

## SURFACE FOR FILTERING A PLURALITY OF FREQUENCY BANDS

Field of the invention

The present disclosure relates to a frequency-selective surface, that is, a surface capable of shielding  
5 electromagnetic waves belonging to certain frequency bands.

Discussion of prior art

Frequency-selective surfaces are generally called FSS  
in the art. They comprise a set of identical elementary con-  
ductive patterns, repeated according to a periodic layout on a  
10 surface of a dielectric support. The shape and the dimensions of  
the elementary pattern, the arrangement of the periodic layout,  
and the characteristics of the conductive material of the pat-  
tern and of the dielectric material of the support are the main  
factors determining the filtering properties of the surface.

15 One of the targeted applications relates to the selec-  
tive shielding of a building or of a room of a building against  
certain electromagnetic waves. The frequencies which are gener-  
ally desired to be filtered especially comprise the carrier  
frequencies of GSM-type mobile telephony systems (0.9, 1.8, and  
20 2.1 GHz), as well as the carrier frequencies of Wi-Fi-type wire-  
less computer network systems (2.4 and 5.4 GHz).

The dielectric support may be a substrate based on  
epoxy or on plastic on which the conductive patterns are formed  
by deposition of conductive layers, according to manufacturing  
25 methods similar to printed circuit manufacturing methods. It has  
also been provided to form frequency-selective surfaces directly  
on paper- or cardboard-type supports, for example, by printing  
with a conductive ink. This last embodiment especially has the  
advantage of significantly decreasing the cost of such surfaces.

30 Figure 1 is a top view schematically showing an  
elementary conductive pattern 1 of a frequency-selective  
surface. Pattern 1, formed on a surface of a dielectric support  
10, is a tripole formed of three identical segments 12a, 12b,

and 12c of length  $L_s$ , extending in a star from a center 14. Segments 12a to 12c form, two-by-two, angles of approximately  $120^\circ$ .

Figure 2 is a top view schematically showing a portion of a frequency-selective surface formed by the repeating, according to a periodic layout on dielectric support 10, of elementary pattern 1 of Figure 1. Pattern 1 is repeated by translation along each of the directions of segments 12a to 12c of the tripole, so that a same non-zero distance  $D_m$  separates each outer end of a segment of a pattern from the center of a neighboring pattern. The translation is repeated until it covers the entire targeted surface.

The surface thus formed has a resonance frequency essentially depending on the parameters relative to length  $L_s$  of the tripole segments and to distance  $D_m$  between neighboring patterns. Such a surface has the property of filtering the electromagnetic waves belonging to a frequency band centered on its resonance frequency. The filtering efficiency also depends on width  $W$  and on the thickness (not shown in the drawing) of the pattern, as well as on the thickness (not shown in the drawing) of dielectric support 10.

A disadvantage of the frequency-selective surface described in relation with Figures 1 and 2 is that its frequency response depends on the angle of incidence of the electromagnetic waves with respect to the surface, as well as on the polarization of the incident electromagnetic waves.

Further, this surface only enables to filter a single frequency band centered on its resonance frequency. Thus, to filter different bands, for example GSM frequencies (on the order of 0.9, 1.8, and 2.1 GHz) and/or Wi-Fi frequencies (on the order of 2.4 and 5.4 GHz), frequency-selective surfaces adapted to each of the targeted bands should be stacked.

#### Summary

Embodiments of the present invention provide a frequency-selective surface overcoming at least some of the disadvantages of existing solutions.

Embodiments of the present invention

provide such a surface having filtering properties independent from the angle of incidence and from the polarization of incident electromagnetic waves.

5           Embodiments of the present invention

provide such a surface which is capable of filtering several different frequency bands.

Embodiments of the present invention

10          provide such a surface having a relatively low conductive pattern coverage rate.

