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(54) FREQUENCY SELECTIVE SURFACE

(57) Provided in the embodiments of the present disclosure is a frequency selective surface unit, comprising: a first band-pass branch and a dielectric substrate used for fixing the first band-pass branch. The first band-pass branch comprises a first metal wire and two first metal patches: the two first metal patches are spaced apart to form a first capacitor having a physical width of L. L being a positive number; the first metal wire is connected to the two first metal patches to form a first inductor; and connection positions of the first metal wire and the two first metal patches are located at L/4 to 3L/4 of the physical width L of the first capacitor.

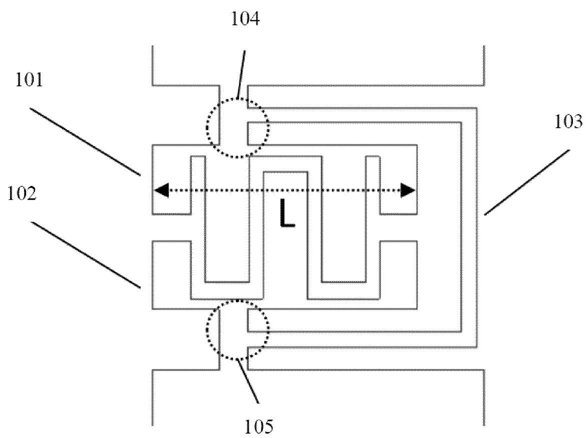

Fig. 5

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Description

Cross-Reference to Related Application

[0001] This disclosure is based upon and claims the benefit of priority from Chinese patent application CN 202211021655.8, entitled "Frequency Selective Surface" filed on 24 August 2022, the disclosure of which is incorporated herein by reference in its entirety.

Technical Field

[0002] Examples of the present disclosure relate to the field of communications, and in particular, to a frequency selective surface.

Background

[0003] Frequency selective surface, FSS, is an artificial electromagnetic material having a special filtering function, and is widely applied in fields such as radar, aviation, and communications. In a communication system with an increasingly high integration degree, multi-band integration is an important direction, and an antenna with an electromagnetic opening characteristic gradually emphasizes a problem of mutual interference between frequency bands in the multi-band integration, and research on a multi-band FSS has become a great emphasis.

[0004] In previous studies, the multi-band FSS often uses a multi-layer cascaded FSS technology, or a multi-resonant stub technology. The multi-layer cascaded FSS increases the complexity and cost of design and fabrication, and is greatly limited in the civil field. The multi-resonant stub technology refers to integrating multiple stubs within a single FSS unit, and generating passbands of multiple frequency bands by means of resonance of the multiple stubs. The issue with this technique is that when the wavelength of a second passband is much smaller than that of the first passband, the filtering performance of the FSS structure in the second passband is difficult to ensure, since the size of the FSS unit is always determined by the first passband. When the size of the FSS unit is too large relative to the wavelength of the second passband, causing the filtering performance of the second passband to deteriorates sharply. This includes the case where, after the electromagnetic wave is transmitted, its direction characteristics generate a first level of distortion, and when the electromagnetic wave is incident at a 60-degree wide angle, transmission loss is a big problem.

Summary

[0005] The examples of the present disclosure provide a frequency selective surface, so as to at least solve the problems in the related art that the single-layer FSS can support fewer passbands and the wide-angle filtering performance is poor.

[0006] According to one example of the present disclosure, a frequency selective surface unit is provided, including at least one first bandpass stub, wherein the two first metal patches are spaced apart to form a first capacitor of physical width L, L is a positive number, the first metal wire is connected to the two first metal patches to form a first inductor, wherein connection positions of the first metal wire and the two first metal patches are both located within the range of L/4 to 3L/4 of the physical width L of the first capacitor; and a dielectric substrate, for fixing the first bandpass stub.

[0007] According to another embodiment of the present disclosure, a frequency selective surface is further provided, which includes multiple frequency selective surface units as described above.

Brief Description of the Drawings

[0008]

Figure 1 is a block diagram of a frequency selective surface unit according to an embodiment of the present disclosure;

Figure 2 is a block diagram of a frequency selective surface unit according to an embodiment of the present disclosure;

Figure 3 is a block diagram of a frequency selective surface unit according to an embodiment of the present disclosure;

Figure 4 is a structural block diagram of an FSS unit according to a scenario embodiment of the present disclosure;

Figure 5 is a schematic structural diagram of a first bandpass stub according to a scenario embodiment of the present disclosure;

Figure 6 is a schematic structural diagram of a second bandpass stub according to a scenario embodiment of the present disclosure;

Figure 7 is a schematic structural diagram of a first bandstop stub according to a scenario embodiment of the present disclosure;

Figure 8 is a graph of a transmission-coefficient curve of an FSS according to a scenario embodiment of the present disclosure;

Figure 9 is a structural block diagram of a first bandpass stub according to a scenario embodiment of the present disclosure;

Figure 10 is a structural block diagram of a first bandpass stub according to a scenario embodiment of the present disclosure;

Figure 11 is a structural block diagram of an FSS according to a scenario embodiment of the present disclosure;

Figure 12 is a graph of a transmission-coefficient curve of an FSS according to a scenario embodiment of the present disclosure.

Detailed Description of the Embodiments

[0009] Examples of the present disclosure will be described below in detail with reference to the accompanying drawings and in conjunction with examples.

[0010] It should be noted that, terms such as "first" and "second" in the description, claims, and accompanying drawings of the present disclosure are used to distinguish similar objects, but are not necessarily used to describe a specific sequence or order.

[0011] According to an embodiment of the present disclosure, a frequency selective surface unit is provided. Figure 1 is a structural block diagram of a frequency selective surface unit according to an embodiment of the present disclosure, As shown in figure 1, the frequency selective surface unit 10 includes at least one first bandpass stub 110, wherein, the first bandpass stub 110 includes two first metal patches and a first metal wire, wherein the two first metal patches are spaced apart to form a first capacitor having a physical width of L, L is a positive number, a first metal wire is connected to two first metal patches to form a first inductor, and the connection positions of the first metal wire and the two first metal patches are both located within the range of L/4 to 3L/4 of the physical width L of the first capacitor;

A dielectric substrate 120 for fixing the first bandpass stub 110.

