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(54) FREQUENCY SELECTIVE SURFACE AND SPATIAL FILTERING METHOD

(57) Provided are a frequency selective surface and a spatial filtering method. A frequency selective surface unit comprises: a first surface, composed of a plurality of first metal strips interleaved with one another; a second surface, composed of a plurality of second metal strips, wherein each of the second metal strips is provided with a second inter-strip gap, and metal strips at two sides of the second inter-strip gap are connected by means of a metal strip line, so as to form a parallel resonant LC circuit in an H frequency band; and a support plate, the first surface and the second surface being fixed on the same surface or front and back surfaces of the support plate.

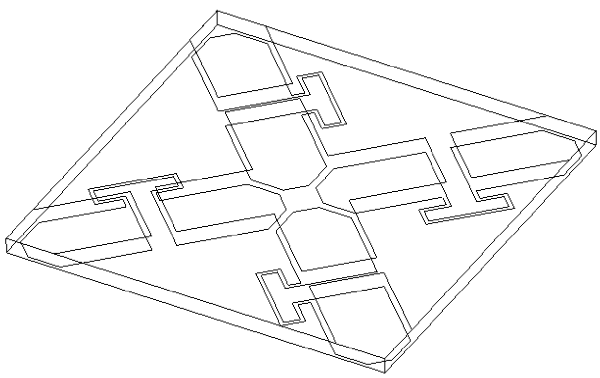

Fig. 8

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Description

Cross-Reference to Related Application

[0001] The present disclosure is based on Chinese patent application no. CN 202211021650.5 filed on August 24, 2022 and entitled "Frequency Selective Surface and Spatial Filtering Method", and claims priority to the patent application, the disclosure of which is incorporated in the present disclosure by reference in its entirety.

Technical Field

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

Background

[0003] The deployment of a 5G active antenna surface faces three major challenges: 1. a new site cannot be added; 2. a 5G active antenna surface cannot be additionally deployed at an existing site deployed with a 4G passive antenna surface; and 3. a 5G active antenna surface can be additionally deployed at an existing site, but the limited height constraints optimal signal coverage. To this end, a 4G passive antenna surface and 5G active antenna surface integration scheme, i.e. an A+P (Active plus Passive, A+P) antenna, is proposed. The A+P antenna is a multi-frequency shared-aperture antenna that uses an integrated interleaving scheme to embed the 5G active antenna surface into the back of the 4G passive antenna surface, so as to achieve integrated deployment. The A+P antenna may be aligned with existing networks in performance, and supports separate maintenance and independent deployment of an active antenna surface and a passive antenna surface, thereby greatly reducing operation costs and satisfying the requirements of smooth device upgrade.

[0004] In order to meet the A+P antenna performance, a frequency selective surface (FSS) needs to be designed to implement perfect integration of a passive antenna surface and an active antenna surface.

Summary

[0005] Embodiments of the present disclosure provide a frequency selective surface and a spatial filtering method, so as to at least solve the problem in the related art that a 4G passive antenna surface cannot be perfectly integrated with a 5G active antenna surface.

[0006] According to some embodiments of the present disclosure, a frequency selective surface unit is provided, comprising: a first surface, composed of a plurality of first metal strips interleaved with one another; a second surface, composed of a plurality of second metal strips, wherein each of the second metal strips is provided with a second inter-strip gap, and metal strips at two sides of the second inter-strip gap are connected by means of a metal strip line, so as to form a parallel resonant LC circuit in an H frequency band; and a support plate, the first surface and the second surface being fixed on the same surface or front and back surfaces of the support plate.

[0007] According to some other embodiments of the present disclosure, a frequency selective surface is further provided, which is formed by periodic extension of the described frequency selective surface unit.

[0008] According to still some other embodiments of the present disclosure, a spatial filtering method is further provided. The spatial filtering method is implemented using the described frequency selective surface, and comprises: L values or C values of a series resonant LC circuit and a parallel resonant LC circuit are adjusted, so as to control a transmission frequency band and a reflection frequency band of the frequency selective surface unit.

Brief Description of the Drawings

[0009]

Fig. 1 is a schematic diagram of the principle of an FSS-based A+P antenna scheme according to embodiments of the present disclosure;

Fig. 2 is a structural block diagram of a frequency selective surface unit according to embodiments of the present disclosure;

Fig. 3 is a structural block diagram of a first metal strip of a first surface according to embodiments of the present disclosure;

Fig. 4 is a structural block diagram of a second metal strip of a second surface according to embodiments of the present disclosure;

Fig. 5 is a flowchart of a spatial filtering method according to embodiments of the present disclosure;

Fig. 6 is a flowchart of a spatial filtering method according to embodiments of the present disclosure;

Fig. 7 is a schematic structural diagram of an upper surface and a lower surface of an FSS unit according to scenario embodiments of the present disclosure;

Fig. 8 is a side view of a perspective structure of an FSS unit according to scenario embodiments of the present disclosure;

Fig. 9 is a schematic structural diagram of an upper surface of an FSS according to scenario embodiments of the present disclosure;

Fig. 10 is a schematic structural diagram of a lower surface of an FSS according to scenario embodiments of the present disclosure;

Fig. 11 is a construction principle diagram of a four-order series-parallel resonant circuit according to scenario embodiments of the present disclosure;

Fig. 12 is a schematic diagram of the shape of an FSS unit according to embodiments of the present disclosure;

Fig. 13 is a schematic structural diagram of a multi-layer FSS according to scenario embodiments of the present disclosure;

Fig. 14 is a schematic structural diagram of a distributed LC circuit according to scenario embodiments of the present disclosure;

Fig. 15 is a schematic structural diagram of a distributed LC circuit according to scenario embodiments of the present disclosure;

Fig. 16 is a schematic structural diagram of a distributed LC circuit according to scenario embodiments of the present disclosure;

Fig. 17 is a schematic structural diagram of a distributed LC circuit according to scenario embodiments of the present disclosure;

Fig. 18 is a schematic structural diagram of a distributed LC circuit according to scenario embodiments of the present disclosure;

Fig. 19 is a schematic structural diagram of an FSS unit according to scenario embodiments of the present disclosure;

Fig. 20 is a schematic structural diagram of an FSS unit according to scenario embodiments of the present disclosure;

Fig. 21 is a schematic structural diagram of an FSS unit according to scenario embodiments of the present disclosure; and

Fig. 22 is a schematic structural diagram of an FSS unit according to scenario embodiments of the present disclosure.

Detailed Description of the Embodiments

[0010] Hereinafter, embodiments of the present disclosure are described in detail with reference to the accompanying drawings and in conjunction with the embodiments.

[0011] It should be noted that the terms "first", "second", etc. in the description, claims, and accompanying drawings of the present disclosure are used to distinguish similar objects, and are not necessarily used to describe a specific sequence or order.

[0012] An A+P antenna is a multi-frequency shared-aperture antenna that uses an integrated interleaving scheme to embed a 5G active antenna surface into the back of a 4G passive antenna surface, so as to achieve integrated deployment. The A+P antenna may be aligned with existing networks in performance, and supports separate maintenance and independent deployment of an active antenna surface and a passive antenna surface, thereby greatly reducing operation costs and satisfying the requirements of smooth device upgrade.