          According to an aspect of the present invention, there is provided a surface capable of filtering a plurality of frequency bands, this surface comprising a set of separate identical elementary conductive patterns, repeated according to a periodic layout on  
15   a dielectric support, the elementary pattern comprising: a tripole formed of three identical segments extending in a star from a center; and two branches extending symmetrically from an intermediate point of each segment, this intermediate point being located at a same distance from the center for each of the  
20   segments, the general directions of the two branches forming an angle of approximately  $120^\circ$  and defining an outward-pointing arrowhead, the branches associated with two different segments being non-secant.

          According to an embodiment of the present invention,  
25   the segments of the tripole form, two-by-two, angles of approximately  $120^\circ$ .

          According to an embodiment of the present invention, the elementary pattern further comprises two first identical fins extending symmetrically from the end of each segment, the  
30   first fins forming an angle of approximately  $120^\circ$  and defining an arrowhead directed towards the outside of the pattern.

          According to an embodiment of the present invention, the elementary pattern further comprises two first identical fins extending from the free end of each branch, each second fin

forming an angle of approximately  $60^\circ$  with the general direction of the branch.

According to an embodiment of the present invention, the second fins of each branch form together an angle of approximately  $120^\circ$  and defining an arrowhead directed towards the outside of the pattern.

According to an embodiment of the present invention, the second fins of each branch are aligned along a same direction, this direction intersecting the direction of the segment from which the branch originates.

According to an embodiment of the present invention, the branches comprise at least one crenel-shaped extension along a direction intersecting the general direction of the branch.

According to an embodiment of the present invention, the elementary pattern is repeated by translation along each of the directions of the segments of the tripole so that a same distance separates each end of a segment of a pattern from the center of a neighboring pattern.

According to an embodiment of the present invention, the surface is capable of filtering three frequency bands respectively centered on 0.9, 1.8, and 2.1 GHz.

According to an embodiment of the present invention, the surface is capable of filtering two frequency bands respectively centered on 2.4 and 5.4 GHz.

According to an embodiment of the present invention, the dielectric support is a paper- or cardboard-type support and the conductive patterns are formed by printing with a conductive ink.

Another aspect of the present invention provides a use of the above-mentioned surface to filter three frequency bands located within the range from 0.9 to 5.4 GHz, wherein the overall dimensions of an elementary pattern approximately range from 1 to 10 centimeters, the lengths of each of these segments, branches, and fins being adjusted to select the three targeted frequency bands.

### Brief description of the drawings

The foregoing and other objects, features and advantages of the present invention will be discussed in detail in the following non-limiting description of specific embodiments in connection with the accompanying drawings, among which:

Figure 1, previously-described, is a top view schematically showing an elementary conductive pattern of a frequency-selective surface;

Figure 2, previously-described, is a top view schematically showing a portion of a frequency-selective surface formed by repeating of the elementary pattern of Figure 1;

Figure 3 is a top view schematically showing an embodiment of an elementary conductive pattern of a frequency-selective surface;

Figure 4 is a top view schematically showing a portion of a frequency-selective surface formed by repeating of the elementary pattern of Figure 3;

Figures 5 to 9 are simplified top views showing different alternative embodiments of the elementary conductive pattern of Figure 3; and

Figure 10 is a diagram showing the frequency responses of a surface formed from the elementary pattern of Figure 5, for elementary waves having different angles of incidence.

### Detailed description

For clarity, the same elements have been designated with the same reference numerals in the different drawings and, further, the various drawings are not to scale.

Figure 3 is a top view schematically showing an embodiment of an elementary conductive pattern 31 of a frequency-selective surface.

As an example, the conductive material may be aluminum, gold, copper, silver, carbon, iron, platinum, graphite, or a conductive alloy of several of these materials. Generally, the higher the electric conductivity of the material, the better the filtering performed by the surface.

Pattern 31, formed on a surface of a dielectric support 10, comprises a basic tripole formed of three approximately identical segments 12a, 12b, and 12c of length  $L_s$ , extending in a star from a center 14. Segments 12a to 12c form, two-by-two, angles of approximately  $120^\circ$ , for example, ranging between  $110^\circ$  and  $130^\circ$ .