[0012] In the described example, a frequency selective surface unit is provided, including a first bandpass stub 110 and a dielectric substrate 120 for fixing the first bandpass stub 110, the first bandpass stub 110 includes two first metal patches and a first metal wire, wherein the two first metal patches are spaced apart to form a first capacitor having a physical width of L, L is a positive number, a first metal wire is connected to two first metal patches to form a first inductor, and the connection position of the first metal wire and the two first metal patches is located at L/4 to 3L/4 of the physical width L of the first capacitor, the problems in the related art that the single-layer FSS can support fewer passbands and the wide-angle filtering performance is poor are solved, and the effect of improving the FSS filtering performance is achieved.

[0013] In an exemplary example, the manner of fixing the first bandpass stub 110 on the dielectric substrate 120 includes: two first metal patches being fixed on the same side of the dielectric substrate; or the two first metal patches are respectively fixed on opposite sides of the dielectric substrate, and the first metal wires are fixed on the opposite sides of the dielectric substrate and are connected through the metallized via.

[0014] In the example of the present disclosure, the first metal wire may comprise multiple metal segments fixed on the opposite sides of the dielectric substrate, and the multiple metal segments are connected through multiple metallized vias. The shape of the first metal patch may be circular, triangular, rectangular, or irregular polygonal.

[0015] In an exemplary example, figure 2 is a block diagram of a frequency selective surface unit according to an embodiment of the present disclosure, as shown in figure 2, the frequency selective surface unit 20 further includes a second bandpass stub 210 in addition to the components in figure 1, the second bandpass stub 210 and the first bandpass stub 110 can be connected through a metal wire, and the second bandpass stub 210 includes two second metal patches and a second metal wire.

[0016] In the example of the present disclosure, the two second metal patches may be distributed on opposite sides of the dielectric substrate 120 to form the second capacitor, the second metal wires may be distributed on the opposite sides of the dielectric substrate 120 and connected through the metalized vias to form the second inductor, and the second inductor and the second capacitor are connected in parallel.

[0017] In the example of the present disclosure, the second metal wire may comprise multiple metal segments fixed on the opposite sides of the dielectric substrate, and the multiple metal segments are connected through multiple metallized vias. The shape of the second metal patch may be circular, triangular, rectangular, or irregular polygonal.

[0018] In one exemplary example, figure 3 is a block diagram of a frequency selective surface unit according to an embodiment of the present disclosure, as shown in figure 3, in addition to the components in figure 2, the frequency selective surface unit 30 further includes at least one first bandstop stub 310, the first bandstop stub 310 is connected to the first bandpass stub 110 via a metal wire, and the first bandstop stub 310 includes two third metal patches and a third metal wire.

[0019] The two third metal patches may be distributed on opposite sides of the dielectric substrate 120 to form a third capacitor, and the third metal wire is configured to connect the second bandpass stub 210 and the first bandpass stub 110 to form a third inductor.

[0020] In examples of the disclosure, the shape of the third metal patch may be circular, triangular, rectangular, or irregular polygonal.

[0021] According to another example of the present disclosure, there is provided a frequency selective surface including multiple the above frequency selective surface units.

[0022] In an exemplary example, two adjacent frequency selective surface units share two third metal patches, so that two adjacent frequency selective surface units share a third capacitor.

[0023] In one exemplary example, a third capacitance of the first bandpass stub is shared between adjacent frequency selective surface units in diagonally opposing corner locations of the frequency selective surface.

[0024] In order to enable those skilled in the art to better understand the technical solutions of the present disclosure, the present disclosure will be described below with reference to specific scenarios.

Scenario example 1

[0025] Disclosed is an FSS unit. The FSS unit has the characteristics of a low-cost and miniaturized single layer with stable multi-band and 60-degree wide-angle performance, and can solve the problems in the prior art that the single-layer FSS can support fewer passbands, the wide-angle filtering performance is poor, and the cost of a multi-layer FSS is high.

[0026] Figure 4 is a structural block diagram of an FSS unit according to an example of the present disclosure. As shown in figure 4, the FSS unit structure includes a first bandpass stub 100, a second bandpass stub 200, a first bandstop stub 300, and three stubs being composed of a metal structure and partial metallized vias which are located on opposite sides of a dielectric substrate, three stubs are connected through a metal wire, each stub respectively corresponds to a different passband/stopband, and electromagnetic waves of a passband frequency band can pass through the FSS structure, thereby achieving transmission; The electromagnetic wave of the stopband frequency band cannot pass through the FSS structure, thereby implementing reflection.

[0027] Figure 5 is a schematic structural diagram of a first bandpass stub according to a scenario embodiment of the present disclosure. As shown in figure 5, the first bandpass stub 100 includes a first metal structure 101, a second metal structure 102, and a third metal structure 103, where the first metal structure 101 and the second metal structure 102 have a certain distance therebetween to form a capacitor, and the physical width of the capacitor is L; the third metal structure 103 is a metal wire, so as to form an inductor, in which the narrower the metal wire is, the higher the inductance value is; the positions of connections between the inductor and the capacitor are respectively a first connection position 104 and a second connection position 105, in which the first connection position 104 and the second connection position 105 can move in a range of (L/4,3L/4), and when 104 and 105 are located at the central L/2 position in the width direction, a better resonance characteristic can be obtained. By optimizing the position where the inductor is connected to the capacitor, the first bandpass stub improves the resonance characteristics of the bandpass stub when the incident light is at a wide angle of 60 degree, thereby achieving stable wide angle performance of the FSS unit.

[0028] A person skilled in the art should know that the first metal structure 101 and the second metal structure 102 of the first bandpass stub are the first metal patches in the foregoing embodiment, and the first metal structure 101 and the second metal structure 102 may be in the same layer, or may be in different layers of the dielectric substrate, and may be in various shapes such as rectangle, triangle, and circle. The third metal structure 103 is the first metal wire in the foregoing embodiment, and the third metal structure 103 may be in one layer, and may also be multiple segments of metal wires distributed on the opposite sides of the dielectric substrate, and are connected through metal vias. A first connection location 104 and a second connection location 105 of the inductor and capacitor connection structure, which may be a direct connection of a metal structure, and may also be a connection of a metallized via; the linkage position range was also (L/4,3L/4).

