

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
21 September 2006 (21.09.2006)

PCT

(10) International Publication Number
WO 2006/098587 A1

(51) International Patent Classification:
H01P 1/203 (2006.01)

Apt., Wonpyeong-dong, Gumi-si, Gyeongbuk 730-010 (KR).

(21) International Application Number:
PCT/KR2006/000934

(74) Agent: **SHINSUNG PATENT FIRM**; 2-3f, Line Bldg., 823-30,, Yeoksam-dong, Kangnam-ku,, Seoul 135-080 (KR).

(22) International Filing Date: 15 March 2006 (15.03.2006)

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10-2005-0021383 15 March 2005 (15.03.2005) KR
10-2005-0041180 17 May 2005 (17.05.2005) KR

(71) Applicant (*for all designated States except US*): **ELECTRONICS AND TELECOMMUNICATIONS RESEARCH INSTITUTE** [KR/KR]; 161, Gajeong-dong, Yuseong-gu, Daejeon 305-350 (KR).

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

(72) Inventors; and

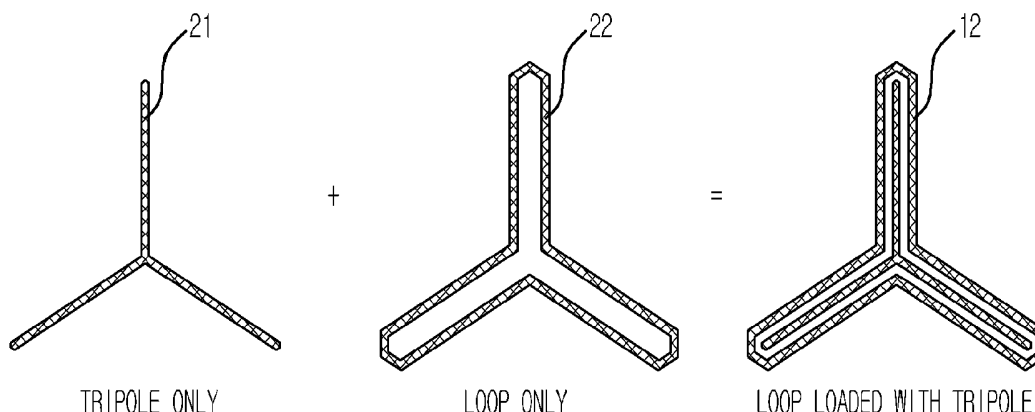
(75) Inventors/Applicants (*for US only*): **KIM, Dong-Ho** [KR/KR]; #201-1103 Songnim Maeul Site 2, Hagi-dong, Yuseong-gu, Daejeon 305-358 (KR). **CHOI, Jae-Ick** [KR/KR]; #202-402 Kukhwa Apt., Samcheon-dong, Seo-gu, Daejeon 302-782 (KR). **KIM, Byung-Chan** [KR/KR]; #105-505 Sambu Apt., Yangji Maeul Site, 1, Banseok-dong 612, Yuseong-gu, Daejeon 305-150 (KR). **SIM, Dong-Uk** [KR/KR]; #202-801 Samjeong Apt., Yullyang-dong, Sangdang-gu, Cheongju-si, Chungbuk 360-210 (KR). **KO, Ji-Hwan** [KR/KR]; #107-203 Jugong

Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: FREQUENCY SELECTIVE SURFACE FOR THE FILTERING OF FREQUENCY BAND AND DESIGN METHOD THEREOF



(57) Abstract: A Frequency Selective Surface (FSS) for the filtering of a frequency band and its design method are provided. The inventive FSS comprises a dielectric layer and a plurality of unit cells. The plurality of the unit cells are periodically arrayed on an upper end of the dielectric layer, each of the unit cells having a tri-pole and a ternary tree type loop connected without overlapping. In addition, the inventive method comprises the steps of bending a square shape loop at least once to obtain a meandrous square shape loop and adjusting a length of the meandrous square shape loop when forming unit cells in the FSS, and arranging the unit cells such that the FSS is comprised of geometrically identical unit structures or cells to tune a resonant frequency.

WO 2006/098587 A1

Description

FREQUENCY SELECTIVE SURFACE FOR THE FILTERING OF FREQUENCY BAND AND DESIGN METHOD THEREOF

Technical Field

- [1] The present invention relates to a Frequency Selective Surface (FSS) and a design method thereof, and more particularly, to a spatial FSS for an FSS that cuts off or transmits predetermined single or multiple frequency bands and a design method thereof.

Background Art

- [2] It is known that an FSS has a structure that conductors or slots are periodically arranged on a dielectric slab. The FSS serves as a kind of a spatial filter and has characteristics that transmit or reflect only a specific frequency.
- [3] Such an FSS has been widely utilized in various application fields ranging from classic fields such as a radome of an antenna, a dichroic reflector, a reflection array lens, etc. to modern fields such as an Electro-Magnetic Interference (EMI) protection, an increase of Radar Cross Section (RCS), stealth technologies, an Artificial Magnetic Conductor (AMC) and so on.
- [4] In the FSS, a structure corresponding to a single period is named as a unit cell. This FSS has frequency response characteristics that are severely varied depending on a geometrical shape, an array form, and an array period of a unit cell, and material characteristics of dielectrics and conductors adopted therein. Generally, structures of identical shapes of rectangle, concentric circle or the like but of different sizes are utilized as unit cells.
- [5] One of conventional FSSs is 'Bandpass Frequency Selective Surface' (US Patent No. 5,384,575, issued on January 24, 1995)(hereinafter, 'The first prior art'). The first prior art employs an FSS to transmit only a frequency band desired by a user wherein a resonant frequency of FSS can be adjusted by varying a width and a whole length of a dielectric slot.
- [6] Since, however, a shape of conductor constituting a unit cell used in such FSS is of a rectangular loop, there exists a problem that an area of the unit cell itself is varied when altering the length of the loop.
- [7] Meanwhile, one of methods that design FSS that resonates in a desired frequency band while reducing an area of a unit cell is 'Convolutional array elements and reduced size unit cells for frequency-selective surfaces' that form the unit cell using a structure known as Hilbert curve among fractal structures (IEEE PROCESSINGS-H, vol. 138, no.1, February 1991, pp 19-22, E. A. Parker and A. N. A.El Sheikh)(hereinafter, 'The

second prior art. However, this second prior art has a drawback that a shape of conductor constituting the unit cell used in FSS is of a convoluted square and thus the resonant frequency is varied depending on an incident (vertical or horizontal) polarization.

- [8] Namely, the above-mentioned prior art FSS has drawbacks that the frequency selective characteristics are varied depending on the polarization of electromagnetic waves, and it cannot accurately block electromagnetic waves at a frequency of multi-band. Moreover, since the conventional FSS merely adjusts a length of conductor or aperture surface to tune a cut-off frequency, it results in an increase of cost due to such design change.

Disclosure of Invention

Technical Problem

- [9] It is, therefore, an object of the present invention to provide an FSS that allows multiple cut-off frequency bands to be easily adjusted without being affected by the polarization of electromagnetic waves by using a structure that a tri-pole and a ternary tree shape loop as a unit cell are connected without overlapping.
- [10] Another object of the invention is to provide a design method of an FSS that can block or transmit a predetermined frequency band by modifying geometrical structure characteristics such as a whole length of meandrous square loops used as unit cells in the FSS and intervals between the loops and electrical characteristics of dielectrics and conductors adopted in the FSS.

Technical Solution

- [11] In accordance with one aspect of the present invention, there is provided a Frequency Selective Surface (FSS) for the filtering of multiple frequency bands, the FSS comprising: a dielectric layer; and a plurality of unit cells periodically arrayed on an upper side of the dielectric layer, each of the unit cells being composed of a tri-pole and a ternary tree shape loop connected without overlapping.
- [12] Further, the FSS is implemented in such a way that an end portion of the tri-pole is meshed with an internal end point of the ternary tree shape loop.
- [13] Furthermore, the FSS is implemented such that adjacent unit cells among the unit cells are geometrically meshed with each other.
- [14] In addition, the FSS is fully coated with a dielectric to vary a resonant frequency.
- [15] In accordance with another aspect of the present invention, there is provided a Frequency Selective Surface (FSS) for the filtering of a single frequency band, the FSS comprising: a meandering square shape loop for being formed as a conductor or a dielectric layer; and a plurality of unit cells for being made of a conductor or a dielectric layer.

- [16] In accordance with another aspect of the present invention, there is provided a method for designing an FSS for the filtering of a frequency band, the method comprising the steps of: bending a square shape loop at least once to obtain a meandrous square shape loop and adjusting a length of the meandrous square shape loop when forming unit cells in the FSS; and arranging the unit cells such that the FSS is comprised of geometrically identical unit structures or cells to tune a resonant frequency.
- [17] Moreover, in accordance with the invention, the frequency band (e.g., mobile phone band 1.81 GHz, 2.4 GHz, ISM band, or the like) to be filtered can be adjusted by varying a length and interval of the meandrous square loop inside the unit cells of FSS, an interval between the unit cells, a thickness of the dielectric, a permittivity, etc. In other words, the desired frequency band can be blocked or passed by adjusting a geometric length, size, location, thickness, and material of the meandrous square shape loop, dielectric, etc. forming the FSS.
- [18] The other objectives and advantages of the invention will be understood by the following description and will also be appreciated by the embodiments of the invention more clearly. Further, the objectives and advantages of the invention will readily be seen that they can be realized by the means and its combination specified in the claims.

Advantageous Effects

- [19] The present invention is advantageous that it can enable a fine tuning of multiple cut-off frequencies by adjusting an electric capacitance between a tri-pole and a ternary tree shape loop.
- [20] Furthermore, the present invention is allowed to selectively block or transmit a pre-determined frequency band desired by a user. Moreover, the invention has an advantage that it is possible to adjust a frequency to be filtered by varying a length of meandrous square loops constituting unit cells, a thickness of dielectric, and an interval between the unit cells, without any variation of each of the unit cells itself.
- [21] And also, the invention employs a unit cell with user-desired adjustable area and also has superior characteristics that are not affected by the variation of polarization of incident electromagnetic waves. In addition, an advantage is that the present invention can be used for various purposes such as masking of frequency bands for indoor silence or usage prohibition of a mobile phone, masking of frequency bands for protecting industry information by preventing an outflow of wireless LAN frequency bands, or the like.

