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(54) Title: METAMATERIAL BASED REFLECTIVE UNIT CELL FO REFLECTIVE SURFACES AND METHOD OF MANUFACTURING THEREOF

(57) Abstract: A reflective meta-surface (102) and a method (500) of manufacturing the reflective meta-surface (102) is provided. The reflective meta-surface (102) comprises a plurality of unit cells (112) arranged in a pre-defined pattern. The plurality of unit cells (112) is formed by disposing a loading plane (206) on a first top surface (204) of a first dielectric substrate (202). A second dielectric substrate (211) is disposed on the first top surface (204) of the first dielectric substrate (202) sandwiching the loading plane (206). Further, disposing a conducting plane (216) on a second top surface (212) of the second dielectric substrate (211). The conducting plane (216) is a negative conjugate of the loading plane (206).

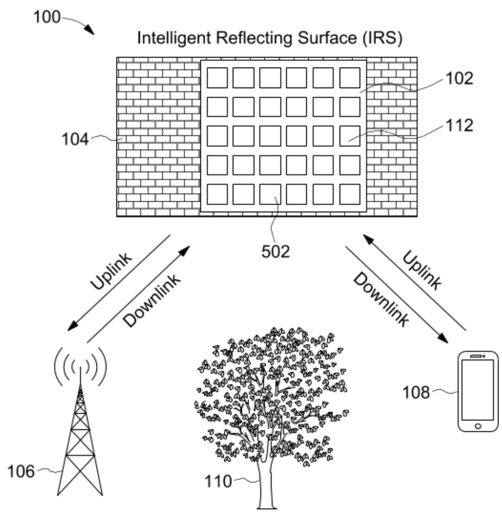

FIG. 1

FORM 2

THE PATENTS ACT 1970
(39 OF 1970)
&
The Patent Rules, 2003

Complete Specification

(See Section 10 and Rule 13)

1. TITLE OF THE INVENTION

METAMATERIAL BASED REFLECTIVE UNIT CELL FOR INTELLIGENT REFLECTIVE SURFACES AND METHOD OF MANUFACTURING THEREOF

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3. PREAMBLE TO THE DESCRIPTION

COMPLETE

The following specification particularly describes the invention and the manner in which it is to be performed.

DESCRIPTION

Technical Field

[001] This disclosure relates generally to reflective surfaces and more particularly to metamaterial based reflective unit cell for intelligent reflective surfaces.

BACKGROUND

[002] Line of sight (LOS) wireless propagation environment is an important factor to ensure an effective wireless communication in 5G and beyond networks. 5G and beyond networks offer various advantages such as ultra-high data rate and energy efficiency, global coverage, connectivity, extremely high reliability, and low latency. In real-world deployment, obstructions like trees, buildings, or fog can block or degrade microwave data transmissions. Since 5G and beyond networks are based on millimeter-wave and terahertz bands, there is an increase in path loss as the wavelengths decrease. Therefore, the development of propagation and channel models for designing and planning the new emerging wireless networks, considering the patterns and parameters (i.e., gain, beamwidth, radiation/reception directions) of the antenna systems, is important. Some solutions include deployment of more active nodes and using more antennas (i.e., super MIMO) so as to compensate for their higher propagation loss over distance. To ensure LOS, cell towers are often placed high above ground level, and technologies like beamforming are used to focus the radio signal in a specific direction towards the receiver. However, such solutions are not sustainable and increase the cost of deployment, energy consumption and are complex to implement.

[003] Therefore, there is a requirement to ensure effective transmission of millimeter-waves by mitigating distortion in non-line of sight scenarios.

SUMMARY OF THE INVENTION

[004] In an embodiment, a reflective meta-surface is disclosed. The reflective meta-surface may include a plurality of unit cells that may be arranged in a pre-defined pattern. In an embodiment, each of the plurality of unit cells may include a first dielectric substrate that may include a loading plane on a first top surface of the first dielectric substrate. Further, each of the plurality of unit cells may include a second dielectric substrate that may include a conducting plane on a second top surface of the second dielectric substrate. In an embodiment, the loading plane may be sandwiched between the first dielectric substrate and the second dielectric substrate. In an embodiment, the conducting plane may be a negative conjugate of the loading plane. Further, the loading plane may include a set of dual split rings concentrically arranged around a center. Further, each split ring of the set of dual split rings may be separated from each other by a predefined distance. In an embodiment, each of the set of dual split rings may have two angular splits disposed diametrically opposite to each other.

[005] In another embodiment, a method of manufacturing a reflective meta-surface is disclosed. The method may include arranging a plurality of unit cells in a pre-defined pattern. In an embodiment, each of the plurality of unit cells may be formed by disposing a loading plane on a first top surface of the first dielectric substrate. The method may further include disposing a second dielectric substrate on the first top surface of the first dielectric substrate sandwiching the loading plane. The method may further include disposing a conducting plane on a second top surface of the second dielectric substrate. In an embodiment, the conducting plane may be a negative conjugate of the loading plane. In an embodiment, the loading plane may include a set of dual split rings concentrically arranged around a center. In an embodiment, each split ring of the set of dual split rings may be separated from each other by a predefined distance. Further, each of the set of dual split rings may have two angular splits disposed diametrically opposite to each other.

[006] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF THE DRAWING

[007] The accompanying drawings, which are incorporated in and constitute a part of this disclosure, illustrate exemplary embodiments and, together with the description, serve to explain the disclosed principles.

[008] **FIG. 1** illustrates an exemplary deployment scenario of the IRS, in accordance with an embodiment of the present disclosure.

[009] **FIG. 2** illustrates an exploded view of the unit cell of the reflective meta-surface of **FIG. 1**.

[010] **FIG. 3A** illustrates a methodology of forming the conducting plane, in accordance with an embodiment of the present disclosure.

[011] **FIG. 3B** illustrates a top view of the loading plane, in accordance with an embodiment of the present disclosure.

[012] **FIG. 3C** illustrates a design specification of a dual split ring, in accordance with an embodiment of the present disclosure.

[013] **FIG. 3D** illustrates a design specification of the loading plane, in accordance with an embodiment of the present disclosure.

[014] **FIG. 4A** and **FIG. 4B** illustrate a top perspective view and a bottom perspective view of the unit cell respectively, in accordance with an embodiment of the present disclosure.

[015] **FIG. 5** illustrates a flowchart of a methodology of manufacturing the reflective meta-surface, in accordance with an embodiment of the present disclosure.

[016] **FIG. 6** illustrates an S-parameter graph depicting total transmission coefficient and total reflection coefficient graph, in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION OF THE DRAWINGS

[017] Exemplary embodiments are described with reference to the accompanying drawings. Wherever convenient, the same reference numbers are used throughout the drawings to refer to the same or like parts. While examples and features of disclosed principles are described herein, modifications, adaptations, and other implementations are possible without departing from the scope of the disclosed embodiments. It is intended that the following detailed description be considered exemplary only, with the true scope being indicated by the following claims. Additional illustrative embodiments are listed.

[018] Further, the phrases “in some embodiments”, “in accordance with some embodiments”, “in the embodiments shown”, “in other embodiments”, and the like mean a particular feature, structure, or characteristic following the phrase is included in at least one embodiment of the present disclosure and may be included in more than one embodiment. In addition, such phrases do not necessarily refer to the same embodiments or different embodiments. It is intended that the following detailed description be considered exemplary only, with the true scope being indicated by the following claims.