[0029] The first bandpass stub adopts a wide-angle design, i.e. a position where an inductor is connected to a capacitor in parallel; and in the centre of the width L of the capacitor, the position thereof can be adjusted in a range from L/4 to 3L/4. By improving the position where the inductor and the capacitor are connected in parallel, the filtering performance of the FSS is stable when the incident angle is 60 degrees.

[0030] Figure 6 is a schematic structural diagram of a second bandpass stub according to a scenario embodiment of the present disclosure. As shown in figure 6, the second bandpass stub 200 includes a fourth metal structure 201 and a fifth metal structure 202 on the front side of the dielectric substrate, a sixth metal structure 203 and a seventh metal structure 204 on the back side of the dielectric substrate, and a metallized via 205 connecting the front side and the back side of the dielectric substrate. Wherein the fourth metal structure 201 and the sixth metal structure 203 are respectively located on opposite sides of the dielectric substrate to form a plate capacitor, and in a direction perpendicular to the dielectric substrate, the more projected overlapping portions of the fourth metal structure 201 and the sixth metal structure 203 are, the larger the capacitor is; the fifth metal structure 202 and the seventh metal structure 204 are connected through a metallized via 205 to form an inductor. In a specific example, the fifth metal structure 202 and the seventh metal structure 204 may be metal wires, and the narrower the metal wire is, the higher the inductance value is; the capacitor and the inductor are connected in parallel. The second bandpass stub forms a capacitor by means of metal structures distributed on two surfaces of a substrate, and compared with a capacitor structure located on the same side, a gap between metal structures on the same side is replaced by a distance of the thickness of the substrate, thereby reducing the length of the stub on the same plane, and realizing miniaturization.

[0031] A person skilled in the art should know that the fourth metal structure 201 and the sixth metal structure

203 in the second bandpass stub are the second metal patch in the above example, and the fourth metal structure 201 and the sixth metal structure 203 may be rectangular, or may be circular, triangular, polygonal or other non-standard shapes. The fifth metal structure 202 and the seventh metal structure 204 are the second metal wires in the foregoing embodiment, and the fifth metal structure 202 and the seventh metal structure 204 may be two-segment metal wires, or may be multi-segment metal wires, and are connected through multiple metallization vias.

[0032] The second bandpass stub uses a miniaturized design, and a metal structure respectively located on the opposite sides of a plate forms a capacitor, metal wires extending out from the opposite sides of the metal structure are connected through a metalized via to form an inductor, and the capacitor and the inductor are connected in parallel to form a second pass-band.

[0033] Figure 7 is a schematic structural diagram of a first bandstop stub according to a scenario embodiment of the present disclosure. As shown in figure 7, the first bandstop stub 300 includes an eighth metal structure 301, a ninth metal structure 302, and a twelfth metal structure 305 on a front side of a dielectric substrate, a tenth metal structure 303, an eleventh metal structure 304, and a thirteenth metal structure 306 on a back side of the dielectric substrate. The eighth metal structure 301, the eleventh metal structure 304, the twelfth metal structure 305, and the thirteenth metal structure 306 are metal connecting wires between the stubs, and form an inductor together with other stubs. The ninth metal structure 302 and the tenth metal structure 303 form a capacitor respectively on opposite sides of the substrate. The first bandstop stub forms a capacitor by means of a ninth metal structure 302 and a tenth metal structure 303 respectively belonging to two adjacent FSS units, so that two adjacent FSS units share one capacitor, i.e. a series equivalent capacitance value C; compared with the non-shared unit structures connected in series, where the capacitance is halved to C/2, thereby achieving the effect of doubling the capacitance value. Similarly, in the case where the required capacitance value is determined, the optimized first bandstop stub structure capacitance value is reduced by half, i.e. the capacitance metal area is reduced by half, thereby realizing the miniaturization of the bandstop stubs.

[0034] A person skilled in the art should know that the opposite sides of the dielectric substrate of the first bandstop stub, the ninth metal structure 302 and the tenth metal structure 303 are the third metal patches in the foregoing embodiment, and the ninth metal structure 302 and the tenth metal structure 303 may be circular, may also be triangular, rectangular, polygonal, or other irregular shapes.

[0035] The first bandstop stub is of a miniaturized design, and a capacitor is formed by metal structures located on opposite sides of a plate, wherein the front and back metal structures respectively belong to two adjacent units in positive and negative 45 directions. When a single unit capacitor is 2C, two capacitors of adjacent units are in a series connection relationship, so that an actual capacitance value is halved to C. By sharing a capacitor by adjacent units, a capacitance value equivalent to the unit capacitor C is C. Compared with a unit capacitor of 2C, a required capacitance value is reduced, that is, the area of a capacitor metal is reduced, thereby realizing the miniaturization of bandstop stubs.

[0036] A person skilled in the art should know that the metal structure mentioned in this scenario embodiment may be a metal patch, a metal strip, a metal line, and the like, which is not limited herein.

Scenario example 2

[0037] The FSS provided in this scenario embodiment is an FSS minimum repeatable sub-array, and the sub-array includes four basic units with consistent functions. Each base unit includes a first bandpass stub, a second bandpass stub, and a first bandstop stub. Adjacent basic units at diagonal positions share the capacitance of the first bandstop stub 300, and therefore, the same-function stubs of adjacent basic units are respectively located on opposite sides of the dielectric substrate, that is, assuming that the first bandpass stub of one basic unit is located on the front side of the dielectric substrate, the first bandpass stub of one diagonal adjacent basic unit is located on the back side of the dielectric substrate. The size of the miniaturized FSS unit is 20 mm, which is equivalent to 0.17λ@2.6 GHz and 0.23λ@3.5 GHz.