Brief Description of the Drawings

- [22] The above and other objects and features of the present invention will become apparent from the following description of the preferred embodiments given in

conjunction with the accompanying drawings, in which:

- [23] Fig. 1 is a cross-sectional view of an FSS in accordance with a first embodiment of the present invention;
- [24] Fig. 2 shows an array structure of unit cells of the FSS in accordance with the first embodiment of the present invention;
- [25] Fig. 3 illustrates a detailed configuration of the unit cell depicted in Fig. 2;
- [26] Fig. 4 represents details of adjacent unit cells shown in Fig. 2;
- [27] Fig. 5 provides graphs showing resonant frequency characteristics of the FSS with respect to the unit cell structure;
- [28] Fig. 6 presents graphs showing variations of the resonant frequency with respect to the thickness of the dielectric coating layer of the FSS in accordance with the first embodiment of the present invention;
- [29] Fig. 7 offers graphs showing variations of resonant frequencies with respect to an interval between the unit cells of the FSS in accordance with the first embodiment of the present invention;
- [30] Fig. 8 provides graphs showing changes of resonant frequencies with respect to a width of the tri-pole of the FSS in accordance with the first embodiment of the present invention;
- [31] Fig. 9 represents graphs showing analysis results of the FSS in accordance with the first embodiment of the present invention, which is manufactured depending on frequency bands of the mobile communication service;
- [32] Fig. 10 presents graphs showing predicted values and experimental values for frequency characteristic of the FSS which does not include the dielectric coating layer in accordance with the first embodiment of the present invention;
- [33] Fig. 11 shows an array of FSS unit cells for the filtering of a frequency in accordance with a second embodiment of the present invention;
- [34] Fig. 12 is a view showing a detailed configuration of the FSS unit cell for the filtering of the single frequency in accordance with the second embodiment of the present invention;
- [35] Fig. 13 depicts a detailed configuration of the FSS unit cell for the filtering of the single frequency in accordance with the second embodiment of the present invention;
- [36] Fig. 14 is a cross-sectional view of the FSS unit cell for the filtering of the single frequency having a bandstop function in accordance with the second embodiment of the present invention;
- [37] Fig. 15 is a view showing resonant frequency characteristics of the spatial filter composed of the FSS unit cell shown in Fig. 12 for the filtering of the single frequency in accordance with the second embodiment of the present invention; and
- [38] Fig. 16 is a view showing resonant frequency characteristics of the spatial filter

composed of the FSS unit cell shown in Fig. 13 for the filtering of the single frequency in accordance with the second embodiment of the present invention.

Best Mode for Carrying Out the Invention

- [39] The above-mentioned objectives, features, and advantages will be more apparent by the following detailed description in association with the accompanying drawings; and based on this, the invention will be readily conceived by those skilled in the art to which the invention pertains. Further, in the following description, well-known arts will not be described in detail if it seems that they could obscure the invention in unnecessary detail. Hereinafter, a preferred embodiment of the present invention will be set forth in detail with reference to the accompanying drawings.
- [40] Fig. 1 is a view showing an FSS in accordance with a first embodiment of the present invention.
- [41] As shown in Fig. 1, the FSS of the present invention are configured in a such manner that a plurality of unit cells 12 composed of conductors are periodically arrayed on an upper side of a thin dielectric layer 11.
- [42] Each of a lower side of the thin dielectric layer 11 and an upper side of the unit cells 12 is formed by a dielectric coating layer 13. Here, each unit cell 12 has a structure that a tri-pole and a ternary tree shape loop are coupled without overlapping. This will be set forth in detail in the following embodiment.
- [43] First of all, various parameters used in designing the FSS of the invention and doing experiments on its frequency characteristics will be defined below. In Fig. 1, h_1 indicates a thickness of the dielectric layer 11, ϵ_1 denotes a relative permittivity of the dielectric layer 11, h_2 represents a thickness of the dielectric coating layer 13, ϵ_2 is a relative permittivity of the dielectric coating layer 13, and t implies a thickness of a conductor portion 12 of the unit cell.
- [44] Fig. 2 is a view showing a unit cell array structure of the FSS in accordance with the first embodiment of the present invention, and Fig. 3 is a view illustrating a detailed configuration of the unit cell depicted in Fig. 2.
- [45] As shown in Fig. 2, the FSS of the present invention is implemented such that the unit cells 12 are periodically arrayed on the upper side of the dielectric layer 11, each of which includes a tri-pole 21 and a ternary tree type loop 22 connected without overlapping. Accordingly, the FSS of the prevent invention is not affected by the polarization of electromagnetic waves due to the connection of the tri-pole 21 and ternary tree shape loop 22.
- [46] Meanwhile, the FSS of the invention may use, as the unit cells 12, the tri-poles 21 only or the ternary tree type loops 22 only. As shown in Fig. 3, however, if there are adopted the unit cells 12 having the tri-poles 21 arranged without overlapping within

the ternary tree type loop 22, resonant frequency characteristics are varied depending on a change of a length of the tri-pole 21 and the ternary tree shape loop 22, and an interval between the tri-pole 21 and ternary tree type loop 22, thereby determining a cut-off frequency band.

[47] Fig. 4 illustrates adjacent unit cells depicted in Fig. 2. In Fig. 4, reference numeral 400 indicates an enlarged junction portion of two unit cells, wherein an end portion 401 of one unit cell is exactly meshed with a bent portion 402 of the other unit cell. Also, an endmost portion 403 of a tri-pole in said one unit cell is exactly meshed with an endmost point 404 inside a ternary tree shape loop.

[48] In the meantime, parameters needed to design the FSS of the invention and conduct experiments on frequency characteristics will be defined below. In Fig. 4, dy and dx indicate longitudinal and horizontal distances between center points of two unit cells, respectively. And, g denotes an interval between unit cells; a indicates a width of the tri-pole; w indicates a width of a conductor strip of the ternary tree shape loop; b represents a width of the ternary tree shape loop; angle means an angle at which a center line connecting two unit cells is tilted with respect to a horizontal direction; l_1 represents a distance from a center of a unit cell to an endmost portion of the ternary tree shape loop; l_2 implies a distance from a center of a unit cell to an endmost portion of the tri-pole; and c_1 denotes a distance between the tri-pole and ternary tree shape loop.

[49] Further, intervals c_1 , c_2 and c_3 between structures inside the unit cells and the interval g between the unit cells are set to be started from a minimum value of ~ 0 . This minimum interval value enlarges an available range for fine tuning of the resonant frequency in the course of the design process of the FSS.

[50] Fig. 5 shows graphs illustrating resonant frequency characteristics of the FSS for several unit cell structures. These graphs show resonant frequency characteristics in case where the unit cell of FSS is of a tri-pole 510, a ternary tree shape loop 520, and a combined shape 530 of the tri-pole and the ternary tree shape loop in accordance with the present invention, respectively.

[51] Table 1 below presents a design condition of the FSS in accordance with the present invention.

[52]

[53] Table 1

Parameter	a	b	c_1	w	g	t	e_1	e_2
Length(mm)	1.5	5.0	1.0	1.0	1.0	0.035	3.3	4.5
Parameter	h_1	h_2	angle	l_1	l_2	dx	dy	-
Length(mm)	0.0762	1.6	30	25.8	21.2	26.96	15.57	-

[54]

[55] If the unit cells of the FSS consist of the tri-pole 510, there exists a single resonant frequency 511; and if the unit cells of the FSS are formed by the ternary tree shape loop 520, there are two resonant frequencies 521 and 522. Meanwhile, if the unit cells are composed of both 530 of the tri-pole and the ternary tree shape loop in accordance with the present invention, there are three resonant frequencies 531, 532 and 533.

[56] As can be seen from Fig. 5, with the unit cells in accordance with the present invention, the resonant frequencies are all lowered, compared to the conventional instance that uses either the tri-pole or the ternary tree shape loop. This lowering of the resonant frequencies is because an electronic capacitance between the tri-pole and the ternary tree shape loop increases. Accordingly, this leads to a reduction of a size of the unit cell, thereby decreasing an overall size of the FSS.

[57] As described above, the FSS in accordance with the present invention generates the three resonant frequencies. In the following first embodiment of the present invention, among the three resonant frequencies, the first and second order resonant frequencies generated by the ternary tree shape loop are given by reference numerals 61 and 62, and the first order resonant frequency created by the tri-pole is given by reference numeral 63.

[58] Fig. 6 offers graphs illustrating variations of the resonant frequency with respect to a thickness of a dielectric coating layer of the FSS in accordance with the first embodiment of the present invention.

[59] As shown in Fig. 6, the FSS in accordance with the first embodiment of the present invention allows the resonant frequencies to be abruptly and then slowly lowered as the thickness h_2 of the dielectric coating layer increases.

[60] Fig. 7 provides graphs illustrating variations of the resonant frequency with respect to an interval between the unit cells of the FSS in accordance with the first embodiment of the present invention.

[61] As shown in Fig. 7, the FSS in accordance with the first embodiment of the present invention reduces the interval between the resonant frequencies as the interval g between the unit cells becomes large.

[62] Fig. 8 presents graphs showing variations of the resonant frequency with respect to a width of the tri-pole of the FSS in accordance with the first embodiment of the present invention.

[63] As depicted in Fig. 8, the FSS in accordance with the first embodiment of the present invention reduces amplitudes of the first and second order resonant frequencies 61 and 62 generated by the ternary tree shape loop as the width a of the tri-pole increases.