[019] Ranges can be expressed herein as from “about” one particular value, and/or to “about” another particular value. When such a range is expressed, another aspect includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent “about,” it will be understood that the particular value forms another aspect. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

[020] Reference will now be made to the exemplary embodiments of the disclosure, as illustrated in the accompanying drawings. Wherever possible, same numerals have been used to refer to the same or like parts. The following paragraphs describe the present disclosure with reference to **FIGs. 1-6**. As summarized above, in one broad aspect, the present invention provides a reflective meta-surface and a method of manufacturing a reflective meta-surface thereof.

[021] It is to be noted that metamaterials are engineered to manipulate electromagnetic waves of specific wavelength to achieve the desired outcome. Metamaterials have precise shape, geometry, size, orientation, and arrangement that makes it capable of manipulating electromagnetic waves: by blocking, absorbing, enhancing, reflecting or bending waves in case of non-line of sight communication. Metamaterials that exhibit a negative index of refraction for wavelengths have been the focus of a large amount of research. Since, metamaterials do not require external power source as the current is generated due to inductance and conductance properties, they are energy efficient and are widely preferred in the practical application in field of wireless communication.

[022] **FIG. 1** illustrates an exemplary deployment scenario 100 of a reflective meta-surface 102, in accordance with an embodiment of the present disclosure. The reflective meta-surface 102 alternatively referred to as an intelligent reflective surfaces (IRS) 102 may be attached to a surface of an obstruction 104 such as a wall, trees, etc. As can be seen in FIG. 1, line of sight communication between a base station 106 and a user equipment (UE) 108 is obstructed by a tree 110. Thus, in absence of the line of sight communication, the signals from the base station 106 may not be transmitted to the UE 108. Accordingly, IRS 102 provided on the wall 104 may reflect signals between the base station 106 and the UE 108 in order to enable uninterrupted exchange of communication signals between the base station 106 and the UE 108 even in presence of the obstruction 110. As can be seen, the reflective meta-surface 102 may include a plurality of unit cells 112 arranged in a predefined pattern to cover a planar surface of the wall 104. In an embodiment, the predefined pattern may include a first set of unit cells of the plurality of unit cells 112 arranged in x-direction and a second set of unit cells of the plurality of unit cells 112 arranged in y-direction to form a planar structure. The plurality of unit cells 112 may be repeated periodically to form a planar structure to build the meta-surface 102 that may function as an IRS. Accordingly, the reflective meta-surface 102 may act as a network node that may help in controlling the channel by reflecting the electromagnetic signal in a desired direction, thus improving the network throughput by providing a strong non-line-of-sight (NLOS) path in case of a non-line of sight between the base station 106 and the UE 108. The reflective meta-surface 102 may be configured to reflect electromagnetic waves having an incident angle in a range of 0-30 degrees with respect to a normal of the reflective meta-surface 102. Further, the reflective meta-surface 102 may be configured to reflect electromagnetic waves in a predefined frequency range of about 26.5 GHz to 29.5 GHz. Each of the plurality of unit cells 112 may be designed in a manner that it may reflect electromagnetic waves having an incident angle in a range of about 0-30 degrees with respect to a normal of each of the plurality of unit cells 112. Details of the design of each of the unit cells 112 and the method of manufacturing the same are explained in greater detail in FIGs. 2-6. Thus, the IRS 102 allows to direct the radio waves to blind spots and fill in gaps in the network coverage. Accordingly, the IRSs 102 of the current disclosure, can provide an alternative low-cost solution to reconfigure the beam’s direction towards fixed unserved spots instead of the high-cost RIS.

[023] The IRS 102 may be designed as a metamaterial that may be engineered to change their phase responses and may be used to reflect and redirect millimeter waves in order to facilitate non-line-of-sight communication. IRS 102 also referred to herein as reflective meta-surface 102 that may be programed or designed to cause parasitic reflections in a constructive way so that the N257 bandwidth can be used more efficiently. This helps in complementing signals in blind spots and bending them around obstacles to improve the robustness of connection between the base station 106 and the UE 108.

[024] Referring now to **FIG. 2**, an exploded view 200 of a unit cell 112 used to make the reflective meta-surface (also referred to as IRS) 102 is illustrated, in accordance with an embodiment of the present disclosure.

[025] The exploded view 200 depicts that a unit cell 112 may include a first dielectric substrate 202 made of a dielectric material such as, but not limited to, FR-4, FR-2,polyamide , polytetrafluoroethylene, etc. In an embodiment, the first dielectric substrate 202 may have a dielectric constant of about 4.4. Further, the first dielectric substrate 202 may be quadrilateral shaped with a center C1 and may include a first top surface 204 and four side surfaces 206A-D. Further, the first dielectric substrate 202 may have thickness T1 in a range of 0.1mm to 0.5mm.

[026] Further, a loading plane 206 may be disposed on the first top surface 204 of the first dielectric substrate 202. The loading plane 206 may be made of an electrically conductive material. In an embodiment, examples of the electrically conductive material may include, but is not limited to, copper, aluminium, silver, gold, brass, bronze, graphite, carbon nanotubes, conductive polymers, etc. Further, the loading plane 206 may be shaped to include a set of dual split rings 208A-C concentrically arranged around the centre 210. The dual split rings 208A-C may act as split ring resonators (SRRs) and are utilized in order to enhance the efficiency of the reflection of the electromagnetic waves. In general, the dual split rings 208A-C may be etched on the first dielectric substrate 202.

[027] Further, the unit cell 112 may include a second dielectric substrate 211 disposed on the first top surface 204 of the first dielectric substrate 202. It is to be noted that the loading plane 206 is sandwiched between the first dielectric substrate 202 and the second dielectric substrate 211. Further, the second dielectric substrate 211 may have thickness T2 in a range of 0.01*(wavelength) to 0.1*(wavelength). In an embodiment, the second dielectric substrate 211 may be made of dielectric material such as, but not limited to, Rogers 5880, RT/duroid 6002, etc. The second dielectric substrate 211 may be quadrilateral shaped with a center C2 and may include a second top surface 212 and four side surfaces 214A-D. In an embodiment, the second dielectric substrate 211 may have a dielectric constant of about 2.2.

[028] Further a conducting plane 216 may be disposed on the second top surface 212 of the second dielectric substrate 211. In an embodiment, the conducting plane 216 may be a negative conjugate of the loading plane 206. The methodology of designing the loading plane 206 and the conducting plane 216 has been explained in detail in conjunction to FIG. 3. It is to be noted that both the loading plane 206 and the conducting plane 216 are made of an electrically conductive material such as, but is not limited to, copper, aluminum, silver, gold, brass, bronze, graphite, carbon nanotubes, conductive polymers, etc. Further, the center C3 of the conducting plane 216 is colinear with the center C2 of the second dielectric substrate 211 and center 210 of the loading plane 206 and the center C1 of the first dielectric substrate 202.

[029] In an embodiment, the disposition of the conducting plane 216 and the loading plane 206, the first dielectric substrate 202 and the second dielectric substrate 211 may configure the unit cell 112 to have inductance and capacitance such that it reflects electromagnetic waves in a predefined frequency range of about 26.5 GHz to 29.5 GHz. Electromagnetic waves having an incident angle in a range of 0-30 degrees with respect to a normal of the unit cell 112 may be reflected.

[030] In an exemplary embodiment, the loading plane 206 may be designed in a manner to generate an about band stop effect. Accordingly, the first dielectric substrate 202 that may also be referred to as prepreg layer, may minimize radiation into more reflective nature. Further, the loading plane 206 may enable in-phase addition of coupled signal through the first dielectric substrate 202, the second dielectric substrate 211 and the the conducting plane 216 and control the inductance and capacitance values such that the unit cell 112 acts as a reflector for waves of predefined frequencies.