[0013] A frequency selective surface (FSS) is a periodic artificial electromagnetic material, and can regulate and control electromagnetic waves with specific frequencies or polarized electromagnetic waves. By using the filtering function of an FSS for spatial electromagnetic waves, reflection of low-frequency signals (690-960 MHz, L frequency band) and transmission of high-frequency signals (2490-2690 MHz or 3400-3800 MHz, H frequency band) can be realized. The FSS technology can meet the development requirements of A+P products, and achieve perfect integration of passive and active antenna surfaces.

[0014] Fig. 1 is a schematic diagram of the principle of an FSS-based A+P antenna scheme. As shown in Fig. 1, from top to bottom, a passive antenna surface working in an L frequency band, an FSS and an active antenna surface working in an H frequency band are respectively provided. The FSS has the characteristics of low-impedance and high-pass for spatial electromagnetic waves, and can be used as a reflector for the passive antenna surface and a radome for the active antenna surface. At the same time, the spatial filtering function of the FSS can reduce inter-frequency coupling between an L-band antenna and an H-band antenna, thereby improving the antenna performance. Finally, the FSS-based A+P antenna can ensure the independence of a 4G passive antenna surface and a 5G active antenna surface, i.e. support independent design, independent deployment, and independent maintenance of the active and passive antenna surfaces.

[0015] The present embodiment provides a frequency selective surface unit. Fig. 2 is a structural block diagram of a frequency selective surface unit according to embodiments of the present disclosure. As shown in Fig. 2, the frequency selective surface unit 20 comprises: a first surface 210, composed of a plurality of first metal strips interleaved with one another; a second surface 220, composed of a plurality of second metal strips, wherein each of the second metal strips is provided with a second inter-strip gap, and metal strips at two sides of the second inter-strip gap are connected by means of a metal strip line, so as to form a parallel resonant LC circuit in an H frequency band; and a support plate 230, wherein the first surface 210 and the second surface 220 may be fixed on the same surface or front and back surfaces of the support plate 230.

[0016] In the frequency selective surface unit provided in the foregoing embodiment of the present disclosure, the first surface is composed of a plurality of first metal strips interleaved with one another; the second surface is composed of a plurality of second metal strips, wherein each of the second metal strips is provided with a second inter-strip gap, and metal strips at two sides of the second inter-strip gap are connected by means of a metal strip line, so as to form a parallel resonant LC circuit in an H frequency band; and the first surface and the second surface are fixed on the same surface or front and back surfaces of the support plate, thereby solving the problem in the related art that a 4G passive antenna surface cannot be perfectly integrated with a 5G active antenna surface.

[0017] In some exemplary embodiments, first inter-strip gaps are distributed at two ends of each first metal strip, and in cases where the first surface and the second surface are fixed on the front and back surfaces of the support plate, the second inter-strip gaps are located in a preset area above or below the first inter-strip gaps, so as to form a series resonant LC circuit in an L frequency band.

[0018] In some embodiments of the present disclosure, the first inter-trip gaps may be symmetrically distributed at two ends of the first metal strip, and the second inter-trip gaps may be located right below the first inter-trip gaps. The positional relationship between the second inter-trip gaps and the first inter-trip gaps is not specifically limited, that is, the positional relationship between the first surface and the second surface is not limited. The second surface may be located right below the first surface, and may also be located right above the first surface; and the second surface may also be in the same layer as the first surface and distributed on the left side, the right side or the left and right sides of the first surface. The foregoing solution of the second surface being in the same layer as the first surface is only a change in the positional relationship, and the specific connection relationship and spatial coupling relationship involved may be the same as those when the second surface is located right below the first surface, that is, the series-parallel connection modes of elements for forming a parallel resonant LC circuit and a series resonant LC circuit are the same, which will not be further described herein.

[0019] In some exemplary embodiments, Fig. 3 is a structural block diagram of a first metal strip of a first surface according to embodiments of the present disclosure. As shown in Fig. 3, the first metal strip 30 further comprises: a first central metal strip 310 and two first side end metal strips 320, wherein the first central metal strip 310 is located in the middle of the first metal strip 30, and the two first side end metal strips 320 are respectively distributed at two ends of the first metal strip 30 and each forms a first inter-strip gap with the first central metal strip 310.

[0020] In some exemplary embodiments, Fig. 4 is a structural block diagram of a second metal strip of a second surface according to embodiments of the present disclosure. As shown in Fig. 4, the second metal strip 40 further comprises: two second side end metal strips 410, wherein the two second side end metal strips 410 are distributed at two sides of the second inter-strip gap and are connected by means of the metal strip line 420.

[0021] In some exemplary embodiments, the second inter-strip gaps being located in a preset area above or below the first inter-strip gaps so as to form a series resonant LC circuit in an L frequency band comprises: a first central metal strip 310, two first side end metal strips 320, two second side end metal strips 410 and a metal strip line 420 are connected in series, so as to form the series resonant LC circuit in the L frequency band.

[0022] In some exemplary embodiments, the first metal strips 30 and/or the second metal strips 40 are at least one of the following: elongated metal strip lines; bent metal strip lines; metal coils; and metal via holes. In some embodiments of the present disclosure, the elongated metal strip line refers to a metal strip line of which the length is greater than or equal to five times the width.

[0023] In some exemplary embodiments, the connection mode of the first metal strips 30 and the second metal strips 40 is one of the following: coplanar coupled line connection; non-coplanar coupled line connection; and interleaved line connection.

[0024] In some exemplary embodiments, the support plate is one of the following: a dielectric substrate; a ceramic; a sheet metal strip line; and a metal body.

[0025] According to some other embodiments of the present disclosure, a frequency selective surface is provided, which is formed by periodic extension of the described frequency selective surface unit.

[0026] In some exemplary embodiments, the frequency selective surface is one of the following: single-layer periodic extension of the frequency selective surface unit; double-layer periodic extension of the frequency selective surface unit; and multi-layer periodic extension of the frequency selective surface unit.

[0027] According to still some other embodiments of the present disclosure, a spatial filtering method is provided, which is implemented using the described frequency selective surface. Fig. 5 is a flowchart of a spatial filtering method according to embodiments of the present disclosure. As shown in Fig. 5, the flow comprises the following step:

step S502: L values or C values of a series resonant LC circuit and a parallel resonant LC circuit are adjusted, so as to control a transmission frequency band and a reflection frequency band of a frequency selective surface unit.

[0028] In some exemplary embodiments, Fig. 6 is a flowchart of a spatial filtering method according to embodiments of the present disclosure. As shown in Fig. 6, the flow comprises the following steps:

step S602: L values or C values of a series resonant

LC circuit and a parallel resonant LC circuit are adjusted, so as to control a transmission frequency band and a reflection frequency band of a frequency selective surface unit; and

step S604: the number of series resonant LC circuits and parallel resonant LC circuits are adjusted, so as to control a transmission bandwidth and a reflection bandwidth of the frequency selective surface unit.

[0029] A person skilled in the art should know that the execution order of the described steps may be interchanged, which is not specifically limited herein.

[0030] To make a person skilled in the art better understand the technical solutions of the present disclosure, hereinafter, the technical solutions will be described in conjunction with specific scenario embodiments. In some scenario embodiments of the present disclosure, the upper surface is the first surface, and the lower surface is the second surface.

Scenario embodiment I

[0031] The present scenario embodiment provides a low-impedance and high-pass FSS.

