Conversion from LP to CP by a tunable FSS with Embedded Microstrip Lines as Feeding Network

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***Abstract*—The design of a tunable Frequency Selective Surface (FSS) structure by means of PIN diodes is presented in this paper. Some significant FSS-related applications such as polarization control, polarization filtering, and spatial filtering are represented in the frequency band from 2 to 14 GHz. Using of a control network (CN) as a new configuration for biasing the active elements to compensate the symmetry breaking is also suggested.**

***Index Terms*—Frequency Selective Surfaces (FSSs), control network (CN)**

I. Introduction

Periodic structures [1]–[3], which are created by the 2D repetition of the unit-cells, are also uses as Frequency Selective Surfaces (FSSs). These constructions, due to their characteristics, are becoming important in various fields of science. FSS structures are well-known as spatial filters in order to transmit, absorb or reflect the electromagnetic waves. These structures are widely used in reducing radar cross-section (RCS), with applications to radoms, or even for domestic use such as Microwave ovens. In the FSS structures the essential requirements can be considered as the level of cross-polarization for reflected and transmitted waves, the degree of band separation and the bandwidth of the structure.

The major limitation of conventional FSS structures can be considered as being the dependency characteristics as reflection and transmission on the angle of the incidence of the electromagnetic waves. To tackle this issue, some methods have been proposed such as multiplexing of frequencies [4], harmonic generation [5], etc. while using the lumped elements in the structure becomes popular among designers. For applying lumped elements there are two main ways *(i)*: Varactor diodes [6] and *(ii)*: PIN diodes [7].

In this paper, we relied on PIN diodes, which can be mentioned as an effective way because, contrary to varactor diodes, the behavior of the elements is not dependent on the biasing voltage. In the case of using the PIN diodes, two operating conditions exist *first*: open circuit (indicates a capacitance in the structure) *second*: short circuit (corresponds to the small resistance) [8]. Using the lumped elements in the structure requires the presence of a DC bias network. However, using it in the structure may increase the complexity of the assembly and change the response to incident waves. Therefore, to overcome hinted problem, in this paper, instead of biasing the PIN diodes directly, we used as feeding network a microstrip line which is located at the bottom of the composition [9]. The main innovation of this work is the conception of an elliptic structure which allows controlling anisotropy of the FSS [10] due to the presence of the CN.

This paper is organised as follows: Section II presents the structure design with the insertion of the PIN diodes, and the nominal values of the equivalent circuit elements in both ON and OFF states. The control biasing network is also described and simulation results are reported. Conclusions are drawn in the last part of the paper.

II. Structure Model and Result

In this part, the ellipses structure (built on an FR-4 substrate with $\epsilon_r = 4.3$ and $\tan\delta = 0.025$) is represented as it is shown in Fig. 1 (left). The geometry of the proposed structure is

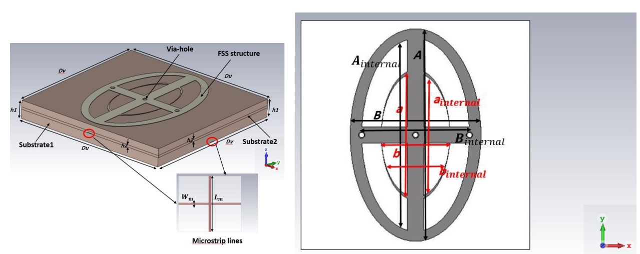

Fig. 1. The ellipses structure (Unit cell), schematic form side-view (left), front-view schematic (right).

defined by the following parameters: $A = 7$ mm, $B = 4$ mm, $A_{internal} = 6.4$ mm, $B_{internal} = 3.3$ mm (Large Ellipses) and $a = 4$ mm, $b = 2.6$ mm, $a_{internal} = 3.8$ mm, $b_{internal} = 2.6$ mm are the dimensions for the small ellipses in Fig. 1 (right). Moreover, the position of via-holes in the structure as illustrated in Fig. 2 is $op1 = 3.7$ mm and $op2 = 7$ mm.

The purpose of introducing the ellipses structure is to fulfill the requirements for the following applications: polarization filtering, polarization conversion, and also full notch.

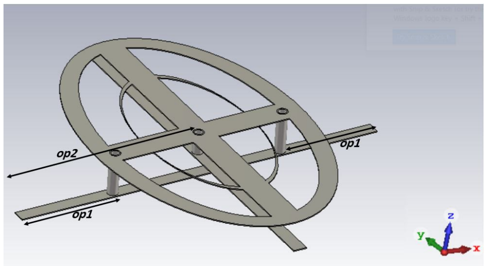

Fig. 2. The position of via-holes in the structure.

