Design of a Microwave Dual-band Filter Using Frequency Selective Surfaces

Masoomeh Khalilzadeh
Communications and Computer Research Center
Ferdowsi University of Mashhad
Mashhad, Iran
khalilzadeh_bargh82@yahoo.com

Mir Mojtaba Mirsalehi
Electrical Engineering Department
Ferdowsi University of Mashhad
Mashhad, Iran
mirsalehi@um.ac.ir

Abstract— **A dual-band frequency selective surface (FSS) made of double ring is presented. The design has been carried out with one layer of FSS. In the first step, two single band FSSs with different radii rings were designed for two resonant frequencies of 7 GHz and 4.8 GHz with a 20 dB bandwidth of 0.3 GHz around each frequency. In the second step, the two rings were merged to obtain a dual-band FSS. The proposed dual-band FSS is a compact structure that is stable against angle and polarization of incident wave with a rejection level better than -20 dB in the bands.**

Keywords-component; dual-band FSS; double ring; frequency selective surface

I. INTRODUCTION

Frequency selective surfaces (FSSs) are planar periodic structures in which the surface is assembled with identical conducting patch or aperture elements that are replicated periodically in a one or two-dimensional array. They are similar to electromagnetic filters, but their frequency response depends on the angle and polarization of the incident wave, as well as the frequency. This is in contrast to the classical filter frequency response which only depends on the frequency. The oldest reference to periodic structures was a patent granted to Marconi and Franklin for making parabolic reflector in 1919. However, FSSs were not studied until the 1960 decade. Since then, FSSs have been widely utilized in various fields such as radoms, dichroic reflectors, dual-reflector antennas and beam splitters. Today, there is a growing demand on multi-functional antennas for telecommunication systems. Therefore, the development of FSS with multiband characteristics is needed [1,2].

Dual-band FSSs have been studied by many researchers. Hill created a dual-band filter by applying a perturbation technique to a single band filter, though attenuation lower than -10 dB was obtained [3]. Wu created a four-band by two layers separated by Kevlar honey comb which each layer contained double square loop patch elements [4]. This structure was very complex.

Haung designed a tri-band FSS made by a dual-layer FSS that reflected the X-band signal and transmited the Ku- and S-band signals [5]. This filter reflected only one band and it was relatively complex. Reed used single layer FSS for creating a dual-band filter [6]. Each unit cell consists of a group of square patches with different dimensions. Furthermore, first band attenuation was lower. Kim and Choi proposed a tri-band filter with a ternary tree loop combined with a triple as the unit cell geometry [7]. The proposed structure was beneficial, though the elements were complex and difficult to analyse. Parker and Eli Sheikh designed a multiple band FSS by convoluted elements derived from linear and crossed dipoles [8,9]. The structures utilized elements with fractal and created two or three frequency bands. These fractal elements are complex and difficult to analyze. Zhou proposed a dual-band filter with three layers of FSS which had acceptable frequency response, but was not compact [10]. A double ring structure can be used to design a dual-mode resonator. Soong and Liu used this structure for wide band pass filter design [11,12].

In this paper, we propose a dual-band filter which consists of only one layer of FSS with a rejection level better than -20 dB in all bands. This compact structure has adequate stability against angles and polarization of the incident wave. We have used a simulation software, CST Microwave studio (MWS) to analyze the proposed dual-band filter. Section 2 is devoted to a brief description of frequency selective surfaces and the important parameters of their designs. In section 3, we investigate two single-band structures. In section 4, the results of a dual-band structure with double ring are provided, and finally the conclusions are made in section 5.

II. FREQUENCY SELECTIVE SURFACES

Frequency selective surfaces (FSS) are periodic surfaces that behave as filters for electromagnetic waves. Based on their geometries, FSSs can be categorized into four types of filters: band-stop, band-pass, low-pass and high-pass.

There are several factors that control the frequency response of a FSS. These include shape, size, conductivity, spacing between elements, dielectric constant and the incident angle [1,2].

A. Shape

Different shapes are used to design FSSs. Each shape has its unique frequency response. According to Munk, element shapes can be divided into center connected, such as dipoles, loop types, such as square loops and rings, solid interior types,

such as circular patches, and combinations. The elements utilized for high performance FSSs are combinations of any of the center connected, loop or solid interior geometry. Some element shapes reveal severe sensitivity against incident angle and polarization, though they provide a rapid transition between the pass and stop bands. We use the elements that provide a trade-off between rapid transition and stability against incident angle and polarization.

B. Size

If the length of a dipole is an integer multiple of half wavelength, it resonates and re-radiates the energy efficiently. If such dipoles are arranged in a two-dimensional array, the energy will be re-radiated from all the elements in the same direction. This is because the induced current on each element has a specific delay with respect to its neighbor.