[64] Based on the results as shown in Figs. 6 to 8, the cut-off frequency of the FSS in

accordance with the present invention can be precisely predicted by deducting the electric capacitance between the tri-pole and the ternary tree shape loop within the unit cell.

[65] Fig. 9 shows graphs illustrating analysis results of the FSS in accordance with the present invention, which is manufactured based on frequency bands of the mobile communication service.

[66] Design parameters for the analysis results shown in Fig. 9 are defined below in Table 2. Here, the type I indicates that the FSS does not have the dielectric coating layer 13, while the type II shows that the FSS has the dielectric coating layer 13 whose thickness h_2 is 1.6 mm.

[67] Table 2

Parameter	a	b	c_1	w	g	t	e_1	e_2
Type I	1.0	7.5	2.25	1.0	1.0	0.035	3.3	4.5
Type II	1.5	5.0	1.0	1.0	1.0	0.035	3.3	4.5
Parameter	h_1	h_2	angle	l_1	l_2	dx	dy	-
Type I	0.0762	0	30	47.2	40.2	47.37	27.35	-
Type II	0.0762	1.6	30	25.8	21.2	26.96	15.57	-

[68]

[69] Meanwhile, mobile communication service frequency bands to be blocked are given in the following Table 3.

[70] Table 3

Frequency(MHz)Service	Frequency range		Overall bandwidth	Center frequency of overall available band	Difference between center frequencies
	Mobile station transmission (bandwidth)	Mobile station reception (bandwidth)			
Cellular	824~849(25)	869~894(25)	70	859	1.0
PCS	1,750~1,780(30)	1,840~1,870(30)	120	1,810	2.107
Wireless LAN, Bluetooth, etc.	2,400~2,483.5		83.5	2,441.75	2.84

[71]

[72] Referring to Table 3 above, the center frequencies of the cellular service, the PCS

service and the wireless LAN service are 859 MHz, 1,810 MHz and 2,442 MHz, respectively.

[73] As shown in Fig. 9, the FSS in accordance with the first embodiment of the invention having the parameters shown in Table 2 above has resonant frequencies of f_1 (859 MHz), f_2 (1,810 MHz), and f_3 (2,442 MHz); and these resonant frequencies are consistent with the above-stated center frequencies of bands to be blocked.

[74] Fig. 10 shows graphs illustrating predicted values and experimental values for the frequency characteristics of the FSS in accordance with the first embodiment of the present invention that has no dielectric coating layer. Namely, Fig. 10 shows a comparison of the predicted values and experimental values for the frequency characteristics of the FSS in accordance with the invention that is designed as type I defined in Table 2 above.

[75] In Fig. 10, reference numeral 110 indicates a predicted frequency characteristic value of the FSS in accordance with the present invention without the dielectric coating layer. Reference numeral 120 (H, H) and 130 (V, V) indicate experimental values for the frequency characteristics of the FSS in accordance with the present invention, respectively, when polarizations of transmission and reception antennas are all horizontal and vertical ones.

[76] As shown in Fig. 10, the frequency characteristic prediction values of the FSS in accordance with the present invention that is designed as type I in Table 2 are relatively precisely consistent with the actually measured experimental values. Accordingly, it is possible to design the FSS that can be precisely resonant at a predetermined cut-off frequency based on the analysis results as shown in Figs. 6 to 8.

[77] In addition, the FSS in accordance with the present invention is not affected by the polarization of the electromagnetic waves, as shown in Fig. 10.

[78] Hereinafter, a method to design an FSS in accordance with a second embodiment of the present invention will be described.

[79] Fig. 11 shows an array of unit cells of FSS for the filtering of a frequency in accordance with a second embodiment of the present invention.

[80] To design it in such a way that a length of a loop constituting unit cells is geometrically maximized with respect to its unit area (implying that the resonant frequency is lowered as the length extends), the loop of the unit cells should be complexly bent but not overlapped.

[81] Therefore, the FSS of the invention is comprised of an array of unit cells 1100 (an array of geometrically same unit structures) with a meanderingly bent square shape loop 1110, as shown in Fig. 11. In other words, to make the loop of the unit cell 1100 lengthy, that is, to lower the resonant frequency, the unit cell 1100 is configured to have a meandrous square shape loop 1110 that is formed by meanderingly bending the

square shape loop many times.

[82] Each of the unit cells 1100 consists of the meandrous square shape loop 1110 and a portion 1120 excepting the loop 1110.

[83] For example, if the meandrous square shape loop 1110 is conductor and the remaining portion 1120 is dielectric in each unit cell 1100, the FSS of invention is operated as a bandstop filter; and conversely if the meandrous square shape loop 1110 is dielectric and the remaining portion 1120 is conductor, the FSS is operated as a bandpass filter.

[84] The frequency band to be blocked causes the overall length of the meandrous square shape loop 1110 to be varied based on its bent number of times; and also is adjustable by modifying an interval between loops, an interval between the unit cells 1100, and electrical characteristics such as material and permittivity of dielectric and conductor, thereby tuning the resonant frequency. The meandrous square loop 1110 within each unit cell 1100 accurately has a bilateral symmetric structure and is not affected by the polarization of incident electromagnetic waves. That is, the frequency band to be filtered can be adjusted by varying the length and interval of the meandrous square loops 1110 forming the unit cells 1100 of FSS, the interval between the unit cells 1100, the thickness of the dielectric, the permittivity, etc.

[85] For this, it is implemented in such a manner that the resonant frequency is not affected by the variation of the incident polarization by making the meandrous square loop 1110 constituting the unit cell 1100 symmetrical with respect to both of the longitudinal and horizontal directions. At this time, the area of the unit cell 1100 may also be adjusted by modifying the width and bent number of times of the meandrous square loop 1110.

[86] Each of the unit cells 1100 in Fig. 11 may be configured, as shown in Figs. 12 and 13. For instance, if the unit cells 1200 and 1300 of FSS shown in Figs. 12 and 13 are designed as a bandstop filter, a cross-sectional view of the FSS unit cells 1200 and 1300 is shown in Fig. 14 as reference numeral 1400.

[87] The FSS unit cell 1400 shown in Fig. 14 serves as the bandstop filter, wherein the meandrous square loop 1410 is conductor and the remaining parts 1420 and 1430 are dielectric.

[88] As shown in Fig. 14, if the FSS unit cell 1400 is operated as the bandstop filter, it is formed by etching a conductor 1410 on a dielectric board ₁ 1420. In this case, the dielectric board 1420 and the conductor 1410 may be coated with dielectric to make a dielectric layer ₂ 1430.

[89] For example, if the FSS unit cell 1400 is operated as a bandpass filter, the portions of the dielectric board ₁ 1420 and the conductor 1410 are changed to each other. In such a case, however, the dielectric coating layer ₂ 1430 is not changed.

- [90] Among others, in order to make the resonant frequency of the FSS unit cell 1400 lowered, the meandrous square loop 1410 should be extended, meaning that the bent number of times thereof is great, and ϵ_2 of the dielectric layer 1430 should be high. In other words, the more the meandrous square loop 1410 is long and ϵ_2 of the dielectric layer 1430 is high, the more the resonant frequency is low. Of course, there may be any limitations associated with the bilateral symmetric structure, etc.
- [91] Now, details of the FSS unit cells 1200 and 1300 will be described below with reference to Figs. 12 and 13.
- [92] In Fig. 12, reference numeral `1200` indicates a unit cell, reference numeral `1210` represents a meandrous square loop, and reference numeral `1220` denotes portions excepting the loop 1210 in the unit cell 1200.
- [93] For example, if the meandrous square loop 1210 is conductor and the rest portion 1220 (strictly, the dielectric board 1 1410 shown in Fig. 14) is dielectric, the FSS unit cell 1200 in Fig. 12 is operated as the bandstop filter. Conversely, if the meandrous square loop 1210 is dielectric and the rest portion 1220 (strictly, the dielectric board 1 1420 shown in Fig. 14) is conductor, the FSS unit cell 1200 in Fig. 12 is operated as the bandpass filter. However, in case where the FSS is operated as the frequency-selective filter for bandstop or bandpass, there is no change of the dielectric coating layer 2 1430 shown in Fig. 14 among the portions 1220 excepting the meandrous square loop 1210.
- [94] For instance, if the FSS unit cell 1200 in Fig. 12 is designed as the bandstop filter, the resonant frequency characteristics of the FSS are given in Fig. 15.
- [95] Meanwhile, as shown in Fig. 12, if the unit cell 1200 of the FSS having the meandrous square loop 1210 has the same area as that of the first prior art having the general square loop merely as introduced early, the resonant frequency can be lowered, compared to the first prior art, since the length of the loop 1210 is extended. Therefore, if the FSS unit cell 1200 shown in Fig. 12 has the same resonant frequency as that of the first prior art, the size of the unit cell can be further reduced.
- [96] Fig. 15 shows a comparison of simulation result and actual experimental result when the FSS unit cell 1200 in Fig. 12 is designed as the bandstop filter. Detailed parameters used when the FSS unit cell 1200 is designed as the bandstop filter are defined below in Table 4. In Fig. 15, the cut-off center frequency of the FSS is fixed to 1.81 GHz that is a center frequency of the domestic PCS band.

[97] Table 4

Parameter	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	g_x	g_y
Length (mm)	8.265	5.816	3.367	0.918	0.918	2.449	1.837	0.6	0.305	0.305

Parameter	w_1	W_2	p_x	p_y	t	h_1	h_2	l_1	l_2	
Length (mm)	0.61 2	0.612	20.2	20.2	0.017 5	0.035	0.0	3.2	1.0	45

[98]

[99]

On the other hand, the area of the FSS unit cell 1200 in Fig. 12 can be adjusted by varying the width and the bent number of times of the meandrous square loop 1210 of the FSS unit cell 1200, as shown in Fig. 13. Namely, the size of the FSS unit cell 1200 can be reduced by more greatly setting the width and the bent number of times of the meandrous square loop 1210. Accordingly, if the FSS unit cell 1300 shown in Fig. 13 has the same size as that of the unit cell 1200 in Fig. 12, the resonant frequency can be more lowered.

