3^{rd} URSI AT-AP-RASC, Gran Canaria, 29 May – 3 June 2022

Polarization independent dual function metasurface using transparent materials

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Abstract

A dual function metasurface with transparent materials is investigated. The design has been inspired from both high impedance surface (HIS) and frequency selective surface (FSS) theories. In order to obtain reflective and transmissive functionality for different sides of the suggested surface, two different geometries are designed on each side of a quartz substrate. The front geometry of the unit cell comprises four stripes that contribute to the reflection of TE mode and the rear layer of the unit cell comprises a slotted patch that functions as a polarization filter for the TE mode allowing transmission of TM mode. The design and simulation of the unit cell presented within this document was produced using full wave simulation software (CST Microwave Studio). The single unit cell is simulated with periodic boundary conditions at the operating frequency of 26.5GHz. Materials such as ITO, quartz and silver have been used for the rear element, the substrate and the ultra-thin stripes respectively, thus we can assume that the structure is at least semi-transparent.

1. INTRODUCTION

Metasurfaces and their corresponding applications have attracted great interest by academia during the last few decades. Several applications, regarding manipulation and beam forming of electromagnetic waves, have been developed so far in various areas of electromagnetic spectrum. Metasurfaces with important applications include frequency selective surfaces, high impedance surfaces and phase-gradient transmissive or selective surfaces as mentioned in [1].

As a consequence, except for the single polarized incident waves, dual polarized orthogonal incident waves can be manipulated through corresponding designs. There are many cases referred in literature of structures that are designed to reflect one orthogonal incident wave and transmit the other [2],[3]. Despite the fact that there is a variety of such arrangements, increasing phase control of metasurfaces by virtue of multiple layers within the same unit cell leads to bulky structures. It is of great importance to improve and investigate single-layer designs [4] as we are facing an era where communication systems need to be integrated in mobile platforms with limitation in spatial arrangement.

On the other hand, exploiting the advantages of transparent materials is an equally challenging aspect of recent innovations. Transparent semiconductors have been used in electronic applications and optics with success. Transistors, solar cells, touch panels, crystal displays were some of the earliest applications [5].

Amid other transparent materials, ITO is a material increasingly used in emerging such technologies including IRS metasurface designs, either passive or reconfigurable as described in [6]. Key features of this transparent conductor are high transparency and low resistivity of 10^{-4} Ωcm in visible spectrum. ITO used in combination with a substrate of quartz provide a final structure that is fully transparent.

In this paper we present, as shown in Fig. 1 and Fig.2, a unit-cell that consists of four ultra-thin silver stripes on one side of a quartz substrate and U-shaped slotted geometry that lies on the rear side of the substrate. The operating frequency of the unit-cell is 26.5GHz. Dimensions and design parameters are depicted in Table 1. The operating frequency could serve, among other applications, 5G network applications and sensors for self-driving vehicles (24-77GHz).

