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Araştırma Makalesi / Research Article

An Easily Optimizable Frequency Selective Absorber Design for X-Band

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Keywords
Frequency Selective Surface; FSS; Absorber; Periodic Structures

Abstract

In this paper, a novel frequency selective absorber surface (FSAS) is designed for electromagnetic and radio frequency interference reduction and for to use in stealth technology in X-band (8–12 GHz). At the proposed FSAS, minimum 10 dB reflection loss is achieved for the incidence angles up to 30 degrees. Lumped resistors are inserted into periodic conduction geometries to achieve absorption frequency behavior. Equivalent circuit model of periodic geometries is used in the design and optimization stages. The main advantage of the design is its resonance frequency can easily be optimized by one parameter which controls the equivalent capacitance. In order to achieve this goal, a novel FSAS geometry has been designed in which equivalent capacity is dominant in determining the resonant frequency of the surface.

Eniyilemesi X-Bandında Kolaylıkla Gerçekleştirilebilen Frekans Seçici Soğurucu Yüzey Tasarımı

Anahtar kelimeler
Frekans Seçici Yüzey; FSY; Soğurucu Yüzeyler; Periyodik Yapılar

Öz

Bu çalışmada, X-bandında (8–12 GHz), elektromanyetik ve radyo frekansı girişim etkilerini azaltma ve görünmezlik teknolojisinde kullanılmak üzere yeni bir frekans seçici soğurucu yüzey (FSSY) tasarımı anlatılmaktadır. Periyodik geometrilerin toplu parametreli dirençlerle beraber kullanması ile soğurucu yüzey davranışı elde edilmiştir. Önerilen FSSY geometrisi 30 derecelik kadar geliş açısına kadar üzerine gelen elektromanyetik dalgaları minimum 10 dB zayıflatarak yansıtmaktadır. Eşdeğer devre modeli tasarım ve eniyileme aşamalarında etkin bir şekilde kullanılmıştır. Önerilen FSSY geometrisinin rezonans frekansının eniyilemesi sadece bir parametresinin değerinin değiştirilmesi ile X-bandı içinde kolaylıkla gerçekleştirilebilmektedir. Bu özellik, eşdeğer devre kapasitesi rezonans frekansı üzerindeki etkisi güçlü olan bir tasarım ile gerçekleştirilmiştir. Tasarımların benzetimi Ansoft HFSS v.19.1 yazılımı ile gerçekleştirilmiştir.

1. Introduction

Nowadays, there is an increasing attention to radar absorbing materials due to the growing demand for stealth technology. Studies are going on intensively for the thin absorber surfaces with a wide absorption frequency band. Absorber materials are also used for EMI (Electromagnetic Interference) and RFI (Radio Frequency Interference) reduction. Absorber designs go back to the early 1940s, where Salisbury (Fante and Mccormack 1988) and Jaumann (Du Toit and and Cloete 1996) absorbers were introduced. A resistant layer is placed at a height of quarter wavelength of the conductive ground in Salisbury absorbers. Multi-layered resistive sheets over a conductive layer are used in Jaumann absorber designs. Jaumann absorbers are bulky, despite having a larger bandwidth than Salisbury absorbers (Munk 2000, Munk *et al*. 2007).

With the use of periodic conducting geometries (named as frequency selective surfaces) in place of resistive sheets, the thickness of the absorbers, their resonance frequencies, and the absorption bandwidths can be optimized appropriately (Munk 2000). In Zadeh and Karlsson (2009), periodic conducting geometries are used in a multilayered structure to achieve an ultra-wideband frequency selective absorber surface (FSAS). In Panwar (2015), fractal frequency selective surface (FSS) in a heterogeneous composite is proposed for a thin absorber in the X-band. Absorption intensity and operating bandwidth are both increased significantly by using magnetic substrates with resistive FSSs (Lopatin *et al*. 2008; Sun *et al*. 2012). To achieve wideband absorption, the use of resistive periodic geometries between plasma and dielectric layers is suggested in Joozdani (2016). Dielectric ceramic coating usage is introduced in Yang (2017) for broadband absorption in an FSS structure with two layers.