[0032] Fig. 7 is a schematic structural diagram of an upper surface and a lower surface of an FSS unit according to scenario embodiments of the present disclosure. As shown in Fig. 7, in the present scenario embodiment, the FSS unit comprises an upper surface 1, a dielectric substrate 2 and a lower surface 3, and the dielectric substrate 2 supports the upper surface 1 and the lower surface 3. The upper surface 1 is composed of two first metal strips 11 interleaved with one another; and from the center to the outer side, each first metal strip 11 sequentially comprises a first central metal strip 111 and first side end metal strips 112. The lower surface 3 is formed by rotation of four second metal strips 31, and each second metal strip 31 comprises second side end metal strips 311, 313 and a second central metal strip 312. The second metal strips 31 are located right below the gaps between the first central metal strips 111 and the first side end metal strips 112. That is, as shown in Fig. 7, the gaps between the second side end metal strips 311, 313 are exactly aligned with the gaps between the first central metal strips 111 and the first side end metal strips 112.

[0033] Fig. 8 is a side view of a perspective structure of an FSS unit according to scenario embodiments of the present disclosure. A person skilled in the art should know that in the present scenario embodiment, the second metal strips 31 are located right below the gaps between the first central metal strips 111 and the first side end metal strips 112, which is used to implement the positional relationship that the lower surface is located right below the upper surface; however, the upper surface and the lower surface are not limited to this positional relationship.

[0034] Each second central metal strip 312 has a width far less than the length, and may be equivalent to an inductor, for example, in the present embodiment, the range of "far less than" may be that the length of the metal strip is greater than or equal to five times the width; and the second side end metal strips 311, 313 are coupled to each other, and may be equivalent to a capacitor. The second central metal strip 312 and the second side end metal strips 311, 313 are connected in parallel, and may form a parallel resonant LC circuit in an H frequency band.

[0035] The second side end metal strips 311, 313 are respectively coupled to the first central metal strip 111 and the first side end metal strip 112, and may be equivalent to capacitors; and the first central metal strip 111, the first side end metal strip 112, and the second central metal strip 312 may be equivalent to inductors. The first central metal strip 111, the first side end metal strips 112, the second side end metal strips 311, 313 and the second central metal strip 312 are connected in series, and may form a series resonant LC circuit in an L frequency band.

[0036] Fig. 9 is a schematic structural diagram of an upper surface of an FSS according to scenario embodiments of the present disclosure; and Fig. 10 is a schematic structural diagram of a lower surface of the FSS according to scenario embodiments of the present disclosure. As shown in Figs. 9 and 10, the FSS is formed by periodic extension of the FSS unit shown in Fig. 7.

[0037] In the H frequency band, the parallel resonant LC circuit is open to generate a reflection zero, so as to realize transmission of electromagnetic waves; and in the L frequency band, the series LC circuit is short-circuited to generate a transmission zero, so as to realize reflection of electromagnetic waves.

[0038] Fig. 11 is a construction principle diagram of a four-order series-parallel resonant circuit according to scenario embodiments of the present disclosure. As shown in Fig. 11, one-order, two-order or multi-order series-parallel resonant circuits can be constructed by increasing the number of metal strips 11.

[0039] Fig. 12 is a schematic diagram of the shape of an FSS unit according to scenario embodiments of the present disclosure. As shown in Fig. 12, the FSS unit is a rectangular FSS unit. A person skilled in the art should know that the shape of the FSS unit provided in some embodiments of the present disclosure may be a square, a rectangle, a triangle, or a polygon, which is not limited herein.

[0040] Fig. 13 is a schematic structural diagram of a multi-layer FSS according to scenario embodiments of the present disclosure. As shown in Fig. 13, the FSS may have a single-layer structure, a two-layer structure and a multi-layer structure.

Scenario embodiment II

[0041] The FSS provided in some embodiments of the present disclosure realizes spatial filtering with low-impedance and high-pass characteristics by designing series LC circuits in an L frequency band and parallel LC circuits in an H frequency band. The series/parallel LC circuits and the equivalent capacitor and inductor elements are not limited to the forms described in scenario embodiment I, for example, the inductors may be designed as elongated straight lines, bent lines, coils, metal via holes, etc.; and the capacitors may be designed as coplanar coupled lines, non-coplanar coupled lines, interleaved lines, etc. Hereinafter, several examples of the structures of series-parallel LC circuits are provided, but they are only described as examples, and are not specifically limited thereto.

[0042] Fig. 14 is a schematic structural diagram of a distributed LC circuit according to scenario embodiments of the present disclosure. As shown in Fig. 14, the distributed LC circuit comprises upper-layer and lower-layer metal strip lines, wherein a coupling region of the upper-layer metal strip line and the lower-layer metal strip line is equivalent to a capacitor, and the upper metal strip line is equivalent to an inductor. The structure can be regarded as a series LC circuit, and can provide a transmission zero in the L frequency band.

[0043] Fig. 15 is a schematic structural diagram of a distributed LC circuit according to scenario embodiments of the present disclosure. As shown in Fig. 15, the distributed LC circuit comprises a single-layer metal strip line, wherein the bent thin line in the middle is equivalent to an inductor, and wide lines on two sides are equivalent to a capacitor (it should be noted that the capacitor may be very small, and the corresponding line width is very narrow). The structure can be regarded as a parallel LC circuit, and can provide a reflection zero in the H frequency band.

[0044] Fig. 16 is a schematic structural diagram of a distributed LC circuit according to scenario embodiments of the present disclosure. As shown in Fig. 16, the distributed LC circuit comprises upper-layer and lower-layer metal strip lines, wherein the bent thin line in the middle of the lower-layer metal strip line is equivalent to an inductor, and metal strip lines on two sides of a thin seam are equivalent to a capacitor, and the two form a parallel LC circuit; and a coupling region of the upper-layer metal strip line and the lower-layer metal strip line is equivalent to a capacitor, and the upper metal strip line is equivalent to an inductor. The structure can be regarded as a parallel LC circuit and a series LC circuit, and can provide a transmission zero in the L frequency band and a reflection zero in the H frequency band.

[0045] Fig. 17 is a schematic structural diagram of a distributed LC circuit according to scenario embodiments of the present disclosure. As shown in Fig. 17, the distributed LC circuit comprises upper-layer and lower-layer metal strip lines, wherein the bent thin line at one side of the lower-layer metal strip line is equivalent to an inductor, and metal strip lines on two sides of a wide seam are equivalent to a capacitor, and the two form a parallel LC circuit; and a coupling region of the upper-layer metal strip line and the lower-layer metal strip line is equivalent to a capacitor, and the upper-layer metal strip line is equivalent to an inductor. The structure can be regarded as a parallel LC circuit and a series LC circuit, and can provide a transmission zero in the L frequency band and a reflection zero in the H frequency band.

[0046] Fig. 18 is a schematic structural diagram of a distributed LC circuit according to scenario embodiments of the present disclosure. As shown in Fig. 18, the distributed LC circuit comprises a single-layer metal strip line, wherein 1/4 wavelength open stub lines on two sides respectively form an equivalent inductor, and two stub lines are coupled with a metal strip line in the middle to form equivalent capacitors. The structure can be regarded as a parallel LC circuit, and can provide a reflection zero in the H frequency band.

[0047] A person skilled in the art should know that the distributed LC circuit structures provided above can be used to replace the overlapping part of the projections of the metal wires or metal strips on the upper and lower surfaces of the FSS unit in the direction perpendicular to the dielectric substrate.

Scenario embodiment III

[0048] The present scenario embodiment provides a spatial filtering method. The resonant frequency of a parallel LC resonant circuit and a series LC resonant circuit can be changed by adjusting L values or C values, so as to control a transmission frequency band and a reflection frequency band; and N series resonant circuits and M parallel resonant circuits are constructed (N and M being greater than or equal to 1), and a transmission bandwidth and a reflection bandwidth can be respectively increased by increasing the value of N or M.