Interaction between the two polarization components of the incident waves when propagating through the structure is required for polarization filtering and conversion purpose. In addition, for full notch, the components of both polarization should be rejected at the notch frequency. Another property of this structure is represented by the condition of polarization conversion from linear (LP) to circular polarized waves (CP). To this purpose, a phase difference (+90° or -90°) must exist between the transmission coefficients for both TE (E parallel to y-direction in normal incidence) and TM (E parallel to x-direction in normal incidence) incidence waves.

As it is shown above in Fig. 1 (left), the control network is built by means of two crossed transmission lines, which create a connection to the main structure through the via-holes.

For realizing the tunable structure, four PIN diodes (PIN diode Model: MADP-000907-14020 manufactured by Macom Technology) are used in design. These active elements are positioned in the cut-slots performed on the main structure, as reported in Fig. 3.

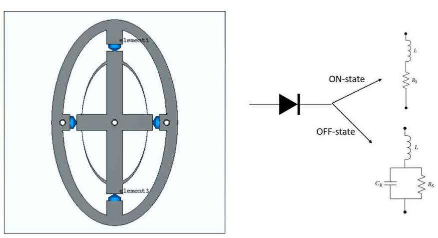

Fig. 3. Ellipses structure with PIN diode (left), PIN diode equivalent circuits (ON and OFF state) (right).

The nominal values in ON and OFF states of the equivalent circuits conditions for the PIN diodes in the structure are presented as follows: In case of ON-state condition when structure behaves as an RL circuit, the components are $L = 30$ pH and $R_s = 7.8\ \Omega$, and when the PIN diode behaves like an LC circuit (OFF-state), the elements are $C_s = 28$ fF and $R_s = 30\ \text{k}\Omega$.

In the next part of this section, the transmittance of the structure obtained by using CST software tool is reported. The frequency range for this analysis is between 2 GHz and 14 GHz. Moreover the simulation result is reported for two different incidence fields namely TE and TM cases. All the results are plotted in the normal incidence ϕ and θ are set to zero, here ϕ and θ are the angles of the spherical coordinates.

According to Fig. 4 the transmittance level for main structure in TE incidence is -33.79 dB at 7.79 GHz which corresponds to the band 6.2 - 8.4 GHz, while in TM incidence, at 7.79 GHz, the structure attenuates 0.6 dB. Moreover, the second frequency band occurs between 12.2 and 12.8 GHz, and the notch is -17.9 dB at 12.93 GHz. But, in TM incidence, -10 dB band-stop is from 11.8 to 13.9 GHz (the attenuation level -26.21 dB at 12.89 GHz).

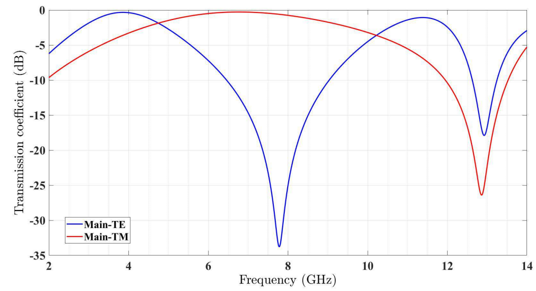

Fig. 4. Responses for TE and TM incidences for main structure.

When it comes to cut-slot structure, as it is shown in Fig. 5 the first notch is -34.8 dB at 6.20 GHz with the bandwidth of 31.71% (TE-incidence) and the second notch is -17.21 dB at 9.32 GHz the covers 5.04%. While the structure attenuation for TM incidence is -16.67 dB at 9.32 GHz.

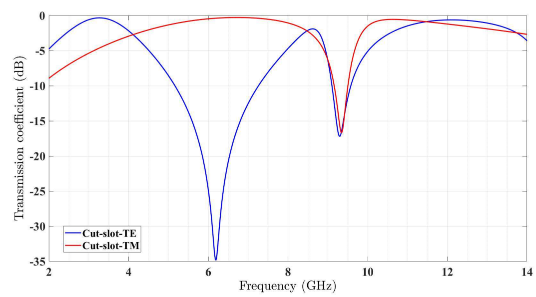

Fig. 5. Responses for TE and TM incidences for cut-slot structure.

According to Fig. 6, at two points 8.18 and 9.86 GHz phase difference (90°) for the main structure happens. For the first frequency the notch is 0.9 dB and 20.33 dB for TE and TM waves, respectively. For second frequency, 9.86 GHz, in TE incidence the transmittance is -5.24 dB and in TM one it is -2.98 dB.

