A Tunable Frequency Selective Surface for Band Pass and Band Stop Applications

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Abstract

In this work, a low-profile reconfigurable frequency selective surface capable of dynamically tuning the frequencies for band-pass and band-stop filtering applications is proposed. To realize this, a single-layered FSS is designed with tapered metal strips separated by a central gap and square metal patches positioned at the corners. Two PIN diodes are embedded in both the top and bottom layers. They are positioned at the center of the 45°-oriented metal strips, and for the frequency tuning, at least one of the diodes must be in the ON state. When both the diodes are ON, the tunable metasurface exhibits band-pass characteristics from 8.56- 14.8 GHz and band-stop characteristics from 3.08- 5.2 GHz. Similarly, when the PIN diode is in OFF state, the transmission window is from 6.25-8.1 GHz and band-stop window is from 3.1- 4.3 GHz. With these transmission and reflection characteristics, the proposed work is best suitable for wireless and radar applications.

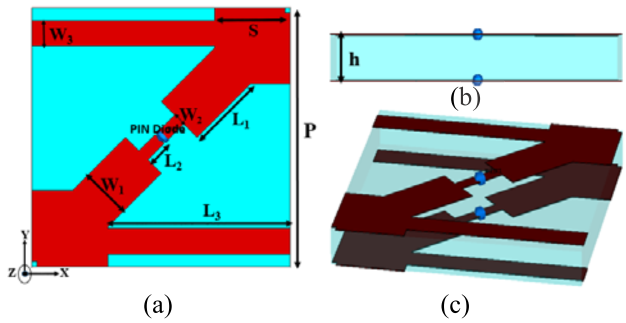
1. Introduction

Frequency Selective Surfaces (FSS) are periodic structures that can filter specific frequencies of electromagnetic waves. Due to their ability to manipulate electromagnetic (EM) wave properties, frequency selective surfaces are widely used are widely used for radomes, electromagnetic shielding, stealth, RF and microwave components, etc [1]-[5]. Traditional FSS described in the literature typically demonstrate static characteristics, whereas reconfigurable FSS overcomes this limitation by offering dynamic adaptability. Tunable FSS designs demonstrated in the literature often utilize multiple dielectric layers or multiple active elements, resulting in complex designs that are challenging to bias effectively [6]- [9], and the same is taken as a design objective in this work.

In this work, a frequency-reconfigurable FSS with band-pass characteristics and stable band-stop characteristics is proposed and validated the same with simulation results. The novelty in the proposed design is, that the frequency reconfigurability is achieved with a simple biasing circuit embedded in the meta-atom. For this, two horizontal metallic strips are placed which connect each meta-atom. The proposed work is organized as follows, the approach to unit cell design to achieve band-pass and band-stop characteristics is discussed in section 2, a valid result analysis is summarized in section 3, and concluding remarks in section 4.

2. Unit Cell Design

A low-profile transmissive/reflective FSS, featuring the stable band-stop characteristics and reconfigurable band-pass characteristics along with the in-built biasing circuit is proposed in this work. The geometry of the proposed meta-atom consists of diagonally oriented rectangular metal strips of width W_1 and a narrow metal strips of width W_2 which are connected to square metal patches placed along the corners. The corners of these square patches are etched to ensure that the corner adjacent meta-atoms are not connected. This complete arrangement is constructed using a single dielectric layer of thickness 1.6 mm and a lossy metallic layer of thickness 0.035 mm. The substrate used for the design is Rogers RT5880 (lossy) material (ε_r=2.2). The bottom layer of the meta-atom mirrors the top layer, thereby simplifying the complexity of the biasing circuit.



(a) (c)

Figure 1. The geometry of meta-atom a) Front view, b) Side-view, and c) Perspective view

The narrow strips placed along the diagonal are separated with a gap of 0.2 mm, where the PIN diodes are placed for switching action. The geometry of the final optimized meta-atom is illustrated in Fig. 1 with its design considerations detailed in Table. I. A novel arrangement is integrated into the design comprising two horizontal metallic layers that help to interconnect the adjacent meta-atom. The top and bottom horizontal metallic layers are shorted and connected to a common supply. A prototype illustrating the biasing procedure for 3x3 FSS structure is shown in Fig.2. In this work, the PIN diodes used in both the top and bottom layers of the meta-atom is the

SMP1320-040LF model from Skyworks which gives the stable operation in the complete band of interest.