[0049] Fig. 19 is a schematic structural diagram of an FSS unit according to scenario embodiments of the present disclosure. As shown in Fig. 19, each of the two orthogonal metal strips of the FSS unit has four parallel LC circuits and two series LC circuits, and can provide four reflection zeros in the H frequency band and two transmission zeros in the L frequency band.

Scenario embodiment IV

[0050] Fig. 20 is a schematic structural diagram of an FSS unit according to scenario embodiments of the present disclosure. As shown in Fig. 20, each of the two orthogonal metal strips of the FSS unit has four parallel LC circuits and two series LC circuits, and can provide four reflection zeros in the H frequency band and two transmission zeros in the L frequency band. The parallel LC circuit is formed by a bent inductive line and thin wires at two ends. As the thin lines at two ends have a narrow width, the capacitance thereof is small. Although the parallel LC circuit is approximately a pure inductor, it still relates to a parallel LC circuit in a strict sense.

[0051] Fig. 21 is a schematic structural diagram of an FSS unit according to scenario embodiments of the present disclosure. As shown in Fig. 21, each of the two orthogonal metal strips of the FSS unit has four parallel LC circuits and two series LC circuits, and can provide four reflection zeros in the H frequency band and two transmission zeros in the L frequency band. The parallel LC circuit is formed by a bent inductive line and thin wires at two ends. As the thin lines at two ends have a narrow width, the capacitance thereof is small. Although the parallel LC circuit is approximately a pure inductor, it still relates to a parallel LC circuit in a strict sense.

[0051] Fig. 21 is a schematic structural diagram of an FSS unit according to scenario embodiments of the present disclosure; and Fig. 22 is a schematic structural diagram of an FSS unit according to scenario embodiments of the present disclosure.

[0052] According to the schematic structural diagram of the FSS unit provided in the scenario embodiments above, a person skilled in the art should know that the FSS provided in some embodiments of the present disclosure has a plurality of structure implementation forms.

[0053] In some embodiments of the present disclosure, by constructing on a periodic metal strip a distributed LC circuit that has a series resonance characteristic in the L frequency band and a parallel resonance characteristic in the H frequency band, a transmission zero and a reflection zero are respectively created in the L frequency band and the H frequency band, thereby achieving the functions of electromagnetic wave reflection in the L frequency band and electromagnetic wave transmission in the H frequency band. By using the method, not only can the characteristics of low-impedance and high-pass for spatial electromagnetic waves be obtained, but also electromagnetic scattering in the H frequency band can be suppressed, thereby ensuring that an antenna working in the H frequency band achieves an excellent conformal radiation pattern effect.

[0054] In conclusion, the FSS provided in some embodiments of the present disclosure has the following features: 1). the FSS can be applied to different carrier materials such as a dielectric substrate, a ceramic, a sheet metal strip line and a metal body; 2) the FSS may have a planar structure or a three-dimensional structure; 3) the FSS may have a single-layer structure or a multi-layer structure; 4) the shape of a unit may be a square, a rectangle, a triangle or a polygon; 5) a plurality of series or parallel resonant circuits may be constructed to obtain one or more transmission zeros or reflection zeros, thereby expanding the stopband and passband bandwidths; 6) only a parallel resonant circuit may be constructed to obtain an optimal reflection zero; and 7) dual-polarized, single-polarized and circularly-polarized electromagnetic waves may be supported.

[0055] The FSS designed according to some embodiments of the present disclosure can realize reflection with a relative bandwidth greater than 35% in the L frequency band, the reflection coefficient being greater than -0.2 dB, and can realize transmission with a relative bandwidth greater than 45% in the H frequency band, the transmission coefficient being greater than -0.3 dB. The frequency ratio of the L frequency band to the H frequency band can reach a minimum of 1.5:1 and a maximum of 5:1. In joint simulation with passive antennas in the L frequency band and active antennas in the H frequency band, the gain of a passive antenna surface in the L frequency band is only reduced by 0.2 dB, and the average gain of the active antennas in the H frequency band is not reduced.

[0056] The FSS provided in the embodiments of the present disclosure is applicable to various specifications and models of active and passive integrated base stations and antenna products, and may be specifically used in the following scenarios: 1. a new site cannot be added; 2. a 5G antenna surface site cannot be added due to factors such as limited wind load; and 3. due to the effect of an early 4G antenna surface, the height of a 5G active antenna surface is relatively low or there are sites with line-of-sight obstructions.

[0057] According to the FSS provided in some embodiments of the present disclosure, a transmission zero and a reflection zero are respectively obtained by constructing a low-frequency series LC circuit and a high-frequency parallel LC circuit in a metal strip, so as to achieve a low-impedance and high-pass filtering effect for spatial electromagnetic waves; and at the same time, on the basis of the FSS design method, a plurality of FSS unit embodiments are provided. The optimal embodiment uses a double-layer structure, which has extremely low transmission/reflection losses and good spatial dispersion characteristics, and can effectively suppress secondary radiation of an induced current in a wave-transmitting frequency band, thereby ensuring antenna surface air interface radiation characteristics. The frequency selective surface has the functions of reflecting low-frequency electromagnetic waves and transmitting high-frequency electromagnetic waves, can suppress inter-frequency coupling while implementing aperture sharing of multi-frequency antennas, and ensure independent deployment and separate maintenance of the multi-frequency antennas.

[0058] The content above merely relates to preferred embodiments of the present disclosure and is not intended to limit embodiments of the present disclosure. For a person skilled in the art, embodiments of the present disclosure may have various modifications and variations. Any modifications, equivalent replacements, improvements, etc. made within the principle of embodiments of the present disclosure shall all fall within the scope of protection of embodiments of the present disclosure.

Claims

1. A frequency selective surface unit, comprising:

a first surface, composed of a plurality of first metal strips interleaved with one another;
a second surface, composed of a plurality of second metal strips, wherein each of the second metal strips is provided with a second inter-strip gap, and metal strips at two sides of the second inter-strip gap are connected by means of a metal strip line, so as to form a parallel resonant LC circuit in an H frequency band; and
a support plate, the first surface and the second surface being fixed on the same surface or front and back surfaces of the support plate.

2. The frequency selective surface unit according to claim 1, wherein first inter-strip gaps are distributed at two ends of each of the first metal strips, and in cases where the first surface and the second surface are fixed on the front and back surfaces of the support plate, the second inter-strip gaps are located in a preset area above or below the first inter-strip gaps, so as to form a series resonant LC circuit in an L frequency band.

3. The frequency selective surface unit according to claim 1, wherein the first metal strips each comprise: a first central metal strip and two first side end metal strips; and the first central metal strip is located in the middle of the first metal strip, and the two first side end metal strips are respectively distributed at two ends of the first metal strip and each forms a first inter-strip gap with the first central metal strip.

4. The frequency selective surface unit according to claim 1, wherein the second metal strips each comprise:
two second side end metal strips, and the two second side end metal strips are distributed at two sides of the second inter-strip gap and are connected by means of the metal strip line.

5. The frequency selective surface unit according to claim 2, wherein the second inter-strip gaps being located in a preset area above or below the first inter-strip gaps so as to form a series resonant LC circuit in an L frequency band comprises:
a first central metal strip, two first side end metal strips, two second side end metal strips and the metal strip line are connected in series, so as to form the series resonant LC circuit in the L frequency band.