A novel FSAS geometry design has been carried out in this work for X-band (8-12 GHz) with a minimum 10 dB ($|S_{21}|=0$, $|S_{11}|<-10$ dB) of reflection loss. Lumped resistors are inserted into periodic conduction geometries to achieve absorption frequency behavior. Since it is used extensively in many applications like military purposes, satellite communication, weather monitoring, air traffic control, marine traffic control, X-band was chosen as the desired frequency band in this study.

The contribution of this work is a miniaturized X-band FSAS design that can be easily optimized. Almost none of the FSAS designs claim a simple optimization stage in the literature. To achieve this goal, a novel FSAS geometry has been designed in which equivalent capacity is dominant in determining the resonant frequency of the surface. The resonance frequency of the proposed design can easily be optimized between 8.62 GHz and 11.2 GHz frequencies by only one parameter of the design. The thickness of the design is only 1.6 millimeters and the miniaturized structure of the design enables stable frequency response up to 30 degrees of incidence angles at TE and TM polarizations.

The equivalent circuit (EC) model of the proposed FSAS is used at the design stage to define the relationship between the FSAS geometries and their frequency responses. (Costa *et al*. 2009, Ghosh *et al*. 2014, Langley and Parker 1982, Lee and Langley 1985). Ansoft HFSS v.19.1 software is used to simulate the proposed FSAS surfaces.

2. Design & Simulation

Surface impedances of FSSs depend on their periodic element geometries, parameter values of these geometries, and substrate on which they are printed on (Taylor *et al*. 2011, Munk 2000). Therefore, the selection of an appropriate FSS element geometry is very important. In this work, in the first stage of design, “Four-Legged Loaded" (Fig.1) is used due to having stable frequency responses, and insensitivity to polarization. (Munk 2000). FSAS (Fig.1) is formed by printing “Four-Legged Loaded” FSS geometry on the other side of the 1.6mm FR4 (ε_r=4.4, tan δ=0.02) substrate coated with a conductor. Lumped resistors are then inserted at the end of each leg of the FSS geometry. 1.6 mm FR4 substrate is selected to easily perform prototype fabrication at the design. Flowing induced currents through the lumped resistors cause absorption behavior at the design. For this reason, "Four-Legged Load" is a very suitable FSS geometry, since the majority of induced currents flow through resistors.

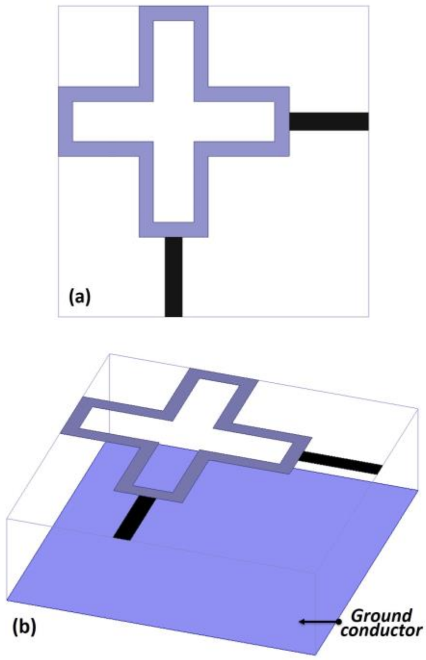

Figure 1. Unit cell geometry of the FSAS (a) Top view (b) Perspective view.

An EC model (Fig.2) of the design (Fig.1) is shown in Figure 2. In this model, FR4 substrate is modeled with a 1.6 mm long (*d*) transmission line. The characteristic impedance of free space is indicated with Z_0. *R is* the resistance of lumped resistor. As shown in Figure 3, equivalent capacitance ($C \propto \frac{w}{g}$) is defined by the width of the gap (*w*) and by the gap (*g*) between periodic element geometries, while equivalent inductance ($L \propto \frac{d}{w}$) is defined by the length (*d*), and the width (*w*) of the current path.

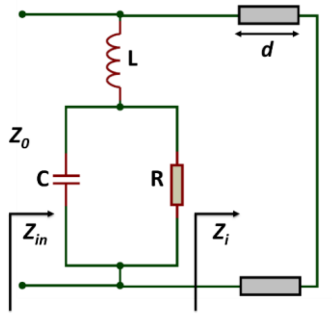

Figure 2. Equivalent circuit model of the FSAS.

