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# Wide-Band Linear Polarizer Based on a Frequency Selective Surface

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## Abstract

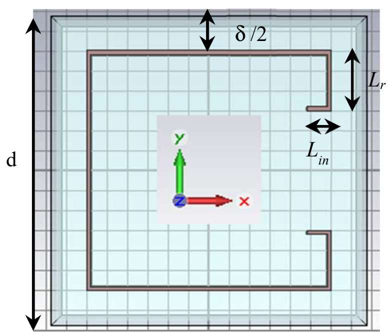
A Frequency Selective Surface built on an FR4 substrate, that exhibits linear polarized transmission field for a generally polarized incident electromagnetic waves in the frequency range below 10 GHz is introduced. Outgoing waves are linearly polarized on two orthogonal directions, in two different frequency bands. The operation of the proposed structure is wide-band, the two bands intersecting at -10 dB. A parametric study demonstrates flexibility in design, also the structure being tested for oblique incidence

## 1 Introduction

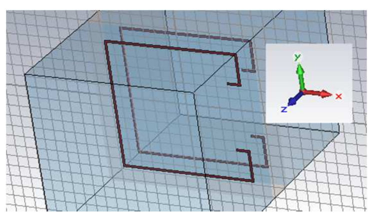
Frequency selective surfaces (FSSs) have gained much attention in the last years due to their convenient properties, wide range of applications and ease of fabrication [1], [2]. Extensive work in this field has been performed in both microwave and optics community [2], [3]. The concept of FSS evolved to that of metasurface, conceived to manipulate at will the wavefront of electromagnetic waves going through the structure [3].
One of the most important properties of plane electromagnetic waves is polarization. Polarization conversion and filtering became important in connection to development of modern wireless communication systems. For example, linear to circular polarization conversion ensures a higher resistance of transmitted waves to variation of propagation channel conditions [3], [4]. Conversion of polarization state has diverse applications in various fields including Microwaves and Optics [5], [6].
An FSS built on an FR4 substrate has been introduced recently by some of the authors, which has provided two distinct frequency bands where incoming plane waves were filtered out to orthogonally linear polarized waves. Frequencies below 10 GHz have been considered in view of Automotive applications [7]. However, the operation bands were quite narrow.
In this paper, we propose a more elaborated structure for the unit cell of the FSS that allows more liberty in frequency tuning without excessively complicating the design. Furthermore, by replicating the metal pattern on both sides of the supporting board, a wide-band operation is achieved. The electromagnetic properties of the proposed FSS are assessed by means of a commercial solver [8].

## 2 Design and Operation of the proposed structure

The FSS has been realized on an FR4 substrate, of thickness 2.6 mm, based on a square unit cell with dimension of the edge equal to $d$=15 mm, Fig. 1 (a). In the extended configuration, the distance between two adjacent metal patterns has been set to $\delta$=3 mm, the other geometrical parameters being initially $L_r$=3 mm and $L_{in}$=1 mm. Moreover, a width of the trace of $w$=0.2 mm has been considered, and initially the metal pattern has been placed on one side only.




**(a)**



**(b)**

**Figure 1.** Unit cell of the FSS: (a) front view; (b) 3D view.

The transmittance of the FSS calculated with [8] is represented in Fig. 2. The red curve corresponds to a normal incidence with the electric vector parallel to the x axis (E||x), while the blue curve corresponds to E||y. The red curve presents a stop-band with -10 dB bounds at $f_l$=4.09 GHz, $f_h$=5.31 GHz and a central frequency $f_c$=4.78

GHz. The transmittance of the blue curve at $f_c$ is $T_2$=-1.60 dB. An arbitrarily polarized plane wave incident on the structure in this frequency band will leave the surface (in the opposite direction with respect to the incidence) mainly normally polarized with E||y.