6. The frequency selective surface unit according to claim 1, wherein the first metal strips and/or the second metal strips are at least one of the following:

elongated metal strip lines;
bent metal strip lines;
metal coils; and
metal via holes.

7. The frequency selective surface unit according to claim 1, wherein the connection mode of the first metal strips and the second metal strips is one of the following:

coplanar coupled line connection;
non-coplanar coupled line connection; and
interleaved line connection.

8. The frequency selective surface unit according to claim 1, wherein the support plate is one of the following:

a dielectric substrate;
a ceramic;
a sheet metal strip line; and
a metal body.

9. A frequency selective surface, formed by periodic extension of the frequency selective surface unit according to any one of claims 1-8.

10. The frequency selective surface according to claim 9, wherein the frequency selective surface comprises one of the following:

single-layer periodic extension of the frequency selective surface unit;
double-layer periodic extension of the frequency selective surface unit; and
multi-layer periodic extension of the frequency selective surface unit.

11. A spatial filtering method, implemented using the frequency selective surface according to claim 10, comprising:
adjusting L values or C values of a series resonant LC circuit and a parallel resonant LC circuit, so as to control a transmission frequency band and a reflection frequency band of the frequency selective surface unit.

12. The method according to claim 11, further comprising:
adjusting the number of series resonant LC circuits and parallel resonant LC circuits, so as to control a transmission bandwidth and a reflection bandwidth of the frequency selective surface unit.

