide tube is configured to feed a radio frequency signal provided by a feed source to the plurality of radiating units.

11. The antenna of claim 10, wherein,

the first substrate and the fourth substrate are bonded by a second bonding adhesive; and

a gap exists between the second bonding adhesive and the plurality of radiating units in the thickness direction of the first substrate.

12. The antenna of claim 10, wherein the first substrate and the fourth substrate are a same substrate.

13. The antenna of claim 1, wherein the at least one microstrip line is floated, or the at least one microstrip line is grounded.

14. The antenna of claim 13, wherein,

the antenna further comprises a ground metal layer;

the ground metal layer is located on a side of the first substrate facing away from the plurality of radiating units, and the ground metal layer at least partially overlaps with the plurality of radiating units in a thickness direction of the first substrate; and

the first substrate comprises a second through hole, the second through hole at least partially overlaps with one microstrip line of the at least one microstrip line in the thickness direction of the first substrate, and the microstrip line of the at least one microstrip line is connected to the ground metal layer through the second through hole.

15. The antenna of claim 2, wherein,

a side of the first microstrip line facing away from the radiating unit group is provided with a first drainage microstrip line, the first drainage microstrip line extends in the second direction, and one end of the first drainage microstrip line is connected to the first microstrip line at a center position of the first microstrip line;

a side of the second microstrip line facing away from the radiating unit group is provided with a second drainage microstrip line, the second drainage microstrip line extends in the second direction, and one end of the second drainage microstrip line is connected to the second microstrip line at a center position of the second microstrip line; and a vertical projection of the first drainage microstrip line on the first substrate and a vertical projection of the second drainage microstrip line on the first substrate are symmetrically disposed about the center point of the vertical projection of the radiating unit group on the first substrate.

16. The antenna of claim **15**, wherein the first drainage microstrip line is grounded, and the second drainage microstrip line is grounded.

17. The antenna of claim **1**, wherein,

the antenna further comprises at least one impedance matching unit, and the at least one impedance matching unit is connected to the at least one microstrip line in one-to-one correspondence; and

one impedance matching unit of the at least one impedance matching unit comprises at least one of a resistance, a capacitance or an inductance.

18. The antenna of claim **1**, wherein the antenna further comprises a radio frequency chip, the radio frequency chip is electrically connected to the at least one microstrip line or is coupled to the at least one microstrip line, and the radio frequency chip is configured to apply an additional radio frequency signal to the at least one microstrip line.

19. The antenna of claim **1**, wherein,

in any one row of radiating units among the plurality of radiating units, any two radiating units disposed adjacent to each other are correspondingly provided with a respective decoupling structure; and

in any one column of radiating units among the plurality of radiating units, any two radiating units disposed adjacent to each other are correspondingly provided with a respective decoupling structure.

20. The antenna of claim **19**, wherein,

at least one microstrip line is shared between any two adjacent rows of radiating units among the plurality of radiating units; and

at least one microstrip line is shared between any two adjacent columns of radiating units among the plurality of radiating units.

* * * * *