[0038] During operation, an electromagnetic wave of a bandstop frequency band is incident on a surface of an FSS, a first bandstop stub generates LC series resonance, which is equivalent to the metal transmission line, and the FSS is equivalent to the metal grid, so as to block the propagation of the electromagnetic wave and reflect same. When electromagnetic waves of a cut-off frequency band are incident on the surface of an FSS, the first or second bandpass stub generates LC parallel resonance to form a high-impedance metal transmission line, the FSS cannot form a metal grid, and the electromagnetic waves pass through the FSS to form transmission.

[0039] Figure 8 is a graph of a transmission-coefficient curve of an FSS according to a scenario embodiment of the present disclosure. As shown in figure 8, it can be seen that the FSS proposed in the second embodiment of the scenario realizes a bandstop function with a transmission coefficient of less than -15 dB in a frequency band of 0.6 GHz-0.96 GHz; in addition, the transmission-coefficient of two frequency bands, i.e. 2.5 GHz-2.7 GHz and 3.4 GHz-3.8 GHz, is greater than -0.5 dB, thereby realizing a dual-frequency bandpass function; when the light is incident at a wide angle of 60 degrees, in a conventional structure, in a first transparent frequency band, the transmission loss sharply increases, and by adopting the miniaturized wide-angle unit of the present disclosure, the loss is greatly improved.

[0040] In a specific implementation process, the structural form of a relevant stub (including a first bandpass stub, a second bandpass stub, and a first bandstop stub) is not specifically limited, and can be adjusted according to actual situations.

[0041] For example, the structure of the first relay node may be located on the opposite sides of the dielectric substrate. Figure 9 is a structural block diagram of a first bandpass stub according to a scenario embodiment of the present disclosure. As shown in figure 9, the first connection terminal includes a fourteenth metal structure 111 and a fifteenth metal structure 112, which are respectively located on opposite sides of a dielectric substrate to form a capacitor, the overall width of the capacitor being L; the first metal wire 113 and the second metal wire 115 are respectively located on opposite sides of the dielectric substrate, and are connected to form an inductor through a metallized via 114; a first inductive loading position 116 and a second inductive loading position 117, which are connected to a capacitor through a metalized via, in which the range of loading positions is (L/4, 3L/4).

[0042] In the example of the present disclosure, there is further provided a first bandpass stub having another structural form. Figure 10 is a structural block diagram of a first bandpass stub according to a scenario embodiment of the present disclosure. As shown in figure 10, the first bandpass stub includes a sixteenth metal structure 121 and a seventeenth metal structure 122, which are located on opposite sides of a dielectric substrate respectively to form a capacitor, the overall width of the capacitor being L; the third metal wire 123 forms an inductor; a third inductor loading position 124 and a fourth inductor loading position 125, wherein the third inductor loading position 124 is connected to a capacitor through a metalized via, the fourth inductor loading position 125 is directly connected to the capacitor, and the ranges of the loading positions are both (L/4, 3L/4).

[0043] Figure 11 is a structural block diagram of an FSS according to a scenario embodiment of the present disclosure. As shown in figure 11, the FSS includes a second bandpass stub 100, a first bandpass stub 200, and a first bandstop stub 300. The positional relationship of the first bandpass stub, the second bandpass stub and the first bandstop stub is a common positional relationship among the three stubs in the embodiment of the present scenario. Since the specific structural forms of the first bandpass stub are different, the structural form between the three stubs may be slightly changed, but the positional relationship is basically similar.

Scenario example 3

[0044] The structure of the FSS provided in the embodiment of the present scenario includes three bandpass stubs and one bandstop stub, i.e. a first bandpass stub, a second bandpass stub, a third bandpass stub and a first bandstop stub.

[0045] Figure 12 is a graph of a transmission-coefficient curve of an FSS according to a scenario embodiment of the present disclosure. As shown in figure 12, in this embodiment of the scenario, a bandstop function of a transmission coefficient of a frequency band of 0.6GHz-0.96GHz being less than -15dB is implemented by using a first bandstop stub; by adding a third bandpass stub 400, the transmission coefficient of the FSS structure in three frequency bands of 2.5GHz-2.7GHz, 3.4GHz-3.8GHz and 4.8GHz-5GHz is greater than -0.7dB, thereby realizing the three-frequency bandpass function. The size of the miniaturized FSS unit of embodiment 4 is 20 mm, which is equivalent to 0.17λ@2.6 GHz, 0.23λ@3.5 GHz, and 0.33λ@4.9 GHz, and the filter performance at a 60-degree wide angle is stably maintained in all of the three transparent frequency bands.

[0046] In summary, during the design process, appropriate bandpass/bandstop stubs and the number thereof can be selected according to requirements. In order to realize the FSS bandstop function, at least one first bandstop stub needs to be comprised; to realize the single-band bandpass function of the FSS, a second bandpass stub or a first bandpass stub is required; in order to realize an FSS multi-band bandpass function, one second bandpass stub + multiple first bandpass stubs are required to be connected in series, or multiple first bandpass stubs are directly connected in series, i.e. when the multi-band bandpass is performed, the number of the second bandpass stubs is 0 or 1, and the other bandpass stubs are all first bandpass stubs.

[0047] A person skilled in the art should know that the above are embodiments of specific scenarios of the present disclosure, which do not constitute any limitation to the present disclosure, and after knowing the content and principle of the present disclosure, a person skilled in the art can make changes to the implementation forms without departing from the principle of the present disclosure, but these changes based on the principle of the present disclosure are still within the scope of protection of the claims and the present disclosure.

[0048] The present disclosure provides an FSS structure, including a dielectric substrate and a resonant stub, realizing passband/stopband characteristics of the FSS structure. A resonant stub includes two parts, i.e. the inductor and a capacitor, and different stubs adopt different optimized structures. By means of a combination of bandpass/bandstop stubs, the effects of bandstop of a frequency band and multi-band-pass can be achieved, all bandstop/bandpass frequency bands can be separately adjustable, and the filtering performance is stable in the case of 60-degree wide-angle incidence.

[0049] The FSS unit of the present disclosure optimizes the filter performance stability of the FSS under 60-degree wide-angle incidence by improving the inductive loading position of the bandpass stub; by means of miniaturized bandpass stubs and bandstop stubs sharing a capacitor with adjacent units, a miniaturized design of the FSS unit is realized, so that under the same unit size, an FSS structure can integrate more frequency bands, and all bandstop/bandpass frequency bands are separately adjustable; Based on the single-layer dielectric substrate design, the process is simple and cost-effective.