[100]

In Fig. 13, reference numeral '1300' indicates a unit cell, reference numeral '1310' represents a meandrous square loop, and reference numeral '1320' denotes portions excepting the loop 1310 in the unit cell 1300.

[101]

The FSS unit cell 1300 depicted in Fig. 13 is constructed such that its size is smaller, while maintaining the same resonant frequency as that of the FSS unit cell in Fig. 12. That is, the FSS unit cell 1300 in Fig. 13 has a narrower meandrous square loop 1310 with once more bent shape 330 while maintaining the same shape as that of the FSS unit cell 1200 in Fig. 12. By doing so, the size of the FSS unit cell 1300 in Fig. 13 can be smaller than that of Fig. 12. If the sizes of the FSS unit cells in Figs. 12 and 13 are the same, the resonant frequency of the FSS unit cell 1300 in Fig. 13 can be lowered, compared to that of Fig. 12.

[102]

Also in the FSS unit cell 1300 of Fig. 13, if the meandrous square loop 1310 is conductor and the remaining portion 1320 (strictly, the dielectric board ₁ 1420 shown in Fig. 14) is dielectric, the FSS unit cell 1300 in Fig. 13 is operated as the bandstop filter. Conversely, in the FSS unit cell 1300 of Fig. 13, if the meandrous square loop 1310 is dielectric and the remaining portion 1320 (strictly, the dielectric board ₁ 1420 shown in Fig. 14) is conductor, the FSS unit cell 1300 in Fig. 13 is operated as the bandpass filter. However, in case where the FSS is operated as the frequency-selective filter for bandstop or bandpass, there is no change of the dielectric coating layer ₂ 1430 in Fig. 14 among the portions 1320 excepting the meandrous square loop 1310.

[103]

For instance, if the FSS unit cell 1300 in Fig. 13 is designed as the bandstop filter, the resonant frequency characteristics of the FSS are presented in Fig. 16.

[104]

Fig. 16 shows a comparison of simulation result and actual experimental result when the FSS unit cell 1300 in Fig. 13 is designed as the bandstop filter. Detailed parameters used when the FSS unit cell 1300 is designed as the bandstop filter are defined below in Table 5. In Fig. 16, the bandstop center frequency of the FSS is also

fixed to 1.81 GHz that is a center frequency of the domestic PCS band.

[105] Table 5

Parameter	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	g_x
Length (mm)	7.15	5.5	3.85	2.2	0.55	0.55	1.65	1.1	0.6	0.275	0.275
Parameter	g_y	w_1	w_2	p_x	p_y	t	h_1	H_2	l_1	l_2	
Length (mm)	0.275	0.275	0.55	16.5	16.5	0.0175	0.035	0.0	3.2	1.0	45

[106]

[107] As can be seen from Figs. 15 and 16, the FSS frequency characteristics of the present invention are relatively well consistent with the actually measured data, and thus are valid in the actual design process.

[108] The present application contains subject matter related to Korean patent application No. KR2005-0021383 filed in the Korean Intellectual Property Office on March 15, 2005 and May 17, 2005, and Korean patent application No. KR2005-0041180 filed in the Korean Intellectual Property Office on May 17, 2005, the entire contents of which are incorporated herein by reference.

[109] While the present invention has been described with respect to certain preferred embodiments, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the scope of the invention as defined in the following claims.

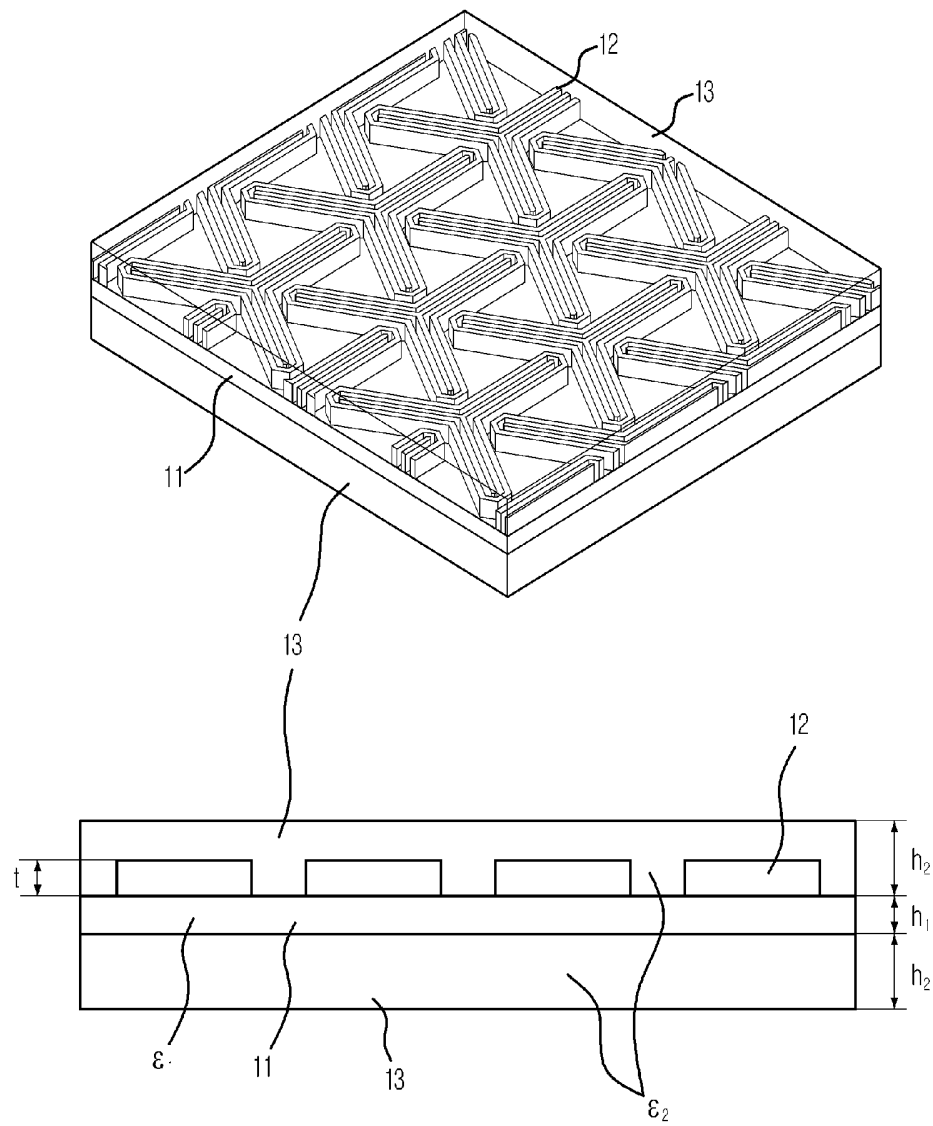
Claims

- [1] A Frequency Selective Surface (FSS) for the filtering of multiple frequency bands, the FSS comprising:
 - a dielectric layer; and
 - a plurality of unit cells periodically arrayed on an upper side of the dielectric layer, each of the unit cells being composed of a tri-pole and a ternary tree shape loop connected without overlapping.
- [2] The FSS as recited in claim 1, wherein an end portion of the tri-pole is meshed with an internal end point of the ternary tree shape loop.
- [3] The FSS as recited in claim 1, wherein adjacent unit cells among the unit cells are geometrically meshed with each other.
- [4] The FSS as recited in claim 1, wherein an outer surface of the tri-pole is parallel to an internal surface of the ternary tree type loop.
- [5] The FSS as recited in claim 1, wherein a resonant frequency is tuned by adjusting lengths of the tri-pole and the ternary tree shape loop.
- [6] The FSS as recited in claim 1, wherein resonant frequencies are tuned by adjusting a width of the tri-pole.
- [7] The FSS as recited in claim 1, wherein resonant frequencies are tuned by adjusting an interval between the tri-pole and the ternary tree shape loop.
- [8] The FSS as recited in claim 1, wherein a dielectric is coated on the overall FSS to vary resonant frequencies.
- [9] A Frequency Selective Surface (FSS) for the filtering of a single frequency band, the FSS comprising:
 - a meandering square shape loop for being formed as a conductor or a dielectric layer; and
 - a plurality of unit cells for being made of a conductor or a dielectric layer.
- [10] The FSS as recited in claim 9, wherein if the meandrous square shape loop is conductor and the remaining portion excepting the loop is dielectric in each of the unit cells, the FSS is operated as a bandstop filter.
- [11] The FSS as recited in claim 9, wherein if the meandrous square shape loop is dielectric and the remaining portion excepting the loop is conductor in each of the unit cells, the FSS is operated as a bandpass filter including a resonant frequency.
- [12] The FSS as recited in claim 9, wherein the resonant frequency is lowered, while identically maintaining sizes of the unit cells without a change of size of each unit cell, by making the square shape loop of each unit cell lengthy by means of bending the loop several times.