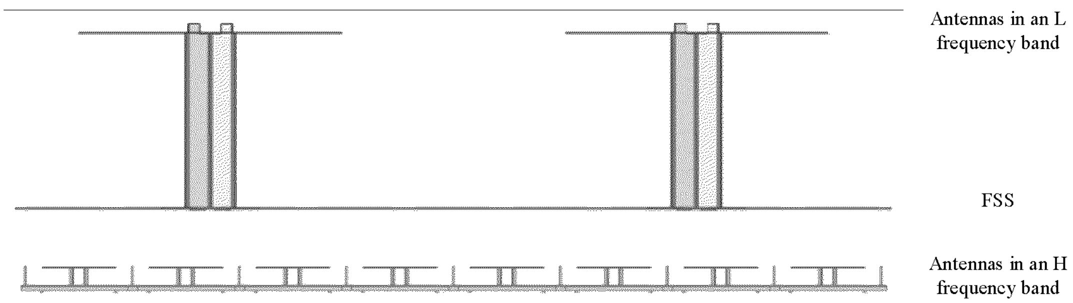

Fig. 1

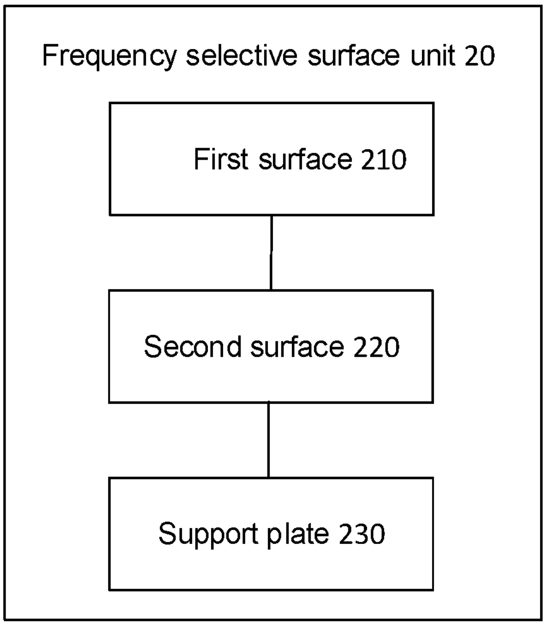

Fig. 2

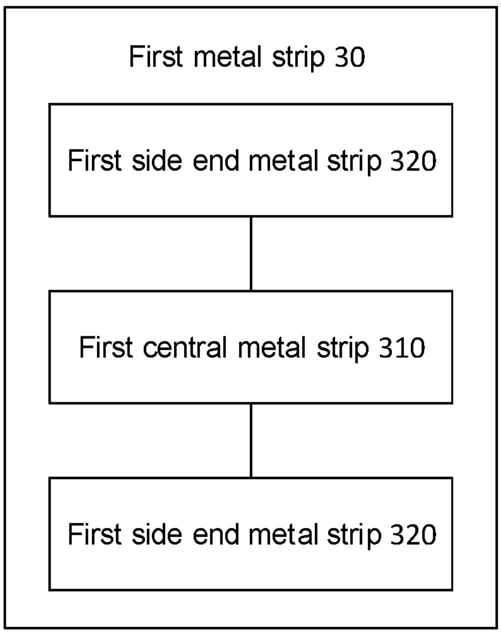

Fig. 3

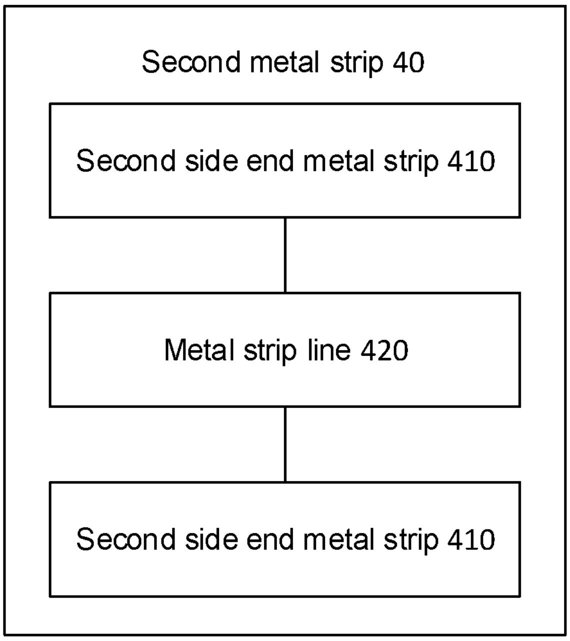

Fig. 4

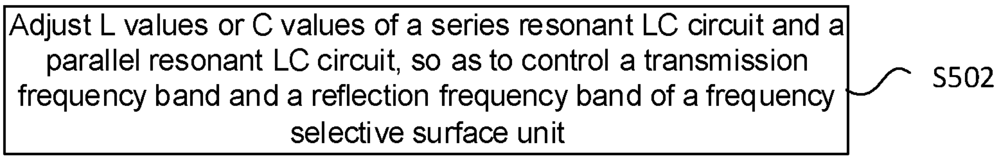

Fig. 5

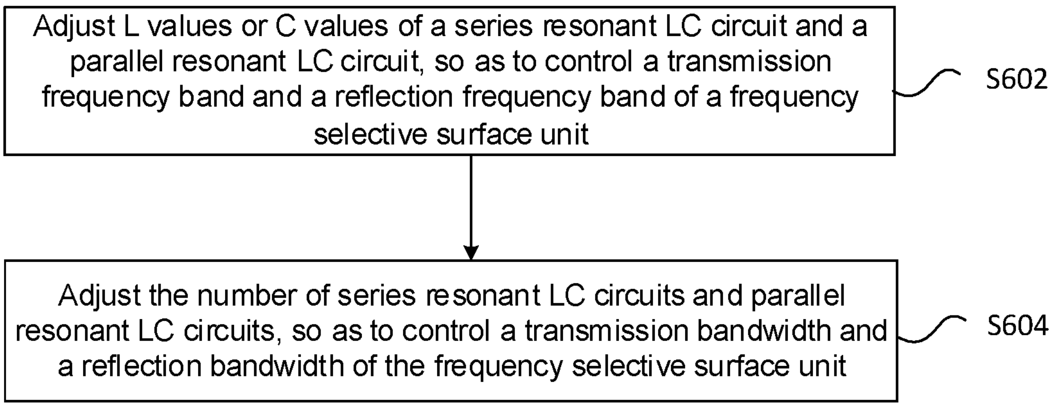

Fig. 6

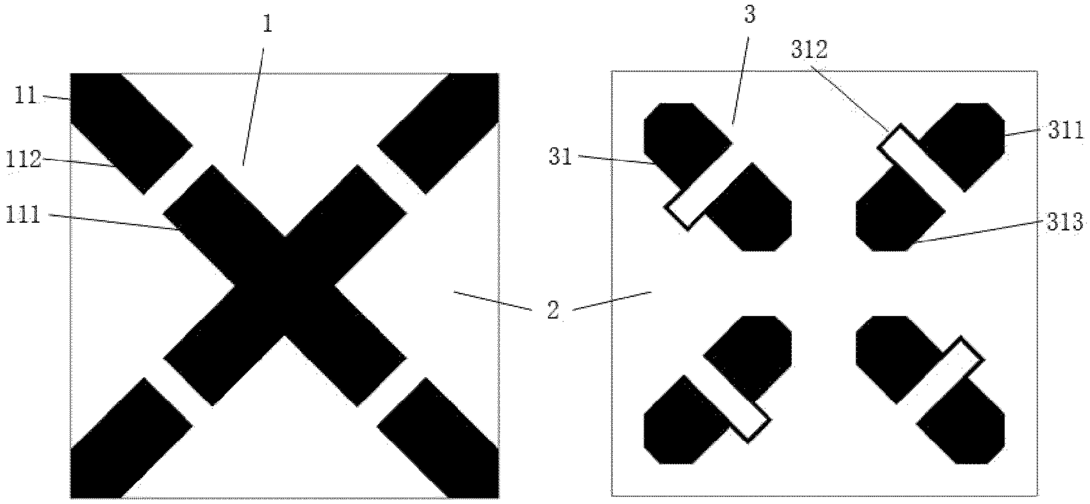

Fig.7

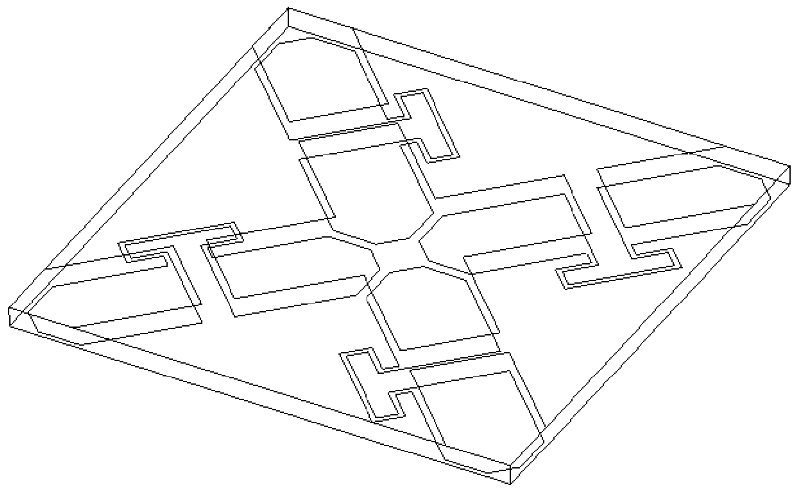

Fig. 8

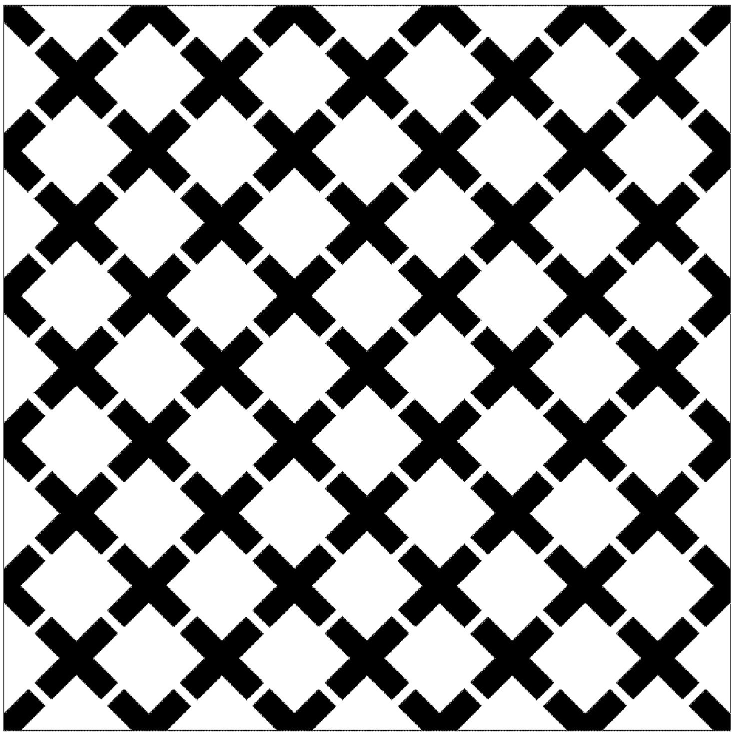

Fig. 9

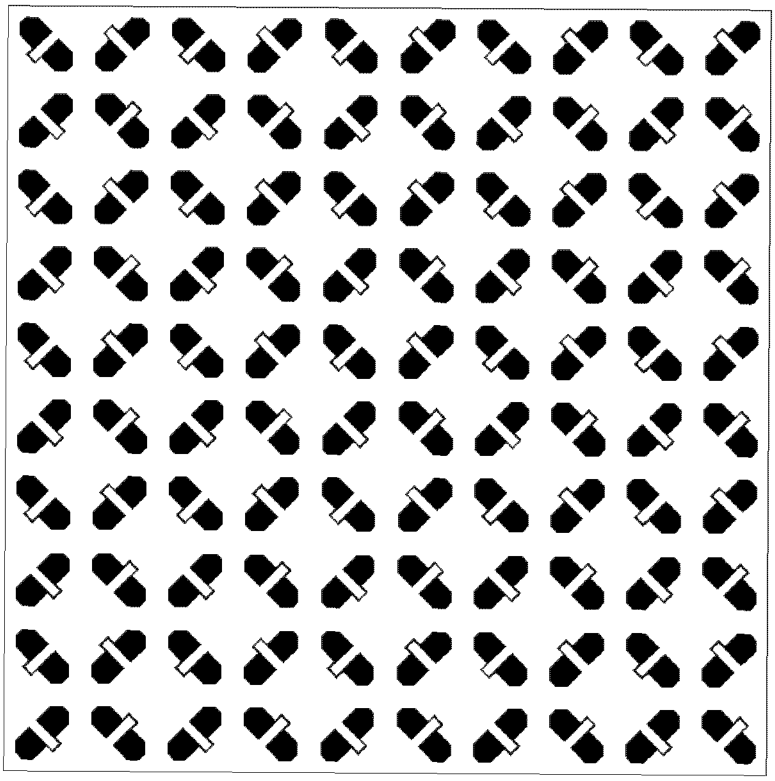

Fig. 10

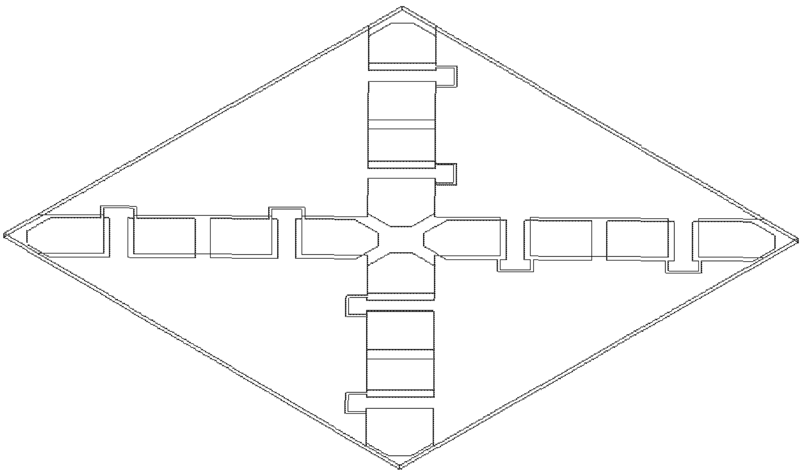

Fig. 11

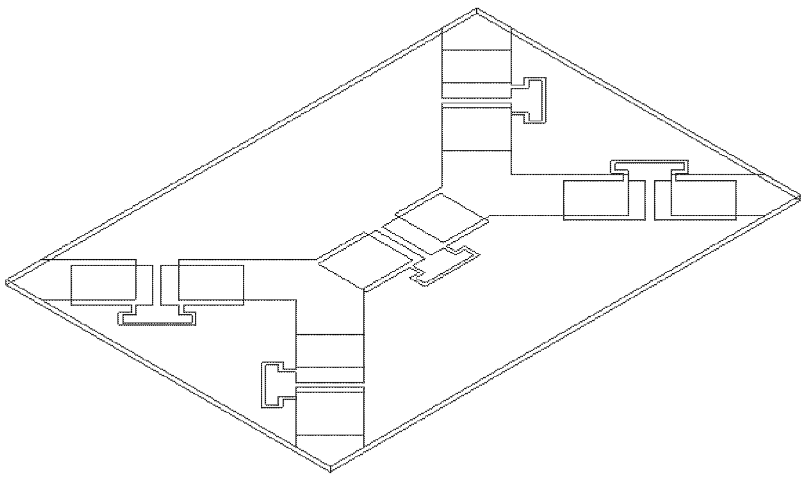

Fig. 12

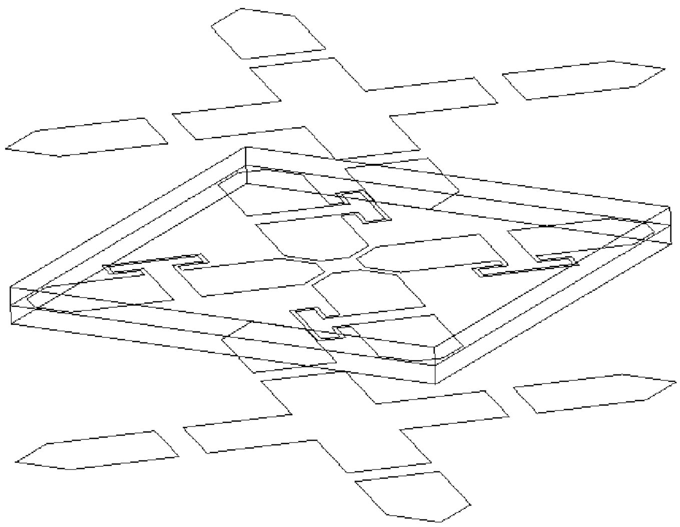

Fig. 13

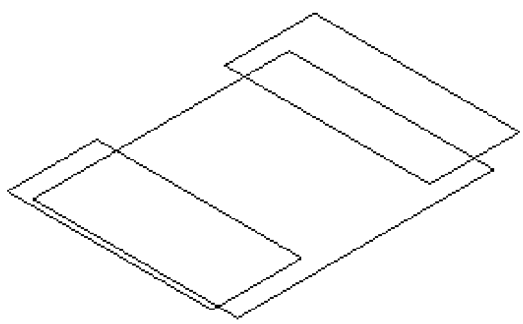

Fig. 14

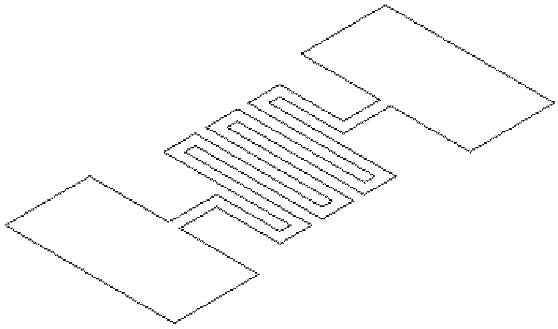

Fig. 15

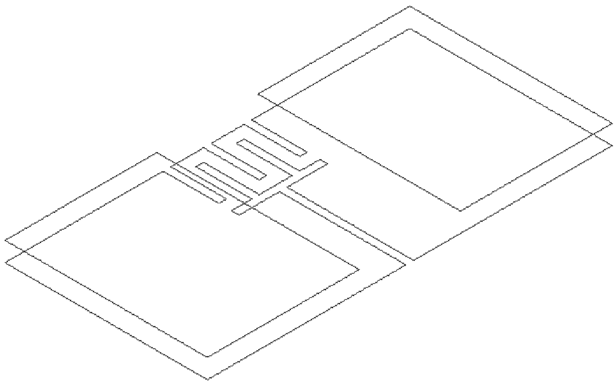

Fig. 16

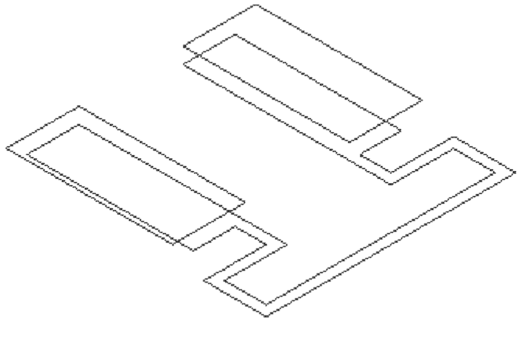

Fig.17

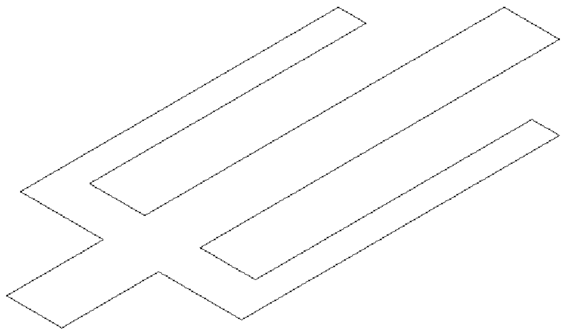

Fig. 18

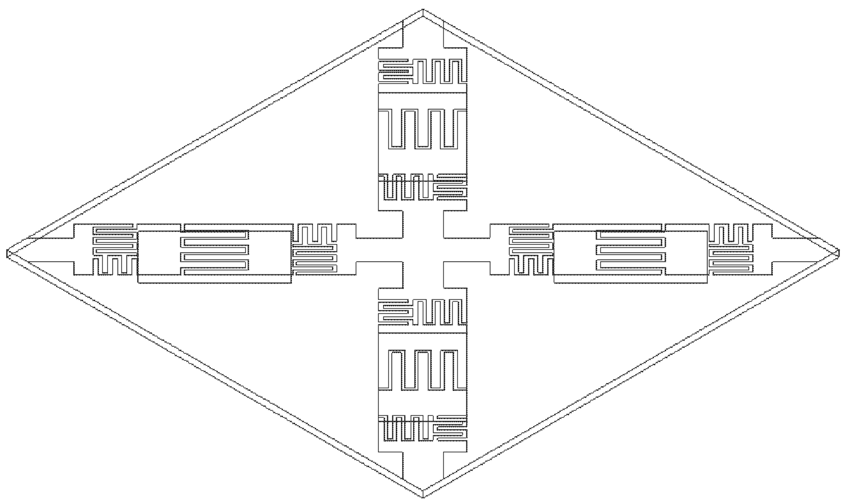

Fig. 19

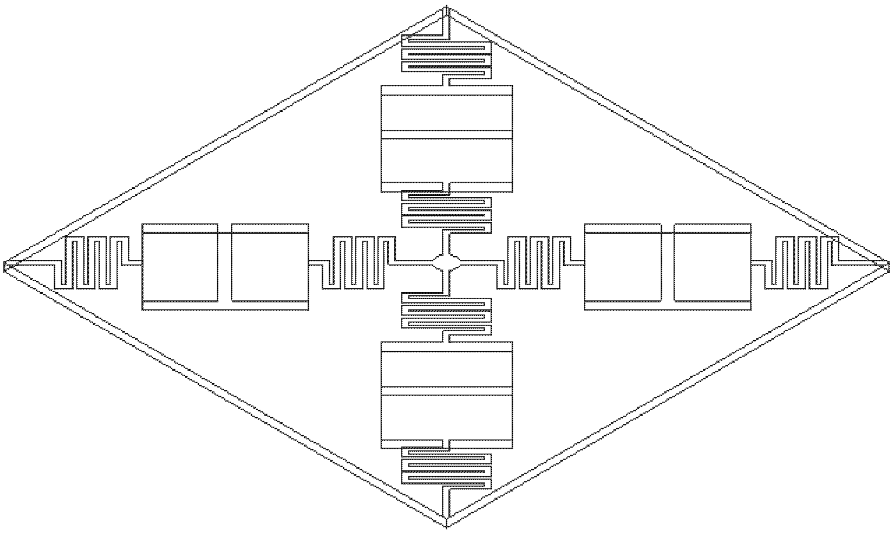

Fig. 20

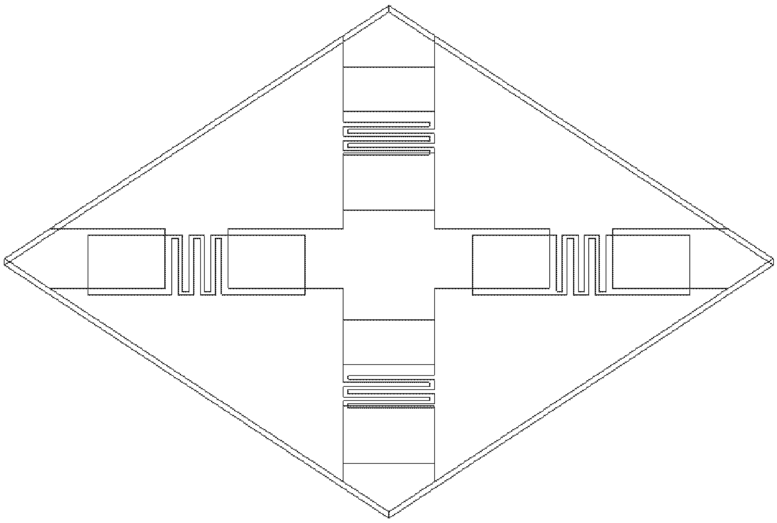