For cut-slot structure, the phase difference (-90°) happens at 4.62 and 5.83 GHz. For the first frequency the attenuation level for TE incidence is -5.71 dB and for the TM one is -1.85 dB. Meanwhile, the frequency notch for the second phase difference frequency is 19.61 dB (TE-incidence) and 0.55 dB for TM waves.

For ON-state condition, in TE incidence the frequency band covers from 6.43 to 9.05 GHz with -29.96 dB attenuation level at 7.78 GHz, and the frequency notch for TM incidence at this condition is -17.92 dB at 12.71 GHz and the bandwidth is 1.57 GHz.

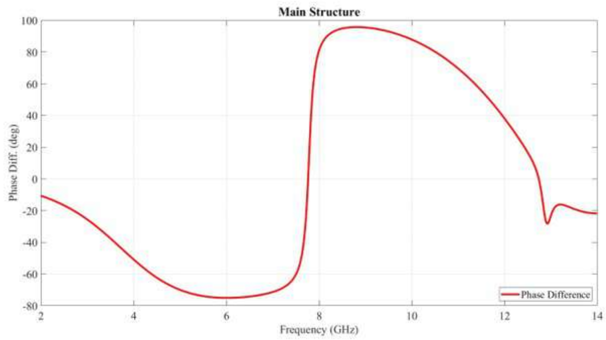

Fig. 6. Phase difference for main structure.

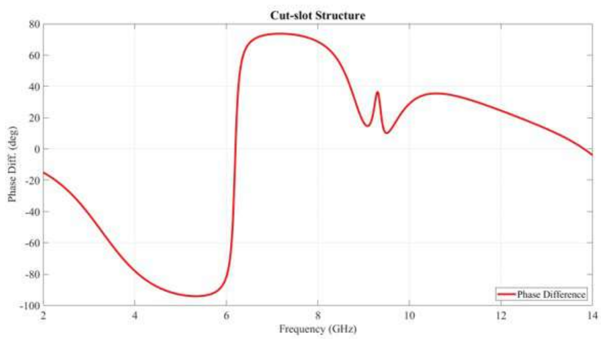

Fig. 7. Phase difference for cut-slot structure.

When diodes are OFF, the first frequency band is between 5.17 and 7.27 GHz (transmittance level is -33.87 at 6.19 GHz) and the second attenuation level occurs at 9.29 GHz which is -16.71 dB (9.10 - 9.58 GHz) in TE incidence. For TM incidence, -10 dB band-stop is at 9.35 GHz with -15.91 dB and the bandwidth of the structure is from 9.16 to 9.51 GHz.

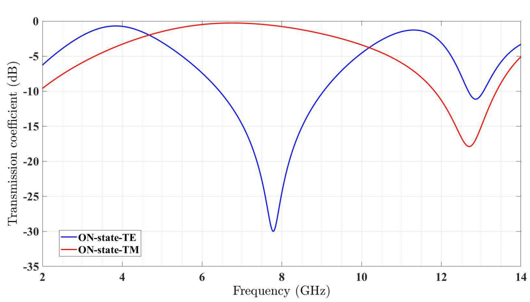

Fig. 8. Responses for TE and TM incidences for ON-state structure.

III. Conclusion

The main purpose of this paper was to design a tunable FSS structure covering S, C, X, and Ku frequency bands. The proposed structure has been built on an FR-4 substrate, and four PIN diodes per unit cell have been used to create two main conditions corresponding to the ON and OFF-state of the diodes. Moreover, the simulation results obtained for the transmittance of the structure have been plotted in both TE

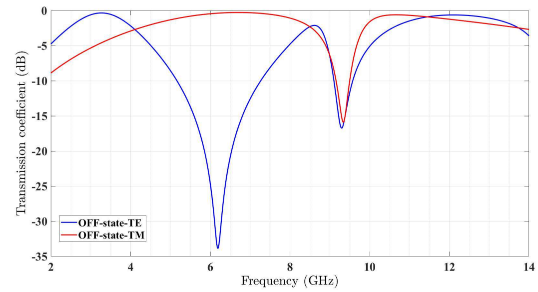

Fig. 9. Responses for TE and TM incidences for OFF-state structure.

and TM incidences. To bias the active elements, two mutually orthogonal microstrip lines have been placed and connected to the main structure through via-holes. The proposed structure has been demonstrated to feature conversion from LP to CP and covered some important targets in FSS structures design.

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