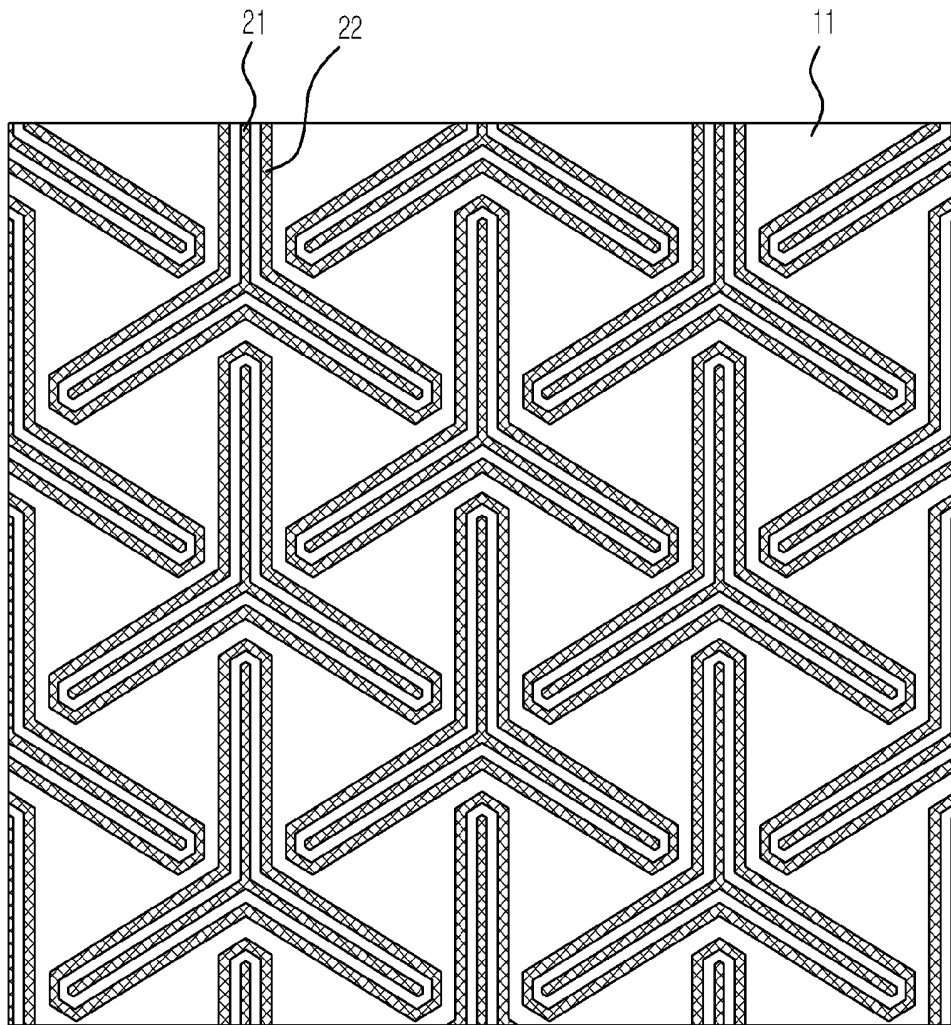
- [13] The FSS as recited in claim 12, wherein the size of each of the unit cells is reduced, while maintaining the same resonant frequency, by decreasing a width of the square shape loop of each unit cell and bending the loop many times to lengthen the loop of each unit cell.
- [14] The FSS as recited in claim 12, wherein the meandrous square shape loop of each unit cell is of upper, lower, left and right symmetric structure so that the resonant frequency is not affected by the polarization of incident electromagnetic wave.
- [15] The FSS as recited in claim 14, wherein the FSS is implemented such that the more the permittivity of the dielectric coating layer is high, the more the resonant frequency is low.
- [16] The FSS as recited in claim 10, wherein the remaining portion excepting the meandrous square shape loop in each of the unit cells includes a dielectric coating layer.
- [17] The FSS as recited in claim 16, wherein the FSS is implemented such that the more the permittivity of the dielectric coating layer is high, the more the resonant frequency is low.
- [18] A method for designing a Frequency Selective Surface (FSS) for the filtering of a single frequency band, the method comprising the steps of:
bending a square shape loop at least once to obtain a meandrous square shape loop and adjusting a length of the meandrous square shape loop when forming unit cells in the FSS; and
arranging the unit cells such that the FSS is composed of geometrically identical unit structures or cells to tune a resonant frequency.
- [19] The method as recited in claim 18, wherein if the meandrous square shape loop is conductor and the remaining portion excepting the loop is dielectric in each of the unit cells, the FSS is operated as a bandstop filter.
- [20] The method as recited in claim 18, wherein if the meandrous square shape loop is dielectric and the remaining portion excepting the loop is conductor in each of the unit cells, the FSS is operated as a bandpass filter.
- [21] The method as recited in claim 18 wherein the resonant frequency is lowered, while identically maintaining sizes of the unit cells without a change of size of each unit cell, by making the square shape loop of each unit cell lengthy by means of bending the loop several times.
- [22] The method as recited in claim 21, wherein the size of each of the unit cells is reduced, while maintaining the same resonant frequency, by decreasing a width of the square shape loop of each unit cell and bending the loop many times to lengthen the loop of each unit cell.

- [23] The method as recited in claim 18, wherein the meandrous square shape loop of each unit cell is of upper, lower, left and right symmetric structure so that the resonant frequency is not affected by the polarization of incident electromagnetic wave.
- [24] The method as recited in claim 23, wherein the FSS is implemented such that the more the length of the meandrous square shape loop is long, the more the resonant frequency is low.
- [25] The method as recited in claim 19, wherein the remaining portion excepting the meandrous square shape loop in each of the unit cells includes a dielectric coating layer.
- [26] The method as recited in claim 25, wherein the FSS is implemented such that the more the permittivity of the dielectric coating layer is high, the more the resonant frequency is low.

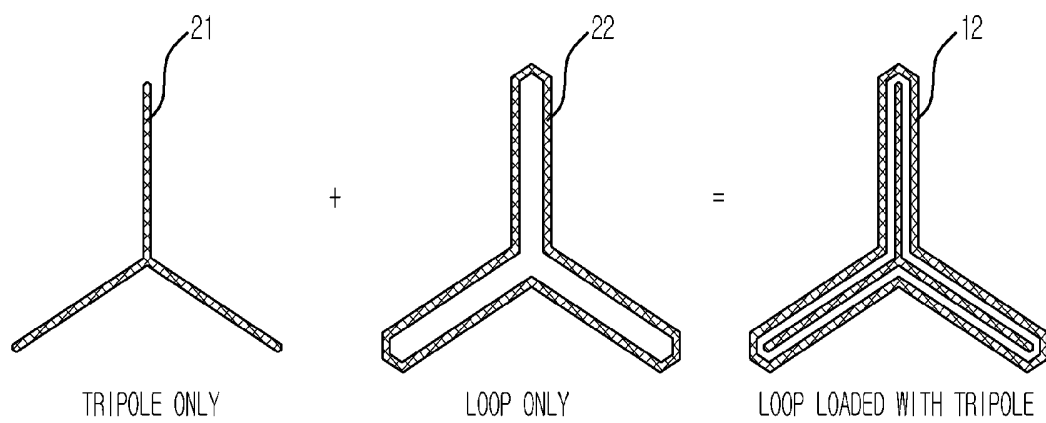
[Fig. 1]



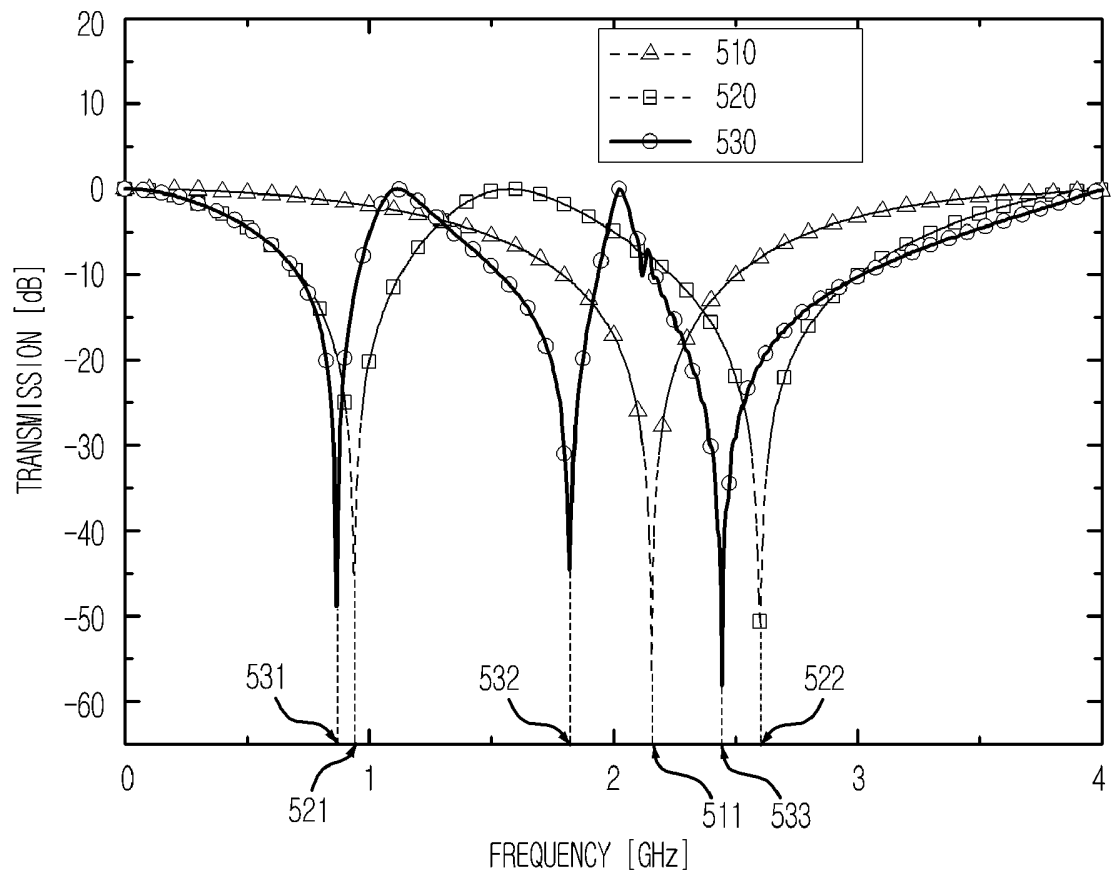
[Fig. 2]