The blue curve in Fig. 2 presents two stop bands for incident plane waves with E||y. The parameters of the stop bands are $f_{l1}$=2.15 GHz, $f_{h1}$=2.49 GHz, $f_{c1}$=2.34 GHz, $T_1$=-2.42 dB and $f_{l2}$=6.09 GHz, $f_{h2}$=6.49 GHz, $f_{c2}$=6.31 GHz, $T_1$=-2.42 dB, respectively. An arbitrarily polarized plane wave incident on the structure in this frequency band will be transmitted being characterized by an almost normally polarization, i.e., E||x.

The difference between the two responses is due to the different geometries. More precisely, in the x direction, there are two identical metallic dipole-like structures, hence with the same resonant frequency. Contrarily, in the y direction, there are a long dipole-like structure and a shorter one of length $L_r$. The different lengths reflect in the two resonances.

The operation of the proposed FSS parallels the one reported in [7]. In order to obtain wide-band operation, we replicated the metal pattern on the other side of the FSS. The 3D CAD view of the unit cell is reported in Fig. 1 (b).

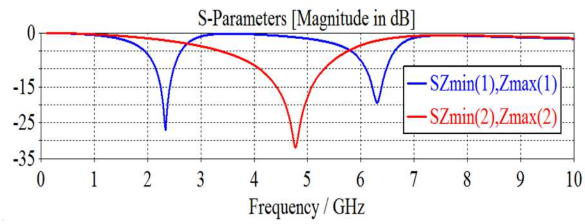



**Figure 2.** Transmittance of the FSS with one patterned surface.

The transmittance of the new FSS is represented in Fig. 3, for the same dimensions of the metal pattern as reported above for the single-sided unit cell. It can be seen that wide-band selectivity has been obtained, as shown by the presence of two distinct resonances in each band. This is the result of replicating the metal pattern on the other side of the board [1].

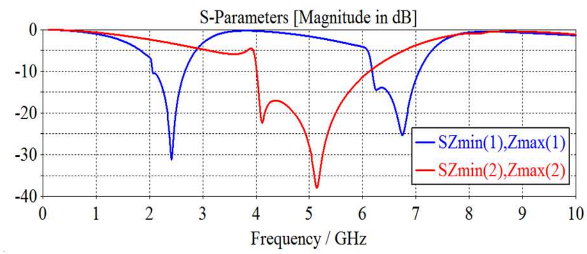



**Figure 3**. Transmittance of the FSS with both faces patterned.

The band limits are reported in the third row of Tab. 1 (in bold). In the first line of the table "Band" corresponds to the red curve in Fig. 3, the "Band 1" to the rightmost stop-band in the blue curve and "Band 2" corresponds to the leftmost stop-band on the blue curve.

**Table 1** Comparison of the effects of the different parameters on the electric performances of the unit cell

| **w (mm)** | **$L_r$ (mm)** | **$L_{in}$ (mm)** | **Band (GHz)** | **Band1 (GHz)** | **Band2 (GHz)** |
|---|---|---|---|---|---|
| 0.2 | 1 | 1 | 4.44-6.80 | 6.86-7.49 | 2.25-2.95 |
| 0.2 | 2 | 1 | 4.16-6.42 | 6.42-4.22 | 2.11-2.78 |
| **0.2** | **3** | **1** | **4.01-6.17** | **6.17-7.07** | **2.05-2.66** |
| 0.2 | 4 | 1 | 3.84-5.88 | 5.88-6.89 | 2.05-2.54 |
| 0.2 | 5 | 1 | 3.69-5.65 | 5.65-6.78 | 2.02-2.38 |
| 0.2 | 5 | 2 | 3.56-5.44 | 5.39-6.64 | 1.92-2.22 |
| 0.5 | 5 | 3 | 3.48-5.63 | 5.26-7.01 | 1.91-2.20 |
| 0.5 | 5 | 5.5 | 3.23-4.66 | 4.82-6.60 | 1.77-1.96 |

Note that "Band" and "Band 1" intersect at almost -10 dB. This occurs when $L_{in}$=1 mm, as results of the parametric study reported in Tab. 1 indicate.

The results of the parametric study from Tab. 1 can be used for adapting the frequency parameters of the transmittance of the FSS to requirements of various applications. In performing the parametric assessment, the other geometrical dimensions have been kept constant at the values reported above.