To have resonance in a ring, half of the ring length must be an integer multiple of half wavelength. In other words, the electrical circumference must be an integer multiple of the wavelength.

C. Conductivity

When an electromagnetic wave is incident on a FSS, currents are induced on the conducting elements. These currents then re-radiate electromagnetic waves. The FSS can be modelled as inductive or capacitive components in the equivalent circuit. The low conductivity of the element is modelled as a resistor in the equivalent circuit. In the case of materials with low conductivities, power is dissipated in the element. Therefore, the FSS performance will be affected. For example, in a filter with square loop elements, if the resistance is increased, the attenuation at the resonant frequency is reduced as shown in Figure 1. Therefore, conductivity of element should be high.

D. Spacing

If the spacing between elements is electrically large, grating lobes are created. Grating lobes transmit or scatter waves in undesired directions and result in wasting the radiant energy. To avoid creation of grating lobe, a general rule is [1]:

$$a_o \le \frac{\lambda_o}{1+\sin\theta} \tag{1}$$

Where a_o is the spacing between elements, λ_o is the free space wavelength and θ is the angle of incident wave. In this study, the proposed structure involves spacing element of 22mm.

E. Dielectric constant

Dielectrics are often utilized to supply structural support. Regarding the dielectric and conductive elements of a FSS, it is divided to two types: (a) an FSS sandwiched between two dielectrics, and (b) a FSS attached to one side of a dielectric substrate. If the thickness of dielectric is greater than 0.05 wavelength, the resonant frequency will be lowered by a

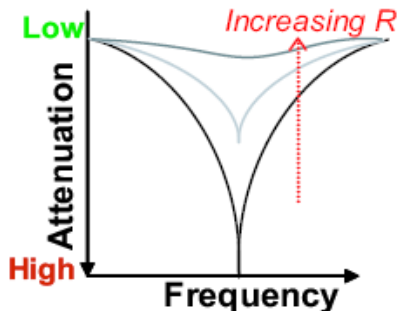

Figure 1. The frequency response of a filter with rectangular loop, by varying element conductivity [1]

factor of $\sqrt{\varepsilon_{eff}}$ in which ε_{eff} is the effective dielectric constant of structure. The value of ε_{eff} equals the dielectric constant ε_r of the substrate for the type (a); and equals $(\varepsilon_r+1)/2$ for the type (b). If the thickness of dielectric is less than 0.05 wavelength, the effective permittivity ε_{eff} becomes a nonlinear function of the substrate thickness. This causes the resonant frequency to be sensitive to the substrate thickness. In this paper, to minimize the electrical size of the element, a polypropylene substrate with $\varepsilon_r = 2.2$ is utilized.

F. Signal incident angles

When a FSS is exposed to an electromagnetic wave at an oblique angle, the effective separation between the elements (w) will be decreased by a factor of $cos\theta$, as illustrated in Figure 2. The effective dimensions of elements with this incident wave will be seen oblique and accordingly the current induced on elements will be different. As a result, the frequency response varies with the incident angle. This causes the values of inductor and capacitor in the equivalent circuit to be a function of the incident angle. Therefore, the resonant frequency is a function of the incident angle. This can be improved with a proper FSS design.

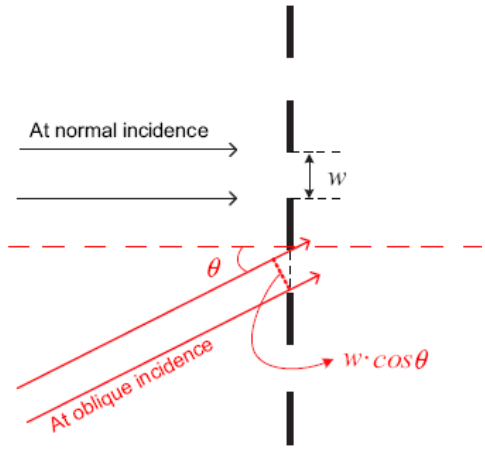

Figure 2. Equivalent separation between elements by an obliquely incident signal [1]

III. SINGLE-BAND STRUCTURE

A single-band structure is composed of a rectangular array of ring elements on a dielectric layer as shown in Figure 3. Among existing dielectrics, polypropylene is more suitable due to its characteristics: it is transparent to visible light, its standard thickness is 20 microns, and it has a good tensile strength. Therefore, it is widely used in industry. The selected dielectric properties in this paper are εr=2.2 and σ=7.34×10-5 S/m.

