Frequency Selective Surfaces for Microwave Frequency Band Applications

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***Abstract*—We analyze periodic arrays of frequency selective surfaces (FSS_s) built from the split ring resonators (SRR_s) and $CSRRs$. FSSs are two-dimensional periodic structures that behave like either passband or stop band filters in the microwave frequency band. SRRs are artificially created structures with non-magnetic loops and small gaps between them. Using COMSOL Multi-physics, we investigate the transmission characteristics of such structures with variation of the physical parameters gap width, dielectric constant, gap separation, and incident angle. This analysis offers a new approach in the design of meta-material based radio frequency(RF) devices.**

I. INTRODUCTION

In recent years, the advent of frequency selective surfaces (FSSs) for microwave/millimeter wave applications have attracted a lot of attention for applications such as polarizers, absorbers, radomes, and reflectors. FSSs are two dimensional periodic structures like 2-D photonic band-gap materials, designed to transmit, reflect, or absorb particular frequencies of electromagnetic waves. FSSs have been designed and implemented using different techniques and unit cell structures. Based on the application and resonance frequency, the split ring resonator (SRR), complementary split ring resonator (CSRR), cross structure, and rectangular SRR are used to design FSSs. FSSs are commonly used in microwave and millimeter wave applications due to small unit cell compared to wavelength and strong electric or magnetic current near resonance. Thus, based on diffraction theory, the secondary grating lobes are suppressed with no coupling between adjacent elements. It was proved using Babinet's principle in [1], that the SRR acts as band-stop filter while CSSR acts as band-pass filter with very narrow-band characteristics. Further, the multilayer structure of such elements or single layer dielectric thickness variation helps to create high Q-factors and narrow filter pass bands. Pendry et al. (1999) demonstrated the use of left handed materials (LHMs) that exhibit negative permeability near magnetic resonance. Smith et al.(2000) realized such meta-materials using one or two-dimensional periodic SRR structures. Meta-materials are sub-wavelength periodic structure that are engineered to produces exotic electromagnetic behavior not found in nature. For SRR, the broadband negative permeability is implemented by using equivalent gap capacitance and negative permittivity by shunt inductance. In contrast, for CSRR, the equivalent dual counterpart of SRRs, is fabricated using a negative image of SRRs [1].

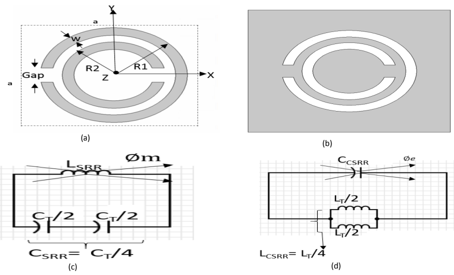

Fig. 1. The FSS unit cell structure of (a) SRR (b) CSRR with grey part copper metal as PEC and white portion Alumina ($\epsilon = 9.8$) as substrate. The geometrical parameters are a=15mm, R1=5mm, R2=3.5mm, Gap=1.5mm, w=0.8mm. (c) The equivalent LC circuit for SRR (d) for CSRR.

Due to low loss, two-dimensional dielectric FSSs or low loss metallic photonic crystals at optical wavelengths are used extensively in applications. This paper explores the design of FSSs using high permittivity alumina as the substrate. Alumina has a high dielectric constant, low dielectric loss, and high electric/ heat resistance [2]. The comparative analysis of different parameters for SRR structure provides the best transmission throughput at the desired frequency band. Invisibility cloaks, super-lensing, negative refraction, diffraction limited image resolution, and massive MIMO antenna design are recent research breakthrough examples using such meta-materials or meta-surface structures [3].

II. DESIGN OF FREQUENCY SELECTIVE SURFACE

The unit cell of SRRs and CSRRs with double concentric rings and opposite gaps are depicted along with equivalent circuits in Fig. 1. When SRRs is excited by an external magnetic field parallel to the SRR axial direction, the magnetic dipole is created due to magnetic loop [1]. Therefore, the presence of equivalent loop inductance and gap capacitance shows strong Lorentzian resonance in the effective permeability. The capacitive contribution of the inner ring reduces the overall resonance frequency and tries to make more homogeneous to electromagnetic excitation by adjusting the wavelength and lattice constant ratio [4]. In Fig. 1 $C_T = 2\pi r_{mean} C_{pul}$ represents total capacitance between the rings, where C_{pul} is the per unit length capacitance between the rings. The resonance frequency of SRR is given as f_{res}= $(L_{SRR}C_{SRR})^{-1/2}/2\pi$.