2. DESIGN AND NUMERICAL RESULTS

A. Design

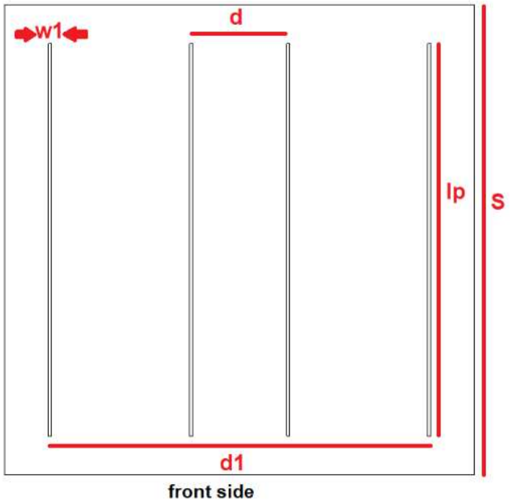

Figure 1. Front view of unit cell design

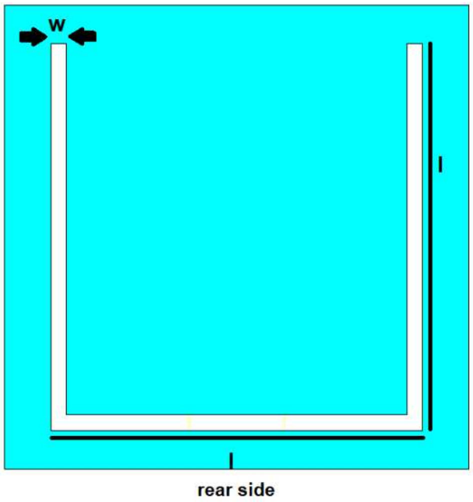

Figure 2. Rear view of unit cell design

We should not omit to mention that the design of the suggested unit-cell was based on both HIS theory for the reflected mode (similarities with study in [6]) and partially FSS theory, especially antenna filter array theory for the transmitted mode. For the last case the design was inspired by [7] reference.

Firstly, referring to the size of the substrate (S), it is of great importance to underline that the dimensions were chosen in order to achieve resonance at the desired operating frequency and the thickness is in compliance with the desired losses and phase range control capability.

In order to explain briefly the functionality concept, we should comment the choice of the two elements deposited on the substrate separately.

All four silver stripes contribute to the reflection of the TE mode of the incident wave and their length corresponds to the operation frequency expected. Their orientation allows the proper mode to reflect. Additionally, the use of silver instead of ITO was dictated by extreme reflection losses (material loss and penetration of the structure by the electromagnetic wave due to ITO low conductivity) regarding the suggested geometry. Furthermore, each couple of stripes (interior-exterior) cause a secondary resonance due to mutual coupling and this phenomenon was mitigated by defining the proper distance between them.

The slotted patch on the rear side of the substrate is designed in order to filter TE mode and allow the transmission of TM. Thus, the total length of the slot was picked at approximately λ/4 and the orientation of the slot deprives transmission of TE mode. The latter technique emulates partially techniques referred in [7]. In addition to the other parameters the notch of the back layer of the unit-cell should not be fully aligned with the stripes on the front side along x-axis. Simulations proved that mutual coupling between these two substitutes could lead to interference between each other splitting the resonance into two resonances overlaying each other.

Concluding the description of the design we should cite the thickness of the substrate that is 0.6 mm (Gs). The thickness of stripes (Gg) is 0.001 mm while ITO's thickness is 0.002 mm (Gt). The materials included in the design are commercially available and the metasurface can be easily fabricated which gives the opportunity for a potential experimental verification. Details about the rest of the features are included in the Table below in mm.

Table 1. Dimensions (mm)

S	**Gs**	**d**	**d1**	**l**
3.0	0.6	0.6	1.2	2.5
lp	**w**	**w1**	**Gg**	**Gt**
2.5	0.1	0.02	0.001	0.002

B. *Numerical Results*

In order to certify that the suggested design operates at the proper frequency in the aforementioned way, simulations in CST Microwave studio have been carried out providing the corresponding results beginning with the magnitude and phase response diagram of S11 and S12 of TE and TM mode respectively as shown in Fig. 3 and 4.

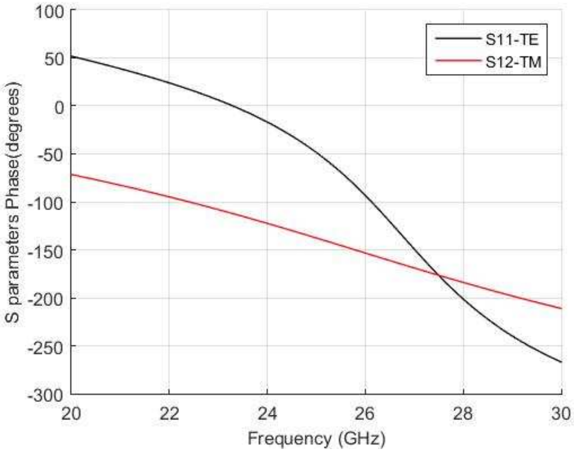

Figure 3. Phase response of S11 and S12 parameters for TE and TM modes respectively