[031] **FIG. 3A** illustrates a methodology of forming the conducting plane 216, in accordance with an embodiments of the present disclosure. As shown in FIG. 3A, a metal plate 302 of predefined thickness and dimensions may be cut using a metal cutting technique such as, but not limited to, laser cutting, etc. to form the loading plane 206. The remaining area of the metal plate 302 after removal of the loading plane 206 may form the conducting plane 216. Accordingly, the conducting plane 216 may be a negative conjugate of the loading plane 206.

[032] Referring now to **FIG. 3B,** a top view 300B of the loading plane 206 is illustrated, in accordance with an embodiment of the present disclosure. FIG. 3B depicts a loading plane 206 that may be sandwiched between the first dielectric substrate 202 and the second dielectric substrate 211. The loading plane 206 may include three dual split rings 208A-C concentrically arranged around the center 210. In an embodiment, each of the set of the dual split rings 202A-C may be of equal thickness 't'. In an embodiment, each of the dual split rings 208A-C are separated from each other by a predefined distance ‘d’. It should be noted a first dual split ring 208A may be placed at a radial distance of ‘d’ from the center 210. Further, the first dual split ring 208A may have two angular splits 304A-1, 304A-2, disposed diametrically opposite to each other. Similarly, the second dual split ring 208B may be concentrically placed around the first dual split ring 208A. The second dual split ring 208B may be separated by a distance ‘d’ from the first dual split ring 208A. Further, the second dual split ring 208B may have two angular splits 304B-1, 304B-2 disposed diametrically opposite to each other. It should be noted that the angular splits 304A-1, 304A-2 of the first dual split ring 208A are perpendicular to the two angular splits 304B-1, 304B-2 of the second dual split ring 208B with respect to the center 210. A. The third dual split ring 208C may be concentrically placed around the second dual split ring 208B. The third dual split ring 208C may be separated by a distance ‘d’ from the second dual split ring 208B. Further, the third dual split ring 208C may have two angular splits 304C-1, 304C-2 disposed diametrically opposite to each other. In an embodiment, the two angular splits 304C-1, 304C-2 of the third dual split ring 208C are perpendicular to the two angular splits 304B-1, 304B-2 of the second dual split ring 208B with respect to the center 210. As can be seen in FIG. 3B, the two angular splits 304A-1, 304A-2 of the first dual split ring 208A and the two angular splits 304C-1, 304C-2 of the third dual split ring 208C are disposed along the Y-axis of the loading plane 206 with respect to the center 210. Further, the two angular splits 304B-1, 304B-2 of the second dual split ring 208B may be disposed along the X-axis of the loading plane 206 with respect to the center 210. Thus, making the two angular splits of each of dual splits of consecutive dual split rings 208A-C perpendicular to each other with respect to the center 210. Further, each of the angular splits 304A-1, 304A-2, 304B-1, 304B-2, 304C-1, 304C-2 subtends a predefined angle ‘θ’ to the center 210. In an embodiment, the predefined angle ‘θ’ subtended by the each of the angular splits each of the angular splits 304A-1, 304A-2, 304B-1, 304B-2, 304C-1, 304C-2 (collectively referred to as angular splits 304) to the center 210 may be about 4°.

[033] **FIG. 3C** illustrates a design specification of a dual split ring 208, in accordance with an embodiment of the present disclosure. It is to be noted that in order for a meta-surface to be reflective, design dimensions of each layer need to be a function of subwavelength distances. In order for a unit cell 112 to be reflective in nature at an incidence angle between 0-30 degrees for wavelength of 10.7 mm and for desired working region of centre frequency of 28 GHz following design parameters may be determined (in mm) as:

x (half wavelength) = (wavelength)*0.5

lsub (length of the first dielectric substrate 202, the second dielectric substrate 211, the conducting plane 216) = x*1.5

wsub (width of the first dielectric substrate 202, the second dielectric substrate 211, the conducting plane 216) = x*1.5

T1 = thickness of first dielectric substrate 202 = 0.2 mm

T2 = thickness of second dielectric substrate 211 = x*0.07

t (R-r) = thickness of the dual split ring 208A-C = x*0.15

$\theta = t*5$

γ (starting angle) = an offset angle with respect to the normal of the dual split ring 208 for starting of θ

[034] **FIG. 3D** illustrates a design specification of the loading plane 206, in accordance with an embodiment of the present disclosure. As can be seen the first dual split ring 208A has a radius of R1, the second dual split ring 208B has a radius of R2 and the third dual split ring 208C has a radius of R3. In conjunction with the embodiment of FIG. 3B, R1= x/5.7, R2= x/2.7 and R3= x/1.7. It is to be noted that, the angular splits 304 are the structural inhomogeneities that are required for the split ring resonators to support resonant wavelengths much greater than the diameter (2R) of the dual split rings 208A-C. The capacitance formed by the angular splits 304 in the rings may be large in value. As the capacitance is inversely proportional to the resonant frequency, a large capacitance may help the resonator to exhibit resonance at frequencies considerably greater than its dimension. It may be understood that the geometry of the SRR, its resonant frequency and related properties are interdependent.

[035] Referring now to **FIG. 4A**, a top perspective view 400A of the unit cell 112 is illustrated, in accordance with an embodiment of the present disclosure. **FIG. 4B** illustrates a bottom perspective view 400B of the unit cell 112, in accordance with an embodiment of the present disclosure.

[036] Referring now to **FIG. 5**, a flowchart 500 depicting a methodology of manufacturing the IRS or reflective meta-surface 102 is illustrated, in accordance with an embodiment of the present disclosure.

[037] At step 502, a plurality of unit cells 112 may be arranged in a pre-defined pattern to form a reflective meta-surface or an IRS 102. In an embodiment, the pre-defined pattern may include a first set of unit cells 112 from the plurality of unit cells 112 arranged in x-direction and a second set of unit cells 112 from the plurality of unit cells 102 arranged in y-direction. as depicted in FIG. 1. Further at step 504, the reflective meta-surface 102 may be configured to reflect electromagnetic waves that may have an incident angle in a range of 0 to 30 degrees with respect to a normal of the reflective meta-surface 102. In an embodiment, the reflective meta-surface 102 may be configurable to reflect electromagnetic waves in the predefined frequency range of n257 band of the electromagnetic spectrum for wireless communication. In an embodiment, the reflective meta-surface 102 may be configured to reflect electromagnetic waves in the predefined frequency range of 26.5 GHz to 29.5 GHz.

[038] In an embodiment, the reflective meta-surface 102 may be configured to reflect electromagnetic waves based on configuration of each of the plurality of unit cells 112. Each of the plurality of unit cells 112 may be formed by disposing a loading plane 206 on the first top surface 204 of the first dielectric substrate 202. Further, the loading plane 206 may be shaped to include a set of dual split rings 208A-C concentrically arranged around the center 210. A second dielectric substrate 211 may be disposed on the first top surface 204 of the first dielectric substrate 202. It is to be noted that the loading plane 206 is sandwiched between the first dielectric substrate 202 and the second dielectric substrate 211. Further a conducting plane 216 may be disposed on the second top surface 212 of the second dielectric substrate 211. In an embodiment, the conducting plane 216 may be a negative conjugate of the loading plane 206. Each of the set of dual split rings 208A-C may include two angular splits 304 disposed diametrically opposite to each other. The second dielectric substrate 211 may be sandwiched between the conducting plane 216 and the loading plane 206. It is to be noted that center 210 of the loading plane 206, the center C1 of the first dielectric substrate 202 and the center C2 of second dielectric substrate 211 and the center C3 of the conducting plane 216 are colinear. Consequently, the second dielectric substrate 211 between two conducting layers leads to generation of the capacitance with gap and charges that are being generated through resonance onto it. Thus, the capacitance and the inductance are controlled. The unit cell 112 itself may produce some inductance and capacitance that satisfies resonant frequency mathematical function, that may match predefined frequency of electromagnetic waves in order to enhance the reflection in non-line of sight communications.