[0050] The present disclosure relates to the technical field of frequency selective surfaces, and is applied to multi-band device integration in the field of communications, and belongs to a 5G A+P integrated product and a potential 6G key technology. Specifically, the present invention may be applied to the field of network communications, for example, an integrated communications device of an A+P type, and a device with a higher integration level in the future.

[0051] The foregoing descriptions are merely exemplary embodiments of the present disclosure, but are not intended to limit the present disclosure. For those skilled in the art, the present disclosure may have various modifications and variations. Any modifications, equivalent replacements, improvements and the like made within the principle of the present disclosure shall fall within the scope of protection of the present disclosure.

Claims

1. A frequency selective surface unit, comprising:

at least one first bandpass stub, wherein each first bandpass stub comprises a first metal wire and two first metal patches, wherein the two first metal patches are spaced apart to form a first capacitor of physical width L, L is a positive number, the first metal wire is connected to the two first metal patches to form a first inductor, wherein connection positions of the first metal wire with the two first metal patches are both located within the range of L/4 to 3L/4 of the physical width L of the first capacitor; and
a dielectric substrate, for fixing the first bandpass stub.

2. The frequency selective surface unit according to claim 1, wherein the two first metal patches are fixed on same side of the dielectric substrate; or the two first metal patches are respectively fixed on opposite sides of the dielectric substrate, and the first metal wire is fixed on the opposite sides of the dielectric substrate and connected through a metallized via.

3. The frequency selective surface unit according to claim 2, wherein the first metal wire comprises multiple segments of metal wires fixed on the opposite sides of the dielectric substrate, and the multiple segments of the metal wires are connected through multiple metallized vias.

4. The frequency selective surface unit according to claim 1, wherein shape of the first metal patches is circular, triangular, rectangular, or irregular polygonal.

5. The frequency selective surface unit of claim 1, further comprising:
a second bandpass stub, wherein the second bandpass stub is connected to the first bandpass stub via a metal wire, the second bandpass stub comprises two second metal patches and a second metal wire, wherein the two second metal patches are distributed on opposite sides of the dielectric substrate to form a second capacitor, the second metal wire is distributed on the opposite sides of the dielectric substrate and connected through metallized via to form a second inductor, wherein the second inductor is connected in parallel with the second capacitor.

6. The frequency selective surface unit according to claim 5, wherein the second metal wire comprises multiple segments of metal wires fixed on the opposite sides of the dielectric substrate, and the multiple segments of the metal wires are connected through multiple metallized vias.

7. The frequency selective surface unit according to claim 5, wherein shape of the second metal patches is circular, triangular, rectangular, or irregular polygonal.

8. The frequency selective surface unit according to claim 1, further comprising:
at least one first bandstop stub, wherein each first bandstop stub is connected to the first bandstop stub via a metal wire, the first bandstop stub comprises two third metal patches and a third metal wire, wherein the two third metal patches are distributed on opposite sides of a dielectric substrate to form a third capacitor, the third metal wire connecting a second bandpass stub and the first bandpass stub to form a third inductor.

9. The frequency selective surface unit according to claim 8, wherein shape of the third metal patches is circular, triangular, rectangular, or irregular polygonal.

10. A frequency selective surface, comprising multiple frequency selective surface units according to any one of claims 1-9.

11. The frequency selective surface according to claim 10, wherein two adjacent frequency selective surface units share two third metal patches, so that two adjacent frequency selective surface units share a third capacitor.

12. The frequency selective surface according to claim 11, wherein adjacent frequency selective surface units located at diagonal positions share a third capacitor of a first bandpass stub.

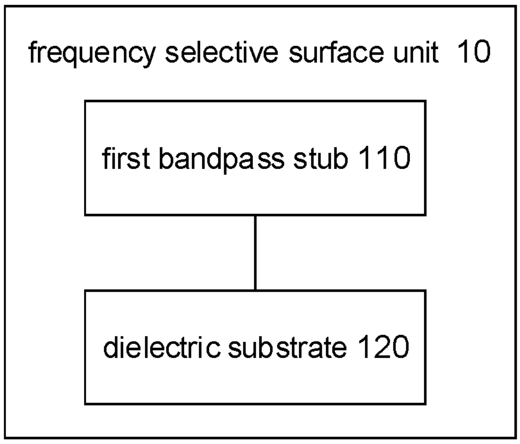

frequency selective surface unit 10
first bandpass stub 110
dielectric substrate 120

Fig. 1

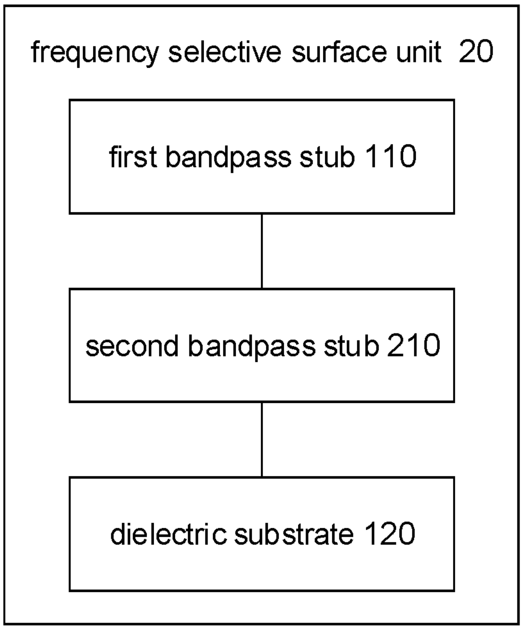

frequency selective surface unit 20
first bandpass stub 110
second bandpass stub 210
dielectric substrate 120