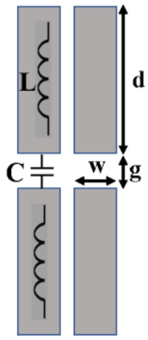

Figure 3. Sample FSS and its EC parameters.

Input impedance of a short-circuited transmission line having a length of d is

$$Z_i = j\,\frac{Z_0}{\sqrt{\varepsilon_r}}\tan\left(\frac{\omega d}{c_r}\right) = jZ_1\,, \qquad (1)$$

where c_r is the speed of electromagnetic wave in FR4 substrate. The surface impedance of the FSAS is then derived as below:

$$Z_{in} = (j\omega L + \frac{R}{1+j\omega CR})//Z_i \qquad (2)$$

$$Z_{in} = \frac{Z_1*(R - \omega^2 RLC + j\omega L)}{Z_1 + \omega L + j(\omega^2 RLC + \omega CRZ_1 - R)} \qquad (3)$$

As shown in Eq.2-3, surface impedance (Z_{in}) is affected by the substrate parameters (thickness and permittivity) and by the FSS geometry. According to the reflection coefficient equation (Eq.4), Z_{in} impedance value must be between 195 Ω and 725 Ω to achieve target absorption level ($|S_{11}|$<-10dB).

$$S_{11} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \qquad (4)$$

Subsequently, for an optimizable and miniaturized FSAS design, “Four-Legged Loaded” geometry is modified by widening the end of the legs as shown in Figure 4. “T” shaped conductors are then inserted to the end of each leg of the FSS geometry to increase and control the equivalent capacitance value. As can be revealed from Figure 4, the equivalent capacity “*C*” is as dominant as the equivalent inductance “*L*” on the resonance frequency. Therefore, it is expected that the resonance frequency of this FSS geometry can easily be adjusted by “*e*” and “*f*” parameters of the “T” shaped geometry.

Proposed final FSAS and its parameters are depicted in Figure 4. The thickness of the FR4 substrate (*h*) is 1.6 mm. Other dimensions (in mm) are *a*=0.7, *b*=1.4, *c*=0.4, *d*=0.25, *e*=0.2, *f*=0.8, *g*=0.2, *s*=0.25, *r1*=1.38, *r2*=0.3, *m*=0.98, *n*=0.3, and p=5.38.

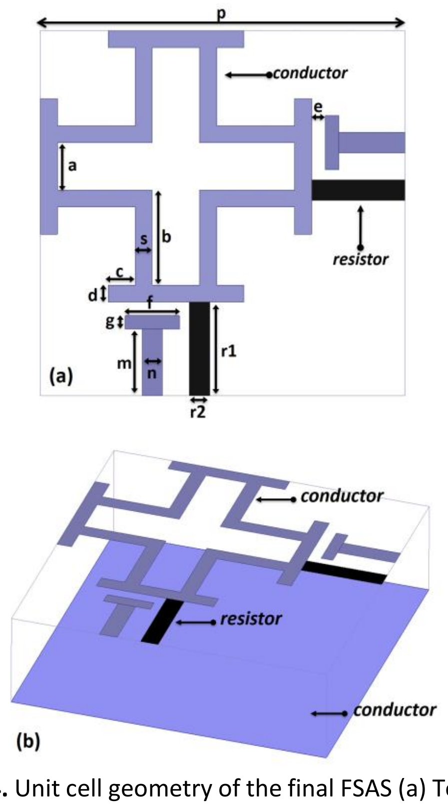

Figure 4. Unit cell geometry of the final FSAS (a) Top view (b) Perspective view.

Analysis of the proposed design was carried out by executing Ansoft HFSS software. The analysis of the infinite periodic structure is accomplished by analyzing the unit cell of the design. As shown in Figure 5, periodic boundary conditions (master, slave) are applied on the sidewalls of the unit cell. Floquet port is assigned on the top boundary and bottom boundary is grounded by perfect electric conductor (PEC). Resistors in the design are modeled with "Lumped RLC" boundary. According to the Floquet theory, Floquet modes are planar waves whose propagation direction is determined by the periodic structure's frequency, phase, and geometry. Due to the nature of the multilayer design, besides to the specular modes, two attenuating Floquet mods are also included in the simulations of the proposed FSS.