Since the structure of the unit cell is not symmetric (even if it presents one symmetry axis), in testing the stability at different angles of incidence the two planes, i.e., x0z and y0z, has to be separately considered. We have tested the stability for colatitude $\theta$ up to 45° (with respect to the reference frame in Fig. 1) for $\varphi$=0 and $\varphi$=90° and both polarizations. One of the four parameterized results is reported in Fig. 4 (parametrization by theta, with $\varphi$=0, and E||x), indicating a very good stability. The other cases are as follows: parametrization by theta, with $\varphi$=90° and E||x (Fig. 5), phi=0, and E||y (Fig. 6), and $\varphi$=90°, E||y (Fig. 7). These results indicate a good stability except for one case when $f_{h1}$ decreases slightly with $\theta$. More information and comments will be delivered at the time of the presentation.

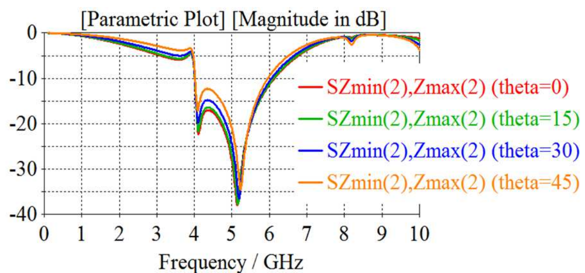



**Figure 4.** Transmittance parametrized by theta with $\varphi$=0 (incidence of E parallel to the x axis).

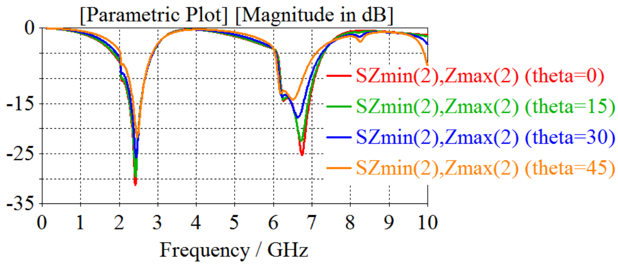



**Figure 5.** Transmittance parametrized by theta with $\varphi$=90º (incidence of E parallel to the x axis).

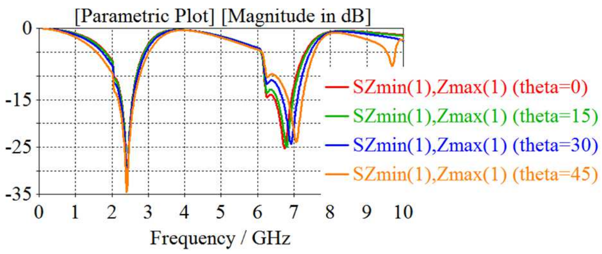



**Figure 6.** Transmittance parametrized by theta with $\varphi$=0 (incidence of E parallel to the y axis).

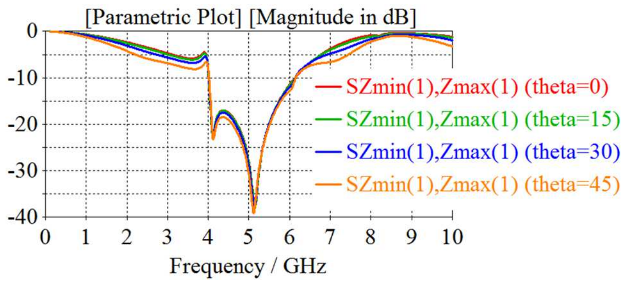



**Figure 7.** Transmittance parametrized by theta with $\varphi$=90º (incidence of E parallel to the y axis).

## 3 Conclusions

An FSS built on an FR4 substrate that achieves differently oriented linear polarizations of the transmitted wave for generally polarized incident electromagnetic waves in two adjacent frequency bands has been proposed. An initial one-sided, narrow-band design has been converted into a wide-band one by replicating the metal pattern on the other side of the substrate. A parametric study has been reported and the operation of the structure has been tested to oblique incidence. This work has been performed in view applications in Automotive environment.

## 4 Acknowledgements

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