[039] **FIG. 6** illustrates S-parameter graph 600 depicting total transmission coefficient and total reflection coefficient graph, in accordance with an embodiment of the present disclosure. The S-parameter graph 600 depicts a total transmission coefficient and the total reflection coefficient (in dB) on the y-axis with respect to frequency of the signal (in GHz) on the x-axis. The S-parameter graph 600 depicts that for frequency range of 26.5 GHz to 29.5 GHz the reflection is constant as the reflection curve 602 is above -3dB mark on y-axis. This means more than half the power that is falling on the IRS 102 is getting reflected. It is to be noted that graph 600 depicts that the reflection is best in the frequency range of 26.5 GHz to 29.5 GHz. In an embodiment, the S-parameter of graph 602 shows that for frequency range of 26.5 GHz to 29.5 GHz the reflection is constant. As the reflection curve 602 is above -3dB mark on the y-axis, more than half the electromagnetic waves that are impinging on it are getting reflected (almost 100% electromagnetic waves are reflecting). Further, the S-parameter graph 600 depicts via the transmission curve 604 that lowest possible transmission is present in n257 frequency band range as the transmission curve is below -10dB mark. Since, the transmission coefficient curve 604 is below -10dB mark on the y-axis, about 90% electromagnetic waves that are incident and are consequently getting reflected, as a result of which the reflection becomes prominent in the unit cell 112.

[040] It should be appreciated that the S-parameter graph 600 depicts that reflective meta-surface design of the present disclosure is effective for mm-wave communications in future networks. The reflective meta-surface 102 may be suitable for being utilized at the n257 5G mm-wave band to provide services in NLoS areas. Thus, the disclosed method and system overcomes the technical problem of existing meta-material designs for intelligent reflective surfaces that can redirect beams or signals around obstacles, enhancing communication in non-line-of-sight scenarios.

[041] As will be appreciated by those skilled in the art, the design described in the various embodiments discussed above are not routine, or conventional, or well-understood in the art. The techniques discussed above provide for parasitic reflections that can redirect beams or signals around obstacles, enhancing communication in non-line-of-sight scenarios. The design discussed above is used to produce parasitic reflections that can redirect beams or signals around obstacles, enhancing communication in non-line-of-sight scenarios. The design discussed above is for a meta-surface intended for applications in the 5G/6G communication utilizing mm-wave band, particularly in the n257 frequency range (24-30 GHz). The design discussed above achieves broadband reflective performance up to an incident angle of 0-30 degrees. The incident angle refers to the angle at which the incoming electromagnetic waves interact with the reflective meta-surface 102.

[042] In light of the above-mentioned advantages and the technical advancements provided by the disclosed method and system, the claimed steps as discussed above are not routine, conventional, or well understood in the art, as the claimed steps enable the following solutions to the existing problems in conventional technologies. Further, the claimed steps bring an improvement in the functioning of the device itself as the claimed steps provide a technical solution to a technical problem.

[043] The specification has described metamaterial based reflective unit cell for intelligent reflective surfaces and method of manufacturing thereof for that can reflect and redirect beams or signals incident at an angle of 0-30 degrees and enhanced millimeter communication in non-line-of-sight scenarios. The illustrated steps are set out to explain the exemplary embodiments shown, and it should be anticipated that ongoing technological development will change the manner in which particular functions are performed. These examples are presented herein for purpose of illustration, and not limitation. Further, the boundaries of the functional building blocks have been arbitrarily defined herein for the convenience of the description. Alternative boundaries can be defined so long as the specified functions and relationships thereof are appropriately performed. Alternatives (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternatives fall within the scope of the disclosed embodiments.

[044] It is intended that the disclosure and examples be considered as exemplary only, with a true scope of disclosed embodiments being indicated by the following claims.

CLAIMS

I/We Claim:

1. A reflective meta-surface (102), comprising:

a plurality of unit cells (112) arranged in a pre-defined pattern,

wherein each of the plurality of unit cells (112) comprises:

a first dielectric substrate (202) comprising a loading plane (206) on a first top surface (204) of the first dielectric substrate (202); and

a second dielectric substrate (211) comprising a conducting plane (216) on a second top surface (212) of the second dielectric substrate (211),

wherein the loading plane (206) is sandwiched between the first dielectric substrate (202) and the second dielectric substrate (211),

wherein the conducting plane (216) is a negative conjugate of the loading plane (206),

wherein the loading plane (206) comprises a set of dual split rings (208A-C) concentrically arranged around a center (210),

wherein each split ring (208A-C) of the set of dual split rings (208A-C) are separated from each other by a predefined distance (d), and

wherein each of the set of dual split rings (208A-C) have two angular splits (304) disposed diametrically opposite to each other.

2. The reflective meta-surface (102) as claimed in claim 1, wherein the two angular splits (304) of consecutive dual split rings (208A-C) from the set of dual split rings (208A-C) are perpendicular to each other with respect to the center (210).

3. The reflective meta-surface (102) as claimed in claim 1, wherein each of the angular splits (304) subtends a predefined angle (θ) to the center (210).

4. The reflective meta-surface (102) as claimed in claim 1, wherein a center (C1) of the first dielectric substrate, the center (210) of the loading plane (206), a center (C2) of the second dielectric substrate (211) and a center (C3) of the conducting plane (216) are colinear.

5. The reflective meta-surface (102) as claimed in claim 1, wherein:

the first dielectric substrate (202) has a dielectric constant of about 4.4,

the second dielectric substrate (211) has a dielectric constant of about 2.2, and the first dielectric substrate (202) and the second dielectric substrate (211) are shaped as a quadrilateral.

6. The reflective meta-surface (102) as claimed in claim 1, wherein the loading plane (206) and the conducting plane (216) are made of an electrically conductive material.

7. The reflective meta-surface (102) as claimed in claim 1, wherein the reflective meta-surface (102) is configured to reflect electromagnetic waves having an incident angle in a range of 0-30 degrees with respect to a normal of the reflective meta-surface (102).

8. The reflective meta-surface (102) as claimed in claim 7, wherein the reflective meta-surface (102) is configured to reflect electromagnetic waves in a predefined frequency range of about 26.5 GHz to 29.5 GHz.

9. The reflective meta-surface (102) as claimed in claim 1, wherein each of the set of dual split rings have equal thickness.

10. The reflective meta-surface (102) as claimed in claim 1, wherein the loading plane (206) comprises three dual split rings (208A-C) concentrically arranged around the center (210).

11. A method (500) of manufacturing a reflective meta-surface (102), the method (500) comprising:

arranging a plurality of unit cells (122) in a pre-defined pattern,

wherein each of the plurality of unit cells (122) are formed by:

disposing a loading plane (206) on a first top surface (204) of a first dielectric substrate (202),

disposing a second dielectric substrate (211) on the first top surface (204) of the first dielectric substrate (202) sandwiching the loading plane (206), and

disposing a conducting plane (216) on a second top surface (212) of the second dielectric substrate (211);

wherein the conducting plane (216) is a negative conjugate of the loading plane (206) comprising a set of dual split rings (208A-C) concentrically arranged around a center (210),

wherein each split ring (208A-C) of the set of dual split rings (208A-C) are separated from each other by a predefined distance (d), and wherein each of the set of dual split rings (208A-C) have two angular splits (304) disposed diametrically opposite to each other.

12. The method (500) as claimed in claim 11, wherein the two angular splits (304) of consecutive dual split rings (208A-C) from the set of dual split rings (208A-C) are perpendicular to each other with respect to the center (210).

