Stretchable Frequency Selective Surfaces for Large-Area-Tuning and High-Power Applications

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Abstract - **Frequency selective surfaces (FSSs) have been widely used in modern communications and military applications such as radomes and RCS reductions. In some circumstances, their filtering responses need to be tuned from one frequency band to another. For most tuning techniques, it's still a challenging problem for large-area FSSs. Take electronic tuning for example, it requires lots of electronic controllable elements and RF/DC isolations depending on the sizes of the FSS. In this research, we investigate a mechanical tuning approach of using stretching to tune the frequency response of a large-area FSS. Instead of exploiting a complicated bias circuit for individual unit cell, the responses can be shifted by increasing the mechanical loadings added on the edges of the entire frame of the FSS. The proposed FSS in this research was composed of two inductive horseshoe-shaped strips separated by a capacitive gap forming a first-order band-stop filter. The mechanical stretch and the induced tuning of a unit cell are studied separately by finite element method and full-wave EM simulations. A prototype was designed, fabricated, and examined with an X-band waveguide measurement. The research results are expected to be beneficial for high-power-microwave devices and mm-wave applications.**

Index Terms — **Stretchable, large area, tunable FSSs, PDMS.**

1. Introduction

In the past decades, frequency selective surfaces (FSSs) have been used in the ranges including RF, microwave, mm-wave, and optical frequencies. FSSs are essential spatial filters which can provide filtering responses including band-pass, band-stop, low pass, and high pass responses. The wide applications include RCS reduction, indoor\outdoor interferences, reflect-array and radomes. For certain applications, the responses of FSSs need to be switched or tuned continuously from one frequency band to another. Various tuning techniques such as liquid, plasma, optics, electronics have been studied by many research groups. However, it's still challenging to tune the responses of large-area FSSs. For example, electronic tuning is a commonly used technique which requires lots of controlling elements such as varactors or diodes for each unit cell as well as bias circuits and RF/DC isolations. Therefore, large areas increase the complexity of fabrications and bias circuits. In addition, electronic tuning technique cannot handle high incident electromagnetic energy.

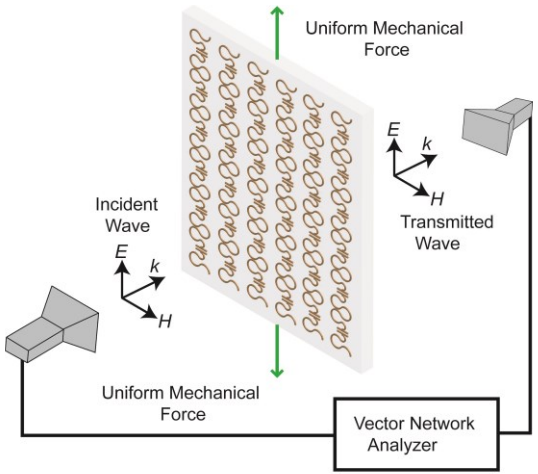

Fig. 1 Schematic illustration of the frequency-response measurements for the proposed stretchable FSS under uniformly mechanical loadings on the edges.

In this research, we investigate a mechanical tuning technique of exploiting stretches to tune the frequency responses of large-area FSSs. The main advantage of stretch tuning is that instead of adding controlling circuits for each unit cell, the mechanically controllable loads are applied at the edges of the entire FSS as shown in Fig. 1. Fig. 1 shows that when the FSS is stretched by uniformly mechanical forces on the top and bottom edges, each unit cell of the FSS is stretched uniformly in the vertical direction. The resulting shifts of the resonant frequencies can be observed by the free-space measurements. Without the needs of complicated bias circuit for each unit cell, stretch tuning is suitable for large-area FSSs. In addition, mechanically tunable FSSs have high-power handling capability since there is no electronic device within FSSs.

2. Designs and Simulations

In general, FSSs are made of metals deposited via standard PCB fabrications or metal-thin films patterned on the substrates but both of them cannot sustain large length variations [1]. Especially, the straight portions of FSSs tend to break or create micro-cracks on the surface which increases the insertion loss. Here, we use the mechanical terminology, stain, to quantify the length variation which is defined as the ratio of the length deformation to the original length.