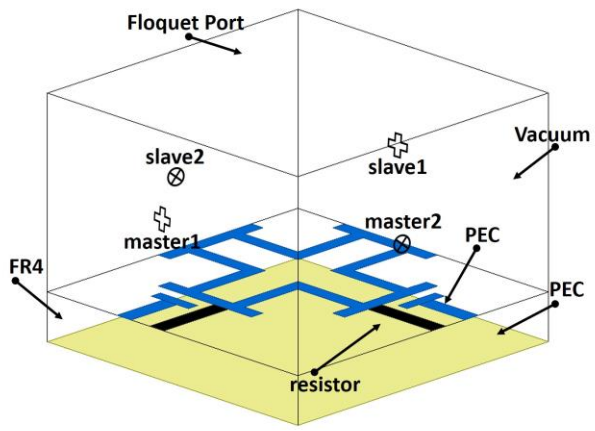

Figure 5. Ansoft HFSS model of the FSS.

According to the simulation results, the capacitance between the "T" shaped geometry and the end of the legs of "Four-Legged Loaded" geometry" affects the resonance frequency, as shown in Figure 6-7. Resonance frequency of the FSAS can simply be optimized between 8.62 GHz and 11.2 GHz by changing the value of parameter "e". The resonance frequency of the FSS can be decreased by increasing the equivalent capacity value without changing the unit cell size. Therefore, it is seen that the FSAS is miniaturized by adding the "T" shaped conductors. "θ" is the incidence angle with respect to FSS surface normal in simulation results.

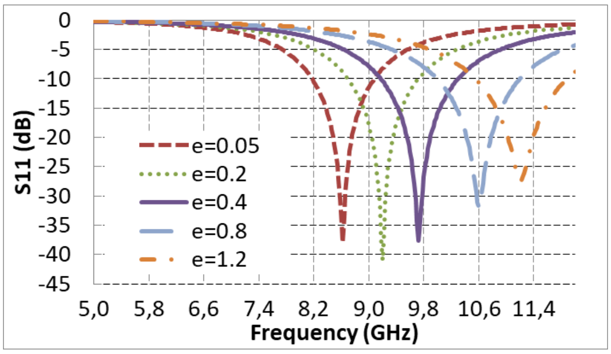

Figure 6. Simulation results for different "*e*" values (TE polarization, θ=0^0).

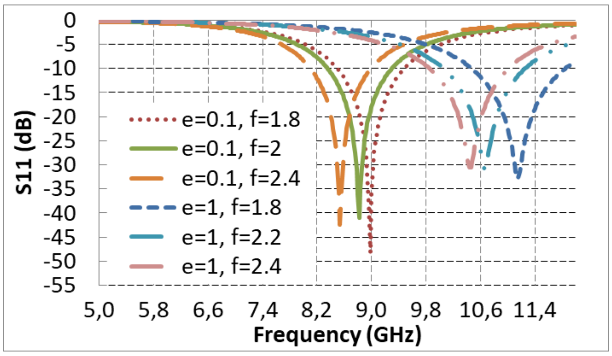

Figure 7. Simulation results for different "*e*" and "*f*" values (TE polarization, θ=0^0).

The effects of lumped resistor values (*R*) on the frequency response of FSAS is investigated in Figure 8. As expected from Figure 2 and Eq.2-3, lumped resistor values lead to change on the reflection coefficient (S_{11}) of FSAS. The resistance of "*R*" is chosen as 1300 Ω in this work.

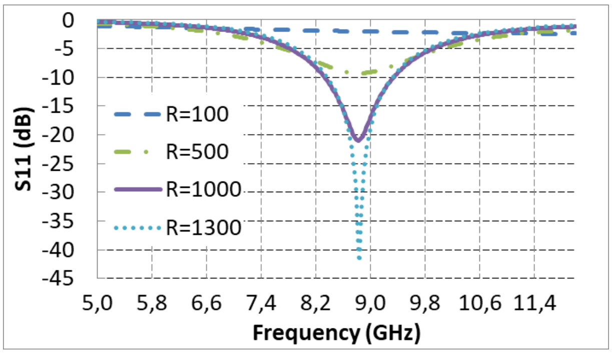

Figure 8. Simulation results for different resistor values (TE polarization, θ=0^0).