13. The method (500) as claimed in claim 11, wherein each of the angular splits (304) subtends a predefined angle to the center (210).

14. The method (500) as claimed in claim 11, wherein the reflective meta-surface (102) is configured to reflect electromagnetic waves having an incident angle in a range of 0-30 degrees with respect to a normal of the reflective meta-surface (102).

15. The method (500) as claimed in claim 14, wherein the reflective meta-surface (102) is configured to reflect electromagnetic waves in a predefined frequency range of 26.5 GHz to 29.5 GHz.

16. The method (500) as claimed in claim 11, wherein the loading plane (206) comprises three dual split rings concentrically arranged around the center (210).

17. The method (500) as claimed in claim 11, wherein a center of first dielectric substrate (C1), the center (210) of the loading plane (206), a center (C2) of second dielectric substrate (211) and a center (C3) of the conducting plane (216) are colinear.

18. The method (500) as claimed in claim 11, wherein:

the first dielectric substrate (202) has a dielectric constant of about 4.4,

the second dielectric substrate (211) has a dielectric constant of about 2.2, and

the first dielectric substrate (202) and the second dielectric substrate (211) are shaped as a quadrilateral.

19. The method (500) as claimed in claim 11, wherein the loading plane (206) and the conducting plane (216) are made of an electrically conductive material.

20. The method (500) as claimed in claim 11, wherein each of the set of dual split rings (208A-C) has equal thickness.

Dated this 10th day of May 2024

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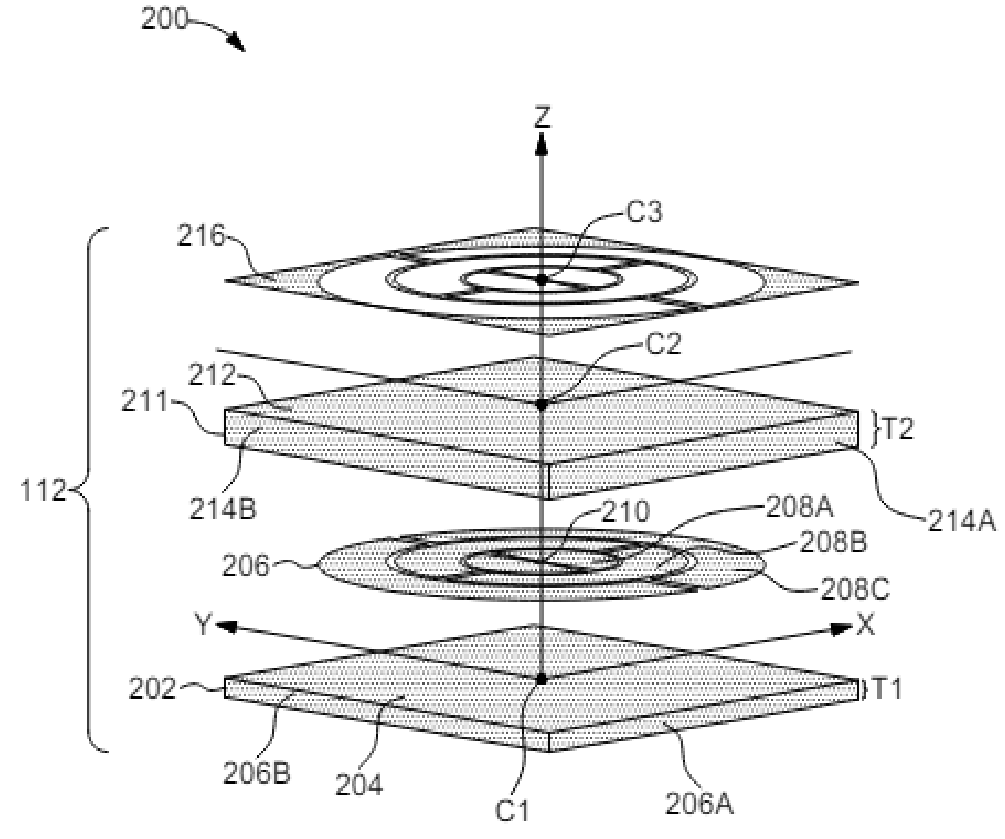
ABSTRACT

METAMATERIAL BASED REFLECTIVE UNIT CELL FOR INTELLIGENT REFLECTIVE SURFACES AND METHOD OF MANUFACTURING THEREOF

A reflective meta-surface (102) and a method (500) of manufacturing the reflective meta-surface (102) is provided. The reflective meta-surface (102) comprises a plurality of unit cells (112) arranged in a pre-defined pattern. The plurality of unit cells (112) is formed by disposing a loading plane (206) on a first top surface (204) of a first dielectric substrate (202). A second dielectric substrate (211) is disposed on the first top surface (204) of the first dielectric substrate (202) sandwiching the loading plane (206). Further, disposing a conducting plane (216) on a second top surface (212) of the second dielectric substrate (211). The conducting plane (216) is a negative conjugate of the loading plane (206).