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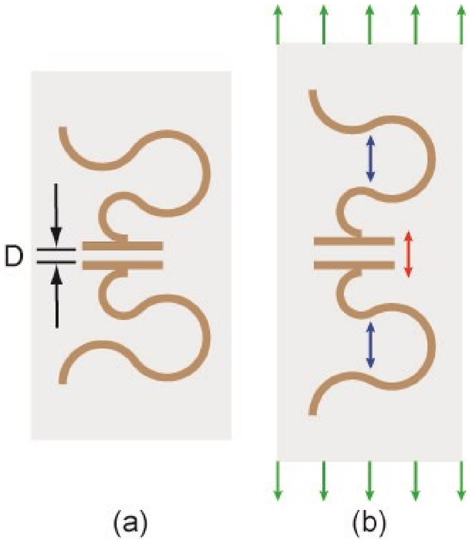

Fig. 2 An unit cell of the proposed FSSs (a) without and (b) with mechanical loading. The red and blue arrows represent the mechanical-loading-induced stains of the capacitive cap and the horseshoe-shaped strips, respective.

In this research, we exploit horseshoe-shaped strips for designing stretchable FSSs because it can provide 10-15 % stain without breaking. The horseshoe-shaped FSSs are coated on highly stretchable substrates such as PDMS (polydimethylsiloxane). PDSM is a kind of polymer and has been widely used for providing large deformation.

Fig. 2(a) shows an unit cell of the proposed FSS in this research which was composed of two inductive horseshoe-shaped strips separated by a capacitive gap forming a first-order band-stop filter. The resonant frequency was inversely proportional to square root of the multiplication of the effective capacitance and inductance. Under an uniformly mechanical load, the FSS stretched in the vertical direction and increased the capacitance results in an increase of the resonant frequency as shown in Fig. 2 (b). Since PDMS substrates stretch larger than metallic FSSs, the stretch ability and the frequency-tuning range were primarily determined by the FSSs.

The device including the FSS and the PDMS was designed with a resonant frequency at x-band via full-wave EM simulation using CST Studio. To estimate the strain distributions under mechanical loads, we used a commercial finite-element software, ANSYS WORKBENCH, to study the deformation distributions of a unit cell as shown in Fig. 3. Fig. 4 shows the simulated transmission coefficient (S21) obtained from CST Studio. It's observed that as the strain increased, the resonant frequency shifted to higher frequency.

3. Fabrication and Measurements

The designed FSS will be patterned on the PDMS substrate via photolithograph fabrications. The frequency responses of the fabricated device will be measured within a x-band rectangular waveguide with a calibrated vector network analyzer. It is demonstrated that waveguide experiments are analogous to 2D periodic structures [2]. The experimental results will be presented in the symposium.

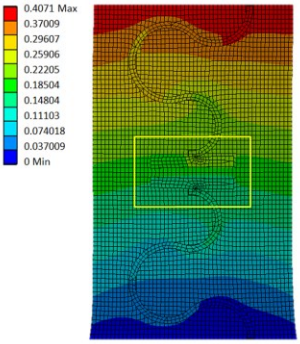

Fig. 3 Simulated strain distributions of the unit cell under 1 N tensile force. The rectangular box indicated that the induced strains were distributed uniformly between two capacitive strips.

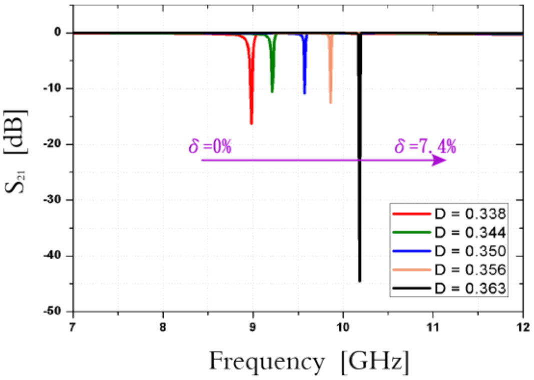

Fig. 4. The transmission responses for different induced strains obtained from full-wave EM simulations. As the strain increased, the resonant frequency shifted to higher frequency.

4. Conclusion

In this research, we proposed a stretchable FSS composed of horseshoe shapes coated on a stretchable PDMS substrate. Based on mechanical and EM simulations, it's demonstrated that under external mechanical force, the stretch of the FSS resulted in a frequency shift of the resonant frequency. The research results are expected to be beneficial for large-area, tunable FSSs since they don't require additional bias circuit for individual unit cell which reduces the manufacturing complexity.

Acknowledgment

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