Pattern 31 further comprises, for each segment 12a, 12b, 12c, two substantially identical branches, respectively 32a1 and 32a2, 32b1 and 32b2, and 32c1 and 32c2, extending from an intermediate point of the segment, substantially symmetrically with respect to the segment direction. In this example, branches 32 have the shape of bars with a length  $L_b$ . On each segment 12, the intermediate point is located approximately at a same distance  $D_b$  from center 14. The general directions of the two branches 32 form an angle of approximately  $120^\circ$ , for example, ranging between  $110^\circ$  and  $130^\circ$ , and defining an arrowhead directed towards the outside of the pattern. Further, branches 32 associated with two different segments 12 are non secant.

Figure 4 is a top view schematically showing a portion of an embodiment of a frequency-selective surface formed by the repeating, according to a periodic layout on dielectric support 10, of elementary pattern 31 of Figure 3. Pattern 31 is repeated by translation along each of the directions of segments 12a to 12c of the basic tripole, so that a same non-zero distance  $D_m$  separates each outer end of a segment of a pattern 31 from center 14 of a neighboring pattern 31. The translation operation is repeated until the entire targeted surface is covered. It should be noted that the dimensions of the elementary pattern and distance  $D_m$  are selected to be such that the elementary patterns are separate.

The frequency response of the surface thus formed essentially depends on length  $L_s$  of segments 12, on length  $L_b$  of branches 32, on distance  $D_b$  between the intermediate starting point of branches 32 of a segment 12 and center 14 of the pattern, and on distance  $D_m$  between neighboring patterns.

The inventors have observed that such a surface has three main resonance frequencies. The first resonance frequency essentially depends on length  $L_s$  of segments 12 and on distance  $D_m$  between neighboring patterns. The second resonance frequency  
 5 essentially depends on length  $L_b$  of branches 32 and on distance  $D_b$  between center 14 of the pattern and the intermediate point of segment 12 from which the branches originate. The third resonance frequency depends on all the above-mentioned parameters.

Such a surface has the property of filtering the electromagnetic waves belonging to three different frequency bands  
 10 centered on its three main resonance frequencies. In practice, a simulation software is used to test different combinations of parameters by performing progressive adjustments to obtain a set of parameters adapted to the targeted frequency bands.

15 In the embodiment of Figure 4, the setting of the first and second resonance frequencies is relatively easy, but it is difficult to adjust the third resonance frequency without modifying the first two frequencies.

Further, the three resonance frequencies of the  
 20 surface of Figure 4 remain slightly dependent on the angle of incidence and on the polarization of electromagnetic waves.

Figure 5 is a top view schematically showing another embodiment of an elementary conductive pattern 51 of a frequency-selective surface. Pattern 51 shows all the elements  
 25 of pattern 31 of Figure 3. It further comprises two substantially identical fins of length  $L_{as}$ , respectively 52a1 and 52a2, 52b1 and 52b2, and 52c1 and 52c2, extending from the outer end of each segment 12, substantially symmetrically with respect to the segment direction. Fins 52 of each segment 12 form together  
 30 an angle of approximately  $120^\circ$ , for example, ranging between  $110^\circ$  and  $130^\circ$ , and define an arrowhead directed towards the outside of the pattern.

In an embodiment, pattern 51 further comprises two substantially identical fins of length  $L_{ab}$ , respectively 54a11  
 35 and 54a12, 54a21 and 54a22, 54b11 and 54b12, 54b21 and 54b22,

54c11 and 54c12, and 54c21 and 54c22, extending from the outer end of each branch 32 (on the side of the branch opposite to the segment from which it originates), substantially symmetrically with respect to the general branch direction. Fins 54 of each  
 5 branch 32 form together an angle of approximately  $120^\circ$ , for example, ranging between  $110^\circ$  and  $130^\circ$ , and define an outward-pointing arrowhead. The pattern dimensions are selected so that fins associated with different segments or branches are not secant and do not intersect the other segments and branches of  
 10 the pattern.