Fig. 21

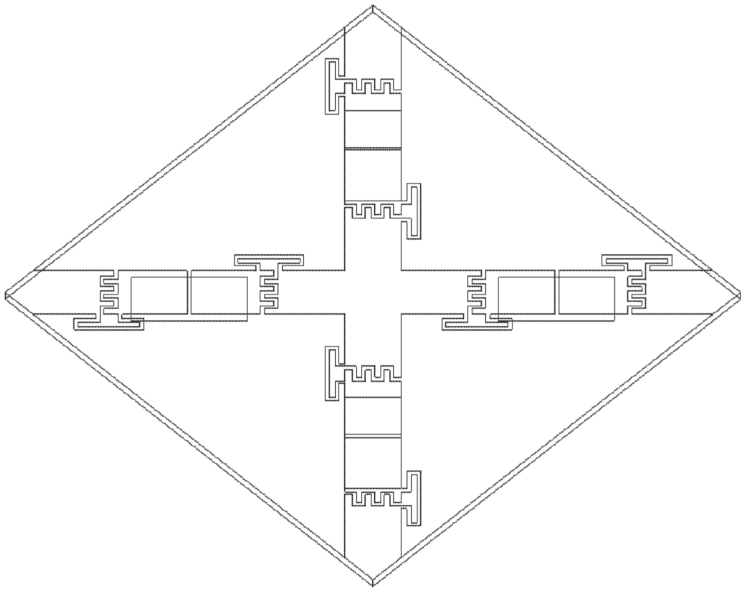

Fig. 22

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2023/108731

A. CLASSIFICATION OF SUBJECT MATTER

H01Q15/00(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 H01P

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; ENTXT; WPABS; DWPI; VEN; VCN; IEEE; CNKI: 频率选择, 表面, 金属, 条带, 第一, 第二, 间隙, 缝隙, 电感, 电容, 并联, 谐振; frequency select+, surface, FSS, metal, strip, first, second, gap, inductance, capacitance, parallel, resonance, LC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CN 215680980 U (COMBA TELECOM TECHNOLOGY (GUANGZHOU) CO., LTD. et al.) 28 January 2022 (2022-01-28) description, paragraphs 41-46, and figures 1-3	1-12
Y	CN 111786122 A (NATIONAL UNIVERSITY OF DEFENSE TECHNOLOGY OF PLA) 16 October 2020 (2020-10-16) description, paragraphs 16-23, and figures 1-3	1-12
Y	US 2003142036 A1 (DANIELS J S et al.) 31 July 2003 (2003-07-31) description, paragraphs 47-73, and figures 1-27B	2, 3, 5-8, 10-12
A	CN 103490175 A (MOBI ANTENNA TECHNOLOGIES (SHENZHEN) CO., LTD. et al.) 01 January 2014 (2014-01-01) entire document	1-12
A	CN 110416735 A (XIDIAN UNIVERSITY) 05 November 2019 (2019-11-05) entire document	1-12
A	US 2003071763 A1 (ACTIONTEC ELECTRONICS, INC.) 17 April 2003 (2003-04-17) entire document	1-12

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

* Special categories of cited documents:
- “A” document defining the general state of the art which is not considered to be of particular relevance
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- “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
18 September 2023	**19 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/CN2023/108731

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
CN 215680980 U	28 January 2022	None	
CN 111786122 A	16 October 2020	None	
US 2003142036 A1	31 July 2003	None	
CN 103490175 A	01 January 2014	None	
CN 110416735 A	05 November 2019	None	
US 2003071763 A1	17 April 2003	US 7071889 B2	04 July 2006

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 202211021650 **[0001]**