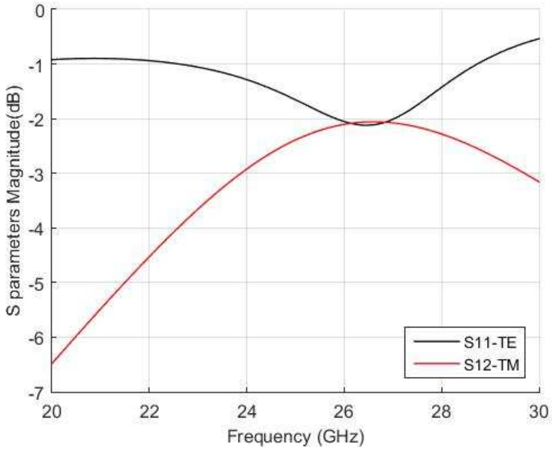

Figure 4. Magnitude of S11 and S12 parameters for TE and TM respectively (dB)

It is obvious that the losses for both functions hardly increase more than 2dB around the operating area while there is an indication that both phases are artificially controlled. The latter fact allows further evolution of the design in order to perform phase range optimization.

Separate tuning of the two elements is a potential study of this design due to the independence of the two functions.

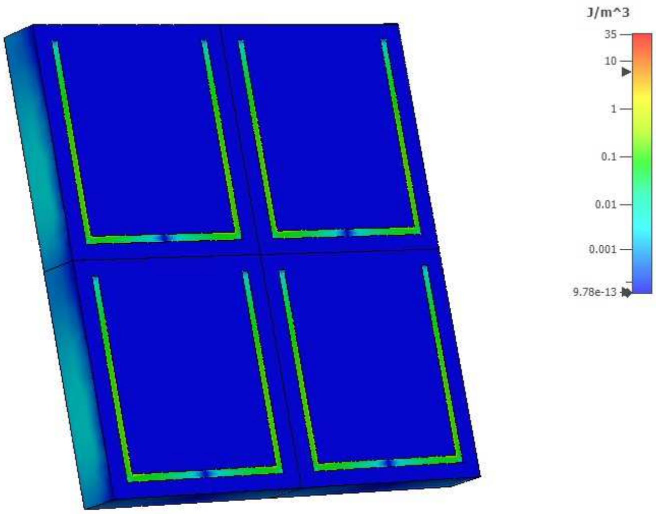

Figure 5. Electromagnetic field energy density for TM mode (back view of unit-cell)

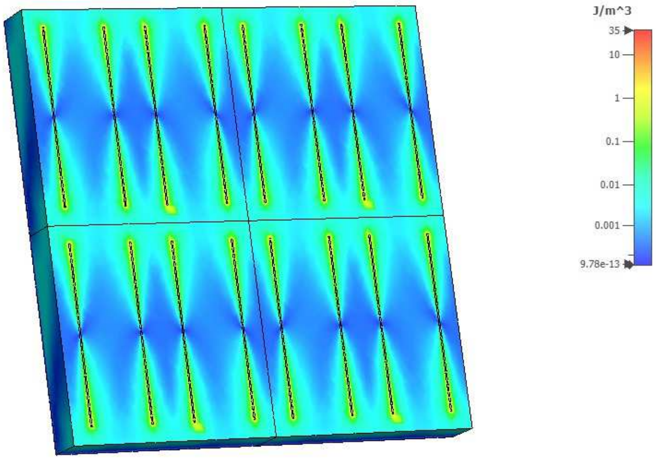

Figure 6. Electromagnetic field energy density for TE mode (front view of unit-cell)

The electromagnetic field energy density shown in Figures 5 and 6 verify that our design enables independent function of both transmission and reflection with minimum mutual coupling. More specifically the electromagnetic field energy density around the four stripes emulates the exact power density of simple radiating dipoles.

3. CONCLUSION

This paper presents a unit-cell that can be utilized in order to fabricate a metasurface with dual functionality. In order to fulfill these criteria, the design is based on filtering one mode of an orthogonal polarized wave of the same frequency. A combination of HIS and FSS theory is implemented for such purpose. The materials that have been used are transparent with the exception of the stripes deposited on the substrate. Despite the use of silver, the density of the stripes and their dimensions (width) may hardly affect the transparency of the whole structure.

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