Figure 5 shows, in dotted lines, a portion of a pattern 51' corresponding to a translation of pattern 51 along the direction of segment 12a of pattern 51. In this example, fins 52 of the segment of pattern 51' closest to center 14 of  
 15 pattern 51 are located in the space delimited by segments 12b and 12c and by branches 32b2 and 32c1 of pattern 51. A non-zero distance  $D_m$  separates center 14 of pattern 51 from the end of the closest segment 12. It should be understood that other patterns (not shown) of a frequency-selective surface are formed  
 20 similarly, by translation along the directions of the other segments 12, according to a periodic layout of the type described in relation with Figure 4.

The surface thus formed has three main distinct resonance frequencies. These three resonance frequencies are independent from the angle of incidence and from the polarization of  
 25 electromagnetic waves. Further, the introduction of additional parameters  $L_{as}$  and  $L_{ab}$  relative to the length of fins 52 and 54 increases resonance frequency setting possibilities.

The strong interleaving of the elementary patterns is  
 30 considered to contribute to ensuring a behavior of the surface independent from the angle of incidence and from the polarization of electromagnetic waves. Thus, it will be ascertained to maintain parameter  $D_m$  relative to the distance between neighboring patterns relatively low.

Figure 6 is a top view schematically showing an alternative embodiment of the elementary conductive pattern of Figure 5. Pattern 61 of Figure 6 differs from the pattern of Figure 5 by the orientation of the fins associated with branches 32. In  
 5 pattern 61, two identical fins 64 (respectively 64a11 and 64a12, 64a21 and 64a22, 64b11 and 64b12, 64b21 and 64b22, 64c11 and 64c12, and 64c21 and 64c22) associated with a branch 32 each form an angle of approximately  $60^\circ$ , for example, ranging between 55 and  $65^\circ$ , with the general branch direction, and are substan-  
 10 tially aligned along a same direction, this direction intersecting the direction of segment 12 from which branch 32 originates.

Like pattern 51 of Figure 5, pattern 61 provides surfaces with three resonance frequencies. It especially enables to obtain resonance frequencies different from those obtained  
 15 from pattern 51, and has the same setting possibilities and the same insensitivity to the orientation and to the polarization of electromagnetic waves as pattern 51.

Figure 7 is a top view schematically showing an alternative embodiment of the elementary conductive pattern of Figure  
 20 6. Pattern 71 of Figure 7 differs from the pattern of Figure 6 by the shape of the branches originating from segments 12. Pattern 71 comprises two branches 72 (respectively 72a1 and 72a2, 72b1 and 72b2, and 72c1 and 72c2) extending from an intermediate point of each segment 12 along the same general direc-  
 25 tion as branches 32 of the pattern of Figure 6. However, unlike branches 32 of the pattern of Figure 6, branches 72 comprise a crenel-shaped extension of height  $H_C$ , extending along a direction approximately orthogonal to the general branch direction, towards the outside of the pattern.

30 Like pattern 61 of Figure 6, pattern 71 provides surfaces with three resonance frequencies. The provision of a crenel-shaped extension on branches 72 enables to vary the length of the branches more, which increases resonance frequency setting possibilities. Further, in the same way as for patterns  
 35 51 and 61 of Figures 5 and 6, the resonance frequencies of the

surfaces obtained from pattern 71 are insensitive to the orientation and to the polarization of electromagnetic waves.