Table 1. Dimensions of meta-atom

Parameter	P	S	L1	L2	L3	W1	W2	W3	h
Length (mm)	10	3	4	0.9	7	2	0.5	1	1.6

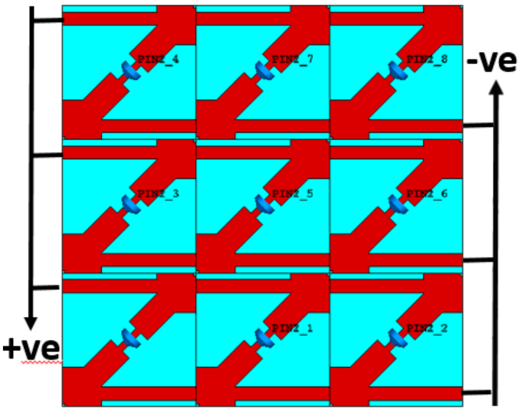
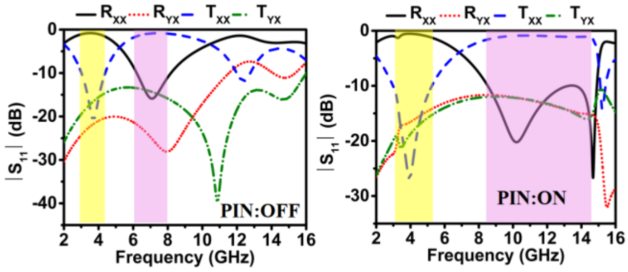


Figure 2. Proposed FSS with biasing circuit.

3. Simulation Results and Discussion

To investigate the proposed transmissive/reflective FSS for bandpass reconfigurability with stable band-stop characteristics, the meta-atom is designed in CST microwave studio Tool, and analyzed its transmission and reflection coefficients using Floquet port analysis. For the X-polarized incidence, the T_{xx}/T_{yx}, and R_{xx}/R_{yx} are evaluated. Initially, the static meta-atom with a short metal patch is placed in the gap to realize the ON condition and then removed to create the OFF state allowing for the desired response. Later, PIN diodes are incorporated in the gap, and a similar response is achieved for the ON and OFF states, and the resultant plots are shown in Fig.3. It is observed that at least one of the PIN diodes must be in the ON state to achieve band-pass reconfigurability. When at least one of the PIN diodes is in the OFF state, it exhibits band-stop characteristics from 3.1- 4.3 GHz, i.e., the magnitude of transmission co-efficient T_{xx} is below -10 dB, and the reflection coefficient is above -1 dB. Similarly, it exhibits band-pass characteristics from 6.25- 8.1 GHz. When both the PIN diodes are in the ON state, the FSS exhibits band-stop characteristics from 3.08-5.2 GHz and band-pass characteristics from 8.56- 14.8 GHz. To realize this stable band-stop characteristic, the width of horizontal metallic layers is optimized. It is observed that the cross-polarized coefficients have magnitudes significantly below -10 dB, indicating that there is no polarization conversion within the frequency band of interest.

These innovative functionalities are achieved using only a single dielectric layer and a simple biasing circuit, distinguishing the design uniquely from existing designs in the literature. Further, an equivalent circuit analysis will be carried out and the final prototype will be fabricated with the biasing circuit as future work by authors.



(a) (b)

Figure 3. S-parameters vs frequency a) ON state, b) OFF state

4. Conclusion

A reconfigurable FSS with band-pass and stable band-stop characteristics is presented and its operation is detailed using relevant simulation results. The proposed design is single-layered with only two PIN diodes incorporated in the top and bottom layers and hence requires a simple biasing circuit. When both the PIN diodes are activated, the structure functions as a bandpass FSS operating between 8.56 and 14.8 GHz. Activation of at least one diode shifts the operational frequency range to 6.25- 8.1 GHz. With these novel functionalities, the proposed design is best-suitable for radomes, RCS reduction, and wireless communication applications.

5. Acknowledgements

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6. References

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