Figure 4 shows the unit cell of a single band structure. The size of the unit cell is *Dx*=*Dy*=22.7 mm and it is composed of a ring on a polypropylene layer of 20 microns thickness. We first design a single band filter which resonates at 4.8 GHz (structure 1) and another one resonating at 7 GHz (structure 2). The frequency responses of these structures are shown in Figure 5. The inner and outer radii of the ring corresponding to the structure 1 are 9.42 and 10.42 mm, respectively while the same parameters of structure 2 are 7.42 and 8.42 mm.

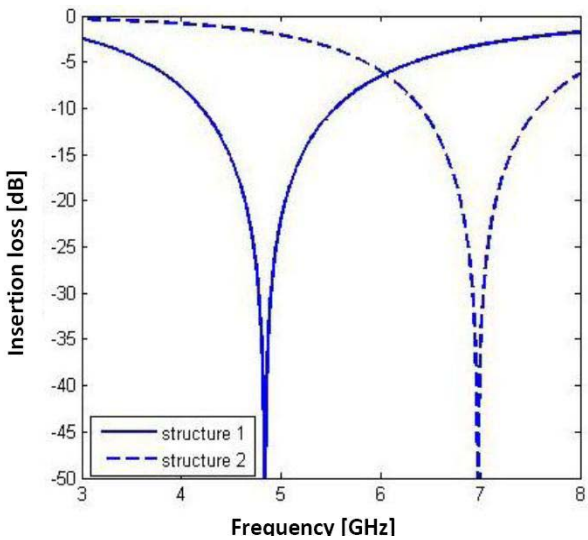

Figure 5. Unit cell geometry of a dual-band structure

IV. DUAL-BAND STRUCTURE

After the simulation of two single-band filters, they are merged together to form one single structure. The proposed unit cell geometry of our dual-band filter is shown in Figure 6. It consists of two rings which were designed in section 3. Figures 7 and 8 show the insertion loss results for the designed dual-band filter. The simulations are done for different angles of incidence from 0 to 45 degrees, and for both TE and TM polarizations. Simulations were run for 3 to 8 GHz. As Figures 7 and 8 show the frequency response of this structure is relatively stable with respect to the angle of incidence and polarization. This seems to be due to the symmetry of the structure. Moreover, the insertion losses in two bands are much greater than -20 dB (about -50 dB). The first resonance with an insertion loss of about -50 dB occurs at 4.5 GHz. The second resonance occurs at 6.5 GHz with similar insertion loss.

Since the two rings in the structure of dual-band have an influence on each other, the resonance frequencies are shifted. To achieve the target frequencies, we have optimized the radii of the rings. The optimized inner and outer radii of the two rings corresponding to 4.8 GHz are 9 and 10 mm and in the case of 7 GHz are 7.35 and 8 mm. Figures 9 and 10 show the insertion loss results for the optimized dual-band filter. Table I

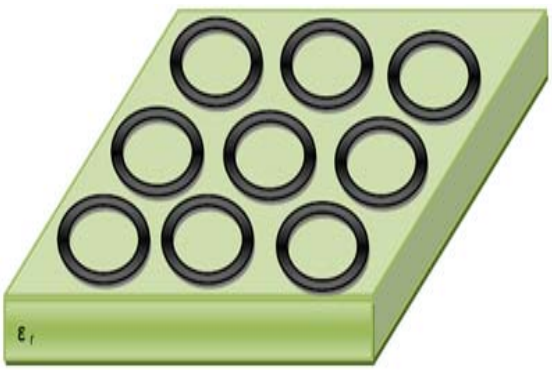

Figure 3. Unit cell geometry of a single band structure, Dx and Dy are periods in two direction x and y.

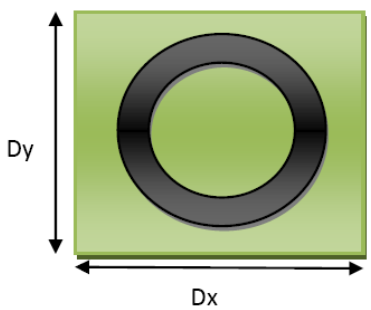

Figure 4. Simulated results of insertion loss for the two single band FSS

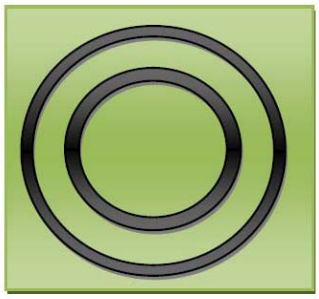

Figure 6. Insertion loss for different angles of incidence (0° to 45°) and TE polarization for dual-band filter