As an example, by repeating pattern 71 according to a periodic layout of the type described in relation with Figure 4,  
 5 the inventors have obtained a surface capable of shielding frequencies on the order of 0.9 and 1.8 GHz, by using the following parameters:

| Parameter  | $L_s$ | $D_b$ | $D_m$ | $L_b$ | $W$ | $L_{as}$ | $L_{ab}$ | $H_c$ |
|------------|-------|-------|-------|-------|-----|----------|----------|-------|
| Value (mm) | 25    | 9.1   | 0.75  | 7.5   | 0.5 | 4        | 5.75     | 5.9   |

10 The inventors have further obtained a surface capable of shielding frequencies on the order of 2.4 and 5.4 GHz by using the following parameters:

| Parameter  | $L_s$ | $D_b$ | $D_m$ | $L_b$ | $W$  | $L_{as}$ | $L_{ab}$ | $H_c$ |
|------------|-------|-------|-------|-------|------|----------|----------|-------|
| Value (mm) | 9.6   | 3.6   | 0.5   | 2.9   | 0.25 | 2        | 1.6      | 1.8   |

15 The two above examples do not consider the third resonance frequency, which however exists.

Figure 8 is a top view schematically showing an alternative embodiment of the elementary conductive pattern of Figure 7. In pattern 81 of Figure 8, each branch originating from a  
 20 segment of the basic tripole comprises three crenel-shaped extensions of height  $H_c$ , extending along directions approximately orthogonal to the general branch direction, towards the outside of the pattern.

As an example, by repeating pattern 81 according to a  
 25 periodic layout of the type described in relation with Figure 4, the inventors have obtained a surface capable of shielding frequencies on the order of 0.9, 1.8 GHz, and 2.1 GHz by using the following parameters:

| Parameter  | $L_s$ | $D_b$ | $D_m$ | $L_b$ | $W$ | $L_{as}$ | $L_{ab}$ | $H_c$ |
|------------|-------|-------|-------|-------|-----|----------|----------|-------|
| Value (mm) | 28.8  | 9.8   | 0.5   | 8.8   | 0.5 | 6.3      | 0.05     | 5     |

Figure 9 is a top view schematically showing an alternative embodiment of the elementary conductive pattern of Figure 8. In pattern 91 of Figure 9, each branch originating from a segment of the basic tripole comprises crenel-shaped extensions of different heights, extending along directions approximately orthogonal to the general branch direction, alternately towards the outside and towards the inside of the pattern. Further, in pattern 91, the fins associated with the branches are arranged in an arrow, as in pattern 51 of Figure 5.

Figure 10 is a diagram illustrating the variation, according to frequency, of the transmission factor (in decibels) of a surface formed by the repeating of an elementary pattern 51 of Figure 5, for electromagnetic waves having different angles of incidence. Curves 101, 102, and 103 show the frequency responses of the surface for electromagnetic waves oriented along directions respectively forming angles of 0, 30, and 60° with the direction orthogonal to the surface plane. The selection of the parameters is such that the surface has three different resonance frequencies, respectively on the order of 0.9, 1.8, and 2.1 GHz. The diagram of Figure 10 shows that the resonance frequencies of the surface, corresponding to negative peaks in curves 101, 102, 103, are independent from the angle of incidence of waves. It should further be noted that the resonance frequencies are also independent from the wave polarization.

According to a preferred embodiment, the frequency-selective surfaces described hereabove are formed on paper- or cardboard-type supports, for example, on wall paper, on paper or cardboard lining plasterboards lined with cardboard, or on any other support capable of lining the walls of a room of a building. The conductive patterns are for example formed by printing with conductive inks.

According to an advantage of the above-described frequency-selective surfaces, the coverage rate of the conduc-

tive patterns is relatively low, for example, smaller than 15%. This enables to maintain a relatively low manufacturing cost for such surfaces.

Specific embodiments of the present invention have  
5 been described. Various alterations, modifications, and improvements will readily occur to those skilled in the art.

In particular, the elementary conductive patterns described in relation with Figures 7 to 9 may give rise to several variations. However, for each of these patterns, it may  
10 be chosen to arrange the fins associated with the branches of the pattern either in an arrow, as described in relation with Figure 5, or aligned along a same direction, as described in relation with Figure 6. Further, it will be within the abilities of those skilled in the art to implement the desired operation  
15 by varying the number, the direction, and the orientation of the crenel-shaped extensions formed of the pattern branches.