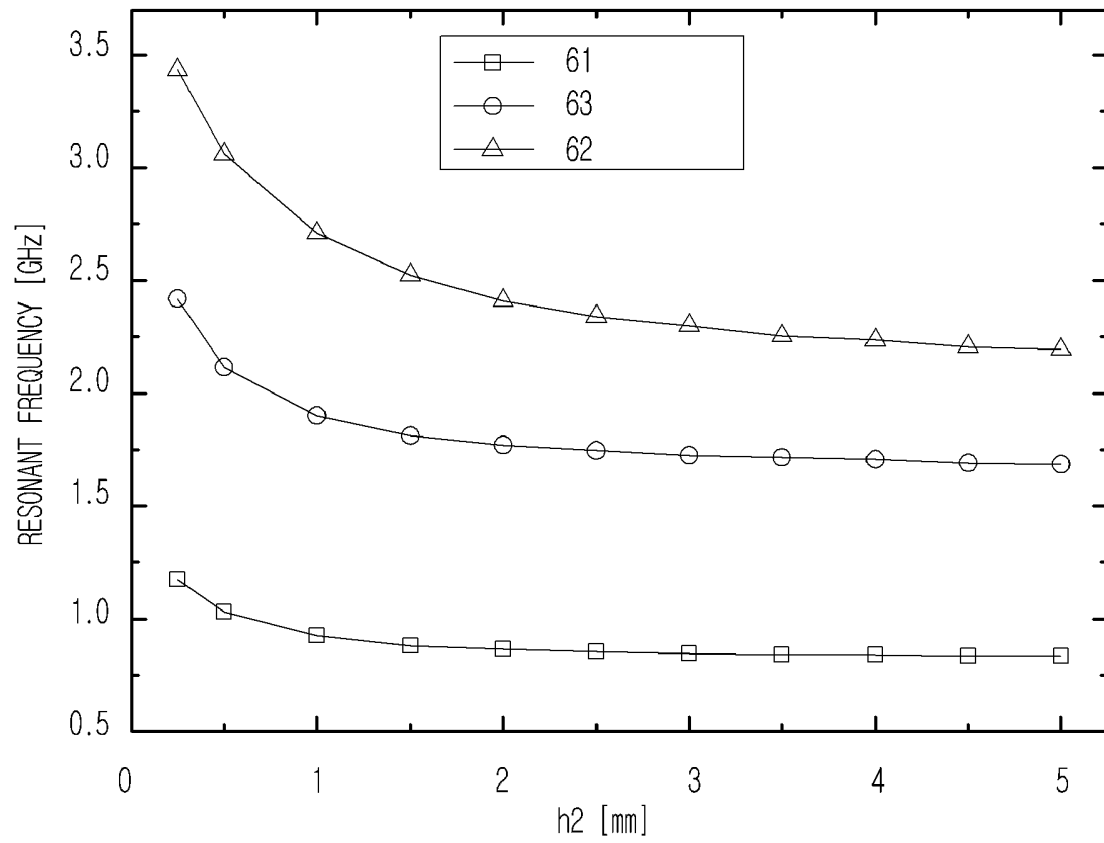
[Fig. 3]



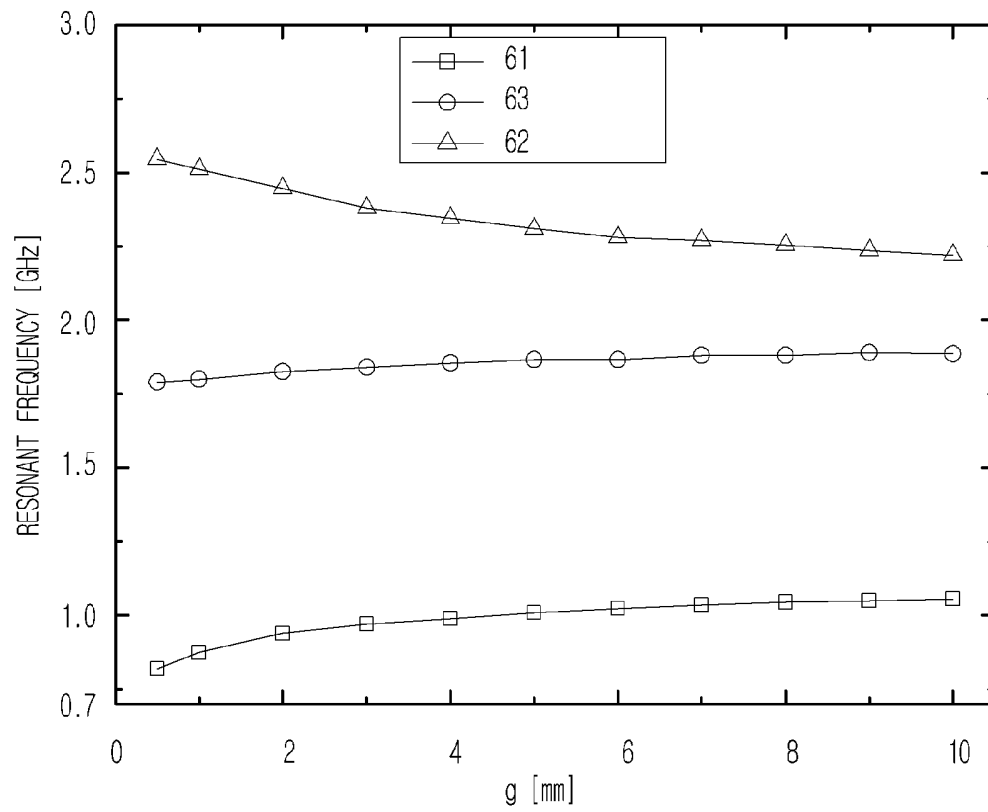
[Fig. 5]



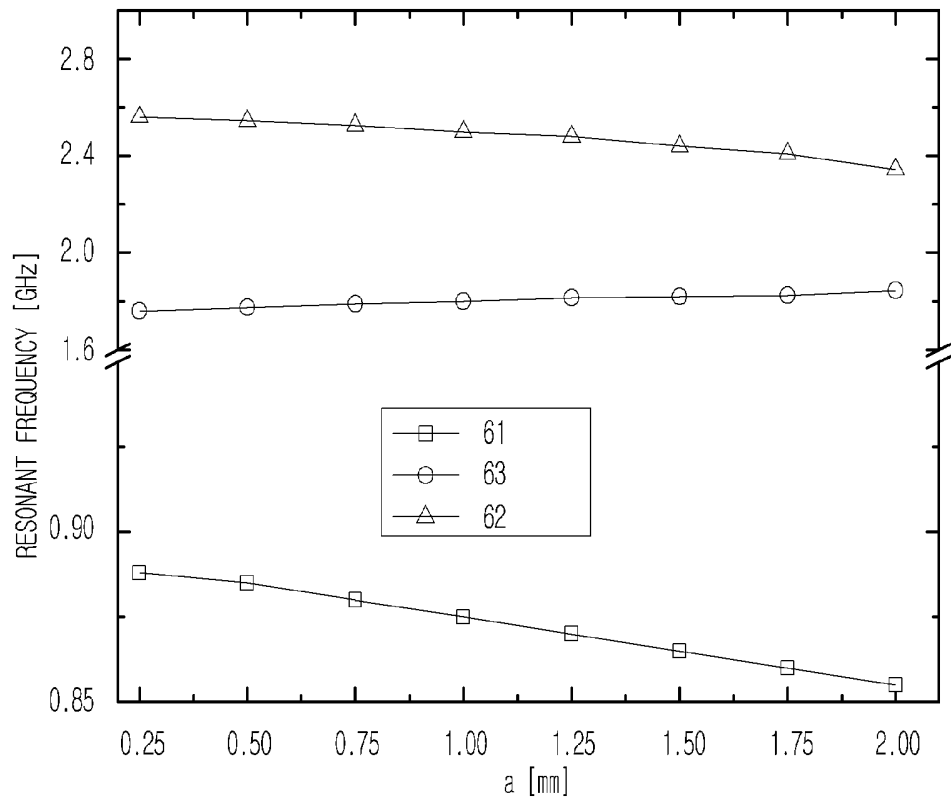
[Fig. 6]



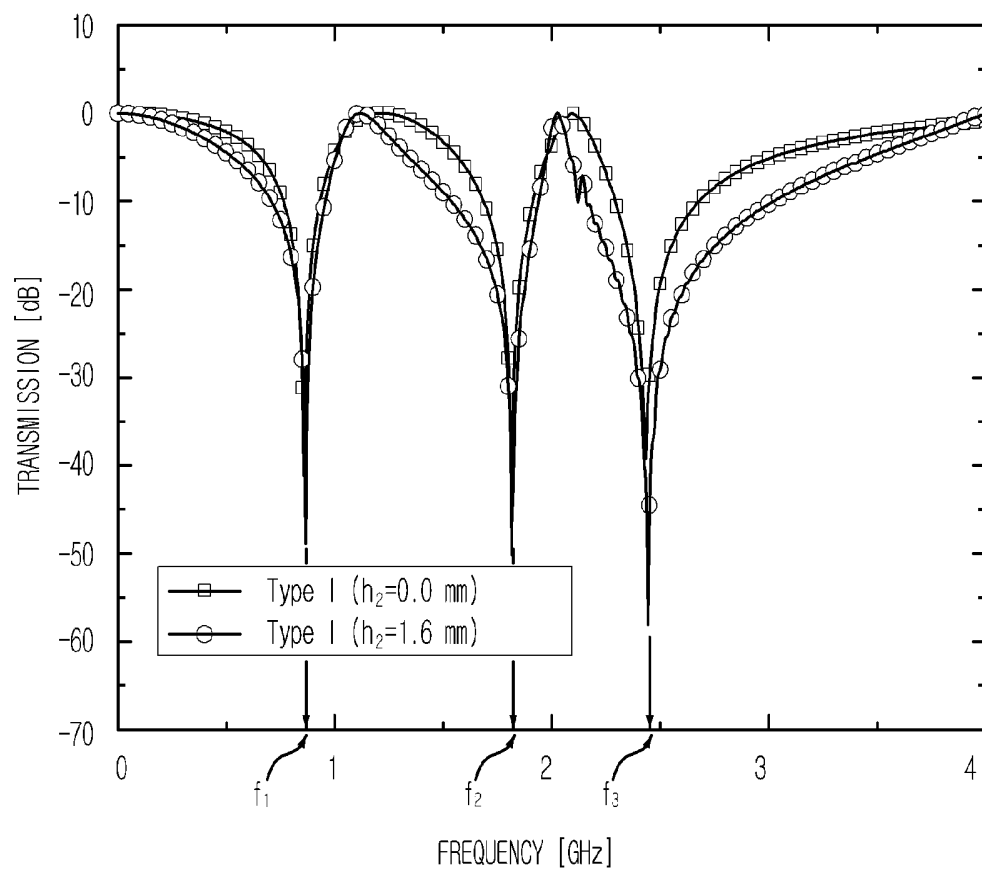
[Fig. 7]