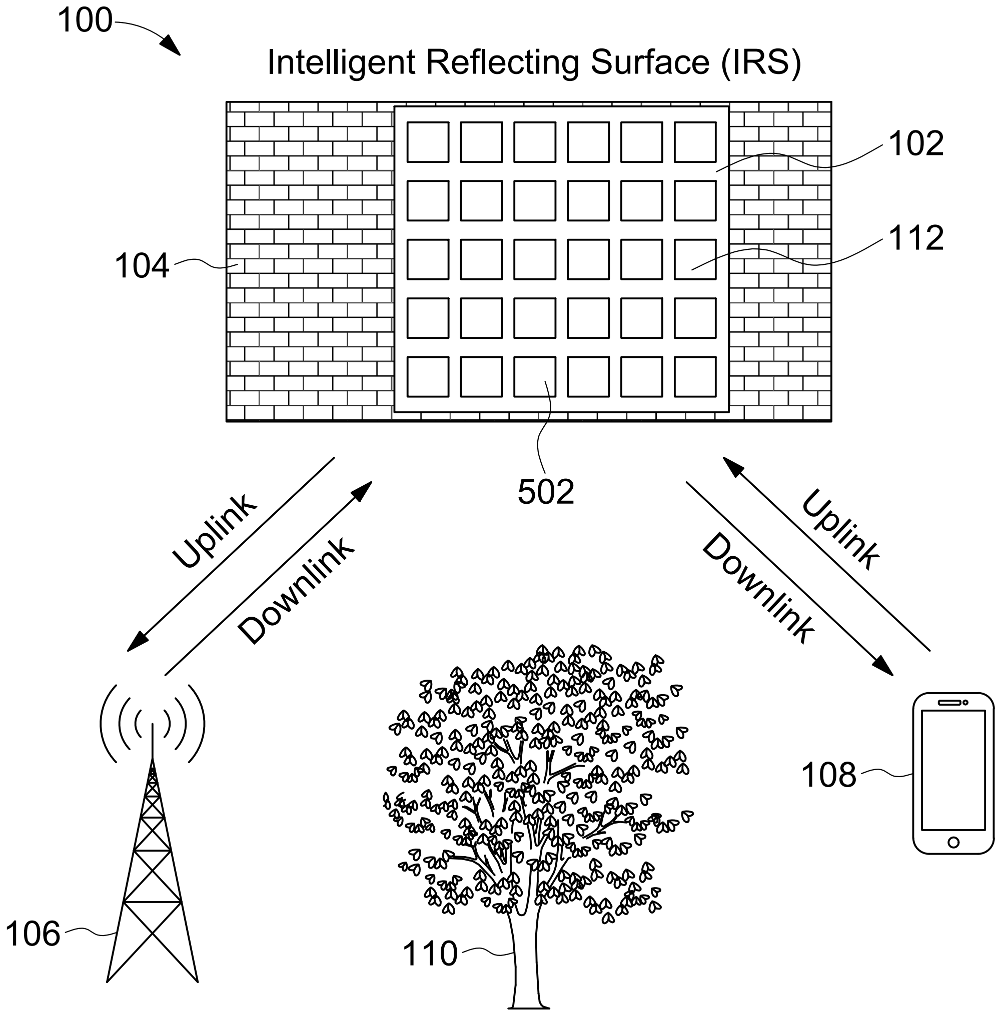


FIG. 1

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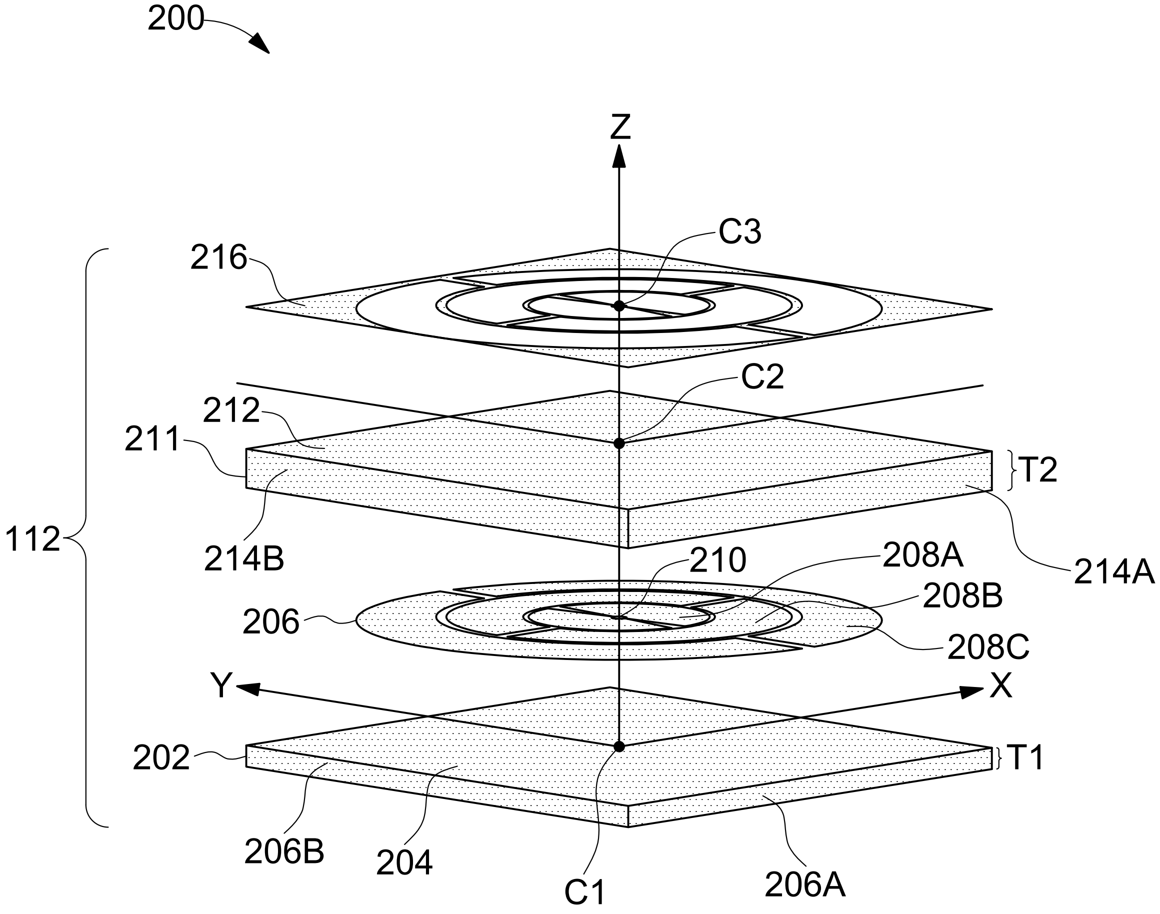

FIG. 2

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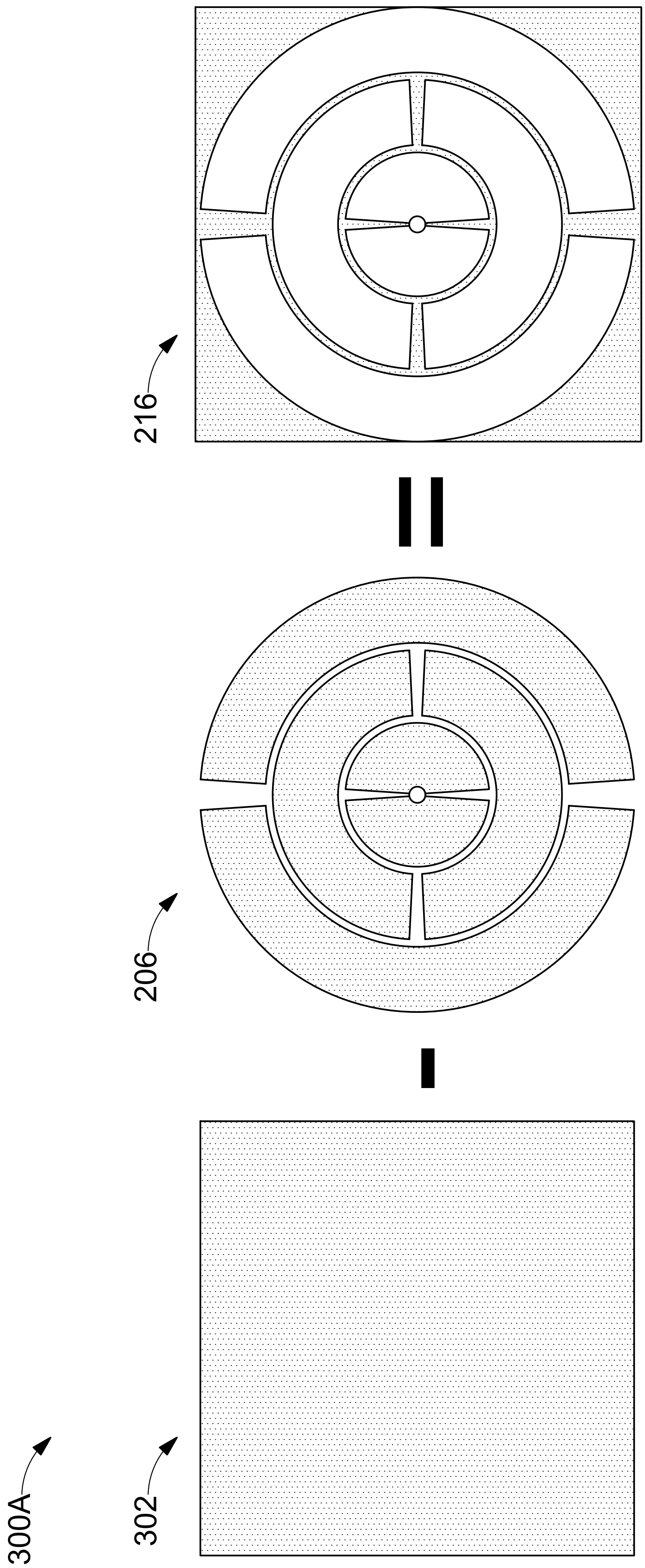