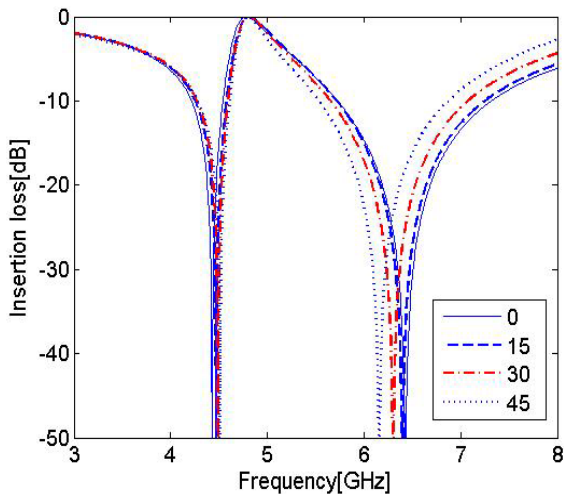

Figure 7. Insertion loss for different angles of incidence (0° to 45°) and TE polarization for dual-band filter

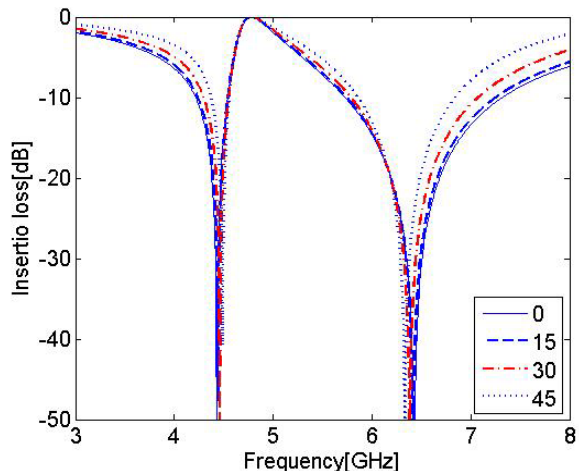

Figure 8. Insertion loss for different angles of incidence (0° to 45°) and TM polarization for dual-band filter

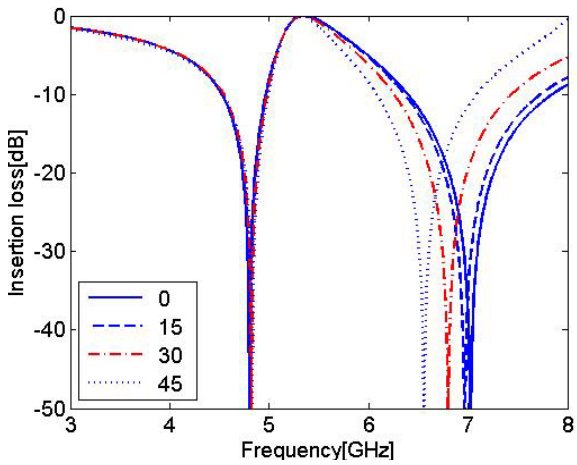

Figure 9. Insertion loss for different angles of incidence (0° to 45°) and TE polarization for optimized dual-band filter

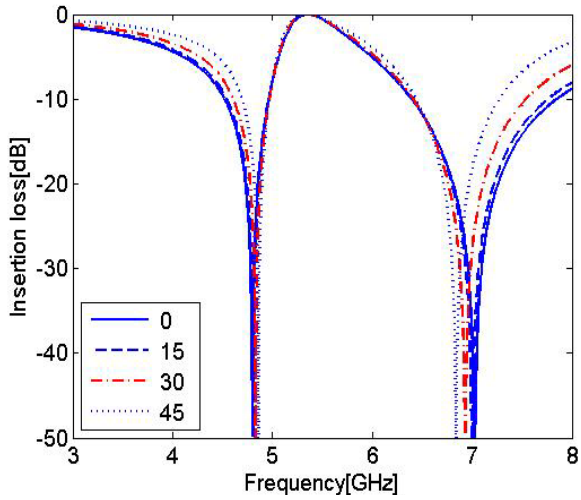

Figure 10. Insertion loss for different angles of incidence (0° to 45°) and TM polarization for optimized dual-band filter

TABLE I. SIMULATED RESULTS OF THE INSERTION LOSS FOR TWO SINGLE-BAND FILTERS AND DUAL-BAND FILTER WITH FSS

Parameter	Structure			
	Steucture1	***Steucture2***	***Dual-band***	***Dual-band optimized***
f_r[GHz]	4.8	7	4.5 and 6.5	4.8 and 7
BW[dB]	0.3	0.3	0.15 and 0.3	0.25 and 0.3
Insertion loss	-50	-50	-50	-50

shows the simulated results for both single-band, dual-band and optimized dual-band filters.

V. CONCLUSION

In this paper, a dual-band frequency selective surface was simulated. The utilized resonant element included two rings with different radii. The proposed structure of the dual-band filter was composed of only one layer of FSS which leads to a more compact structure in comparison to other dual band filters that use two layers. The simulation results revealed that the frequency response of the proposed dual-band filter is stable against angle of incidence and polarization.

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