Further, in the elementary patterns described in relation with Figures 3 to 9, a second generation of symmetrical branches originating from the main branches (32, 72) may be  
20 provided to increase resonance frequency setting possibilities.

CLAIMS

1. A surface capable of filtering a plurality of frequency bands, this surface comprising a set of separate identical elementary conductive patterns (31; 51; 61; 71; 81; 91), repeated according to a periodic layout on a dielectric support  
5 (10), the elementary pattern comprising:

a tripole formed of three identical segments (12) extending in a star from a center (14); and

two branches (32; 72) extending symmetrically from an intermediate point of each segment, this intermediate point  
10 being located at a same distance ( $D_b$ ) from the center (14) for each of the segments (12), the general directions of the two branches forming an angle of approximately  $120^\circ$  and defining an outward-pointing arrowhead, the branches (32; 72) associated with two different segments (12) being non-secant,

15 the elementary pattern being repeated by translation along each of the directions of the segments (12) so that a same distance ( $D_m$ ) separates each end of a segment of a pattern from the center of a neighboring pattern.

2. The surface of claim 1, wherein the segments (12) of the tripole form, two-by-two, angles of approximately  $120^\circ$ .  
20

3. The surface of claim 1 or 2, wherein the elementary pattern (51; 61; 71; 81; 91) further comprises two first identical fins (52) extending symmetrically from the end of each segment (12), the first fins (52) forming an angle of approximately  
25  $120^\circ$  and defining an arrowhead directed towards the outside of the pattern.

4. The surface of any of claims 1 to 3, wherein the elementary pattern (51; 61; 71; 81; 91) further comprises two first identical fins (54; 64) extending from the free end of  
30 each branch (32; 72), each second fin forming an angle of approximately  $60^\circ$  with the general direction of the branch.

5. The surface of claim 4, wherein the second fins (54) of each branch form together an angle of approximately  $120^\circ$  and define an arrowhead directed towards the outside of the  
35 pattern.

6. The surface of claim 4, wherein the second fins (64) of each branch (32; 72) are aligned along a same direction, this direction intersecting the direction of the segment (12) from which the branch originates.

5           7. The surface of any of claims 1 to 6, wherein the branches (72) comprise at least one crenel-shaped extension along a direction intersecting the general direction of the branch.

8. The surface of any of claims 1 to 7, capable of  
10 filtering three frequency bands respectively centered on 0.9, 1.8, and 2.1 GHz.

9. The surface of any of claims 1 to 7, capable of filtering two frequency bands respectively centered on 2.4 and 5.4 GHz.

15           10. The surface of any of claims 1 to 9, wherein the dielectric support is a paper- or cardboard-type support and the conductive patterns are formed by printing with a conductive ink.

11. A use of the surface of any of claims 1 to 10 to  
20 filter three frequency bands located within the range from 0.9 to 5.4 GHz, wherein the overall dimensions of an elementary pattern approximately range from 1 to 10 centimeters, the lengths of each of these segments, branches, and fins being adjusted to select the three targeted frequency bands.

## SURFACE FOR FILTERING A PLURALITY OF FREQUENCY BANDS

The invention relates to a surface suitable for  
5 filtering a plurality of frequency bands, said surface  
including a set of separate identical basic conductive  
units (31) that are reproduced in a periodic arrangement on  
a dielectric substrate (10). The basic unit includes: a  
tripole consisting of three identical segments (12) that  
10 extend radially from a center (14); and two arms (32) that  
extend symmetrically from an intermediate point of each  
segment, said intermediate point being located at a common  
distance ( $D_b$ ) from the center (14) for each of the segments  
(12). The general directions of both arms form an angle of  
15 approximately  $120^\circ$  and define an arrowhead pointed toward  
the outside, wherein the arms (32) corresponding to two  
separate segments (12) do not intersect.

Figure 3