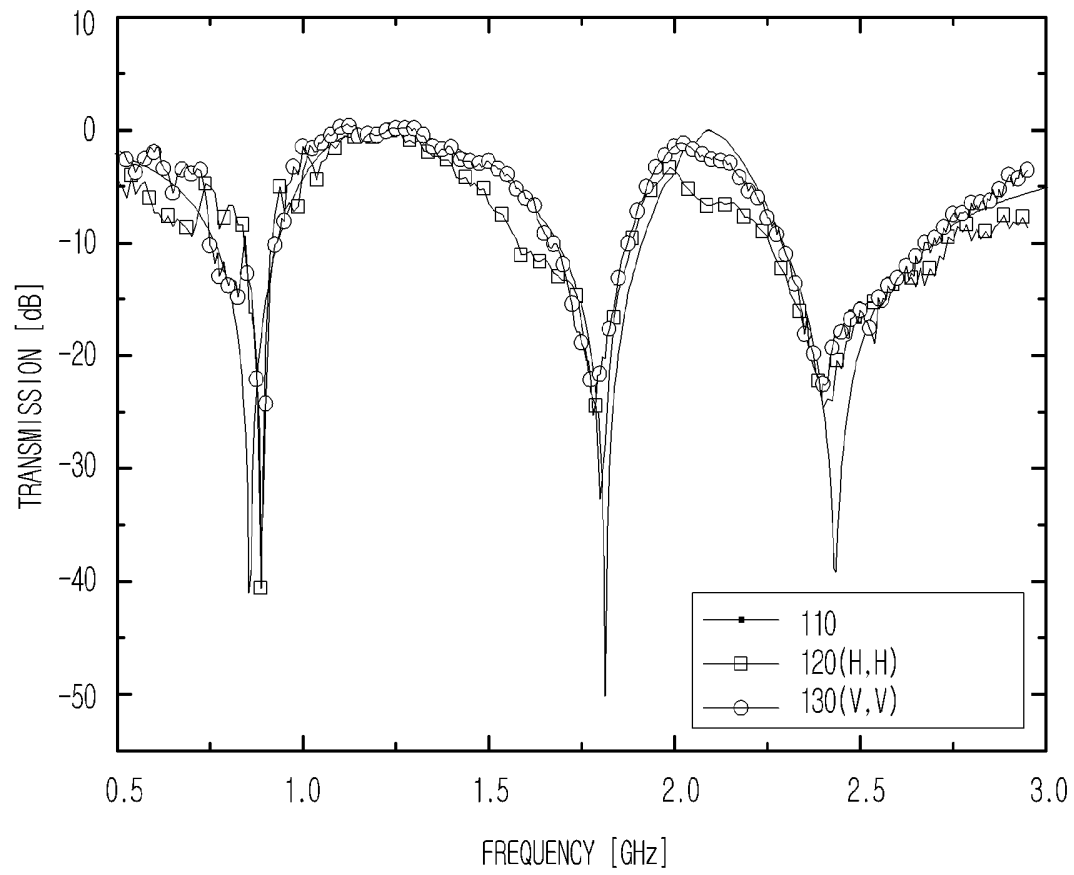
[Fig. 8]



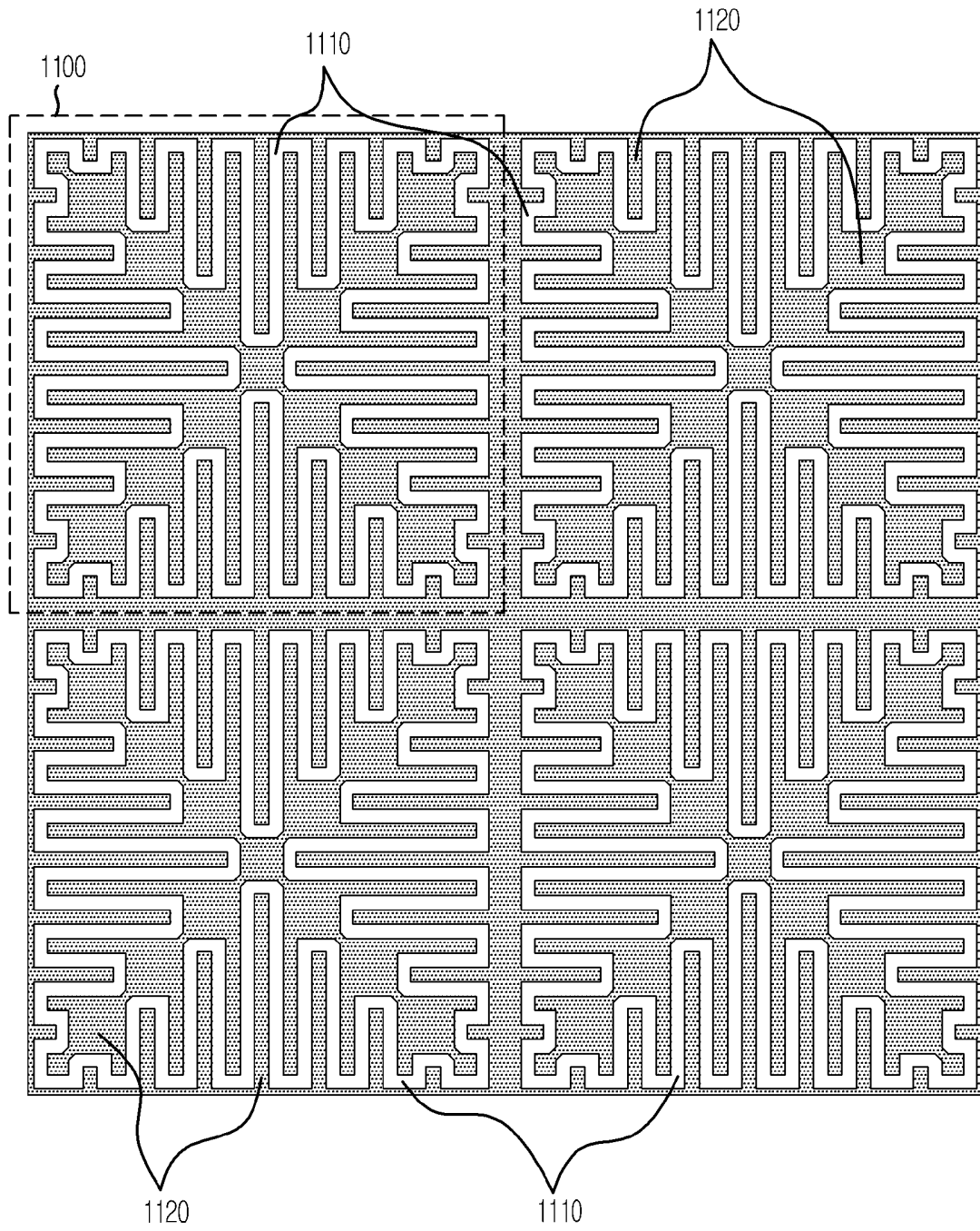
[Fig. 9]



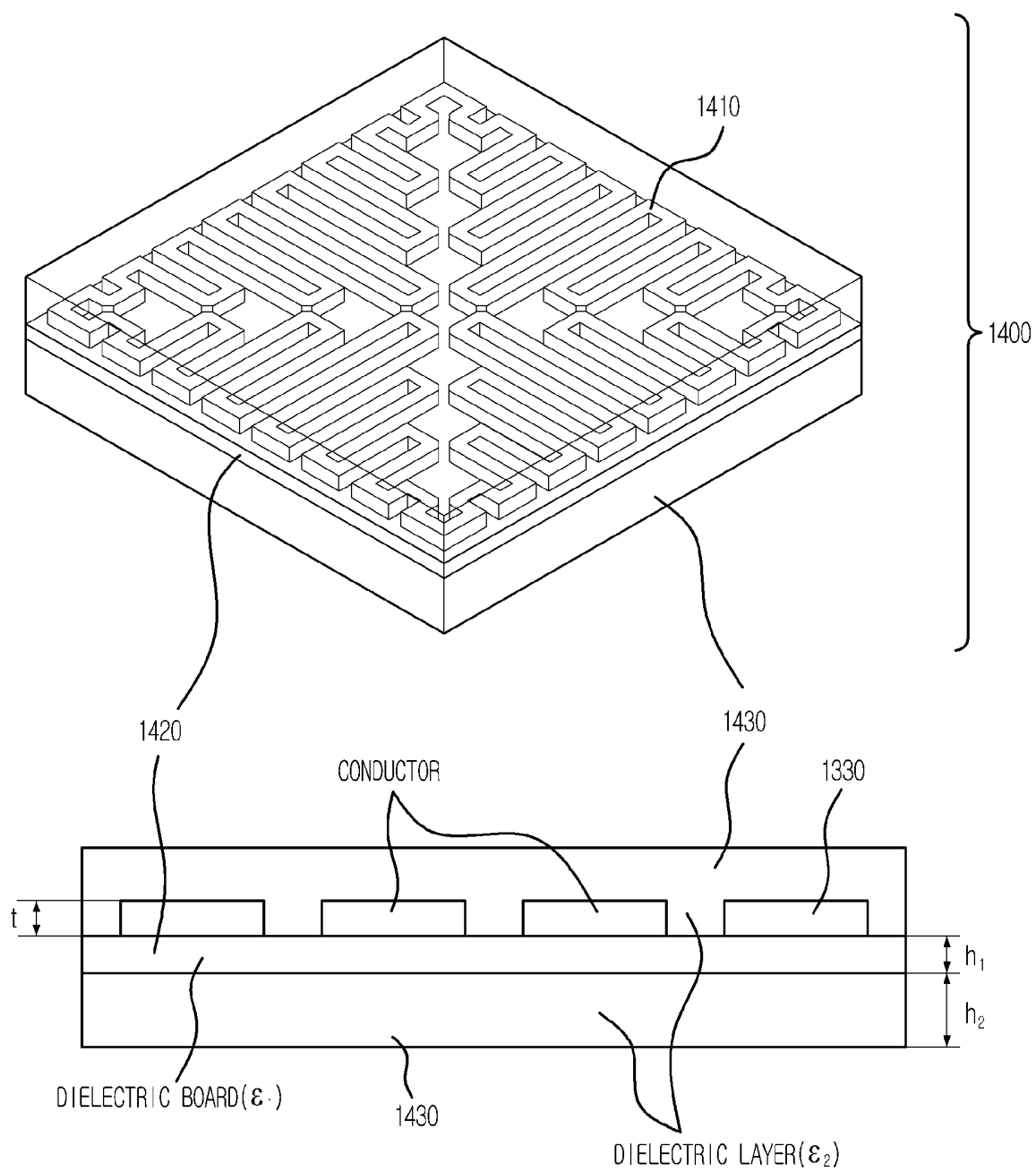
[Fig. 10]