Fig. 2

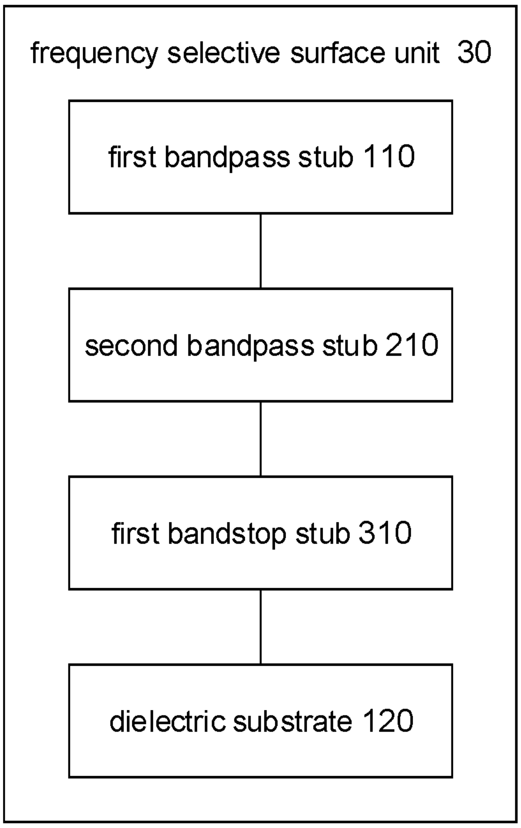
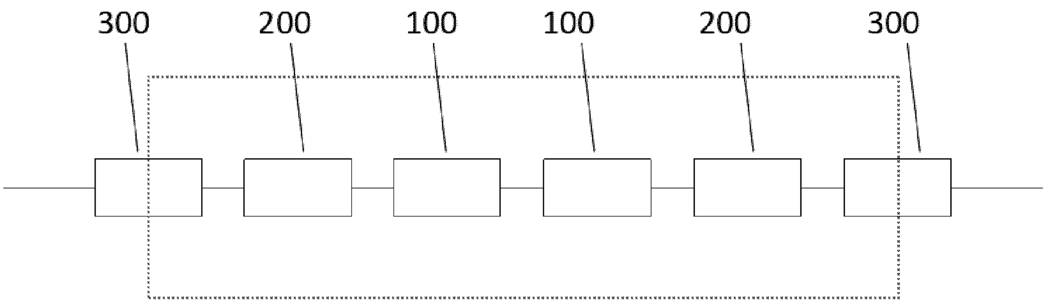

frequency selective surface unit 30
first bandpass stub 110
second bandpass stub 210
first bandstop stub 310
dielectric substrate 120