Stability of the frequency response of FSAS to the deviations of incidence angles is investigated in Figure 9-10 for TE (Transverse Electric) and TM (Transverse Magnetic) polarizations, respectively.

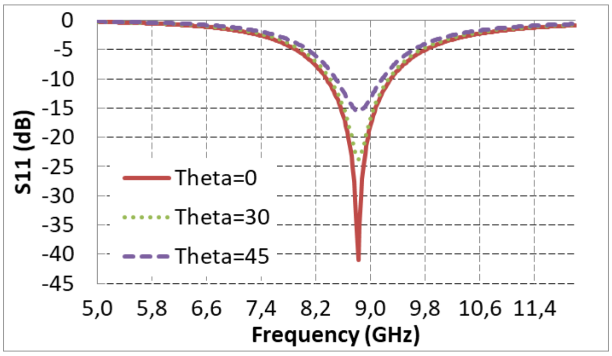

Figure 9. Simulation results for different incidence angles (θ) at TE polarization.

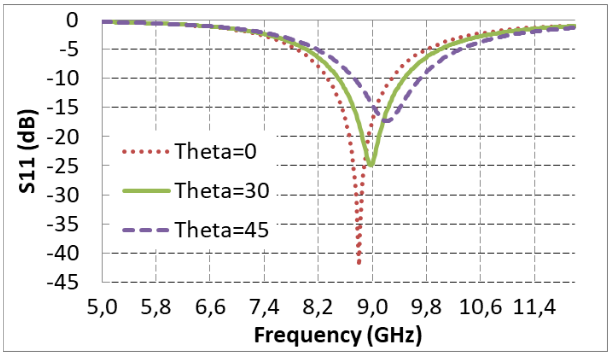

Figure 10. Simulation results for different incidence angles (θ) at TM polarization.

According to the achieved simulation results in Figure 9-10, proposed FSAS has a stable frequency response up to 30^0 of incidence angles for all polarizations.

3. Conclusion

A novel FSAS has been presented for EMI and RFI reduction and the stealth technology in X-band. At the proposed FSAS, achieved reflection loss for the incidence angles up to 30 degrees is a minimum of 10 dB. The resonance frequency of the design can be easily optimized to the desired frequency within the X-band. In order to obtain this feature, a novel geometry design has been realized, which enables the equivalent capacity (C) to determine the resonance frequency. Periodic conductive structures must have a minimum number of cells in order to exhibit frequency-selective surface behavior. The miniaturized unit cell size (5.38 mm) and the thickness (1.6 mm) enables the design to use for EMI and RFI reduction in industry. By inserting PIN diodes where the "e" parameter of the proposed design indicates, the design can be converted into an active FSAS, whose resonance frequency can be adjusted by controlling the DC supply voltage, and this design can used in stealth technology. The proposed design is also compared with similar designs in Table 1 in terms of bandwidth, thickness, and number of layers. The number of layers in the design can be a decisive parameter in terms of ease of manufacture. Thickness is a very important parameter in absorber designs. As the thickness of the absorber designs decreases, it becomes very difficult to obtain a wide absorption band.

Table 1. Comparison of the design with similar works [R=Resonance Frequency (GHz), FBW= (-10 dB reflection bandwidth) / R, H=Thickness (mm), N=Number of layers]

Ref.	R	FBW	H	N
This work	8.28	10.94%	1.6	1
(Sohrab ve Atlasbaf 2013)	10	53%	3	3
(Kong vd. 2015)	4.1	24%	5	1
(Panaretos, Brocker, ve Werner 2015)	11	36%	2	2
(Schuchinsky vd. 2014)	10	34%	3	2
(Costa, Monorchio, ve Manara 2010)	7.6	23%	2.4	1

As can be seen in Table 1, the proposed design features a simple structure and the thickness is small if it is compared with similar works. However, the proposed design has a narrower absorption bandwidth.

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