FIG. 3A

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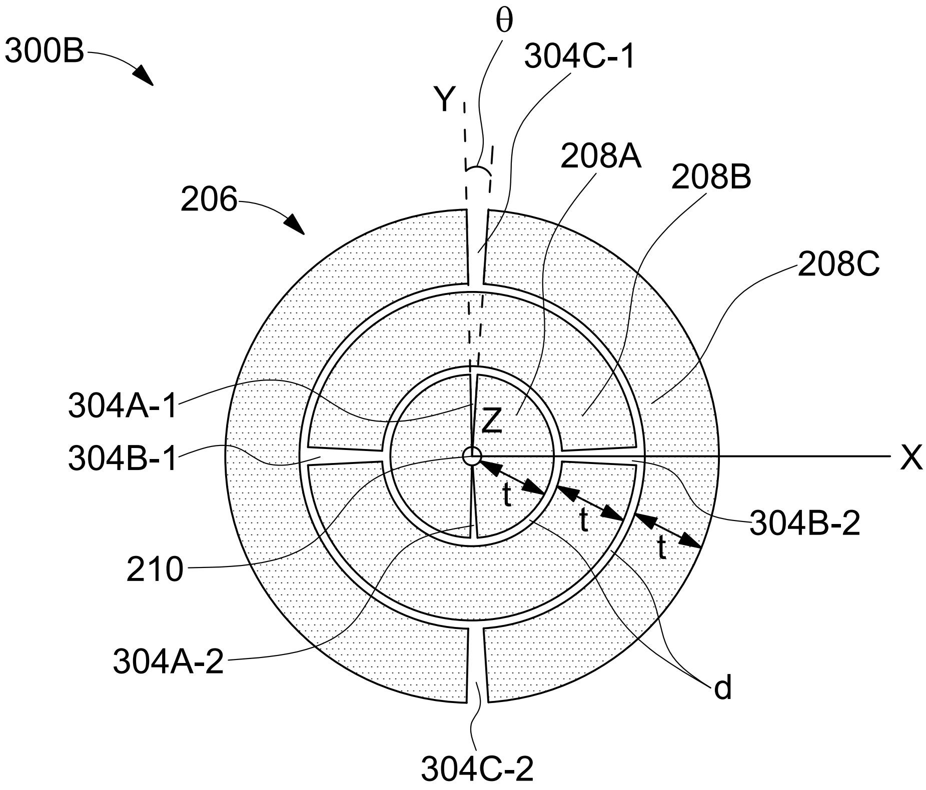

FIG. 3B

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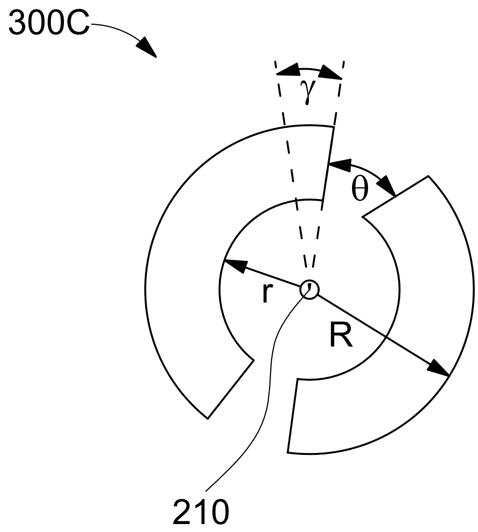

FIG. 3C

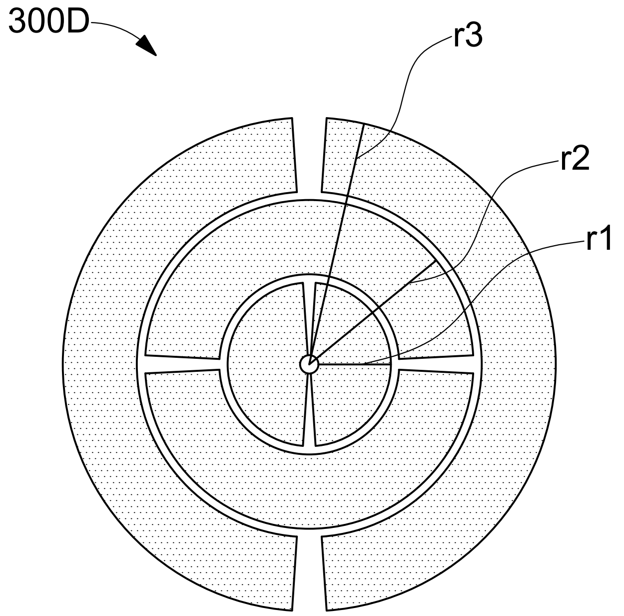

FIG. 3D

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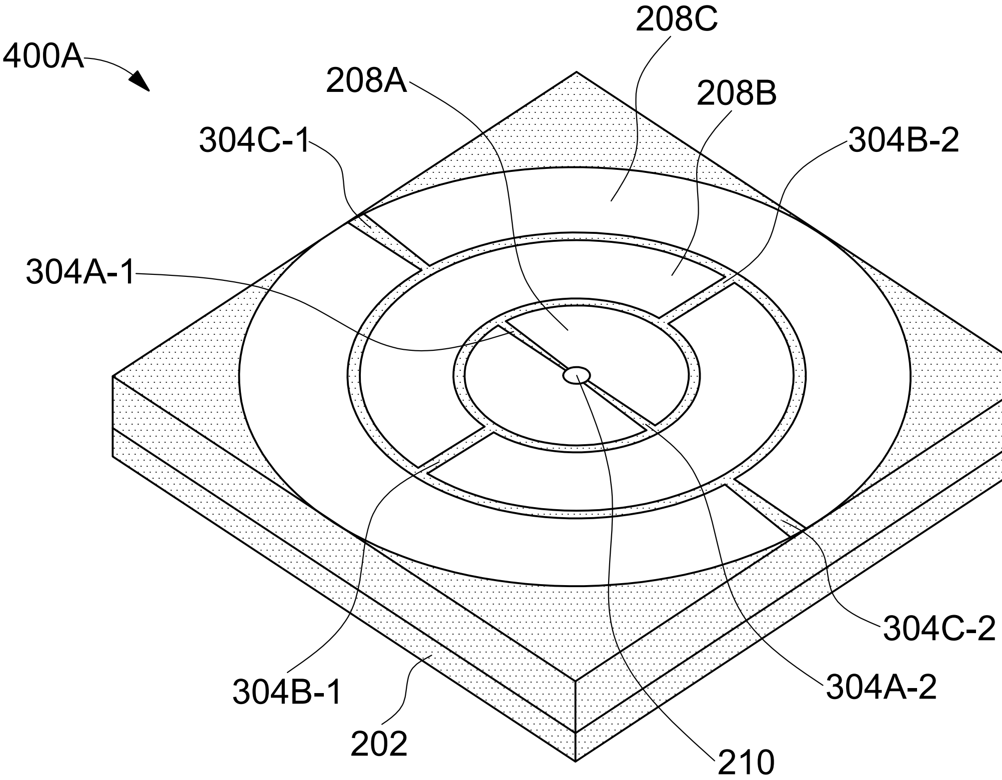