Fig. 3


300
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100
100
200
300

Fig. 4

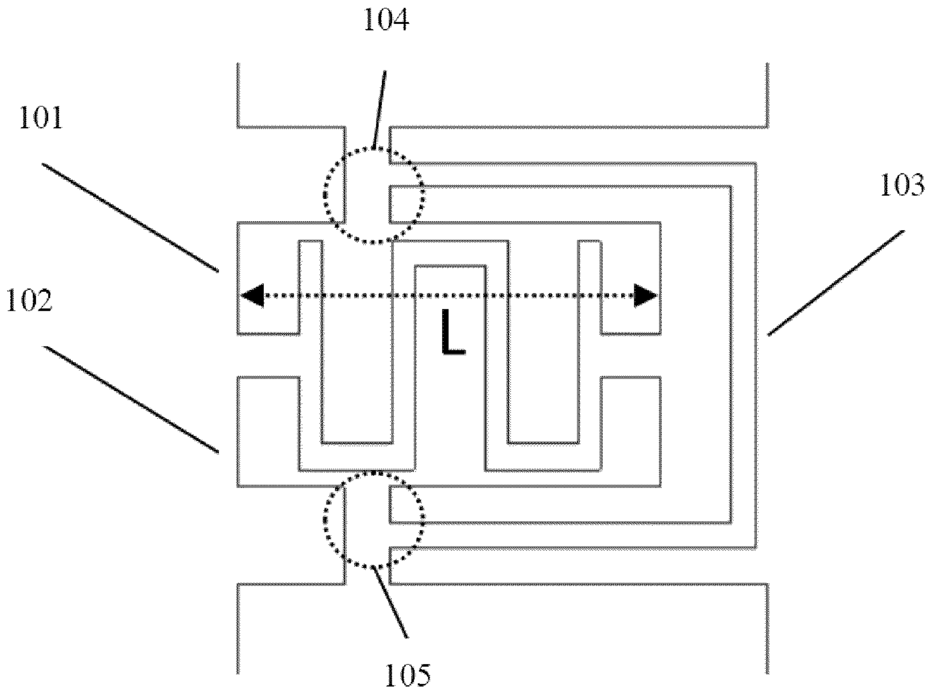


Fig. 5

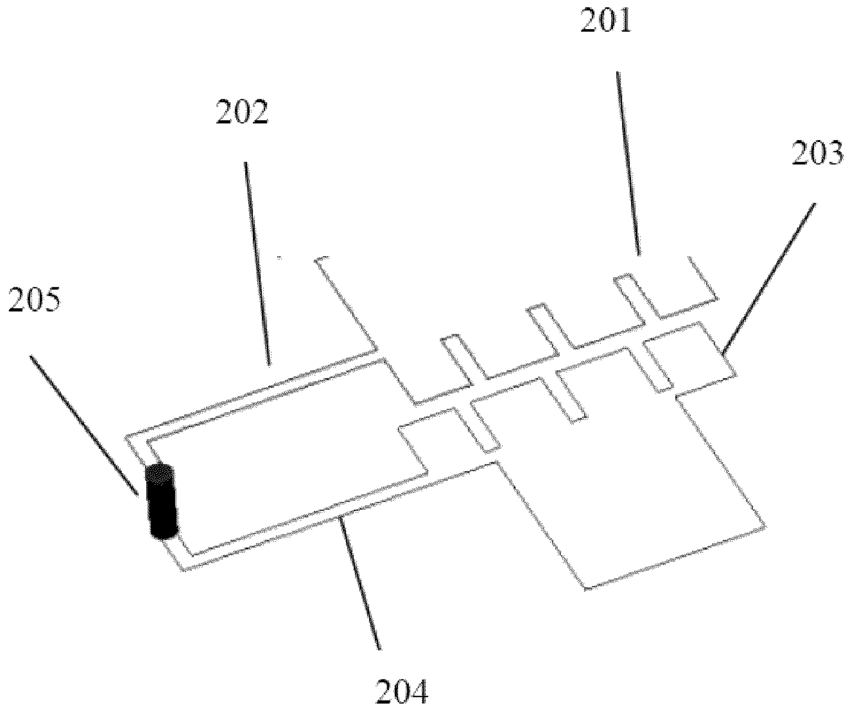


Fig. 6

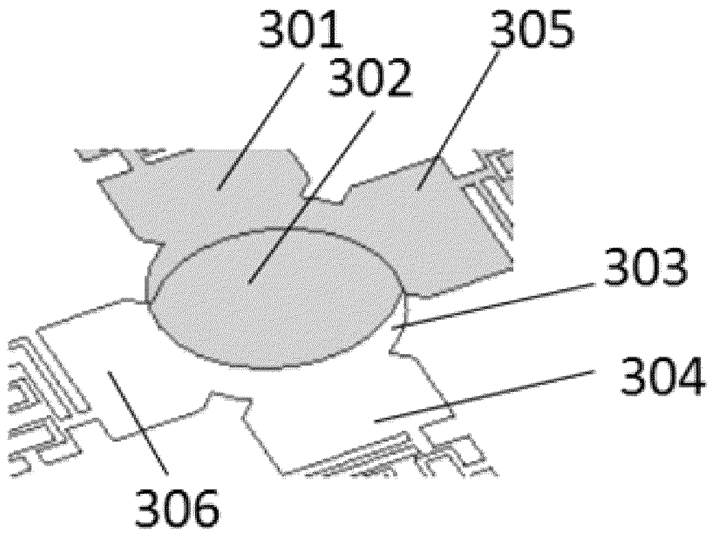

301
302
305
303
304
306

Fig. 7

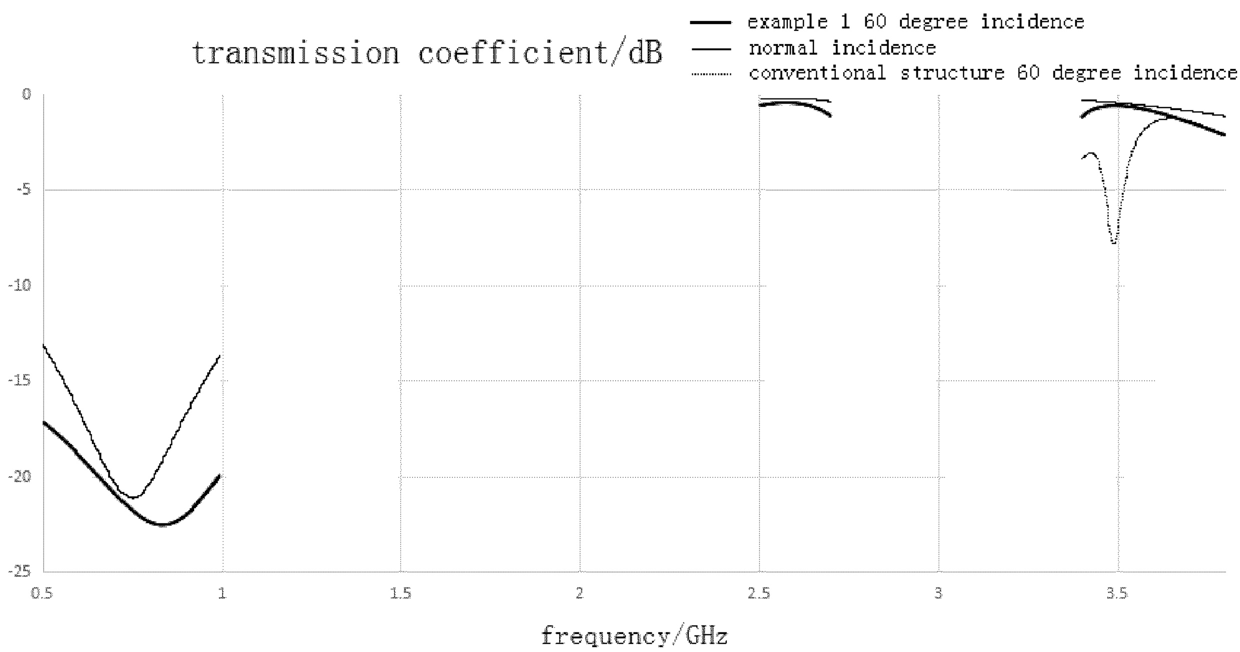

transmission coefficient/dB
example 1 60 degree incidence
normal incidence
conventional structure 60 degree incidence
0
-5
-10
-15
-20
-25
0.5
1
1.5
2
2.5
3
3.5
frequency/GHz