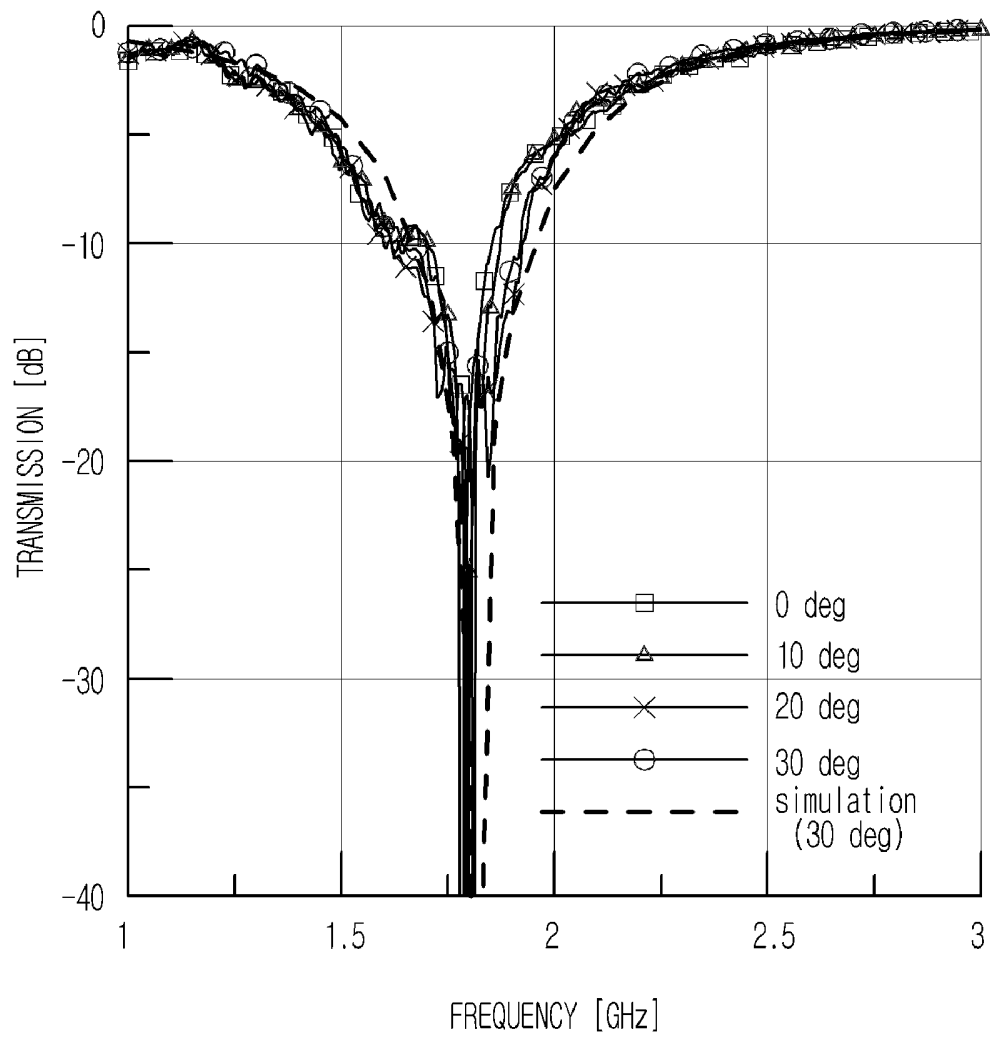
[Fig. 11]



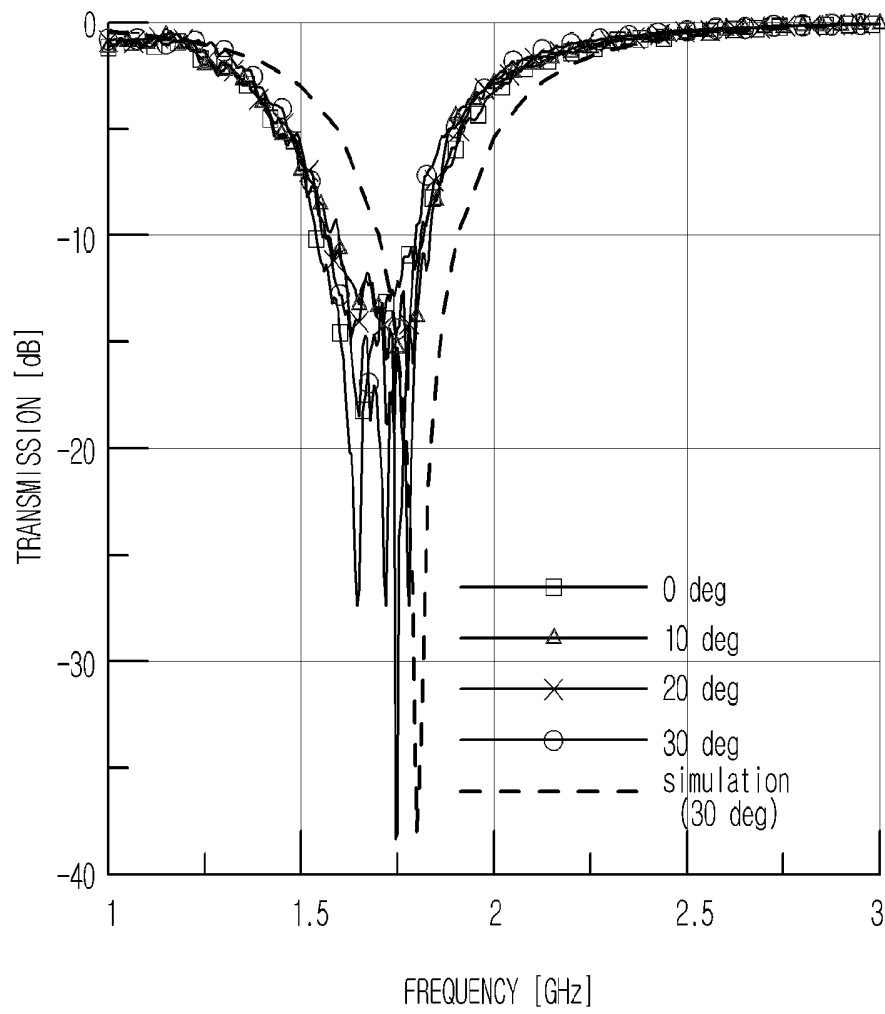
[Fig. 14]



[Fig. 15]



[Fig. 16]



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2006/000934**A. CLASSIFICATION OF SUBJECT MATTER****H01P 1/203(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 8 H01Q, H01P

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

Korean Patents and applications for inventions since 1975

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

eKIPASS "frequency selective surface, FSS"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 6,806,843 B2 (HARRIS CORPORATION) 19 OCT 2004 See Col. 8-9 & Fig.2 - 4	1-8 9, 18
Y	US 2003/0006940 A1 (WASHIRO et al.) 9 JAN 2003 See paragraphs [0005]-[0044], [0058]-[0073] & Fig.6-11	9, 18
A	US 6,670,932 B1 (E-TENNA CORPORATION) 30 DEC 2003 See Col. 9-11 & Fig.11-21	1-8
A	US 6,400,339 B1 (ALLGON AB) 4 JUN 2002 See Col.3-5 & Fig.2-6	9-26
A	IEEE PROCEEDING-H Vol.138, No.1, FEBRUARY 1991, pp 19-22 See the whole document	1-26



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

"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 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

23 JUNE 2006 (23.06.2006)

Date of mailing of the international search report

23 JUNE 2006 (23.06.2006)

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
920 Dunsan-dong, Seo-gu, Daejeon 302-701,
Republic of Korea

Facsimile No. 82-42-472-7140

Authorized officer

HAN, Choong Hee

Telephone No. 82-42-481-8475



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/KR2006/000934

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6,806,843 B2	19-10-2004	WO 2004/008570 A2	22-01-2004
US 2003/0006940 A1	09-01-2003	EP 1258945 A2	20-11-2002
		JP 2003-037428 A	05-11-2003
		KR 2002-0087878 A	23-11-2002
US 6,670,932 B1	30-12-2003	EP 1195847 A2	10-04-2002
		JP 2002-204123 A	19-07-2002
		KR 2002-0027225 A	13-04-2002
US 6,400,339 B1	04-06-2002	WO 1999/060665 A1	25-11-1999