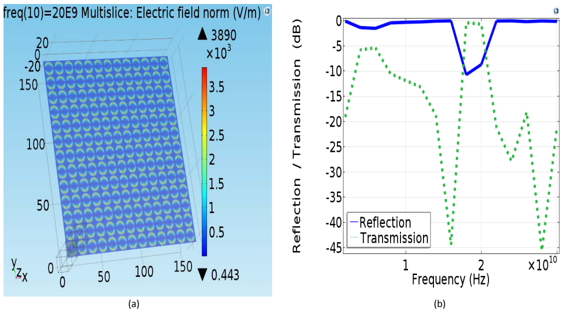

Fig. 2. (a) 13× 13 FSS model (b) Trasmission and reflection characteristics for unit cell of FSS.

All the designs are simulated in three-dimensional COMSOL Multiphysics with the copper layer thickness less than skin depth in given frequency range. Thus, a Perfect electric conductor (PEC) is used to model this metallic copper layer and Perfect matched layers (PMLs) on the top and bottom are used to absorb all the port and higher order mode signal. The magnetic field, H_x is applied through interior source port 1 via a slit.The scattering boundary after the port 2 helps to scatter all the signal coming out of the SRR. The wavelength of $2\pi / \mid k_0 cos\theta \mid$ in the PML is dependent on the angle of incidence so that we can observe the variation characteristics of peak passbands and stop bands in transmission (S_{21}) and reflection (S_{11}). Finally, the periodic boundry condition is set to get identical $13{\times}13$ arrays of dielectric FSSs.

III. Results and discussion

The transmission characteristics for different angles of incidence and various physical parameters like ring width and gap separation are analyzed with the applied external magnetic field. The normalized electric field distribution and reflection/ transmission characteristics around 20 GHz are illustrated in Fig. 2 showing very good transmission response over the simulated frequency range. The maximum field is observed across the surface of the SRR compared to vicinity of the gap portion.

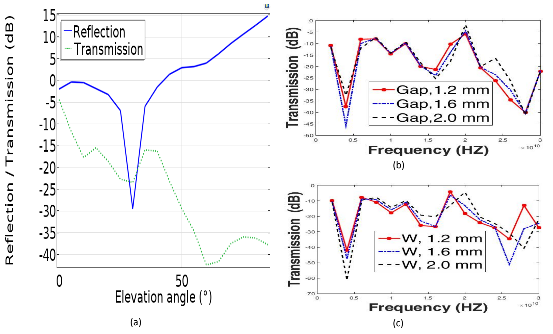

Fig. 3. (a) Trasmission and reflection characteristics as function of incident angle (b) Transmission characteristics as function of split gap seperation (c) Split ring width.

It is found that, the transmission of CSRR gradually decreases for increasing angle of incidence. Changes in the split gap and width dimension varies the capacitance. Changes in gap between inner and outer rings varies the inductance of the CSRR. Better transmission is obtained when both gap and width are increased, with slight change in resonance frequency, because of confinement of more field locally compared to free space due to refraction and diffraction phenomena. These characteristics are clearly shown in Fig. 3 which shows that increased number of cuts reduces the resonance frequency and gives better transmission due to increment in overall capacitance. Likewise, the resonance frequency is decreased for continuously rising dielectric constant of the substrate material as illustrated in Fig. 4.

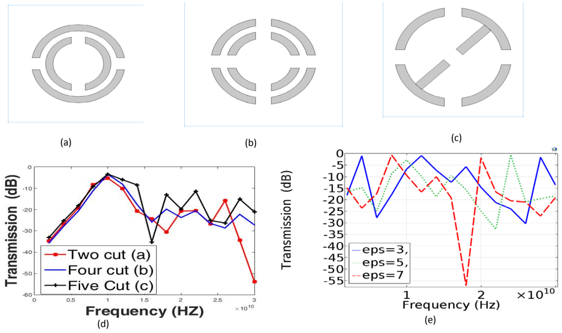

Fig. 4. (a) CSRR with two cuts (b) CSRR with four cuts (c) Single ring with rectangular cut (d) The transmission characteristics for different (a,b and c) CSRR structure (e) Dependent of dielectric constant on transmission.

IV. Conclusion

We present transmission characteristics of various SRR structures. By analyzing the SRR and CSSR with equivalent LC resonance circuits, we can change the magnetic resonance by altering physical parameters like dielectric constant, split width, and gap etc. We found that the increment on number of cuts and dielectric constant in SRR reduces the frequency due to increase in overall capacitance. The good transmission ability of FSS is possible by increasing the gap and split width. The qualitative design and analysis of such structures will have application in negative index meta-materials, high resolution imaging, 5G antenna design, and RF device design.

References

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