Fig. 8

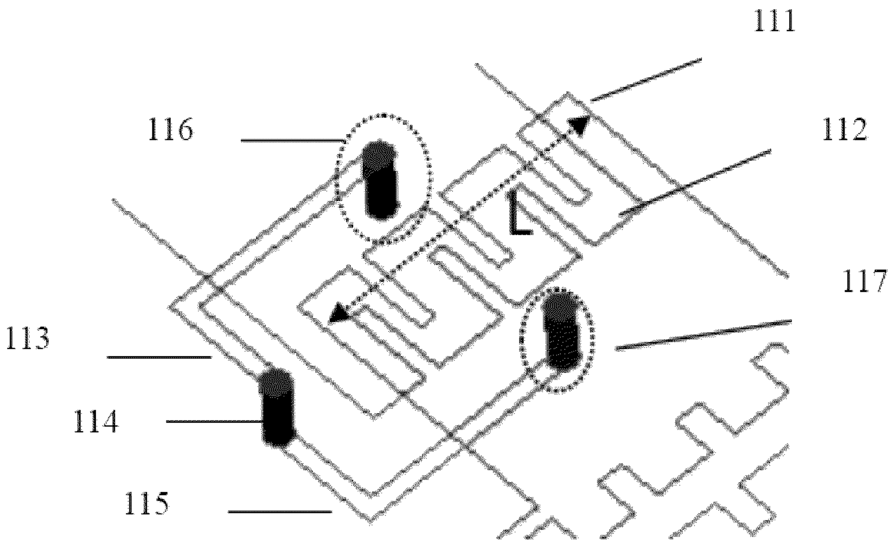


Fig. 9

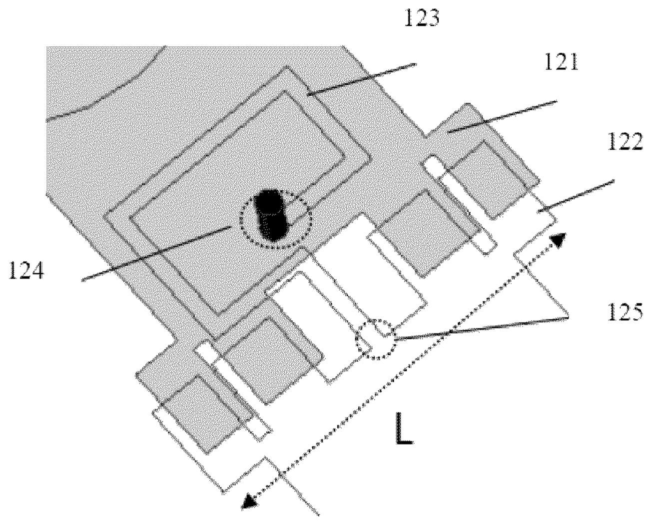
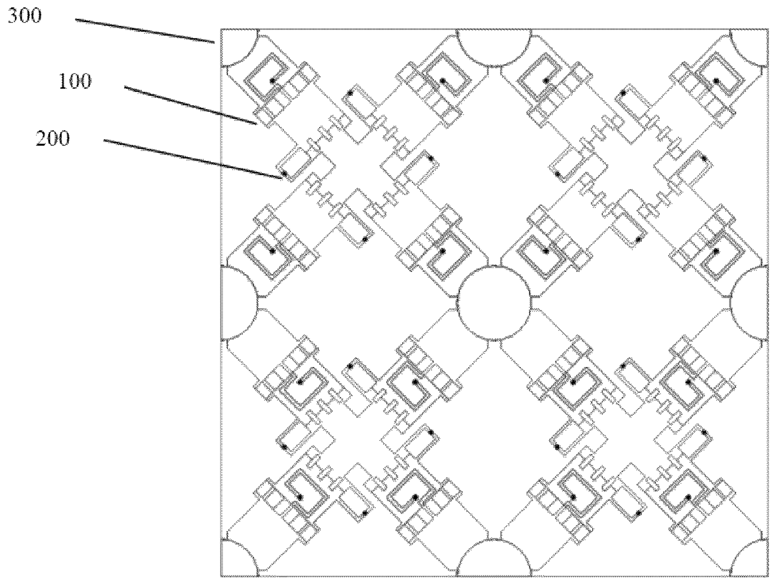


Fig. 10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100
200

Fig. 11

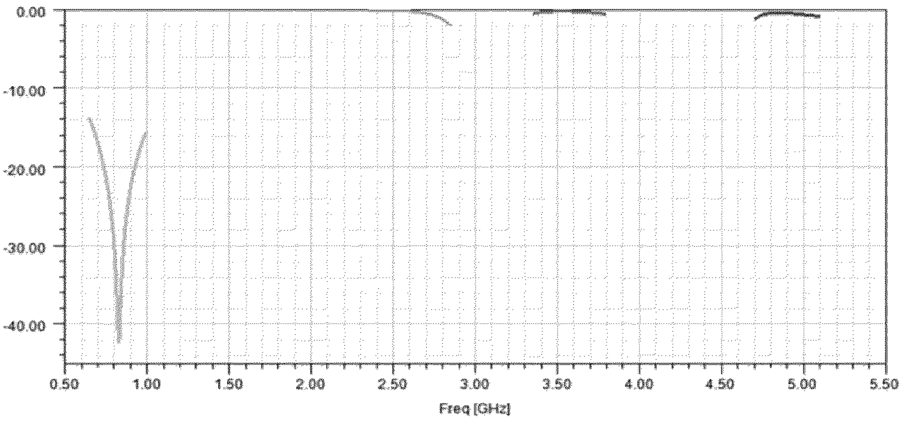
0.00
-10.00
-20.00
-30.00
-40.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
Freq [GHz]

Fig. 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2023/107304

A. CLASSIFICATION OF SUBJECT MATTER

H01Q 15/00(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: H01Q

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

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

CNTXT, ENTXTC: 电感, 电容, 频率选择, 面, 贴片, 通孔, 过孔; FSS: inductance, capacitance, frequency selection, surface, patch, via

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 114824812 A (NATIONAL UNIVERSITY OF DEFENSE TECHNOLOGY OF PLA) 29 July 2022 (2022-07-29) description, paragraphs 0041-0054, and figures 1-6	1-12
A	CN 108832303 A (XIDIAN UNIVERSITY et al.) 16 November 2018 (2018-11-16) entire document	1-12
A	CN 110718765 A (WUHAN LINGDOM TECH CO., LTD.) 21 January 2020 (2020-01-21) entire document	1-12
A	CN 114843725 A (JIANGSU VOCATIONAL COLLEGE OF ELECTRONICS AND INFORMATION) 02 August 2022 (2022-08-02) entire document	1-12
A	WO 2004013933 A1 (E-TENNA CORP.) 12 February 2004 (2004-02-12) entire document	1-12

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
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"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07 September 2023	**14 September 2023**

Name and mailing address of the ISA/CN	Authorized officer
China National Intellectual Property Administration (ISA/CN) **China No. 6, Xitucheng Road, Jimenqiao, Haidian District, Beijing 100088**	Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2023/107304

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
CN 114824812 A	29 July 2022	None	
CN 108832303 A	16 November 2018	None	
CN 110718765 A	21 January 2020	None	
CN 114843725 A	02 August 2022	None	
WO 2004013933 A1	12 February 2004	AU 2002323025 A1	23 February 2004

Form PCT/ISA/210 (patent family annex) (July 2022)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- CN 202211021655 **[0001]**