FIG. 4A

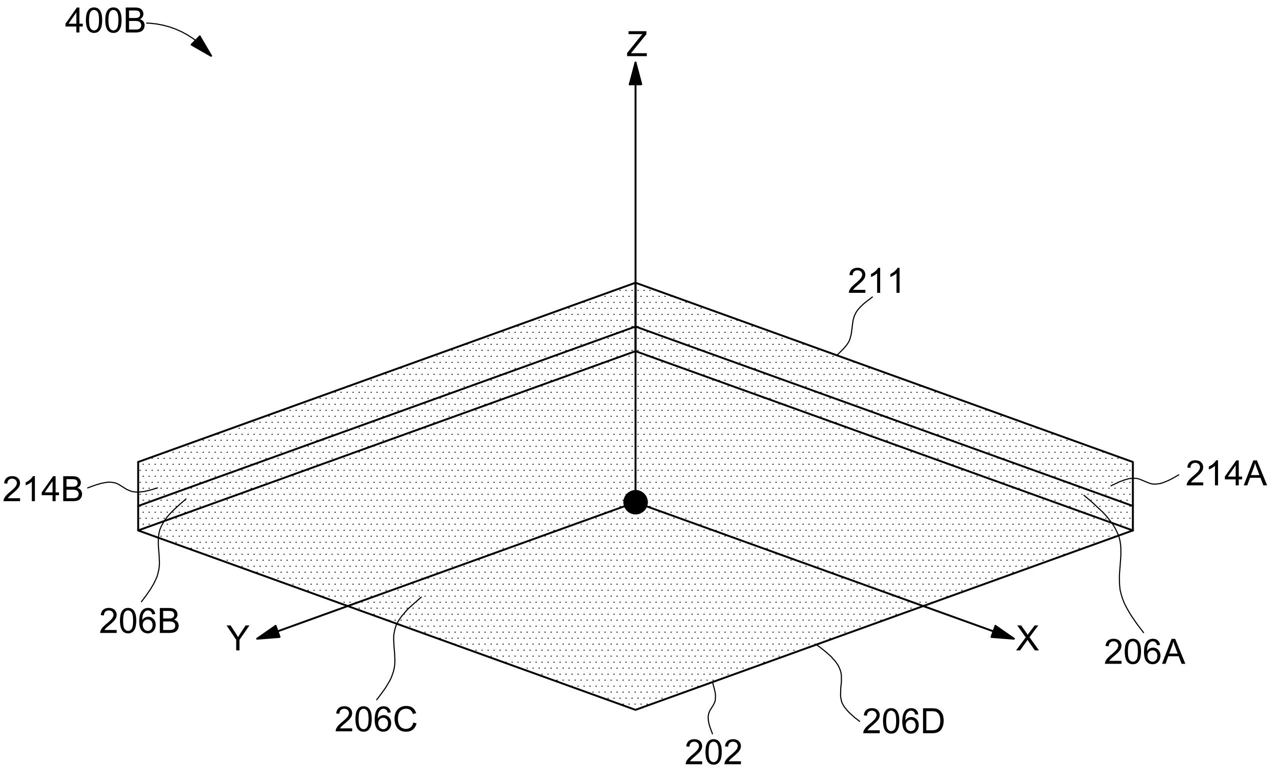

FIG. 4B

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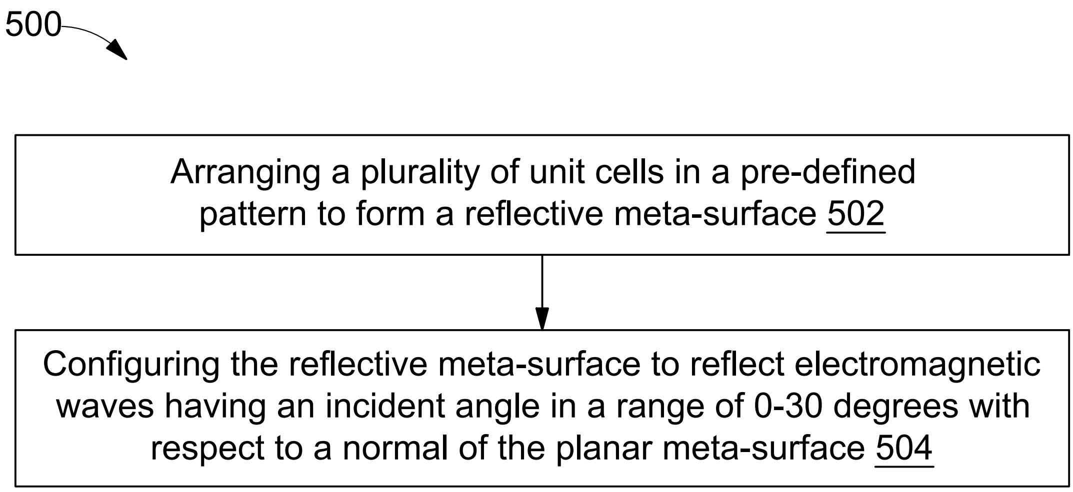

FIG. 5

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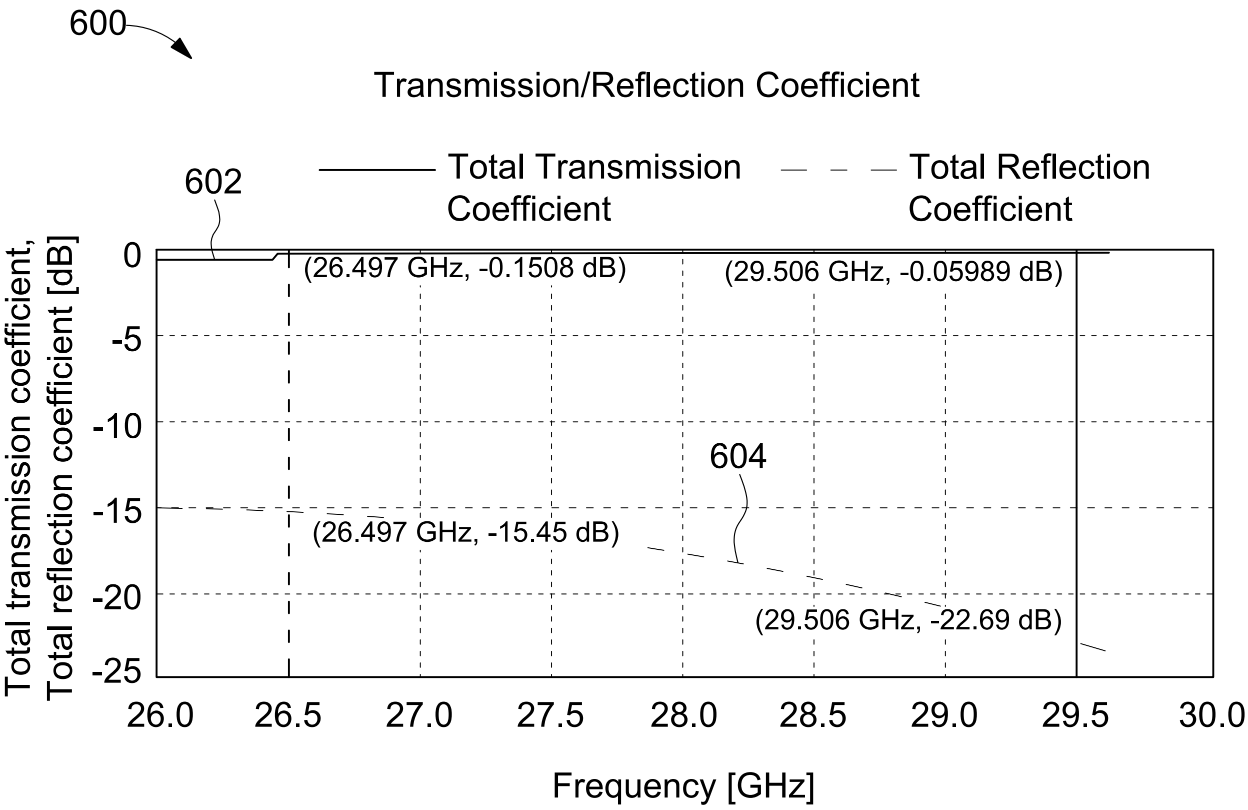

FIG. 6

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